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CHALLENGES TO NATIONAL DEFENCE IN CONTEMPORARY GEOPOLITICAL SITUATION

CNDCGS-2024

Proceedings Book of the 4th International Scientific Conference

GENERAL
JONAS ŽEMAITIS
MILITARY ACADEMY
OF LITHUANIA

University
of Defence

UNIVERSITY OF DEFENCE, BRNO, CZECH REPUBLIC
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MINISTRY OF DEFENCE OF REPUBLIC OF LITHUANIA
NATO ENERGY SECURITY CENTRE OF EXCELLENCE LITHUANIA
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The proceedings of the 4th International Scientific Conference CHALLENGES TO NATIONAL DEFENCE IN CONTEMPORARY GEOPOLITICAL SITUATION contain selected papers of topics: Defence Technologies and Aviation, Cyber Threats and Security Issues, Democracy, Contemporary Threats and Warfare, Modern Technologies and Social Sciences, Multi-Criteria Decision-Making, Sustainable Defence Solutions, The Impact of New Defence Technologies on Humans, Education and Physical Training for National Defence, Environmental Issues and Modern Technologies, and Challenges to Face New Defence Technologies.

All proceedings were reviewed by independent reviewers.

The style and language of authors were not corrected. The quality of language of papers is under the authors' responsibility. Only minor editorial corrections have been carried out by the Publisher.

PREFACE

The fourth international conference Challenges to National Defence in a Contemporary Geopolitical Situation (CNDCGS'2024) held on 11 – 13 September 2024, Brno, Czech Republic is organized by University of Defence, Brno (Czech Republic), General Jonas Žemaitis Military Academy of Lithuania, Ministry of National Defence of the Republic of Lithuania, cooperation with the NATO Energy Security Centre of Excellence, National Defence Foundation and the Lithuanian Riflemen's Union.

The conference invites practitioners and researchers to discuss important issues related to current and future challenges to European defence capabilities and to collect great innovative ideas for future development. Also, an important contribution is made to defence innovation. The conference aims to attract the attention of the European society and increase the attention of the international political community and the U.S. and European decision-makers to the security of the Baltic region.

The aims of CNDCGS-2024 were to share the latest topical information on the issues of national defence in a contemporary geopolitical situation. The papers in the Abstracts presented the following areas:

- Defence Technologies and Aviation
- Cyber Threats and Security Issues
- Democracy, Contemporary Threats and Warfare
- Modern Technologies and Social Sciences
- Multi-Criteria Decision-Making
- Sustainable Defence Solutions
- The Impact of New Defence Technologies on Humans
- Education and Physical Training for National Defence
- Military Operation in Multidomain Environment
- Challenges to Face New Defence Technologies

The invitations to CNDCGS-2024 include instructions on preparing reports, abstracts, and manuscripts, as well as deadlines for submission. The guidelines for submitting scientific research papers, including specific requirements and deadlines, were published online under the "Publication Opportunities" section at: https://forum.lka.lt/guidelines/.

The CNDCGS 2024 participants presented their research results in the form of extended abstracts, ranging from 500 to 1000 words, for publication in the conference Abstract Book, as well as full-length papers, approximately ten pages in length, for publication in the conference Proceedings Book. The Scientific Editorial Committee selected authentic and original full articles that had never been published before. All submissions were evaluated based on their topicality, originality, and overall quality. After a rigorous double-blind review process, all accepted full-length papers were included in the Conference Proceedings Book. As a result, the Proceedings became a valuable resource of new information, allowing for the evaluation of research conducted by scientists from various countries.

This conference was the result of a collective effort, and I must extend my appreciation to all those who made CNDCGS 2024 possible. First, I commend the organizing committee members for their strong motivation and smooth progress in organizing the conference. I also want to thank all the authors for contributing their papers. Finally, I would like to express my deepest gratitude to the Scientific Editorial Committee for ensuring the quality of the accepted papers.

Prof. Svajonė Bekešienė
Chairman of the CNDCGS-2024

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Possibilities of Using Unmanned Aerial Vehicle in Geospatial Support in the Czech Army

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Abstract

The importance of digital geographic data has been growing very rapidly in recent decades. It is hard to imagine a current military operation in which there is no need to plan, model, or visualize the environment using digital geographic data. The creation and distribution of this data is one of the basic tasks of geographical support in most armies. Most of these data models are created using photogrammetric methods from image data or aerial laser scanning technology. The creation of data using these traditional procedures makes it possible to create robust geodatabases from a large area, but it is often lengthy and does not allow responding to current changes in the area of interest and the needs of the troops for accurate and especially up-to-date geographic data. A faster alternative for creating current geographical data or updating existing geodatabases is the use of unmanned aerial vehicle (UAV). Evaluation of the possibilities of using the AgEagle eBeeX UAV for selected tasks of data collection and creation of data models is the main goal of this article. The article will describe and evaluate selected tasks suitable for the use of this UAV.

KEY WORDS: *UAV, mapping, geospatial support, DEM, multispectral data, engineering survey, soil moisture*

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1. Introduction

The importance of digital geographic data has been growing very rapidly in recent decades. It is hard to imagine a current military operation without the need to plan, model, or visualize the environment using digital geographic data. The creation and distribution of this data is one of the basic tasks of geospatial support in most world armies. Most of these data models are created using imagery and photogrammetric methods or airborne laser scanning technology. The creation of data using these now common procedures allows for the creation of robust geodatabase covering a large area, but it is often lengthy and does not allow responding to current changes in the area of interest and to the needs of the troops for accurate and especially up-to-date geospatial data. A faster alternative for creating current geospatial data or updating existing geodatabases is the use of unmanned aerial vehicles [1].

Unmanned aerial vehicles (UAVs), also known as drones, are vehicles not having a human crew on board. They are controlled remotely or using an automated system. The use of UAVs is very extensive today. In military applications, UAVs are primarily used for the following tasks [2], [3], [4]:

- reconnaissance, surveillance of enemy positions, information collection and border monitoring;
- targeted attacks, carrying missiles or bombing.

However, UAVs are widely used in a number of civilian applications, some of which can also be used in the security and defense domain [4], [5], [6], [7]:

- reconnaissance of inaccessible or dangerous areas, e.g. inspecting oil pipelines or power lines
- monitoring arable land, monitoring crop growth, detecting diseases and optimizing fertilization
- forest mapping, tree condition monitoring and forest fire detection
- delivering of parcels, monitoring of the traffic situation and inspection of the transport infrastructure
- environmental monitoring
- data collection in geology, meteorology, biology and archaeology

• terrain mapping etc.

This text evaluates the possibilities of using the AgEagle eBeeX UAV for selected tasks of data collection and creation of data models for the needs of geospatial support. The article describes and evaluates selected tasks suitable for the use of this UAV.

2. UAV for Geospatial Support

The use of UAVs for the needs of geospatial support is focused mainly on its use as a quick replacement for large photogrammetric aircraft. The main task of the UAV in the geospatial support system is primarily data collection in the form of panchromatic, multispectral or thermal imagery; laser and radar data. Such data collection is done by both propeller-driven and fixed-wing aircraft, both of which are capable of collecting data with various types of cameras [8], [9], [10], [11].

This text focuses on data collection using a fixed-wing UAV equipped with a panchromatic and multispectral imaging camera. A specific representative of this type of UAV is the fixed-wing AgEagle eBeeX. Technical characteristic of the drone is shown in Table 1.

Table 1.
Main technical characteristics of the UAV AgEagle eBeeX [12]

Drone specifications		**Flight performance**	
Wingspan	45,7 in/116 cm	Cruise speed	11-30 m/s or 25-68 mph (40-110 km/h)
Material	Expanded Polypropylene (EPP)	Max. wind resistance	Up to 12,8 m/s or 28,6 mph (46km/h)
Underbody skin	Curv® Polypropylene thermoplastic composite	Landing type	Automatic linear landing (16,4 ft / 5 m accuracy in 35°angle cone)
Max. take-off weight	3,5 lbs / 1,6 kg	Service temperature	5°to 104°F (-15°to 40°C)
Backpack dimension	75x50x29 cm / 30x20x11 in	Humidity	Light rain resistance
Motor	Low-noise, brushless, electric	Ground avoidance	Yes – LiDAR (range 394 ft / 120 m)
Detachable wing	Yes	Ground resolution	Down to 0,6 in / 1,5 cm
Radio link range	1,9 mi (up to 5 mi) 3 km nominal (up to 8 km)	Max. flight time	90 minutes
Frequency	2,400 – 2,4835 GHz	Coverage at 400 ft / 120 m	543 ac to 1,235 ac / 2,2 km^2 to 5 km^2 / 220 ha to 500 ha
Data storage	SD cart	Linear coverage	Up to 17,2 mi / 27,7 km out and back

The AgEagle eBeeX with an optional RTK/PPK module allows to achieve the absolute accuracy up to 3 cm (1.2 in) without ground control points (GCP). However, the image collection described in this article used the AgEagle eBeeX UAV without RTK/PPK GNSS measurement, which achieves lower accuracy.

According to the technical documentation, this type of UAV is capable of creating images of an area of 300 - 500 hectares in one flight, which is up to 5 square kilometers. However, these values can only be achieved under ideal conditions. The shortening of the flight length is mainly caused by the strength of the wind and the ruggedness of the terrain. Practical experience from using the AgEagle eBeeX wing shows that the optimal area for one flight is approx. 2 square kilometers. If it is possible to use multiple batteries or recharge them directly in the field, it is feasible to cover about 10-15 square kilometers in one day. [12]

The UAV AgEagle eBeeX is compatible with a wide range of interchangeable cameras that are suitable for a wide range of mapping work (3D, thermal, multispectral, …):

• SenseFly Duet T - a two-channel thermal mapping kit that can be used to quickly and easily create thermal maps and digital surface models;
• S.O.D.A. - a camera designed specifically for professional photogrammetry using drones;
• MicaSense RedEdge-MX - a professional multispectral sensor working in the red, green, blue, near-infrared and red edge parts of the electromagnetic spectrum;
• S.O.D.A. 3D - a professional photogrammetric camera capable of changing orientation during flight and capturing three images at a time (two oblique and one in nadir).

The use of MicaSense RedEdge-MX and S.O.D.A. 3D cameras for the following tasks is described as part of the testing of tasks for geospatial support needs.

The first task is the rapid collection of data for the needs of updating existing geodatabases. The need for this solution stems from a relatively long period of updating geodatabases and map products, which are still an irreplaceable geographic basis for decision support. On the territory of the Czech Republic, a regular aerial scanning campaigns takes place every two years [13] and map products can thus be replaced by relatively up-to-date orthophotos. This is not the case everywhere, moreover, in military operations there can be significantly faster changes in the landscape, which need to be captured and transferred to geodatabases. For this reason, the temporal and spatial aspects were tested for the acquisition of current images and subsequent updating of existing vector geodatabases. On the territory of the Czech Republic, regular photogrammetric imaging is carried out every two years. The principle is that one half of the territory is photographed every year. In the case of dynamic phenomena, such as natural disasters or military activity, this period is insufficient. Therefore, it is necessary to look for new alternatives for the needs of geographic security, which could be the use of UAVs.

The second task tested is the creation of an up-to-date digital elevation model for the planning of engineering structures or for the needs of restoring existing structures after their destruction by military, as well as non-military, activities. To solve these tasks, an existing elevation model is usually used as a primary source (DMR5 in the Czech Republic [14]), but it may not be sufficiently accurate or up-to-date for some tasks. Therefore, in the case of a request for an accurate elevation model, the geodetic survey of the given territory is used and the creation of a detailed current elevation model processed in time corresponding to the design activities. UAV means offer a new technology for creating these elevation models, which is faster than terrestrial geodetic measurement. At the same time, the non-contact method enables the creation of a height model even in places that are inaccessible, mainly due to the conduct of military operations.

As the UAV eBeeX also enables data acquisition with a multispectral camera that provides data in five spectral bands (three visible, IR and RedEdge), testing of the use of the UAV for the purpose of detecting the distribution of soil moisture was also carried out in order to refine the soil passability modeling procedures. The goal was to find at least partial dependencies between the measurement of soil moisture by a moisture meter in the area of interest with any of the selected combinations of individual multispectral bands.

3. Rapid Geodatabase Updating

The first task tested was the rapid collection of data for the needs of updating existing geodatabases. As part of this task, temporal and spatial aspects were tested for the acquisition of current images usable for subsequent updating of existing vector geodatabases.

In the case of the need for a quick update of geodatabases, it can be assumed that entry to the area of interest will not be allowed and therefore it will not be possible to create the GCPs. For this reason, a procedure without GCPs was used to verify the accuracy of the created orthophoto and the possibility of using it for updating databases. The test area was located southeast of the village of Slavonice. The size of the territory was 0.25 square kilometers. Using the S.O.D.A. 3D camera, 337 images were taken with 60 percent overlap, both forward and lateral. The orthophoto was processed in the Pix4D program without the use of GCPs, then to verify the accuracy of the created orthophoto, the positions of the geodetic surveyed GCPs were compared with the values determined from the orthophoto. The GCPs were surveyed by the Trimble Geo XR GNSS receiver using the STOP and GO method in real time using the VRS Now corrections. The GCPs were regularly distributed in the corners of the test area. The results can be seen in the Table 2.

Table 2.

Positional accuracy of the created orthophoto

	Geodetic		Ortho			
	E_G	N_G	E_O	N_O	E_O - E_G	N_O - N_G
	m	m	m	m	m	m
Slavonice_1	526935,55	5426440,14	526936,25	5426441,27	0,70	1,13
Slavonice_2	527175,64	5426247,56	527176,37	5426248,48	0,73	0,92
Slavonice_3	526353,47	5426131,35	526353,93	5426132,28	0,46	0,93
Slavonice_4	526260,89	5426299,67	526261,48	5426300,82	0,59	1,15
			Mean Square		0,63	1,04
			Horizontal ERROR			**1,21**

The results show that the root mean square deviation on the GCP is 0.63 meters for the E coordinate and 1.04 meters for the N coordinate, and the positional error is 1.21 meters. These values are slightly worse than the accuracy of the data in the ZABAGED database [15], which is the basis for the creation of the basic military database VMÚ. The achieved accuracy, however, fully corresponds to the accuracy required for updating databases as part of the renewal of medium-scale map products, which is also VMÚ.

In addition to verifying the accuracy of the resulting orthophoto, attention was also focused on verifying the time necessary to process the orthophoto. The Pix4D program was used to process the Slavonice location, allowing to create an orthophoto without operator intervention. The operator uploads images, sets the parameters for the orthophoto and starts the creation process.

The calculation was tested on a computer with the following parameters: processor – Intel Xeon CPU E5-2620 2.10GHz; RAM memory – 16GB; operating system – Windows 10.

For testing purposes, the resulting orthophoto pixel size was chosen: 1 cm, 5 cm, 15 cm, 50 cm, and 100 cm. The results representing the time required for processing are presented in table 2. The value shown in bold corresponds to the resolution value of full-area orthophotos, which are used for updating military or civil geodatabases in the Czech Republic [13].

Table 3.
Orthophoto processing time according to different resolutions

Resolution of the result	1cm	5cm	15cm	50cm	100cm
Processing time	31 hours	65 minutes	56 minutes	19 minutes	19 minutes

The results in the table (see Table 3) show that with a suitably chosen resolution of the resulting orthophoto, the time required for processing is not a limiting factor in the use of UAVs for rapid updating of geodatabases.

From all the above facts, it follows that the use of UAVs for updating databases represents a suitable technology providing a sufficiently accurate orthophoto, and the time required to obtain it is negligible compared to the use of an aircraft. The main limiting factor is the size of the area of interest. Based on the experience gained during the processing of testing areas on the territory of the Czech Republic, it appears that the suitable territory for the use of this type of UAV is up to 100 square kilometers.

4. Generating Surface Models for Construction Planning

Design and implementation of construction works is one of the important tasks of engineering support. The main tasks of engineers are the following: mobility support, counter-mobility support, survivability support, general engineer support. It allocates special column to perform rescue and liquidation work during crisis as a part of the Integrated Rescue System (IRS) to fulfill humanitarian tasks. The spectrum of these tasks is very broad and the requirements for geospatial data vary both in terms of content and accuracy.

In this text, attention is focused on tasks for which geodetic support is currently used. These tasks usually require the calculation of the volume of earthworks, or the complete processing of the project of special military constructions. These are, for example, the following tasks [16], [17]:

- construction of military bridges and maintenance of permanent bridges
- design, construction, repair and renovation of command posts
- design, construction, repair and modification of the airport in the area of deployment
- design, construction, repair and maintenance of field temporary camps and bases, including related facilities and equipment

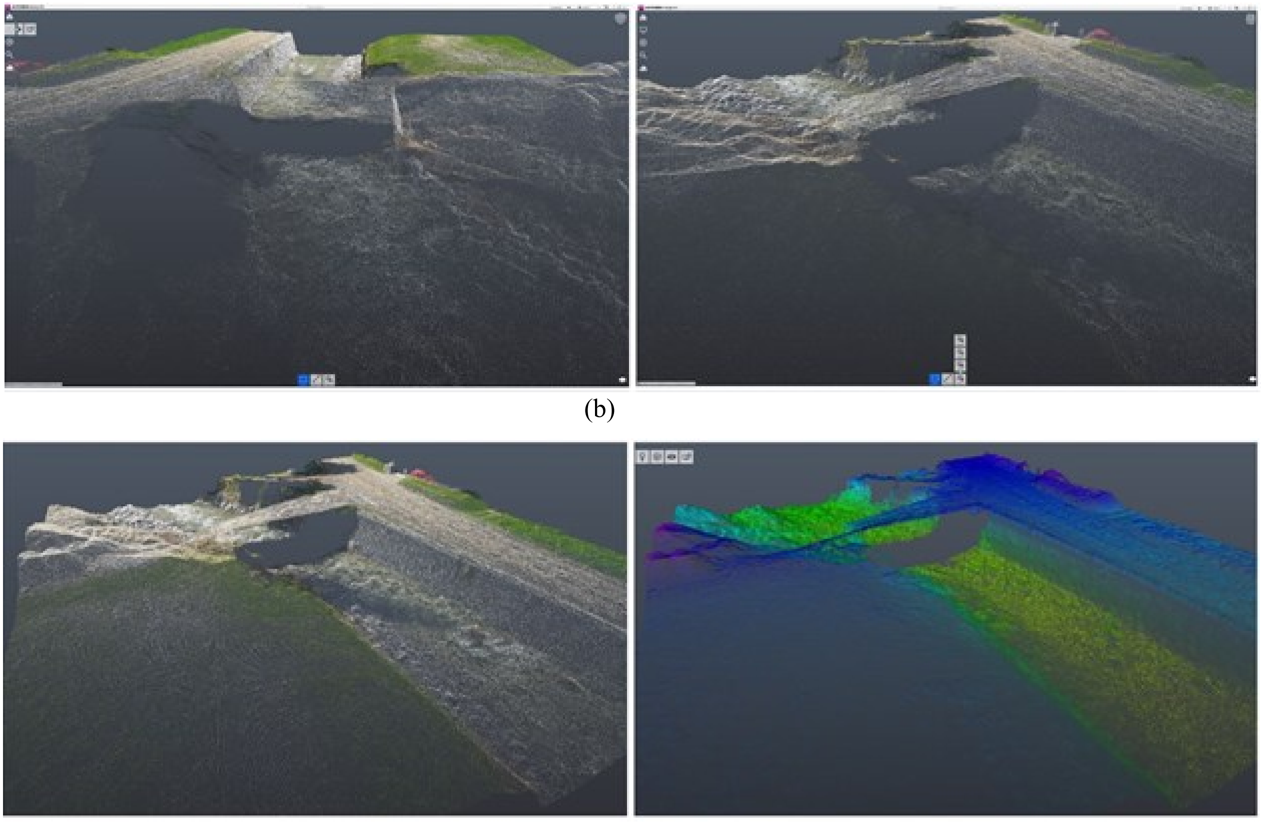
These constructions are almost always associated with the design of earthworks. Currently, modern object applications are used for design with an overlap into design with the use of BIM (Building Information Modeling). The input data for these modern applications are current elevation data from the construction area. This data may have varying levels of accuracy. The requirements for the accuracy of these data vary according to the type of building, the area of implementation and its scope. When determining the requirements for the accuracy of the geodetic survey, an important factor is also the requirement of the construction contractor, who can determine its level based on his requirements.

In general, the most accurate data is important for the construction of military bridges, military roads, airports, and the design of military bases. For designing these types of military constructions, it is advisable to work with data with centimeter accuracy [18].

At present, geodetic data from the construction area, or point clouds acquired by laser scanning are mainly used for these projects. The cloud of points in the national data models correspond to their content at the time of the survey, and the terrain very often undergoes significant changes since then, and the national data models cannot therefore be used. For the needs of engineering support, point clouds can be obtained by acquiring imagery and its subsequent processing.

As an example of the use of the point cloud from AgEagle eBeeX, the processing of temporary bridge projects within the framework of humanitarian aid during the floods in Slovenia in 2023. In August 2023, Slovenia was hit by devastating floods that affected up to two thirds of its territory. The Czech Republic provided a total of 108 meters of heavy bridge sets (TMS) for three locations (Črna na Krkoškom, Mežica and Ljubno ob Savinji).

On the basis of the results of the engineering survey of individual locations, the geodetic surveying was carried out. The Trimble S7 total station, Trimble R12i GNSS receiver and AgEagle eBeeX UAV were used to survey the sites. The survey resulted in very precise orthophoto images of the locations of interest, a geodetic survey scheme and point clouds acquired by the AgEagle eBeeX drone in *.las format (see Fig. 1).



(a) (b)

(c) (d)

Fig.1. Cloud of points acquired by the AgEagle eBeeX drone (location Crna na Koroško): (a) north view; (b) south view; (c) south view after radiometry adjustment; (d) colored point of cloud.

The point cloud was processed in the ReCap2024 application, in which the data was prepared for further use in the creation of a digital terrain model (classification of points, modification of the area of interest). The data was further exported to a format usable in the AutoCAD Civil 3D software suite. This software is used for creating a digital terrain model and its subsequent modification. By default, the terrain is created in the format of a triangular irregular network (TIN). The digital terrain model in TIN generated in AutoCAD Civil 3D is presented in Fig. 2.

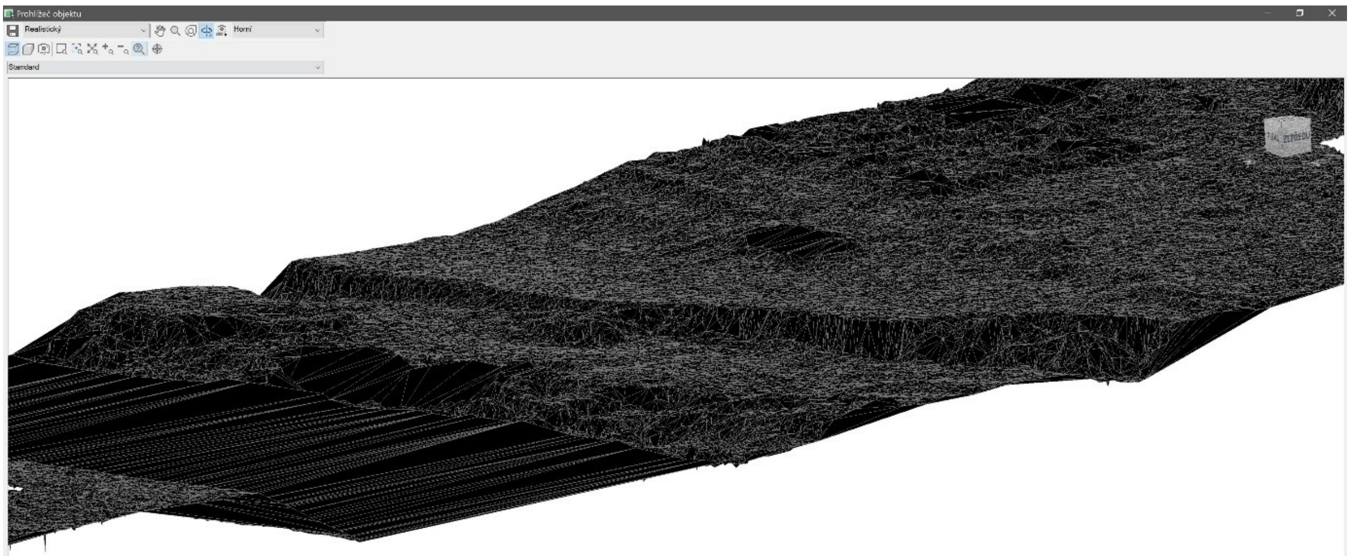


Fig.2. Digital terrain model in TIN generated in AutoCAD Civil 3D.

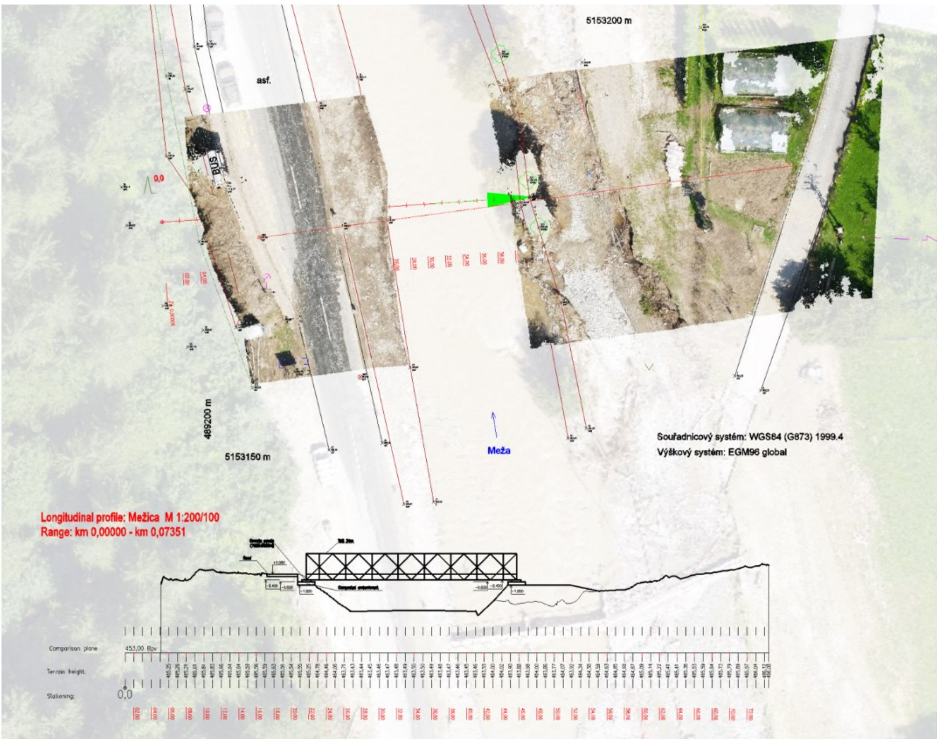


Fig.3. Longitudinal profile in the axis of the planned temporary bridge (Mežica).

For the temporary bridge designer, the starting point is the longitudinal profile in the axis of the planned bridge (Fig. 3). From this profile, information is obtained about the elevation conditions at the construction site and landscape modifications are proposed, which will need to be implemented before the construction of the temporary bridge (modification of the river bed, strengthening of the banks, preparation of places for storing the bridge etc.). For a good height adjustment of the bridge, it is necessary to have a data with centimeter accuracy. The model created using AgEagle eBeeX provided an equally accurate model for design and subsequent construction work as geodetic surveying of sites. The solution with the application of AgEagle eBeeX for design and construction work was also used in other tasks (construction of a training areas for wheeled vehicles, construction of command posts and others).

5. Using Multispectral Imagery for Assessing the Soil Moisture

The last application was focused on the use of a multispectral camera for the purpose of soil moisture detection. The soil moisture is a very important parameter for a number of areas of use that are related to the environment and have the potential to influence human society and its various activities. This means, for example, weather forecasting, drought monitoring, agricultural production management, water resource management, monitoring and management of natural disasters such as fires, landslides or floods, and others [19].

Knowledge of soil properties plays an irreplaceable role for some specific military applications, such as terrain passability. However, the effect of soil moisture on the modeling and prediction of terrain passability by military vehicles has not yet been sufficiently investigated and described, which can be considered a significant shortcoming.

A number of studies have been published for soil moisture estimation based on optical and thermal sensor data processing as well as from active and passive microwave sensor data [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31]. All these papers agree in stating that reliable relationships for the direct derivation of soil properties from spectral data are not yet available.

We performed tests of the possibility of remote detection of surface soil moisture using multispectral image data taken by various sensors located on UAVs.

As part of the testing, the following was performed:

- measurement of soil moisture using the traditional method directly in the field;
- acquisition of multispectral data from the UAV;
- searching and downloading corresponding imagery from selected satellite sensors;
- calculation of spectral indices;
- searching for a correlation between index values and actual soil moisture.

Before the actual measurements in the field, it was necessary to select suitable locations and plan the individual measurements in such a way that they could be repeated in as long a time series as possible. Two testing areas were chosen, which are located near Brno - Nížkovice and Silničná - where the soil type is chernozem. Due to the size of the area that had to be covered by the data, measurements were made at several tens of points that were evenly distributed throughout the area of interest, and the distance between each point was approximately 50 m. Several quantities were measured for each point. The measured quantities were soil moisture, shearing stress, penetrometric resistance. All quantities measured at a given point were located using GNSS measurements [32].

The NDVI (Normalized Difference Vegetation Index) spectral index was used to verify the possibility of using multispectral images. The NDVI is probably the best known and most used vegetation index for analyzing the health of vegetation, but it can also be used to evaluate soil properties, for example its moisture. In the subsequent data analysis, the search for correlation between the images and the soil moisture obtained from the field measurement was carried out. The NDVI was calculated from the image data taken by the UAV, which is calculated from the formula 1:

$$\mathrm{NDVI} = \frac{NIR - Red}{NIR + Red} \qquad (1)$$

where NIR is the spectral band in the near-infrared region of the EMS (Electromagnetic Spectrum) and Red is the band in the red part of the visible region of the EMS.

Subsequently, a correlation dependence was sought between the calculated NDVI index and the measured values of soil moisture.

The statistical method for calculating the Pearson correlation coefficient was used. This coefficient is one of the characteristics of tightness of dependence and is used to determine the linear relationship between two elements. The coefficient can have values between 1 and -1. The closer its value is to 1 or -1, the stronger the correlation. The intermediate values in this interval then indicate the degree of dependence described as very weak, weak, medium, strong or very strong. In total, data from 211 points where repeated measurements took place between November 2020 and April 2021 were analyzed. In the case of UAV data, a weak and very weak positive relationship between the NDVI index and soil moisture was found with values around 0.20.

Most of the studies and articles describing the search for correlation between image or radar data and soil moisture state that the relationships for directly deriving this dependence are not yet available or are not yet robust enough. Admittedly, the results of our testing confirmed this finding.

In order to find reliable results, the involvement of radar data is needed, without them it really is not possible, but it is still a big alchemy and the search for clear relationships will probably take some time. However, the radar sensor is not part of the available sensors for the tested AgEagle eBeeX UAV.

Despite the fact that it was not possible to confirm the possibility of using a UAV with a multispectral camera for the needs of soil moisture assessing, the possibilities of using this tool for other tasks related to geospatial support will continue to be tested.

6. Conclusions

The possibilities of using wing-type UAVs, which have been described in the text, show that the use of unmanned vehicles in geospatial support is promising and will grow in importance. The main advantage of using these means is their operability and relatively low acquisition and operating costs. The quality of the obtained data is comparable to data from piloted aircraft or satellites. Their applicability is provable especially in the area of creation of up-to-date surface models, creation of orthophotos for the needs of visual interpretation and subsequent rapid updating of geodatabases. Unfortunately, it was not possible to find a dependence between soil moisture and multispectral images from the UAV and thereby extend the possibility of applications to the field of terrain passability or cross-country movement. Despite this, testing of the use of these resources will continue to be carried out for other tasks within the geospatial support.

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Methodological Concepts of Appling AI into Military and Economic Capabilities Data Analysis

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Abstract

This paper explores the strategic application of Artificial Intelligence (AI) in enhancing military and economic capabilities. Utilizing a systematic and comparative methodology, this study assesses the potential and challenges of AI technologies, including Large Language Models (LLMs) and their impact on defense and economic sectors. Data from authoritative sources like the United Nations and various strategic studies institutes underpin a comprehensive analysis. Key findings demonstrate that AI significantly advances military efficiency and economic forecasting, akin to its transformative potential observed in digital marketing and cyber defense. The study underscores the necessity for ethical guidelines and robust validation to mitigate AI's inherent biases and misuse. This research not only reaffirms AI's pivotal role in modern strategic contexts but also emphasizes the need for continuous innovation and ethical oversight in its deployment.

KEY WORDS: *military capabilities; economic capabilities; artificial intelligence (AI); large language models (LLM); defence.*

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2. Introduction

A range of studies have explored the use of AI in defense, intelligence, and economic data analysis. According to Atif (2021) AI has potential benefits in military applications, HRMS, decision making, disaster prevention and response, GIS, service personalization, interoperability, extensive data analysis, anomaly and pattern recognition, intrusion detection, and new solution discovery using the highly configurable system and real-time simulation. For example, there is a significant potential for improvement in the effectiveness of special forces and amphibious units through the use of artificial intelligence. The role of artificial intelligence in conventional weapons as a factor in strategic deterrence and nuclear weapons, accelerating the innovation race. As a result, the strategic importance of artificial intelligence as a project of the future, with a comparison to the nuclear race of the mid-twentieth century. However, it is noted that only certain tasks have been solved on data analysis and pattern recognition, text translation. The pivotal role of the AI in in military strength evaluation and national security was emphasized by Utsav (2023).

Truong (2020) conduct a survey of the applications of AI for cybersecurity, discussion on potential security threats from adversarial uses of AI technologies, and the identification of potential research challenges and open research directions of AI in cybersecurity. Leenen (2021) emphasizes the potential of AI and big data analytics in cyber defense, particularly in detecting patterns and correlations in security event data. Big data analytics and artificial intelligence have the potential to enhance cyber defense. Current automated systems based on syntactic rules may not be sophisticated enough to handle the complexity in the cyber defense domain.

Damaševičius (2023) provides a comprehensive overview of AI's impact on various fields, including economics, finance, and innovation. This is further supported by Ruiz-Real (2020), who identifies AI's role in business and economics, particularly in digital marketing and decision making. These studies collectively highlight the transformative potential of AI in these domains, from enhancing forecasting techniques to improving cybersecurity and business operations. Taylor (2019) found that AI-enabled systems enhance defense capabilities, the challenges in acquiring such systems for governmental

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defense, and the need to recognize the misalignment of AI procurement with established procurement elements. According to Ramirez (2020) artificial intelligence methods used to predict economic indicators are artificial neural networks, adaptive systems of diffuse neuro inference, genetic programming, support vector regression, machines extreme learning and other machine learning techniques. One of the most promising AI technologies is LLMs. Despite the fact that it is very difficult to monitor developing new models and architectures, the vast majority of the principles remain the same.

2. Investigation Results

To determine the potential consequences of the use of AI for military and economic capabilities assessment we used a systematic approach. Its components were used as a methodological basis, which made it possible to present a holistic vision of the system architecture of capabilities analysis.

The comparative method allowed authors to compare the potential of different instruments and models that were developed in the area of LLM, and to assess the possible consequences of using them. The basis of the work was the data from different sources: the United Nations (UNROCA), Stochholm International Institute of Peace Research (SIPRI), International Institute of Strategic Studies and Statista. By integrating these approaches and data sources, the study not only underscored the transformative potential of AI in enhancing strategic capabilities but also highlighted the critical need for careful and contextual application of these technologies to avoid unintended consequences.

During the development of necessary architecture, we started from interviewing practioners in defense industry to create the list of requirements for our project. It was necessary to construct a system that could work completely on offline network or locally on only one machine. This could give us a possibility to work with sensitive information. The other consideration was about incorporation of users' metadata to restrict their access according to the privilege level. In our case we tested only local models on CPU/GPU which could be loaded into RAM. The increasing complexity of military operations necessitates robust and secure data management systems. In the modern strategic context, the application of AI into the assessment of military and economic capabilities presents both transformative potential and complex challenges.

Our experimental setup involved interviewing practitioners in the defense industry to tailor AI systems to actual operational needs. This was crucial to ensure that our architecture could operate robustly in sensitive environments, disconnected from any network, hence safeguarding against cyber threats. These findings resonate with Truong et al. (2020) who discuss the dual-edged nature of AI in cybersecurity, stressing both its potential in fortifying cyber defenses and its vulnerabilities to adversarial attacks. To address this, we have developed an architecture designed specifically for data exchange within the defense industry, capable of operating entirely offline at the local level.

This architecture encompasses several critical components, each interlinked to ensure secure, efficient, and rapid data processing and retrieval. The resulting schema is presented in Fig. 1.

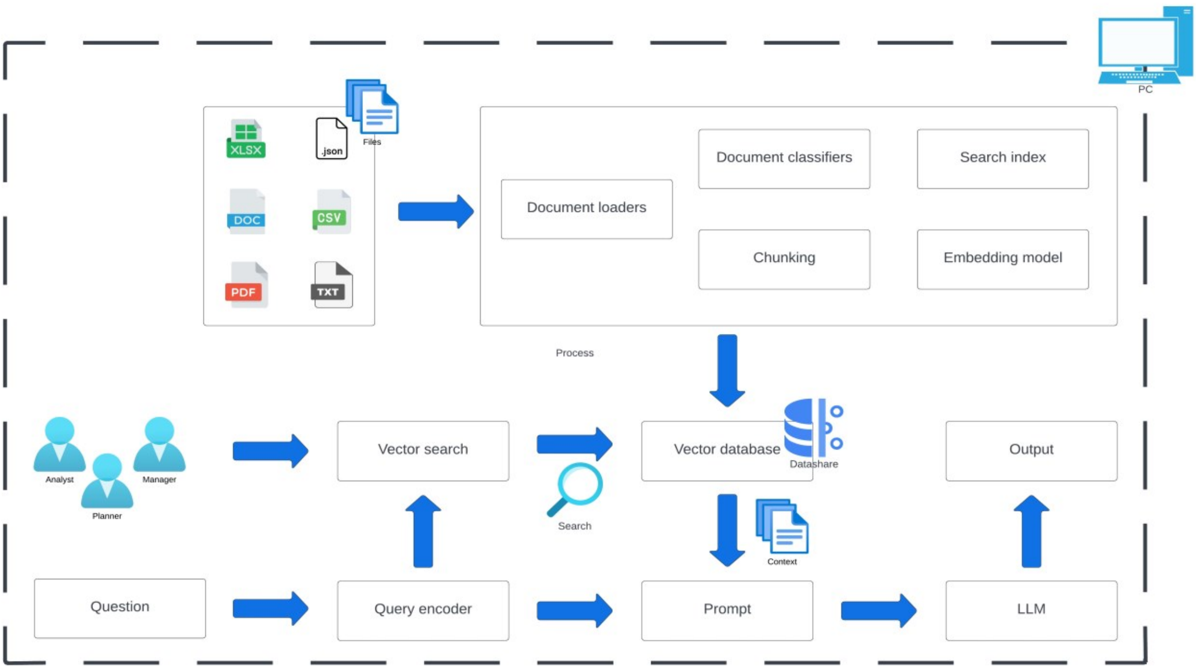

Fig. 1 The architecture of data exchange in defense industry based on offline network at the local level

Fig. 1 illustrates the architecture of data exchange in the defense industry, designed to operate within an offline network at a local level. The diagram shows a multi-layered network structure, emphasizing robust security protocols and isolated data handling mechanisms to ensure secure data flow without external connectivity. This architecture supports localized decision-making and maintains high data integrity and security, crucial for sensitive military environments.

The system is designed to cater to three primary user roles: Analysts, Managers, and Planners. Each role has tailored access to the system, ensuring that users can efficiently perform their specific operational tasks. Analysts are primarily engaged with data analysis, Managers oversee operational integrity, and Planners use the data for strategic decision-making.

Data enters the system through Files, which consist of various documents and data feeds. These are first processed by Document Loaders, which upload and store data within the system. Subsequently, Document Classifiers categorize the uploaded data into relevant groups for easier accessibility. The Chunking process then breaks down large files into smaller segments, enhancing the manageability of data. This processed data is indexed by the Search Index for quick retrieval and further encoded into vectors by the Embedding Model, which facilitates advanced data retrieval techniques based on semantic content.

The core of the system's interactivity with users is the Query process. Users input Questions, which are transformed by the Query Encoder into vector forms. These vectors are used to conduct searches within the Vector Database, which stores all encoded data. The Vector Search mechanism identifies and retrieves the vectors most relevant to the query, ensuring that users receive the most pertinent information.

LLMs are trained on large volumes of text, typically billions of words, that are simulated or taken from public or private data collections. This enables them to interpret textual inputs and generate human-like textual outputs. LLMs already help search engines understand a question and formulate an answer. Breakthroughs in the LLM field have the potential to drastically change the way organizations conduct military and economic capabilities, including enabling the automation of tasks previously done by humans, from generating code to answering questions. A key feature of this architecture is the integration of LLM. The LLM processes Prompts, which are refined queries formulated based on user Questions and the results of the Vector Search. It synthesizes information from the Vector Database to generate Outputs that are contextually relevant and insightful.

The final Output from the LLM is presented back to the users, providing them with actionable insights and answers to their queries. This Output can influence subsequent user interactions with the system, as users refine their questions based on the received information, creating a dynamic and iterative process of inquiry and analysis.

Further, our analysis identified the necessity for AI systems to incorporate user metadata effectively to adjust access based on privilege levels—a critical factor in maintaining data integrity and operational security. This aspect of data management and classification draws parallels with Leenen and Meyer (2021) who advocate for the integration of big data analytics and AI to detect patterns and correlations in security event data, significantly boosting cyber defense mechanisms.

This detailed breakdown provides a comprehensive understanding of how each component functions within the network and their interdependencies. The deployment of such an architecture allows for the safe handling and processing of sensitive information, mitigating the risks of cyber threats and data breaches. By integrating advanced AI capabilities at the local level, this system enhances real-time analytical processing and decision-making. The figure clearly demonstrates a strategic approach to integrating technology with operational needs, providing a scalable solution that can be adapted for various military applications. The ability to operate independently of a central network reduces latency and increases response efficiency, crucial for operations in remote or sensitive environments.

An important advancement in our study was the application of AI in offline settings, utilizing local models that ensure sensitive data remains within the confines of the intended operational environment. This approach aligns with Taylor (2019) who discusses the challenges governmental bodies face in procuring sophisticated AI systems that comply with established standards yet are agile enough to meet contemporary defense needs.

Our research also highlighted the potential of AI to transform economic analysis, as discussed by Ramirez (2020) who explores various AI methodologies like neural networks and support vector regression in predicting economic indicators. These techniques enable a more nuanced understanding of economic trends, which can be pivotal in strategic planning and resource allocation.

The deployment of the AI-driven architecture we developed signifies a methodological innovation in the use of AI for military and economic capabilities data analysis. It not only enhances real-time analytical processing and decision-making but also ensures the safe handling of sensitive information. This dual capability is crucial in a strategic context where both speed and security are paramount.

The synthesis of AI with traditional data analysis methodologies, as explored in our architecture, offers a comprehensive approach to understanding and leveraging AI's capabilities in military and economic contexts. By integrating cutting-edge technology with rigorous validation processes, we can better anticipate and mitigate the risks associated with AI applications, ensuring they contribute positively to national and economic security.

Overall, the deployment of this AI-enhanced architecture signifies a strategic approach to integrating technology with operational needs, providing a scalable and secure solution adaptable to various military applications. It exemplifies a methodological innovation in the use of AI for military and economic capabilities data analysis, ensuring the safe handling of sensitive information while mitigating the risks associated with cyber threats and data breaches.

The security risks associated with AI technology are profound, especially when applied to strategic military and economic domains. Numerous studies have highlighted a variety of security concerns surrounding AI, encompassing ethical issues, technical vulnerabilities, and data integrity. Given these concerns, it is imperative for government bodies to bolster their support through increased financial investment and the establishment of robust policies. Such measures are vital to foster a conducive environment for the sustainable growth of the AI industry within national security frameworks.

At a technical level, our research emphasizes the necessity of developing AI systems that are not only advanced but also secure from potential cyber threats, a challenge that requires significant investment and innovation. On the matter of data and ethical security, the sensitive nature of the data involved—especially in military applications—demands stringent protection measures. This involves crafting laws that safeguard personal and organizational data privacy without stifling AI innovation.

Our approach advocates for AI systems that respect humanistic values and adhere to ethical guidelines, ensuring that AI operations within the defense sector are conducted responsibly. Efforts must be concentrated on discovering and implementing best practices that enhance the ethical decision-making capabilities of AI systems, thus ensuring that these technologies act in ways that are beneficial to society and aligned with broader strategic objectives.

3. Conclusions

This research demonstrated the potential for AI and advanced computational techniques to transform the analysis of military and economic capabilities. Extending these approaches to broader sectors could accelerate discovery and technology development. The data-driven analysis enabled by large language models points towards new possibilities for recognizing patterns and generating insights from vast troves of unstructured data related to economic and military factors. By training LLMs on domain-specific corpora of reports, research, and policy documents, they can surface non-intuitive relationships from across disciplines. Reinforcement learning further allows optimizing complex decisions and strategies through iterative modeling.

Together, the integration of knowledge-driven AI with rigorous statistical analysis and validation provides a methodology for military and economic analysis superior to either humans or AI alone. This study demonstrated the value of mixing computational and experimental methods in a hybrid intelligence approach. Applied thoughtfully, AI can enhance foresight and quantitative modeling to better inform capability planning and policy.

However, care must be taken to validate AI systems to prevent biases and misuse. Ongoing research should ensure transparency and ethics around military and economic AI applications. Overall, this emerging field promises to transform data-driven anticipation of threats and opportunities in a complex world, if deployed responsibly. For the practitioner sphere, this work provides theoretical basis and guidance to those currently employed in the field, enabling them to quickly seize the unlimited potential of AI in military and economic development. Nonetheless, for researchers working in this field, we outline the profile of each topic area and the research gaps, which will have an important enlightening force and stimulating effect on future research in this field.

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Feasibility of Casualty Evacuation by Unmanned Systems

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Abstract

Development of unmanned systems has registered unprecedented progress. They provide a wide range of tasks in contemporary battlefields and the process of finding their new applications is still ongoing. Medical support is one of the areas where unmanned systems have found their application as well. The aim of the paper was therefore to carry out research on feasibility of casualty evacuation (CASEVAC) by unmanned systems. Research was executed as qualitative research using methods of analysis, observation, personal experience, comparison and generalization to comprehensively describe different aspects of CASEVAC executed by unmanned systems. Furthermore, as and quantitative research using method of comparison focused on multiple parameters of unmanned systems that are essential requirements for fulfillment of CASEVAC tasks. Research process started with study of available documents concerning unmanned systems their analysis based on personal experience and identification of factors that influence feasibility of CASEVAC by unmanned systems. Furthermore, we compared multiple parameters of different unmanned system solutions with required ones and identified suitable solutions. We found out that beside unmanned aerial systems that were traditionally deliberated for CASEVAC tasks great development of unmanned ground and aquatic systems has been achieved. The feasibility of unmanned systems for CASEVAC was confirmed and areas of further development have been identified. The paper comprehensively analyzes a variety of aspects that have to be taken into account when considering execution of CASEVAC by unmanned systems and sort them into categories.

KEY WORDS: *unmanned systems, unmanned ground systems, unmanned aerial systems, unmanned aquatic systems, casualty evacuation, medical evacuation*

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1. Introduction

Main task of military medical services is to preserve and restore health and recover fighting ability and combat power. Military medical services therefore provide a full range of medical care, containing preventive measures, treatment and medical evacuation (MEDEVAC).

MEDEVAC is the medically supervised process of moving any person who is wounded, injured or ill to or between medical treatment facilities as an integral part of the treatment continuum. MEDEVAC is executed by dedicated transportation assets, under supervision of medical personnel to most suitable medical treatment facility (MTF).

Complex operational environment and complicated tactical situation not every time offers possibility to transport wounded, injured or ill person by MEDEVAC assets and in escort of medical personnel. According to Brezina and Majchút [3] transport has an essential role in solving crisis events. Above-mentioned facts are the reasons why CASEVAC is sometimes organized to cover insufficiency of sources or to reach medical timelines. CASEVAC is opportunistic transport of casualties executed either by transportation assets not dedicated to MEDEVAC or executed without supervision of medical personnel and in majority of cases both conditions are met.

Unmanned military systems and robots are being used more and more [11] in contemporary military conflicts and executes unprecedented scale of tasks and operations to support military troops. The use of unmanned aerial vehicles in many roles is one of the fastest growing of all fields in military aviation [19]. Unmanned systems provide tasks from purely military tasks to tasks of logistic support. For purposes of medical support are unmanned systems used to resupply forwarded medical capabilities, including resupply of blood and blood products or medical equipment. The range of these tasks and operations will definitely grow in future military operations.

The idea of unmanned systems to be used for CASEVAC is not new. Medical subject matter experts have been dealing with it for more than two decades. The aim of the paper is to comprehensively investigate aspects of the CASEVAC executed by unmanned systems and possibility to use commercially produced unmanned aerial systems, unmanned ground systems and unmanned aquatic systems for military CASEVAC.

2. Different Aspects of CASEVAC Executed by Unmanned Systems

When considering execution of CASEVAC by unmanned systems on battlefield great variety of aspects have to be taken into account. The aim of this chapter is to comprehensively analyze these aspects. Due to the fact that a great number of different issues were identified it will be therefore beneficial to classify them into several categories with similar or akin aspects.

2.1 Technological Aspects

The most important area of the aspects as far as feasibility of CASEVAC by unmanned systems are technological aspects. We can divide them into three subgroups.

We will begin with aspects in connection with unmanned systems alone. The first precondition to use unmanned system for the purposes of CASEVAC is ability to carry enough weight. Unmanned systems have to be able to carry weight of the casualty/casualties itself increased by weight of the medical equipment and medical material. Contemporary development of the majority of unmanned systems allows evacuation maximally two casualties at once. But multiple advantages of transportation only one casualty will be probably decisive for single casualty CASEVAC to the future.

The second precondition is to have the range that is enough to carry out CASEVAC mission. This range is defined as needed distance to evacuate the casualty to the zone where medical continuum of care could proceed by further MEDEVAC or by medical treatment of the casualty in the closest suitable medical capability (Forward Surgical Team, MTF Role 1, MTF Role 2, MTF Role 3, etc.).

Presence of medical equipment on board of the unmanned system necessary to monitor health status of casualty or even medical equipment able to provide limited required medical care would be beneficial for survivability and the prospective treatment of casualties. Such medical equipment could be supervised by artificial intelligence or remotely by medical personnel. Furthermore, the provision of ballistic protection of casualties as not necessarily required feature. But the existence of ballistic protection could increase survivability in case of intentional or unintentional kinetic actions of the enemy.

Moreover, aspects in connection with safe ride standards that include restraints and safety issues concerning air quality, noise levels, temperature levels, vibration levels, lightning and acceleration limits of unmanned systems. The category of unmanned systems which is influenced the most by safe ride standards are unmanned aerial systems. Reaching acceptable levels of mentioned indicators in this category of unmanned systems is the biggest challenge. This fact favors unmanned ground systems and unmanned aquatic systems to be used in greater frequency in the theater of operations.

Chemical, biological, radiological and nuclear (CBRN) environment is the one that creates space for massive use of unmanned systems for CASEVAC purposes. Use of unmanned system will not put another personnel into risk of being contaminated by CBRN agents [9], will provide fast and accurate transportation of casualty to the safe zone in relatively short period of time and will offer time for decontamination of casualty and further treatment according to the needs.

It is important to mention aspects in connection with artificial intelligence which have become ubiquitous in the modern battlefield. This phenomenon must be taken into account where security of CASEVAC executed by unmanned systems is concerned. Recognition of CASEVAC means that are included under protection according to International Humanitarian Law especially the Geneva Conventions and their Additional Protocols is key challenge in development of unmanned systems designated for CASEVAC. On the other hand, strong advantage of unmanned systems using artificial intelligence for CASEVAC purposes could be reliability and removal of human errors. Analyses of aviation incidents cite human factors to be the predominant cause. As unmanned aerial vehicles become increasingly automated, human factors will be mitigated suggesting a future increasing safety profile [8].

2.2 Geographical and Meteorological Aspects

Second area of aspects that influence unmanned systems to be used for CASEVAC are geographical and meteorological aspects, in general aspects that do not dependent on unmanned system itself and at the same time are not dependent on destructive actions of the enemy. Aspects that are interconnected with the condition of not being able to use unmanned system due to the following reasons. Terrain complexity has potential to restrict or vice versa support use of unmanned systems for purposes of CASEVAC, e.g. lowlands, mountainous terrain, swampy terrain, wetlands, terrain with a rich tangle of rivers, seas and oceans etc. Actual weather conditions will definitely impel decisions on the use of unmanned systems in the air, on the ground, on or underwater level. What is more, extremely hot or cold weather conditions will cause limitations of unmanned systems use for CASEVAC purposes or will require special equipment, e.g. ground unmanned system specially adapted for the use in winter conditions on the snow and ice.

2.3 Tactical Aspects

The third area of aspects are tactical aspects, especially those in connection with destructive actions of enemy. Unintentional kinetic actions executed by automatic weapon systems creates necessity to provide unmanned systems by autonomous protective capability IFF [18]. Then deliberate kinetic or non-kinetic actions of enemy despite properly used symbols of Red Cross, Red Crescent or Red Crystal in accordance with Geneva Conventions should not be omitted.

2.4 Clinical Aspects

Clinical aspects are extremely important, and this fourth area covers all aspects related to the clinical status of casualties. Decisive is the fact that casualty prior to the CASEVAC executed by unmanned systems is stabilized due to the impossibility of emergency care provision during transportation. Fully automated or remotely controlled medical devices can partially cover provision of medical care and possibility to react on changing clinical status of the casualty. Nevertheless, treatment of the casualty and ability respond toward stabilization of casualty' medical conditions will be very limited.

More restraints are imposed by combination of casualty clinical status and unmanned system (ground, aerial or aquatic) to be used for CASEVAC. Especially for the CASEVAC executed by the unmanned aerial systems there are numerous limitations but basically can be stated that there are no absolute contra-indications. Each case must be judged on its merits, weighing the advantage of the transfer to the casualty against the possible harmful effects of the evacuation. The crucial moment of every casualty evacuation is time. Medical timelines have to be reached. Generally, the fact of reaching medical timelines is the factor that will be usually in favor of using unmanned systems. The more are medical timelines reduced to minimum the higher is probability of successful prospective treatment in the higher echelons of medical care. Survivability and treatment of casualty would be supported by provision of data on medical status of the casualty to the receiving medical capability gained by medical equipment on board of unmanned system.

2.5 Other Aspects

The fifth area of aspects are ethical ones, and those aspects cannot be excluded. Unmanned systems are to be used for CASEVAC so long as the relative risk to the casualty is not increased by using of unmanned system itself when compared to the clinical status of the casualty and the prospect of CASEVAC benefits. Consequently, there will still always need to be a risk versus benefit decision for the evacuation of wounded military personnel [8, 9].

Economic aspects are ones that will support the use of unmanned systems for every possible purpose on the battlefield and of course this will include the use for the purposes of CASEVAC.

3. Unmanned Systems

Unprecedented development of unmanned systems has been achieved in the last decade. It has been accelerated by ongoing armed conflicts in the world, especially Russo-Ukrainian war [22], Israel-Hamas war, but as well conflict between Israel and Iran, hostilities in Nagorno-Karabakh and other territories in the world. One of the possible purposes that unmanned systems can be used for is evacuation of the casualties. According to Parker [18] four levels of care could be provided on board unmanned aerial vehicles, but the most likely provided care in the near future is the transportation of casualty itself without any other personnel on board. That is why this process of moving the casualty by unmanned system is likely to be referred to as CASEVAC executed by unmanned system.

Large number of different companies worldwide are devoted to the development of unmanned system technologies. Besides traditional unmanned aerial systems also unmanned ground systems and unmanned aquatic systems are undergoing rapid development.

3.1 Unmanned Aerial Systems

Unmanned aerial systems were first to be deliberated as a means of CASEVAC in contested environment. Mainly due to the broad advantages that are connected with transportation of casualties in the air providing great velocity and thus reaching medical timelines. Several defense and commercial companies demonstrated outstanding development of unmanned systems technologies in connection with possible execution of CASEVAC by these systems. Technical solutions are mentioned as follows.

BAE Systems – T-650 is an electrically powered UAV that features an impressive payload capacity of up to 300 kilograms. The system has a range of 30 kilometers with its maximum payload or 80 kilometers without payload. Constructed from lightweight carbon fiber, the T-650 can achieve a maximum speed of 140 kilometers per hour and features extendable arms that can be detached for transportation purposes. The T-650 is an evolution of the T-600, which serves as BAE Systems' testbed platform and technology demonstrator (see Fig. 1).

In September 2023 BAE Systems and Malloy Aeronautics showcased the capabilities of the T-600 during NATO's Robotic Experimentation and Prototyping with Maritime Uncrewed Systems (REPMUS) exercise in Portugal, during which it successfully released an inert Sting Ray training-variant anti-submarine torpedo during a flight mission at sea for the first time.

Fig. 1 BAE Systems T-650 in CASEVAC version. Source: www.euro-sd.com

Currently the T-650 is working on batteries, which justifies the relatively reduced range when loaded. However, BAE Systems sources confirmed to EDR On-Line that development studies are ongoing for a hybrid system based on a thermal engine and batteries, which would considerably increase the range. BAE Systems is planning to have a prototype of the T-650 ready by late 2025, early 2026 [6].

Fig. 2 DPI UAV Systems – DP-14. Source: www.army.mil

DPI UAV Systems – DP-14 Multi Mission UAS is multi-mission unmanned aerial system designed for precision aerial resupply (see Fig. 2). The DP-14's advanced tandem design enables class-leading cargo carrying capacity, range, endurance while minimizing footprint. The system can carry 195 kilograms payload to beyond 130 kilometers and sprint up to 194 kilometers per hour. All terrain landing gear for uneven ground, slopes to 15 degrees and heaving pitching rolling ships [5].

Fig. 3 Tactical Robotics, Ltd. Cormorant UAV. Source: www.vertical.mag.com, www.auvsi.org

Tactical Robotics, Ltd. – Cormorant UAV – can carry two patients, it cruises between 185 and 222 kilometers per hour and has 5 hours loiter time (see Fig. 3). It has two laser altimeters, a Dopler altimeter for use in dust or brown-out situations, GPS, and inertial/electro optical navigation sensors [18].

Tactical Robotics has successfully performed a first "mission representative" demonstration with the Cormorant UAV for its lead customer, the Israel Defense Forces on May 24, 2018 [20].

Table 1.
Unmanned aerial systems - comparison of selected parameters

Parameters	BAE Systems T-650	DPI UAV System DP-14 Multi Mission UAS	Tactical Robotics, Ltd. Cormorant UAV
Range	30 km (maximum payload) 80 km (without payload)	130 km	50 km (maximum payload)
Maximum speed	140 km/h	194 km/h	222 km/h
Payload capacity	300 kg	195 kg	500 kg
Capacity of patients	1	1	2
Onboard generator		4,5 kW with 3 kW available for payloads	
Material of construction	lightweight carbon fiber		carbon (fiber)-composite
Number of rotors	4	2	2
Protection of casualty/casualties	yes	yes	yes

Source: own elaboration

Comparison of selected parameters of unmanned aerial systems confirmed fact that most probable is execution of CASEVAC with one casualty only. Decreased ranges, significant speed in connection with expected payload of one casualty or two casualties are sufficient for reaching adequate medical capability (Forward Surgical Team, MTF Role 1, MTF Role 2, MTF Role 3) in compliance with medical timelines. Provision of casualties' protection is provided but is limited, higher level of protection containing ballistic protection would increase weight of unmanned system itself and decrease the range. Information about source of electricity was mentioned only in case of DP-14 but other unmanned aerial systems can use medical devices with own source of energy therefore functionality of casualty medical status monitoring and provision of medical care is not disabled.

3.2 Unmanned Ground Systems

Unmanned ground systems were firstly not considered as far as CASEVAC is concerned and development of the idea is relatively new. But in contemporary armed conflicts they are demonstrably useful for the purpose. Even though they are not able to transport casualties in short period of time for long distances. When choosing of unmanned system to be used for CASEVAC deliberation of casualty medical status which is an indicator of urgency and transportation means safety are of highest importance. Specific categories of unmanned ground systems are systems that can convert land vehicles to become an autonomously operated platform. Unmanned ground systems of different producers that could be used for CASEVAC are depicted in the following text.

Fig. 2 Hanwha Defense 6x6 Intelligent UGV. Source: www.gbp.com.sg

Hanwha Defense - the Intelligent Unmanned Ground Vehicle (I-UGV) is an artificial intelligence based unmanned ground vehicle which has been designed in the Republic of Korea to meet domestic and export requirements. The I-UGV can carry out remote-controlled operations or GPS-enabled autonomous driving to perform various missions such as surveillance and reconnaissance, transport of cargo and wounded soldiers. The fully electric I-UGV features enhanced mission capabilities, compared to the existing 4×4 Multi-Purpose UGV, or M-UGV, and other UGVs built in South Korea and was on trials with a Republic of Korea Army infantry unit in 2021.

The I-UGV can travel 100 kilometers per charge and move at a top speed of 40 kilometers per hour on paved roads and 20 kilometers per hour on unpaved roads. It has a 500 kilograms payload capacity and a detection range of 4 kilometers both at day and night. The I-UGV is fitted with a high-end remote-controlled weapon station that can lock on to targets automatically using acoustic sensors to determine the source of gunfire during the confusion of combat [7].

Fig. 3 THeMIS Cargo CASEVAC
Source: www.milremrobotics.com

Milrem Robotics - THeMIS Cargo CASEVAC provides rapid evacuation for urgent casualties from the point of injury to higher-level medical facilities. It reduces the need for manpower usually used for CASEVAC. The vehicle facilitates most NATO stretchers used in the armed forces.

Diesel-electric hybrid drivetrain enables low fuel consumption, high reliability, and reduced life cycle cost and offers possibility of full electric mode for silent operations. Zero meter turning radius enables easy maneuverability in narrow surroundings and THeMIS Cargo CASEVAC offers low center of gravity without jeopardizing ground clearance. Compact size allows easy transportability with standard equipment and air transportability is designed according STANAG 3542 [17].

Fig. 4 Ukrainian Unmanned Ground Vehicle
Source: www.defence-blog.com

Ukrainian Unmanned Ground Vehicle (U UGV). The robot has the capability to transport a real person, with a capacity of up to 100 kilograms. It boasts a mission range of up to 10 kilometers, features a secure radio channel, high-definition video streaming, and is equipped with a relay system for unmanned aerial vehicles. Powered by four independent electric motors offers durability and precision.

One of its most distinctive features is its ability to be operated remotely through the UAS-based "Dovbush" system, making it a versatile tool for search and rescue missions in challenging environments. The development of this MedEvac robot represents a significant leap forward in battlefield medical operations, where time is often of the essence [15].

Tab. 2 Unmanned ground systems – comparison of selected parameters

Parameters	**Hanwha Defense Intelligent UGV**	**Milrem Robotics TheMIS Cargo CASEVAC**	**Ukraine UGV**
Range	100 km (per charge)	1,5 h (electric) 15 h (hybrid)	10 km
Maximum speed	40 km/h (paved roads) 20 km/h) (unpaved roads)	20 km/h	
Payload capacity	500 kg	750 kg	100 kg
Capacity of patients	not specified	2	1
Number of motors			4
Protection of casualty/casualties	none	none	none

Source: own elaboration

Comparison of selected parameter of unmanned ground systems can be found in tab. 2. Possibility carry significant payload in I-UGV and THeMIS Cargo CASEVAC allows to transport more than one casualty. All unmanned ground systems provide open air transportation of casualties that made it sensitive to the weather conditions. The range in combination with speed in the terrain predetermines these unmanned systems to be used for transportation of casualties to the closest medical capability that would most likely be Forward Surgical Team or Role 1 MTF.

3.3 Unmanned Aquatic Systems

Unmanned aquatic systems have recently undergone unprecedented technological developments. These systems can be divided into unmanned aquatic water surface systems that are capable of operating on the water surface without any onboard human operator and unmanned aquatic underwater surface systems that operate underwater surface. During investigation has been found that none of the manufacturers of unmanned aquatic systems, despite their level of development, designated its use for CASEVAC purposes. Therefore, none of the unmanned aquatic systems was part of research.

4. Investigation Results

Based on our research we identified essential parameters as well as aspects that have potential to influence unmanned systems feasibility to be used for CASEVAC. By comparison of required parameters with parameter of unmanned systems that are available on open sources. Several solutions suitable for CASEVAC were identified.

All commercial solutions that were part of our investigation for the use of unmanned systems, except for the systems that can convert land vehicles to become an autonomously operated platform, have the very same attribute that is the casualty during evacuation would not have any ballistic protection. That feature must be subject to further development, casualty must have protection comparable to the soft skin, better hard skin ground MEDEVAC assets, or other transportation assets that are used for CASEVAC. A common feature of the unmanned systems is the fact that platforms are being developed for other use and transportation of casualty is just secondary use of the unmanned systems.

Positive outcome of the research is the fact that due to their ability to carry enough weight for long enough distance unmanned systems are feasible solution for CASAVEC. According to the publicly presented development outcomes of unmanned systems for CASEVAC purposes their use in peace conditions could be possible in near future.

Source of a discussion for their use in combat conditions must be also ethical considerations and the fact that casualty should not be put into greater threat than is health risk based on his or her medical conditions. Important is note the fact that one piece of unmanned system would most likely transport one casualty. That creates implications for the value of the target for the enemy with one piece of unmanned system and one casualty, on the other hand limitations for medical planners. As well as the fact that costs and feasibility of such CASEVAC would probably make it executed only when specific conditions are met.

5. Conclusions

The contemporary degree in development of unmanned systems is high and it is expected that the range of tasks executed by unmanned systems to support military operations will grow. A specific way of unmanned systems use is CASEVAC. In the past especially unmanned aerial systems were taken into account as far as CASEVAC is concerned. Nowadays unmanned ground systems are rapidly developing for this purpose and is just a matter of time before unmanned aquatic systems either on or underwater level will be adapted for CASEVAC use as well.

Besides other important considerations, provision of medical care during evacuation supported by medical equipment on board, respectively monitoring of medical conditions and protection of casualty from possible intentional or unintentional enemy kinetic actions are the greatest concerns.

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Risk Assessment in the Selection of Parts for Additive Manufacturing

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Abstract

The article deals with the analysis, assessment and determination of risk associated with the implementation of repairs to the maintenance system after a breakdown of a military wheeled vehicle. During the temporary repair, we assume the replacement of failed parts with spare parts, whose were produced by additive manufacturing process. The article describes a possible approach to the categorization of individual parts of an integrated system (military wheeled vehicle) in terms of their manufacturability using additive manufacturing technologies, especially Fused Filament Fabrication (FFF) technology, assuming the use of all currently available production materials. In case that these technologies are integrated into the logistics chain to ensure preventive or corrective maintenance of equipment, it is theoretically possible to shorten the period of unusable state caused by logistical delays while maintaining the reliability of the equipment. For the purposes of risk analysis for a wheeled vehicle, the analysis method was chosen: Failure Modes and Effects Analysis (FMEA).

KEY WORDS: *temporary repair, military equipment, additive manufacturing, fused filament fabrication, failure modes and effects analysis, risk treatment*

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1. Introduction

Contemporary technology of additive manufacturing in the machine industry makes it possible to produce products from various materials. At present, spare parts from elastomers, plastics, and thermoplastics can be produced using the mentioned technology. The technology of production of stainless steels, aluminum alloys, titanium and high-strength steels is already developed and used [1- 4].

Potential metal products by "Powder bed fusion" and "Direct energy deposition" technologies currently reach maximum dimensions of 300x400x500 mm [5]. Thus, a significant part of the total number of components of a military wheeled vehicle can be produced with these technologies. Of course, the mentioned technology cannot be used on the load-bearing parts of frames, body parts, parts of basic and additional armor protection, drive shafts transmitting the torque between the gearbox, additional gearbox and subsequently to the distribution boxes of individual axles and many other large parts. Using current technology, it is also not possible to produce vehicle suspension elements such as the standard cylindrical coil springs or torsion bars due to the absence of the required internal structure of the material, i.e. the required shape and orientation of the grains. It is still not possible to produce components made of more diverse material, i.e. crystalline material, typically metal and amorphous material. For vehicles, it is rubber that is vulcanized to metal.

In the area of production of products made of plastics, thermoplastics and elastomers, components up to dimensions of 914x609x914 mm can be normally produced [6]. The resulting maximum dimensions of the products will also cover a significant part of the components of military wheeled vehicles made of plastics, rubber and elastomers. The production technology cannot yet produce shaft seals, hoses and belts with a metal or cloth cord.

2. Default Conditions and Risk Assessment Analysis Methods

The full combat capability of military vehicle can be described as the maintenance of four basic functions, which include - mobility, functionality of the fire system (in case of combat vehicle), protection of the crew and also communication. A fundamental condition applies to military equipment as such, which is to maintain the operability of a military vehicle in combat (emergency) conditions, which means ensuring the tactical mobility of military vehicles even at the cost of using temporary repairs.

For purposes of determining the risks of manufacturing spare parts using additive manufacturing, the aspect of complexity of subsequent mechanical processing of the functional surfaces of the components to the nominal size and roughness of the surface was not taken into account. Also, the need for subsequent heat treatment of the components, which would be necessary especially in the case of metal components, in terms of achieving the required mechanical properties of the material (tensile strength, hardness, resistance to dynamic fatigue stress), was also not taken into account. From the point of view of the risk assessment of the use of additive manufacturing, it was possible to simplify, because we assume the use of a temporary repair, which is a physical intervention that allows the object that is in a faulty state to perform its required function for a limited time, until it is possible to carry out the repair [7].

For the temporary repairs purposes, the components of the systems ensuring the function of the engine and vehicle drive were analyzed in terms of the greatest influence on the mobility of military wheeled equipment.

For the purposes of risk analysis, failure modes and effects analysis (FMEA) [8] was used, which is commonly used in machine design in combination with the fault tree analysis (FTA) method.

3. Risk Analysis of Spare Parts Produced by Additive Technologies

3.1. Identification of risks of failures of manufactured spare parts

For the purposes of the subsequent analysis, the following categories of threats were identified that may arise in the event of a failure of a spare part produced by additive technology in terms of their consequences and the likelihood of the threat being realized. For the purposes of the analysis, a failure is meant to be a structural failure of components. For analysis purposes, the following severities of consequence S were identified:

I. The operability of the vehicle's powertrain is maintained to its full extent even after a component failure. It is possible to repair or replace a component that is in a failure state as part of the following planned preventive maintenance, or as a condition-based repair after complete disassembly of units and devices. Possible reduction in comfort and ergonomics of vehicle control. Value (1 – 2 according to severity).

II. The operability of the powertrain is partially reduced, but all functions of the vehicle's powertrain are preserved. There is an increased consumption of fuel or operating fluids. However, it is possible to compensate for excess consumption of operating fluids after stopping the vehicle after completing the task, or as part of regular inspections. It is assumed that the task will be completed with a maximum mileage in units of hundreds of kilometers. There is an increased transmission of vibrations of the powertrain to the ladder frame chassis of the vehicle and subsequently to the cabin of the crew. Increased powertrain noise. However, it is possible to continue operating the vehicle with respect to the need to increase maintenance requirements after use in terms of the time needed to perform it and the consumption of operating fluids and fuels beyond the defined norm. The ergonomics of vehicle control may also be affected by damage to the control elements of the powertrain. Value (3 – 4 according to severity).

III. The operability of the powertrain is greatly reduced and some functions of the powertrain are not preserved. This is the so-called safe mode, when the vehicle's electronic control unit intervenes and disables some functions, as an example it is possible to name: reduced engine power, impossibility to shift all gears, impossibility to shift reduced gears, impossibility to use the drive of both axles, impossibility to operate differential locker. However, it is possible to continue operating the vehicle without causing secondary damage to other components and units that were operable when the fault occurred. On the vehicle, it is necessary to perform a routine repair consisting of replacing or repairing the given component immediately after the task has been completed. Value (5 – 6 according to severity).

IV. The operability of the powertrain is greatly limited, in the order of units to low tens of kilometers, secondary irreversible damage to components and units would occur and, subsequently, to the complete inoperability of the vehicle. These are leakage of mechanical devices and the associated massive leaks of operating fluids, a complete leak in the overpressure part of the air supply system to the engine (overrunning of the turbocharger above the level of maximum operating revolutions). However, it is possible to leave the danger zone with the vehicle and then regroup the crew of the vehicles, transfer the payload and equipment. Value (7 – 8 according to severity).

V. The vehicle is inoperable immediately after the failure. The transmission of torque to the vehicle wheels will be interrupted. The vehicle must then be destroyed and abandoned, or it must be removed using an adequate recovery means. Value (9 – 10 according to severity).

3.2. Evaluation of the probability of failure of the manufactured spare part

Due to the fact that in the case of FFF technology, it is a relatively new production technology for providing a whole range of components from different materials that are suitable for different component shapes and their loads, it is therefore not possible to clearly determine discrete values of the probability of occurrence of a failure for spare parts for military wheeled equipment produced in this way, or intervals of values based on reliability and lifetime of products testing. Currently, these are prototype spare parts for which there is no failure intensity database or data on their failures that could be statistically evaluated. For the purposes of the analysis, the authors therefore proceeded to a qualitative assessment of the occurrence of failure based on the complexity of the topology of the part and the associated high probability of occurrence of internal structure failures of the material. Due to the complex production procedure (scan strategy) and the associated supercritical cooling rate of the material and the subsequent emergence of residual stress and the chosen production technology, delaminations and porosity occur [9 -12]. Another variable that negatively affects the probability of failure is the amount of force or thermal stress on the component.

For the purposes of analysis, the probability of occurrence of a failure is categorized O due to the complexity of the geometry (topology complexity) of the component, the following:

VI. simple thick-walled geometry (1 – 2.5);
I. indented thick-walled geometry (2.5 – 5);
II. simple thin-walled geometry (5 – 7.5);
III. complex thin-walled geometry (shell, lattice structure) (7.5 – 10).
IV.
V. The magnitude of the load on the component also affects the probability of failure, which can be categorized for analysis purposes as follows:

ad I) The component is loaded in one direction with a slight force, small torque, low (atmospheric pressure), atmospheric temperature (e.g. flexible line holders, wiring, components of the engine air supply system - low pressure part, engine filter housing, control levers, boxes for electronic control units, fuse box, battery cover) (1 – 2.5 depending on the size of the load).

ad II) The component is loaded with a compound stress of small force, small torque, low (atmospheric pressure), increased temperature in the engine-transmission compartment (e.g. holders of individual components of groups, power steering pump holder, air compressor holder, air dryer holders) (2.5 – 5 depending on the size of the load).

ad III) The component is loaded with higher force, torque, medium pressure (250 – 760 kPa), medium temperature (approx. 100 – 200 °C), (e.g. engine air supply line - high pressure part, power steering hydraulic fluid line components, components of compressed air brake system, components of the cooling system piping, pipeage of engine oil and hydraulic fluid of the hydrodynamic converter and automatic transmission, components of propulsion of auxiliary aggregates from the engine - components of the hydraulic pump, compressor, oil pump, engine starter, components loaded by the weight of individual units) (5 – 7 .5 depending on the size of the load).

ad IV) Components are loaded with maximum force, torque, maximum pressure (up to 200 MPa), or high temperature (approx. 200 – 1,000 °C). Examples can be components of the high-pressure circuit of the fuel system, components of the exhaust system in front of the oxidation filter, components of the powertrain loaded with the maximum torque of the engine, components loaded with the weight of the vehicle (7.5 – 10 depending on the size of the load).

3.3. Categorization of the difficulty of fault detection

Component fault detection D is categorized into the following groups for analysis purposes:

VI. A very high level of component failure detection capability. The malfunction can be detected, for example, by the lighting of a warning light on the driver's dashboard (MIL warning light, lubrication warning light, pressure drop on brake circuit pressure gauges). By switching the vehicle to safe mode. Detectable by hearing (value 1 – 2).
VII. High level of fault detection capability. The malfunction is evident when checking the vehicle as part of the pre-departure inspection or as part of the inspection at the stops. Especially obvious leaks of operating fluids (value 3 – 4).
I. Medium level of fault detection capability. The fault is detectable during basic vehicle maintenance. This is the detection of leakage of operating fluids during the optical inspection of gauges and leveling tanks (value 5 - 6).
II. Low detection level. The fault can be detected optically when disassembling devices and components from the vehicle (value 7 – 8).
III. The fault is not detectable at the given maintenance level (value 3 – 4).

4. Risk Assessment

4.1. Description of the risk assessment

A total of 878 individual parts of the powertrain were analyzed, while 226 items were assessed as viable for replacement with a part manufactured using additive technology. Among the reasons why in specific cases it is not possible or advantageous to approach this method is another production technology, these are electrical or electronic components, parts created by a specific technology (vulcanization, parts with functional coatings, etc.), parts made of specific functional materials (sliding bearings, rolled sheet metal parts, springs, etc.) and large parts that cannot be segmented for production purposes (die cast housing of units, forgings, sheet metal bending and forming parts) (fig. 1).

For understandable reasons, standardized components (screws, nuts, washers, rivets, locking tongues, bearings, etc.) were excluded from the analysis, due to their great interchangeability and good availability. Their piece production with this technology has no relevant justification.

For the purposes of evaluating risks analyzed by the FMEA tool, the evaluation of the degree of risk, the risk priority number, is used. Based on the combination of the probability of the occurrence of the risk and the seriousness of its consequences, it is possible to determine the degree of risk. In this case, the numerical expression of the risk can be:

$$R = S \cdot P \tag{1}$$

where R – numerical value of the risk, S – the severity of the consequences of the failure and P – the probability of occurrence of the failure [13].

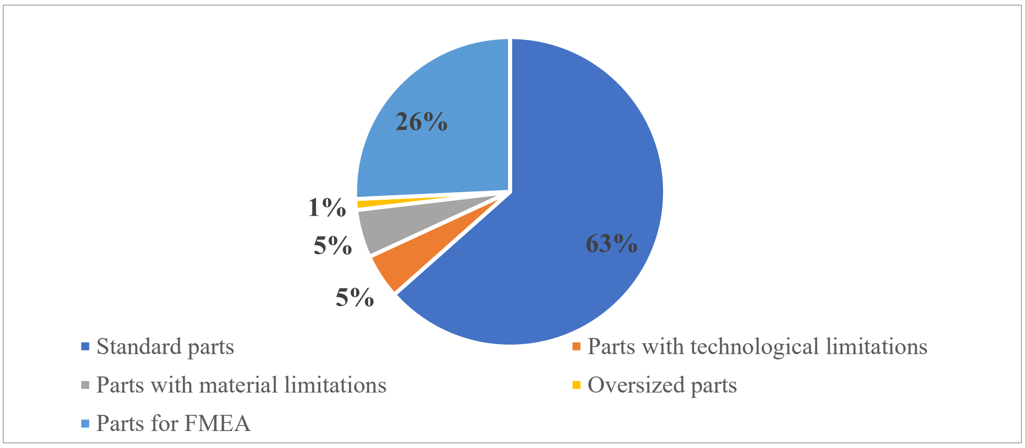

Fig.1. The share of evaluated parts of the powertrain of a military wheeled vehicle in terms of manufacturability using FFF technology [own].

Table 1.
Criticality matrix of individual parts of the powertrain produced by FFF technology – part A

Likehood	Very high				
	Very high				
	High		Screen, covering - (exhaust system)		
	High			Fibre packing - (turbocharger) Spring tube - (engine block) Spring tube - (engine block)	Set rings - (crank mechanism) Fibre packing - (crank mechanism) Coupling - (lubrication system)
	Medium	Holder - (fuel supply system)	Thermoregulator gasket - (cooling system) Thermoregulator gasket - (cooling system) O–ring (non-standard) - (Cooling system) Fibre packing - (valve cover)	Fibre packing - (turbocharger, oil lubrication) Gasket - (cooling system, lubrication system) Asbestos, copper sealing - (air intake system) Fibre packing - (cooling system)	Intake bent tube - (air intake system) Bush, insert - (turbocharger) Plastic tube - (air intake system) Plastic tube - (cooling system)
	Medium	Suction tube holder - (engine block) Filling tube - (lubrication system) Holder - (fuel supply system)	Filter holder - (fuel supply system) Fibre packing - (lubrication system) Bush, insert - (fuel supply system)	Cover ECM - (engine electronics) Special screw - (engine block) Gasket - (lubrication system) Stop gasket - (lubrication system) Plug - (valve cover)	Manifold to engine - (air intake system) Gasket holder - (engine block) Fibre packing - (air intake system)
	Low	Tube gasket - (lubrication system) Filler cap - (lubrication system) Neck - (Crank mechanism) Cover, lid - (drive belt) Holder - (fuel supply system)	Oil T–filling tube - (lubrication system) Coupling - (electrical system)	Gasket holder - (cooling system)	Neck - (engine block) Nozzle - (lubrication system)
	Low	End piece - (lubrication system) Special coupling (Fuel supply system)	Plug - (lubrication system) Protection, protector - (electrical system)	Bent tube turbo - (turbocharger) Blind plate - (engine block)	
	Very low	Neck holder - (lubrication system) Serrated split pin - (crank mechanism)		Coupling - (air intake system)	Bent tube - (engine)
	Very low				
		Operable without limitations		**Partial reduction of operability**	
		Consequence, risk impact on operability			

Table 2.
Criticality matrix of individual parts of the powertrain produced by FFF technology – part B

Likehood							
	Very high						
	Very high						
	High			Exchanger, set of tube - (lubrication system)			Cooling tube EECU of engine - (fuel supply)
	High	Return pipe - (lubrication system)		Holder, LH - (engine) Holder, RH - (engine) Coupling - (thermostat) Screw H c/w shoulder - (cooling system) Cylinder head cover - (engine head)	Return pipe - (turbocharger) Flow screw - (turbocharger)	Flow screw - (fuel supply system) Coupling - (air intake)	
	Medium	Filter cover - (lubrication system) Stop gasket - (lubrication system) Tube, manifold - (air intake system)	Plug - (engine block) Collector - (exhaust system) Gasket - (fuel supply system) Rubber connection - (fuel supply system)	Holder LD CCF - (engine) Holder PD CCF - (engine) Plug - (engine block) Cooler - (lubrication system) Coupling - (cooling system)	Oil pump - (lubrication system) Thermostat body - (cooling system) Plug -(cooling system)	Wrench pin - (crank mechanism) Coupling - (air intake system)	Piston–rod; Crankshaft - (crank mechanism)
	Medium	Rear engine bracket, LH - (engine block) Rear engine bracket, RH - (engine block)	Bush, insert - (engine block) Plug - (oil filter) Stop gasket - (oil filter) Plug - (cooling system)	Flange set - (crank mechanism) Tensing puley - (drive belt) Alternator bracket - (electrical system) Plug - (lubrication system)	Tube, manifold - (cooling system) Bent tube - (cooling system)	Sieve oil - (oil pump)	
	Low	Air wing - (cooling system)	Steel line - (cooling system)	Front bracket, LH - (engine block) Front bracket, RH - (engine block) Tube, manifold - (Lubrication system)	Plug - (engine block) Plug - (engine block) Plug - (engine block)	Pulley - (drive belt)	Special coupling - (fuel supply system)
	Low	Plug - (cooling system)		Neck - (engine block)			
	Very low	Fan carrier - (cooling system)					
	Very low						
		Significant reduction of operability		**Operability is severely limited (very limited range, possibility of secondary damage)**		**Loss of operability**	
		Consequence, risk impact on operability					

Subsequently, it is possible to proceed to the creation of a criticality matrix as a result of the failure (table 1, 2), on the basis of which it is possible to determine the acceptability of the risk and thus, in this particular case, to select specific parts for which their replacement with a part produced by FFF technology is acceptable in terms of criticality. While the acceptable rate is set differently for various areas. In technical applications, as a rule, we do not want to accept the loss of system operability due to a failure with a very high probability of failure. This statement essentially sets a maximum numerical value of risk of $R = 100$.

Parts for which the risk value reaches R=20 are replaceable without serious consequences for the reliability of the system (marked in green in table 1 and table 2 (left part)). The parts that are marked in red in the tables (right part) cannot be replaced under any circumstances, and the replaceability of the parts in the yellow field must be assessed subsequently case by case.

The risk priority number is subsequently used to determine the priority when focusing on mitigating failure modes caused by component failure, whose risk value lies precisely in the interval $R = (20, 40)$, i.e. in the yellow area (middle part) of table 1. The risk priority number (RPN) is determined by calculating [13]:

$$RPN = S \cdot O \cdot D \tag{2}$$

where O – the probability of the occurrence of a type of failure or the class number of the failure mode, D – classifies the failure detection coefficient, i.e. estimates the hope that the failure will be detected, S – the severity of the consequences of failures.

Due to the fact that the risk index R and the risk priority number is the product of the probability of the realization of the threat O, respectively the probability of the occurrence of a failure, the severity of the consequence S and in the second case in addition coefficient of the difficulty of detecting the given type of failure D. Also, on the basis of the performed categorization of the probability of the realization of the threat, two parameters enter the evaluation. One on the side of the product, the other on the side of load distribution, and the influence ratio between these parameters cannot be clearly defined for all parts. For reasons of maintaining proportionality to other coefficients, the category of the probability of failure is therefore determined as the average value of the coefficient due to the complexity of the geometry of the part and the size of the load of the part.

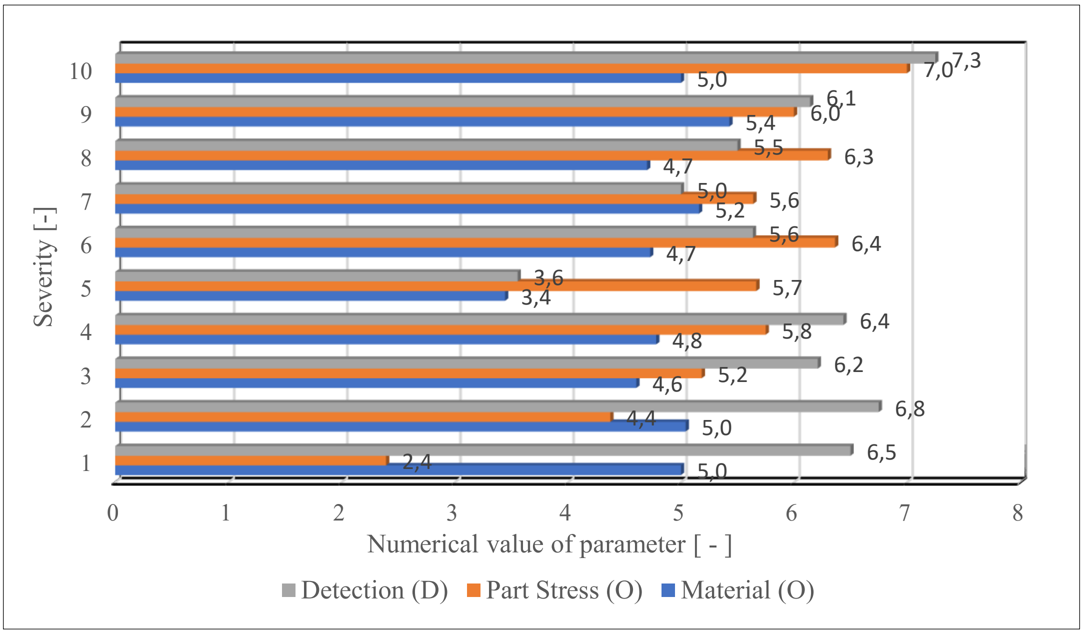

Fig. 2. The graphical interpretation of the relationship between the severity of the consequences of the failure and the other assessed parameters

In the case of failure modes with similar or identical *RPN*, it is necessary to focus attention on those failure modes that have higher value of severity of consequences of failure *S*. From the last graph (fig. 2), the average values of the assessed parameters show the relationship between the severity of the consequences of the failure *S* and the other assessed parameters *O*, *D* [13]. The graph clearly shows a predictable trend, i.e. that together with the increasing stress on the components, be it mechanical, thermal or other, the severity of the consequences of the failure also increases. What may seem surprising, however, is the fact that for components with the highest severity of failure consequences, the value of the failure detection difficulty coefficient reaches the highest values. This is in fundamental contradiction to the basic assumption of the creation of any system, namely that the failure of critical elements from the point of view of system reliability should be the most detectable.

4.2. Risk Treatment is the process of selecting and implementing measures to modify risk

For the area of temporary repairs, we can afford an exceptional procedure consisting in the removal of the source of risk. In practice, this means that for components above the maximum acceptable level of risk, we will not allow a temporary repair by replacing the component with a manufactured spare part. In the event of a failure of a part, the replacement of which in terms of the probability of occurrence of the failure, the severity of the consequences and the level of detectability lies in the area of unacceptable risk, the only alternative is the installation of an approved spare part that meets ISO 9001. In order to restore the operability of the technology, it is therefore necessary to carry out a routine repair in accordance with technological procedures for repairs, regardless of the current availability of a spare part. A temporary repair in the event of a malfunction of such a part does not affect the indicator of maintainability and assurance of maintenance of this technology.

5. Conclusion

Through analysis and risk assessment, specific spare parts from the vehicle powertrain were selected as part of this work. These could be replaced in the event of failure using unapproved spare parts produced by additive manufacturing processes within the temporary repair system designated for military ground equipment. Thus, the risk assessment determined the optimal acceptable risk level of the application of the system of temporary repairs to the corrective maintenance system of the vehicle in specific combat conditions. By the risk treatment, specific spare parts were specified, the replacement of which in the described sense does not have a significant effect on the inherent reliability of the system, in this case the military truck, from the point of view of failure. At the same time, the maintainability and maintenance assurance is improved in the sense of shortening the maintenance time after a failure and logistical delay, especially in the case of deploying technology in foreign operations, where logistical support is more complicated.

For the effective integration of temporary repairs into the corrective maintenance system, the risk assessment and determination of specific parts that may be subject to the system of temporary repairs must be followed by further analyses, in particular the analysis of the manufacturability of the part under the given conditions and the evaluation of production costs.

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Practical Evaluation of Instruments for Determining the Exact Position During Artillery Operations of the Czech Artillery

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Abstract

The thesis deals with the possibility of using civilian devices for position determination in the environment of the artillery of the Czech Army. These devices are discussed in the context of the accuracy of positioning in different environments. For the experiment, widespread and commonly used positioning devices were selected. These means were subsequently measured in spaces corresponding to the spaces in which artillery units could operate if deployed. The experimental results are then used to calculate probable target and firing position errors. Future investigation of the problem will allow the artillery units to be equipped with modern means.

KEY WORDS: *Artillery, determining the exact position, Global Navigation Satellite Systems, Operational Efficiency, Civilian assets in the military.*

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1. Introduction

The primary mission of artillery, along with other combat support units, is to provide support to combat units. Artillery supports combat units primarily by indirect fire. Therefore, for artillery units to conduct fires effectively, they must have accurately calculated firing elements. These elements are calculated according to the technical parameters of the fire vehicle, the ammunition used, the meteorological conditions and the position of the target and the firing position.

The artillery of the Czech Armed Forces can be understood as a system consisting of a target tracking and detection subsystem, an information subsystem for command and control, firing means, ammunition, ammunition supply and security. All these subsystems must have the capability to orient and determine the exact coordinates of their own position and other entities in the battlespace. The accuracy of coordinate determination will be particularly critical and essential for the target acquisition and fire unit subsystems as it will affect firing accuracy, ammunition consumption, and dwell time in firing positions.

There are a multitude of ways to determine position today. For artillery, the means of determining precise position based on satellite navigation system (GNSS) technology, such as the Global Positioning System (GPS) or the European Galileo system, and inertial navigation system (INS) technology are mainly used. These technologies are implemented in assets that are manufactured and dedicated primarily for military use.

Civilian precision positioning technologies, such as smartphones and commercial GPS receivers, offer an interesting prospect for military use in artillery. These devices have become highly accurate and more affordable positioning devices, opening opportunities for their integration into military systems, but with the need to meet strict military standards in terms of communication security and use.

This paper focuses on a practical evaluation of military and civilian precision positioning devices that are currently in use or have the potential for use by the artillery of the Czech Armed Forces. The aim of the investigation is to assess the potential use of commercially available devices for the needs of the artillery of the Czech Armed Forces, including a critical assessment of usability and potential threats.

The analysis will include a comparison of the performance of the devices in different conditions and the possibilities of integration into the artillery of the artillery of the Czech Armed Forces. In support of the proposals resulting from the analysis, a practical experiment based on the identification, comparison, and verification of the accuracy of civilian and military instruments for precise positioning in different terrain conditions was conducted.

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2. Literary Research

Nowadays, when new technologies are rapidly developed and integrated in the military sphere, it is essential to continuously evaluate and improve the instruments used to determine the exact position during the activities of artillery units. A number of studies can be found in the literature that address this topic from different perspectives.

According to a study by Andrle and Nghia (2017), a key element of the accuracy of positioning systems in artillery is the modeling and comparison of tracking loops for GPS signals. These systems must be able to withstand interference and provide high accuracy data in real time, which is essential for effective fire control [1]. Another important area is the integration of topographic-geodetic data into artillery systems, as pointed out by Blaha and Silinger (2018). Software support to address these issues allows for faster and more accurate responses to dynamically changing battlefield conditions, which significantly increases the effectiveness of artillery fire [2]. Blaha et al. (2021) discuss simplification methods for exploiting angular and linear measurement rules. Streamlining these processes is essential to speed up decision making and increase the overall agility of artillery units [3]. The impact of modern technology and its potential vulnerabilities is a topic highlighted by Claus (2018). In particular, the growth in anti-rocket capabilities can seriously compromise the reliability of GPS systems, which are the basis for accurate positioning in artillery [4]. According to the new Army doctrine (2021), emphasis should be placed on the integration of autonomous weapon systems and modern reconnaissance units, which require efficient and accurate reconnaissance and correction procedures. Ivan et al. (2019) [6] and Šustr et al. (2022) [7] this approach leads to further development of artillery tactics and technologies that consider the current and future operational environment.

3. Methodology

The research was conducted as part of an experiment. The experiment to compare the accuracy of the positioning means was conducted using four specific means, two means from each category:

- Moskito TI - a multifunctional military acquisition device,
- DAGR (Defence Advanced GPS Receiver) - an advanced military GPS receiver,
- Smartphone - civilian smart phone,
- Outdoor watch - civilian sports watch.

The aim of the experiment was to quantitatively evaluate and compare the accuracy of the determined means in determining the position in four cycles. The first cycle immediately after switching on the device, the second cycle after 5 minutes from switching on the device, the third cycle after 10 minutes from switching on the device and the fourth cycle after 20 minutes from switching on the device, each cycle comprising five consecutive measurements taken at the shortest possible time interval. A total of 20 measurements were taken with each device, at each site. The individual sites were selected to represent possible artillery exposure environments, which are forest, open space and urban. A database of point arrays was used to control the measurements. The coordinates of the point arrays were used as reference values to calculate the measurement deviations of each technical means.

4. Limitations

All measurements were made in randomly selected civilian areas, without intentional interference, external influence of positional data, magnetic anomalies and other variables affecting the accuracy of the point coordinates determined by the instrument. The influences were based solely on the surrounding environment in which the measurement was made. The baseline against which the deviations were determined was based on the geodetic points of the national geodetic network.

5. Results of the Experiment

The results of the measurements were used to compare individual assets and to verify the hypothesis that civilian assets can be used to the advantage of artillery units under certain conditions. Through experimentation, it was determined which means provides the highest level of accuracy under realistic conditions, and how the measurement results are affected by time and changing spatial conditions.

Table 1.
Results of measurements in the Forest

Forest				
Measure	ΔE	ΔN	ΔA	**distance**
MOSKITO	2,606	4,839	-1,170	**5,496**
	7,206	4,039	5,230	**8,261**
	4,006	4,239	1,030	**5,832**
	2,406	-1,761	1,230	**2,982**
Measure	ΔE	ΔN	ΔA	**distance**
Smart phone	2,406	-0,161	14,630	**2,411**
	2,406	5,639	9,830	**6,131**
	3,606	3,839	8,830	**5,267**
	2,006	3,039	6,830	**3,641**
Measure	ΔE	ΔN	ΔA	**distance**
DAGR	3,806	-2,561	-8,770	**4,587**
	2,806	1,839	-6,570	**3,355**
	6,206	3,639	-1,770	**7,194**
	3,006	1,439	0,630	**3,333**
Measure	ΔE	ΔN	ΔA	**distance**
Outdoor watch	6,606	4,039	3,830	**7,743**
	7,206	1,439	4,430	**7,348**
	4,206	-2,561	0,830	**4,924**
	4,806	-3,961	0,430	**6,228**

Table 2.
Results of measurements in the Open space

Open space				
Measure	ΔE	ΔN	ΔA	**distance**
MOSKITO	3,7	7,732	12,25	**8,571**
	1,3	7,532	7,05	**7,643**
	0,5	5,932	6,45	**5,953**
	-0,5	4,532	4,65	**4,559**
Measure	ΔE	ΔN	ΔA	**distance**
Smart phone	-1,9	8,532	18,25	**8,740**
	-1,3	8,132	17,85	**8,235**
	-2,5	6,532	16,25	**6,994**
	0,7	4,332	14,85	**4,388**
Measure	ΔE	ΔN	ΔA	**distance**
DAGR	-2,5	1,532	-1,15	**2,932**
	-4,7	1,332	-7,95	**4,885**
	0,1	3,932	-0,35	**3,933**
	-0,7	1,132	0,25	**1,330**
Measure	ΔE	ΔN	ΔA	**distance**
Outdoor watch	4,9	8,332	-1,95	**9,666**
	-6,7	6,332	-3,15	**9,218**
	-3,5	2,932	-2,55	**4,565**
	-2,3	0,532	-0,35	**2,360**

Table 3.
Results of measurements in the Open space

Urban				
Measure	ΔE	ΔN	ΔA	**distance**
MOSKITO	7,976	3,509	-7,760	**8,714**
	10,976	6,909	-5,760	**12,969**
	8,976	6,109	2,840	**10,858**
	7,176	1,909	0,840	**7,426**
Measure	ΔE	ΔN	ΔA	**distance**
Smart phone	6,376	0,909	16,240	**6,440**
	5,176	-0,891	15,240	**5,252**
	-1,824	0,509	13,240	**1,894**
	0,176	-0,491	10,240	**0,522**
Measure	ΔE	ΔN	ΔA	**distance**
DAGR	19,776	16,109	7,040	**25,507**
	32,776	24,109	17,240	**40,688**
	10,176	35,309	17,240	**36,746**
	18,176	19,509	25,240	**26,664**
Measure	ΔE	ΔN	ΔA	**distance**
Outdoor watch	20,376	28,309	-3,760	**34,880**
	8,776	13,909	4,240	**16,446**
	7,776	13,709	1,240	**15,761**
	5,576	10,909	1,240	**12,251**

The table 1., 2. and 3. records the average measurement errors of each instrument at all three sites in meters. The error magnitudes are expressed as deviations from the ideal value in east (ΔE), north (ΔN) and altitude (ΔA). From these values the total real distance is calculated.

6. Theory of Artillery Fire Errors

Artillery units conduct mainly indirect fire. In indirect fire, it is not possible to use optical sighting and aim directly at the target. For this reason, it is necessary to know the position of the gun and the target. When these two positional data are available, it is possible to calculate the elements for firing. Under ideal conditions, the calculated elements would be sufficient, but in reality, factors are present during firing that result in the deflection of the projectile's path and thus the position of its impact. These factors cause errors that must be eliminated or at least suppressed in appropriate ways so that they affect the accuracy of the shot as little as possible.

These errors are divided into three types:

- Shot errors;
- scatter errors;
- errors in the determination of the elements to be shot.

The determination of the target position and the errors that arise in this activity are classified in the type of errors of determination of elements for shooting. The magnitude of these errors can be expressed in the form of a probable error in determining the coordinates of the target and firing position, where the most important parameter is the accuracy of the instrument used. The magnitude of these random errors does not change over the course of the firing mission and remains constant for the duration of remaining in firing position or firing at a single target.

Formula for calculating the probable error of target coordinates in distance and direction:

$$E_{x_C} = \sqrt{{E_d}_C^2 + (E_{A_C} * cotg\theta_C)^2} \quad (1)$$

$$E_{z_C} = \sqrt{{E_S}_C^2} \quad (2)$$

Where:

E_{d_C}, E_{S_C} - the probable errors caused by errors in determining the target's coordinates in distance and direction,

E_{A_C} - the probable error due to target altitude errors,

θ_C - the range angle of the projectile, the angle enclosed by the level of the muzzle and tangent to the path of the projectile at the point of range

Formula for calculating the probable error in determining the coordinates of the firing position in distance and direction:

$$E_{x_G} = \sqrt{E_{X_{pp}}^2 + (E_{A_{pp}} * cotg\theta_C)^2} \tag{3}$$

$$E_{z_G} = \sqrt{E_{z_{pp}}^2} \tag{4}$$

Where:

$E_{x_{pp}}, E_{z_{pp}}$ - probable errors due to errors in determining the coordinates of the firing position in range and direction,

$E_{A_{pp}}$ - probable error due to errors in determining the altitude of the firing position.

The probable instrument error is determined at the range and in the direction of fire for each range. Table 4 shows the instrument errors of the instruments used in the Czech Army.

Table 4.

Errors of measurements in the Open space [8]

Means and methods of determining target coordinates	Probable instrument errors	
	In the distance (E_{d_C})	In the direction of (E_{S_C})
Laser rangefinder:		
MOSKITO*	+/- 2 m	+/- 25 m (5 dc)
LEICA-VECTOR IV**	+/- 3 m	+/- 25 m (10 dc)
PLRF 25 C (BT)***	+/-5 m	+/- 10 mil
HALLEM II	+/- 5 m	
LPR-1	10 m	
LDM 38 (PzPK Sněžka, LOV Pz)	+/- 5 m	
Radiolocator ARTHUR:		
20 km	100 m	100 m
40 km	300 m	300 m
* measurements on 5 km, ** measurements on 4 km, *** measurements on 3 km		

According to the latest findings from the ongoing war in Ukraine, it is evident that from the first shot it is standard that the enemy can target and conduct fire on a firing position within 7 minutes. For this reason, it is very useful to conduct fire without being shot. For the artillery of the army of the Czech Republic it is necessary to use an automated fire control system or meteorological preparation which is not followed by adjust fire.

In meteorological preparation are included corrections for ballistic and meteorological conditions in the topographic elements. Therefore, to use meteorological preparation, it is specified that the coordinates of firing positions must be determined by GPS, geodetic means, topographic connector or inertial navigation system and at the same time the target coordinates have been measured with a maximum allowable circular error of 15 m [9]. The effect of survey agent errors in each space over time is listed in Table 5.

Table 5.

Probable errors of positioning devices in distance and side

	Forest		Open space		Urban	
	E_X	E_Z	E_X	E_Z	E_X	E_Z
MOSKITO	5,810	5,496	8,775	8,571	8,915	8,714
	8,473	8,261	7,871	7,643	13,105	12,969
	6,129	5,832	6,243	5,953	11,020	10,858
	3,527	2,982	4,932	4,559	7,661	7,426
	3,059	2,411	8,940	8,740	6,709	6,44

Smart phone	6,414	6,131	8,642	8,235	5,579	5,252
	5,594	5,267	7,243	6,994	2,670	1,894
	4,099	3,641	4,775	4,388	1,954	0,522
DAGR	4,959	4,587	3,484	2,932	25,576	25,507
	3,847	3,355	5,235	4,885	40,731	40,688
	7,436	7,194	4,360	3,933	36,794	36,746
	3,828	3,333	2,305	1,33	26,730	26,664
Outdoor watch	7,969	7,743	9,847	9,666	34,930	34,88
	7,586	7,348	9,408	9,218	16,553	16,446
	5,272	4,924	4,938	4,565	15,873	15,761
	6,507	6,228	3,019	2,36	12,394	12,251

7. Conclusions

The analysis of the results of the research has shown that the use of civilian devices means for determining the exact position is possible, since civilian means achieve the accuracy of military certified means. The proposal resulting from the conducted research is to extend the experiment with additional variables accompanying positioning for the artillery of the Czech Armed Forces and to verify their use directly in the environment of the 13th Artillery Regiment and mortar units of the Ground Forces. Following the verification of the civilian means, analyze the situations in which it is necessary to use the instruments for precise positioning and, according to the specifications of each situation, assign the means for precise positioning that most closely matches the situation.

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Firing Data Accuracy and its Impact on the Effectiveness of Artillery Fire

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Abstract

Artillery fire must be both timely and accurate to be effective. Predicted fire is a method that utilizes available data, such as meteorological, ballistic, and location information, to achieve first-round fire for effect. The level of accuracy required for such firing data may vary depending on the national regulations and tactical situation. In this study, the authors compared the effectiveness of predicted artillery fire using two different levels of firing data accuracy. The findings indicate that utilizing modern assets and instruments to achieve higher accuracy standards can significantly decrease the amount of ammunition required to achieve the same result on the target.

KEY WORDS: *artillery fire, accuracy, fire for effect, ammunition consumption, firing data, predicted fire*

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1. Introduction

Indirect fire support is a crucial element for ground forces in the successful execution of their military operations. The ongoing conflict between Russia and Ukraine serves as a reminder of its significance. According to available sources, approximately 20,000-50,000 pieces of artillery ammunition of various calibers are fired daily and both sides struggle to provide enough ammunition to troops [1]. When planning fire support, artillery commanders must consider principles of fire direction and control. The objective is to achieve the desired outcome with minimal rounds fired. This reduces the risk of detection by the enemy and also minimizes the logistical footprint [2, 3].

Artillery fire must be timely and accurate to be effective. However, its accuracy can be influenced by many factors, such as meteorological conditions, target location errors, and many others. As a result, artillery fire is not always delivered accurately on target. The distance between the mean point of impact of the artillery shells and the target is referred to as the delivery accuracy error. However, this error can be minimized by applying appropriate means and processes, resulting in increased efficiency of artillery fire on the target [4, 5].

The precise firing data needed for truly effective fire for effect (FFE) can be obtained mainly in two fundamentally different ways. The first approach is the adjust fire procedure, which is highly accurate but has the drawback of potentially exposing the location of our guns and allowing the enemy to respond. Alternatively, the second approach, known as predicted fire, entails obtaining precise firing data prior to firing a round. The more accurate the data, the more successful FFE will be, resulting in substantial savings on ammunition [6].

The article emphasizes the importance of acquiring precise firing data to increase the effectiveness of predicted fire. It argues that the implementation and utilization of modern and accurate means by all artillery units would significantly reduce ammunition usage while achieving the same effect on the target.

As a method of investigation, an analysis of currently applied accuracy standards for obtaining first-round FFE firing data was performed [3,7]. Results were compared with the level of accuracy of modern assets commonly used in advanced armies. Based on the accuracy of investigated instruments and methods, authors created increased accuracy standards. Comparative analysis of resulting firing data errors both for current and increased accuracy standards was conducted, using mathematical methods of artillery fire errors reduction and target segmental transformation [8]. The resulting data was used to calculate the optimal consumption of artillery shells needed to achieve the desired effect on three different types of targets.

The research was conducted on a model situation of the Armed forces of the Slovak Republic, where currently valid accuracy standards for first-round FFE were set in 2010 [3,7]. Computations of errors and shell consumption were conducted

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for the Howitzer D-30A and shell OF-462, currently used in eastern Ukraine but also by the Armed forces of the Slovak Republic. Determining the specific amount of ammunition savings for a different weapon system and different doctrinal accuracy standards would require further research.

2. Input Conditions

The accuracy standards of the input data used to prepare firing data indicate the probable errors in determining the individual values that are used in the mathematical model of artillery fire. These errors are essentially determined by the accuracy achieved by the devices or tools used to measure the values involved. In the analytical part of the research, the authors identified two levels of accuracy of source data allowing artillery units to apply the procedure of predicted fire:

- *Current accuracy* – level of relatively inaccurate data, but still allowing first-round FFE, according to current applicable regulations in the Armed forces of the Slovak Republic [3,7].
- *Increased accuracy* – level of accuracy achievable when utilizing modern devices, equipment, and procedures.

The authors meticulously analyzed the modern devices and equipment already in use in the Armed Forces of the Slovak Republic to determine the specific achievable values for the proposed level of increased accuracy. Several types of modern lightweight multifunctional devices, including those installed on vehicles and unmanned systems, are already being used to determine the location of targets within units with high accuracy [9, 10]. For the purposes of this article, the JIM COMPACT device will be considered in conjunction with the TNF STERNA device. According to the manufacturer's information, the probable error of determining the target's location is at the level of 8.2 meters and sometimes even less. Therefore, this value will be used as the level of increased accuracy in this article [11].

Artillery weapon systems can be equipped with navigation and positioning devices that use inertial and/or Global Navigation Satellite System (GNSS) technology. When using a GNSS positioning device, the accuracy of positioning is guaranteed under standard conditions at a level of up to 10 meters. However, in practice, the achieved accuracy is often even higher. For the article, a value of 9 meters will be considered as a level of increased accuracy. Inertial navigation and positioning devices of artillery weapon systems can achieve an accuracy of less than 1 milliradian when determining the azimuth or direction. In addition, current computer technology and access to digital map data, even in field conditions, significantly increase the accuracy when determining altitudes. Most modern armies use digital maps contained in several systems, which offer accurate digital maps for determining altitude with a standard accuracy of 1 meter. This means that the probable error of determining the altitude of the target and the firing position can be reduced to a value of 1 meter and achievable orientation accuracy is 1 mil [12-14].

Through the necessary digitalization of the battlefield, it is now possible to transmit the required data almost instantly. This includes weather information. By using modern meteorological stations to assess the atmosphere and ballistic wind, coupled with powerful computing technology and data linking of different levels of command using modern HARRIS-type connecting means, meteorological data can be provided to artillery fire units almost immediately after the end of the sounding. With automated and secure data transmission, it may soon be possible to provide fire units with meteorological reports immediately before the actual preparation of the fire task. However, this will only be possible in rare cases, as meteorological sounding cannot be carried out continuously due to the airspace above the battlefield being flooded with meteorological sounding balloons. Therefore, the average time of staleness of meteorological reports will be kept at the level of 2 hours when analysing both standard and increased accuracy of firing data during research [15].

Table 1.

Acceptable parameters of the input data used for predicted artillery fire

Input data errors		*Current accuracy*	*Increased accuracy*
Target location probable error magnitude	range	25 m	8,2 m
	deflection	25 m	8,2 m
Weapon location probable error magnitude	range	25 m	9 m
	deflection	25 m	9 m
Altitude probable error magnitude		5 m	1 m
Gun aiming in azimuth probable error magnitude		4 mil	1 mil
Staleness of meteorological data		2 hours	2 hours
Muzzle velocity probable error magnitude		0,4 %	0,1 %
Charge temperature probable error magnitude		1,5 °C	1,5 °C
Sight rectification probable error magnitude	vertical	1 mil	0,5 mil
	horizontal	0,6 mil	0,6 mil
Calculation of firing data probable error magnitude	range	5 m	0 m
	deflection	10 m	0 m

Muzzle velocity radars to accurately determine the initial velocity of projectiles are also available. These radars utilize the Doppler effect and the fast Fourier transformation algorithm to measure the real speed of the projectile, ensuring a much higher level of accuracy compared to the traditional methods of determining cartridge chamber wear, inserting depth gauge, or by shooting at field ballistic station. With modern muzzle velocity radars, an accuracy of better than 0.1% can be achieved, which will be considered as the increased accuracy value for the research. Temperature sensors with higher sensitivity are used to measure the temperature of charges, and their accuracy is better than that of older types of thermometers. Moreover, each gun can determine the temperature of the charge independently, eliminating the inaccuracy caused by the temperature difference of the charges in the entire artillery unit performing the fire mission [16]. The guaranteed accuracy of determining the temperature of the charge is nowadays at the level of 1.5 °C.

The calculation of firing data can be done either using an onboard control system or an external computer with appropriate software for preparing firing data. This means that errors in manual or graphic methods using maps, planchets or graphs, as well as calculation errors due to rounding of partial calculations, are either negligible or have no significant impact on the overall probable error. Therefore, calculation errors for the conditions of increased accuracy standards will not be considered within research (its size will be zero). Current accuracy standards were identified in applicable regulations, field manuals and technical manuals currently valid in the Armed forces of the Slovak Republic. Both current and increased accuracy standards can be found in Table 1.

3. Methodology of Work

It is not always possible to investigate the theory of artillery fire through real shooting. However, by using the theory of probabilities and mathematical statistics, we can study the movement of a projectile along a ballistic curve and its impact on the terrain. This helps us understand the position of a certain point around which all possible values of a random variable are grouped [17], [18]. We can also examine another value that shows how the individual values are scattered around the aiming point. The simplest example of artillery fire is the firing of one gun at a point (small-sized target). To achieve the objective of the article, it is important to take into account a more intricate system. This system would involve an artillery battery engaging larger targets with specific dimensions. This would resemble the reality of the battlefield more closely [19].

From this point of view, it is important to consider three levels of factors. The first level involves the potential errors in firing at a single target using one gun. The second level concerns the possible errors in firing by a battery of artillery pieces. To address this, we need to reduce the probable errors of each gun into a single reduced system of artillery fire errors for the whole unit. Finally, the third level involves firing at a larger target, which requires a segmental transformation of the reduced errors of the firing data.

3.1 Delivery Accuracy Errors of a Single Gun

The system of errors of artillery fire consists of a set of random variables that cause the impact of the bullets to deviate from the center of the target. These errors are unpredictable and can arise from various factors such as target location errors, gun location errors, errors in the detection of meteorological conditions, errors in ballistic and technical preparation, firing table errors, and errors in computations of firing data [20]. These errors follow a normal distribution pattern, which means that the overall random error in distance and direction is also subject to this law. Delivery accuracy errors can be expressed by formulas [4]:

$$Er_{DA} = \sqrt{Er_{TL}^2 + Er_{WL}^2 + Er_{MET}^2 + Er_B^2 + Er_T^2 + Er_{FT}^2 +} \\ \sqrt{Er_{CAL}^2} \tag{1}$$

$$Ed_{DA} = \sqrt{Ed_{TL}^2 + Ed_{WL}^2 + Ed_{AZ}^2 + Ed_{MET}^2 + Ed_T^2 +} \\ \sqrt{Ed_{FT}^2 + Ed_{CAL}^2} \tag{2}$$

where: Er_{DA}, Ed_{DA}– delivery accuracy probable error in range and deflection, Er_{TL}, Ed_{TL} – target location probable error in range and deflection, Er_{WL}, Ed_{WL} – weapon location probable error in range and deflaction, Ed_{AZ} – gun azimuth aiming error in deflection, Er_{MET}, Ed_{MET} – meteorological data probable error in range and deflection, Er_B – ballistic factors probable error in range, Er_T, Ed_T – technical factors probable error in range and deflection, Er_{FT}, Ed_{FT} – firing tables probable error in range and deflection, Er_{CAL}, Ed_{CAL} – calculation of firing data probable error in range and deflection.

Another group of errors that affect the deviation of the impact of individual rounds from the mean point of impact is the dispersion or round-to-round errors. Dispersion errors are random and non-recurring errors that occur with each subsequent shot. These errors manifest themselves differently each time. The causes of dispersion errors are small random deviations of the influences acting on the projectile when fired in the barrel and outside it, and during its flight along the ballistic path. In the past, it was confirmed by calculations and experiments that the dispersion of rounds follows the law of normal distribution. The firing tables of each artillery weapon system provide numerical values of the probable dispersion errors in range, direction, and height.

Knowing the delivery accuracy and round-to-round errors allows us to determine the total errors [4]:

$$Er_{TE} = \sqrt{Er_{DA}^2 + Er_{RR}^2} \tag{3}$$

$$Ed_{TE} = \sqrt{Ed_{DA}^2 + Ed_{RR}^2} \tag{4}$$

where: Er_{TE}, Ed_{TE}– total probable errors in range and deflection, Er_{DA}, Ed_{DA}– delivery accuracy probable error in range and deflection, Er_{RR}, Ed_{RR}– round-to-round probable error in range and deflection.

3.2 Reduction of Delivery Errors for an Artillery Unit

When carrying out artillery fire with multiple guns, the battery's system of errors needs to be taken into account. To simplify the calculations of this system, a method was developed to reduce the errors. This involves replacing the battery's fire error system with a fictitious gun's error system. By doing this, we can reduce the actual structure of the system of errors of artillery fire. Basic principle of the reduction of the system of firing errors is, that it is essentially a redistribution of partial components of the system of firing errors, but not a change in overall accuracy. Therefore, the basic requirement of the reduction can be expressed as the total probable error of the must be the same before and after the reduction. It means [4]:

$$Er_{TE} = \sqrt{Er_{RDA}^2 + Er_{RRR}^2} \tag{5}$$

$$Ed_{TE} = \sqrt{Ed_{RDA}^2 + Ed_{RRR}^2} \tag{6}$$

where: Er_{TE}, Ed_{TE}– total probable errors in range and deflection, Er_{RDA}, Ed_{RDA}– reduced delivery accuracy probable error in range and deflection, Er_{RRR}, Ed_{RRR}– reduced round-to-round probable error in range and deflection.

Reduced delivery accuracy probable errors can be calculated using relations [4]:

$$Er_{RDA} = \sqrt{Er_{DA}^2 \times rr_B} \tag{7}$$

$$Ed_{RDA} = \sqrt{Ed_{DA}^2 \times rd_B} \tag{8}$$

where: Er_{RDA}, Ed_{RDA}– reduced delivery accuracy probable error in range and deflection, Er_{DA}, Ed_{DA}– delivery accuracy probable error in range and deflection, rr_B, rd_B– reduction coefficients in range and deflection.

Reduction coefficients can be determined using the correlation coefficients of an individual gun and a battery. Correlation coefficients characterize the interdependence between individual gun shots and between the shots of individual pieces of the battery [4]:

$$rr_B = \sqrt{\frac{{cr_G}^2+(k-1)\times {cr_B}^2}{k}} \tag{9}$$

$$rd_B = \sqrt{\frac{{cd_G}^2+(k-1)\times {cd_B}^2}{k}} \tag{10}$$

where: rr_B, rd_B– reduction coefficients in range and deflection, k – number of guns in battery, cr_G, cd_G – correlation coefficients of gun in range and deflection, cr_B, cd_B – correlation coefficients of battery in range and deflection.

3.3 Segmental Transformation of Reduced Errors of Firing Data

The system of errors of artillery fire and its reduction deals with the case when shooting at a point target is considered. For the case of engaging targets with specified dimensions, artillery fire theory considers the so-called segmental transformation. It is a transformation of the dimension of the target to a size that ensures that the elemental target is located with equal probability in any location of the transformed target size. However, this transformation is only applicable to repeating phenomena, specifically delivery accuracy errors. Additionally, the target's dimensions are defined by its width and depth, with the width being perpendicular to the firing direction and the depth being in the direction of fire. This yields a rectangular shape, which can be segmented using the aforementioned process. Segmental transformation of reduced delivery accuracy probable errors are defined by the relations [4]:

$$Er_{RDA}' = \sqrt{{Er_{RDA}}^2 + 0{,}038 \times D^2} \tag{11}$$

$$Ed_{RDA}' = \sqrt{{Ed_{RDA}}^2 + 0{,}038 \times W^2} \tag{12}$$

where: Er_{RDA}', Ed_{RDA}'– segmentally transformed reduced delivery accuracy probable error in range and deflection, Er_{RDA}, Ed_{RDA}– reduced delivery accuracy probable error in range and deflection, rr_B, rd_B– reduction coefficients in range and deflection, D- depth of the target, W- width of the target

3.4 Determining the Consumption of Ammunition to Achieve the Desired Effect

To achieve the expected firing effect of a target, there are fundamentally two methods that can be employed. The first method is based on continuously engaging and observing the target to judge when, or if, the desired effect occurred. The advantage of this method is that, usually no more ammunition is consumed than is necessary to achieve the desired effect. On the other hand, surprise caused by a massive fire may not be achieved at the beginning, which can significantly reduce its effectiveness. Similarly, it can be very difficult for an observer to estimate in real time the extent of damage caused by artillery fire and thus the achievement of the desired effect. Also, this method of determining the necessary consumption to achieve the expected effect of the artillery fire does not apply to fire support planning.

The second method is based on the prediction of the effectiveness of the specific artillery fire mission. It is applicable also for engaging unobserved targets and for ammunition consumption planning. Knowing artillery fire error budget, ammunition lethality parameters, and target dimensions it is possible to calculate predicted ammunition consumption for achieving the desired effect on the target. The method is based on the principle of the shelling parabolic density and is expressed by the following formula [8]:

$$N = q \times \frac{Er'_{RDA} \times Ed'_{RDA}}{AL \times \tau} \qquad (13)$$

where: N - number of rounds, q – efficiency coefficient, Er'_{RDA}, Ed'_{RDA} – segmentally transformed reduced delivery accuracy probable error in range and deflection, AL – ammunition lethal area, τ – rectification function.

4. Research Outcomes

The study of artillery fire cannot be conducted without a deep knowledge of its theory. In addition, the theory often cannot be verified in practice for logical reasons. The authors calculated the numerical characteristics of the error budget based on the determined conditions, using the theory of artillery firing and the chosen mathematical model of fire. These characteristics have been reduced for the entire firing artillery unit. The dimensions of the targets were transformed so that in the end it was possible to achieve the resulting values necessary for the calculation of the consumption of ammunition for different targets.

Table 2.

Numerical characteristics of errors of artillery fire for different accuracy of firing data elements

Analysed parametres	Unit	Accuracy standards					
Target number		1		2		3	
Accuracy standard level		Current accuracy	Increased accuracy	Current accuracy	Increased accuracy	Current accuracy	Increased accuracy
Delivery accuracy error in the range	Er_{DA} [m]	60,6327	38,7673	81,9551	63,0788	110,8428	93,0420
Delivery accuracy error in the deflection	Ed_{DA} [m]	45,1562	17,1410	59,4522	28,6889	78,5840	44,8840
Correlation coefficient of the gun in the range	cr_G	0,9494	0,8846	0,9950	0,9873	0,9969	0,9944
Correlation coefficient of the battery in the range	cr_B	0,7375	0,8296	0,6173	0,9060	0,6447	0,9495
Correlation coefficient of the gun in the deflection	cd_G	0,9940	0,9600	0,9986	0,9938	0,9987	0,9961
Correlation coefficient of the battery in the deflection	cd_B	0,9877	0,9176	0,9884	0,9504	0,9873	0,9612
Reduced delivery accuracy probable error in the range	Er_{RDA} [m]	54,4143	37,6883	54,4844	39,8599	73,7668	63,7939
Reduced delivery accuracy probable error in the deflection	Ed_{RDA} [m]	45,0289	16,8036	59,1835	28,1290	78,1854	44,1835
Reduction coefficient of the battery in the range	rr_B	0,7646	0,8361	0,6712	0,9156	0,6939	0,9547
Reduction coefficient of the battery in the deflection	rd_B	0,9884	0,9226	0,9896	0,9554	0,9886	0,9652
Segmentally transformed reduced delivery accuracy probable error in the range	Er'_{RDA}	61,7731	47,7012	61,8349	49,4349	79,3508	70,1759
Segmentally transformed reduced delivery accuracy probable error in the deflection	Ed'_{RDA}	53,6899	33,7248	70,8709	48,0753	87,3668	58,9252
Rounds consumption to achieve effect	N [pcs]	238	115	78	43	672	401
Difference in consumption (pcs)		123		35		271	
% difference in consumption		51%		46%		40%	

The above-mentioned work methodology was applied to model situations of predicted fire of an artillery battery armed with 122 mm H D-30 howitzers, OF-462 projectile and fuze KZ-88. The whole battery occupies one firing position and consists of 8 howitzers. The currently valid minimum accuracy standard of the elements of firing data was applied, but also the increased accuracy proposed by the authors, both enabling first-round FFE. In the model examples, the battery engaged the following targets:

- *target number 1 – personnel in defensive positions*, dug in, target dimensions 150 x 150 m, desired effect *neutralization*, range of fire 6 km, charge 2,

- *target number 2 – personnel in an offensive position*, dimensions 200 x 150 m, desired effect *destruction*, range of fire 10 km, charge Zm (reduced),
- *target number 3 – self-propelled light artillery battery*, dimensions 200 x 150 m, desired effect *destruction*, range of fire 14 km, charge P (full).

The results of the analysis of the system of artillery fire errors and ammunition consumption for individual model examples, i.e. targets, are presented in Table 2. For clarity, the results in Table 2 are also color-coded.

A chart was created to illustrate the achieved results, as shown in Figure 1. It is evident that by adjusting the minimal accuracy standards for the preparation of firing data, there was a significant reduction in the total ammunition required to achieve the desired effect in all model examples.

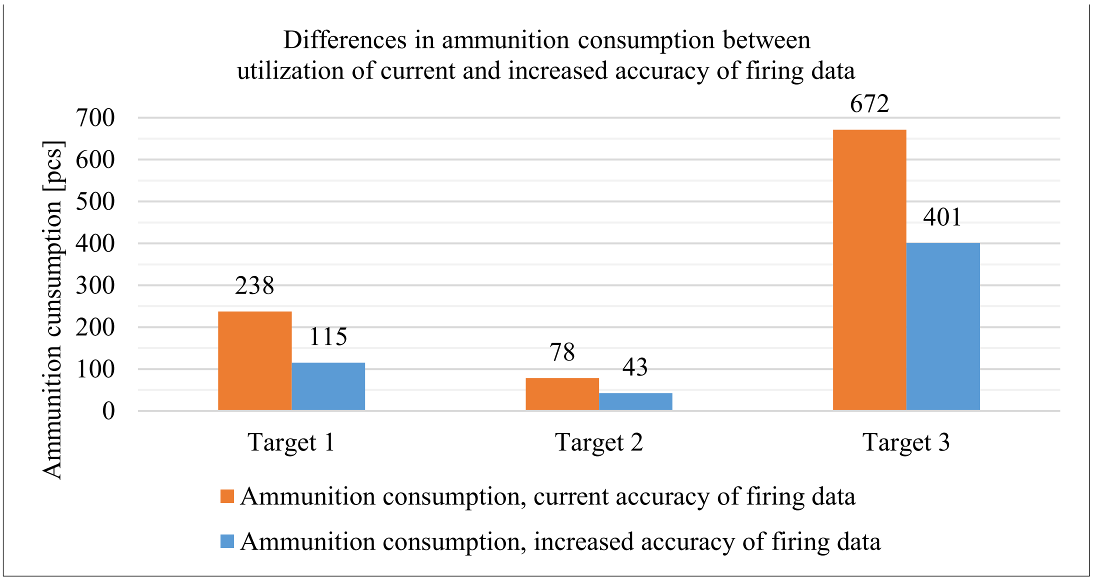

Fig. 1 Differences in ammunition consumption between utilization of current and increased accuracy standards for obtaining first-round FFE firing data.

For the individual targets, this resulted in a 51%, 46%, and 40% decrease in the total consumption of ammunition. Therefore, it can be concluded that by enhancing the accuracy of input data used for calculation of firing data, it is possible to significantly improve the efficiency of artillery fire. The situation in Ukraine highlights the need to consider the economy of fire support. Ukraine, like most NATO coalition states, does not have sufficient economic capacity to meet the requirements for fire support with a surplus [21, 22].

5.Conclusions

Through the analysis of the artillery fire on model examples, it was demonstrated that by improving the conditions under which the firing data are prepared, it is possible to achieve the same effect with a significant reduction in the ammunition used. This creates a clear objective for artillery commanders: to utilize the most precise methods and take advantage of the potential of modern devices and means to the fullest extent [23].

In theory, the number of firing guns is not the most important factor in achieving the desired effect. Rather, it is the amount of accurately delivered ammunition that matters. However, artillery experts might not agree with this statement. From a practical and tactical perspective, it is also crucial to consider how quickly the required number of shots can be delivered to the target area.

Enhancing the accuracy of artillery fire can lead to improved efficiency and reduced ammunition consumption. This phenomenon translates into a higher likelihood that the desired effect is achieved with fewer shots and a shorter amount of time spent in the firing position. In the contemporary era of advanced intelligence, surveillance, and target acquisition capabilities, the significance of these benefits cannot be overstated, as they can significantly increase the survival rate of an artillery unit on the battlefield. By reducing ammunition consumption and enhancing efficiency, the cost and logistic footprint of firing will decrease. In today's era of ammunition scarcity, every round saved can be crucial.

The article suggests guidelines for preparing firing data, taking into account the current technological equipment and its capabilities. This involves analyzing the error systems of each artillery weapon system and determining lethal areas for all available ammunition types. Using this information, recommended standards for ammunition consumption for different targets can be established. These standards will be useful for artillery commanders and fire support planners to plan fire support for maneuver units effectively, efficiently, and economically.

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The Role of Artificial Intelligence in Military

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Abstract

The artificial intelligence has become a phenomenon of nowadays. It has a significant impact on many fields, including military art and military science, what is also one the of research directions announced by NATO.

The article briefly describes the status and possibilities of using artificial intelligence in the Czech Republic and its possible applications in the Czech Armed Forces. The Artificial Intelligence creates conditions and environment for a number of areas where it can make commanders, staffs and soldiers more efficient in their activities in everyday peacetime life, its management, in the stage of their preparation for the performance of combat tasks, planning of combat, as well as in the stage of its management. The article describes the process of experimentation with conversational robots, available on the Internet, as potential means of decision support for commanders, the results achieved and gives suggestions on how to use them in military practice. In the next part, it describes possible areas in which artificial intelligence can be used in the Czech Army to make soldiers' preparation for combat tasks more efficient, to conduct credible war games, in routine processing of documents and information, in military logistics (warehouse management, diagnostics and servicing of military equipment, analysis and processing of data (image, sound, video recordings) and for deception.

The article presents an overview of theoretical works on the utilization of artificial intelligence in the Czech Army with emphasis on data and information analysis in documents, rationalization of work with documents and decision support. All in an unclassified mode at the stage of conducting experiments.

Currently, the use of so-called chat robots (Chat Robots, Chatbots) has become very widespread. Major IT companies such as Microsoft or Google have introduced various versions of chatbots for use by the general public. Their use for decision support appears to be very advantageous and available. The authors tested the COPILOT and GEMINI chatbots. The purpose and reason for the tests and experimentation of the mentioned tools was to verify how faithfully and precisely the required information compiled by artificial intelligence is true, accurate and complete. The two systems were also chosen because they draw information from the extensive databases both companies have and which are publicly available to answer user questions.

KEY WORDS: a*rtificial intelligence, decision making process, phases of artificial intelligence, military, military chatbot*

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1. Introduction

Artificial intelligence, its practical utilization, has enabled a significant increase in the field of quality and performance of informatics. The same is true of other technical elements and technologies such as virtual reality (in all its forms) and quantum computers.

The use of AI tools can be considered as subsystem of "command and control function" at all levels. AI is included into "smart" weapons, weapon systems and processes (combat robots [1], [2] transport, supply chains, targeting etc.), training simulators [3] is being explored in the MASA software (By Sword Co.), but its further role will lie in the need to eliminate inaccuracies in tactical decision-making, increasing the effectiveness of commanders' decision-making. The aim of this paper is to describe possible tools that will support commanders' decision making using artificial intelligence. The AI is constantly developing, thanks to machine learning (better sayed deep learning). It is possible to go deeper into the topic, using references [4], [5].

2. Method of Investigation

Military sources are, for obvious reasons, non-public and a disposal of information is limited. Therefore, a literature research and analysis of documents available in public sources such as the proceedings of I/ITSEC conferences in 2016-2023

[6], published papers in military-themed proceedings (Czech Military Review - Czech Republic [7], [8] or specialized journals (CHIP) and papers in the national environment (Czech Republic) has been utilized. Analogically to the LikPik system [9] (Masaryk University Brno), using deduction and synthesis, an idea of variant using chatbots to support commanders' decision making was built. To test the outputs, the available chatbots (Bing AI, ChatGPT-3,4) were utilized.

The chatbots were asked by identical questions, related to specific military topics, commonly used during Military decision-making process, Troop leading procedure, Intelligence cycle or Targeting. Finally, the answers and proposals were evaluated, esp. agreement/disagreement, completeness or incompleteness in the final text and overall logic of respond. Here, heuristic methods, based on expertise were used to investigate the validity of the chatbot responses.

3. Investigation Results

3.1. Using Chatbots as Decision Support Tools

Awareness of the use of artificial intelligence in everyday life has significantly expanded thanks to the creation of so-called conversational robots (known under the English term Chatbot – Chat robot). Obtaining information, documents for decision-making, but also complete documents and material from chatbots has become a non-negligible activity not only of school students, but also of workers in various areas of social life. The data that the artificial intelligence, based on the request of the discussant, obtains from public sources. The most famous chatbots (GEMINI, COPILOT or CLAUDE, which is currently only available in the USA) have practically established themselves and started to be successfully used (even at the cost of incredible investments by the parent companies) and improved. Commu- nication with artificial intelligence is currently possible in 40 languages (GEMINI system). The speed of query processing and response generation is determined by the architecture used (Transformers). The use of a chatbot as a decision support tool would be beneficial both from the point of view of the army's management needs in ordinary peaceful life, as well as in the phase of its deployment in an armed conflict. COPILOT and GEMINI were tested for the purpose of verifying the possibility of using a chatbot in a military environment (which were available and are rated as relatively high-quality systems from the point of view of reliability). The quality and reliability of the answers was tested by entering the same set of questions and comparing the summary information, always given at the end of the answers. Test questions and shared answers are archived by the authors. Due to the possible scope of this article, they are not part of its content. It can be stated, however, that the answers were fast, reasonably detailed, but with the fact that in both systems the sources from which the interview robot compiled the answers were stated at the end. In other words, the answers were credible depending on what source was used to construct the answer.

As an example of a summary of the answer to the question "Compare the Leopard 2A8 and T14 tanks from a tactical point of view, see Fig. 1 (Snapshot of Answer from COPILOT). This system also lists the sources from which it drew information and compiled the answer.

Fig. 1 Snapshot of Answer from COPILOT (Source: COPILOT and own snapshot by Windows tool).

The test questions were written in the Czech language; therefore, the answers are also written in the Czech language. For the completeness, the text of the summary of the answer in English is also given: „Both tanks are equipped with advanced fire control and active defence systems. However, the Leopard 2A8 has a slight advantage in power and speed, with a more powerful engine and higher top speed. In terms of armour, both tanks are protected by composite armour and ERA (Explosive Reactive Armor). <u>The Leopard 2A8 has slightly thicker armour and an active protection system that is more advanced than that of the T-90 [7]</u>", while under [7] in Fig. 1 indicated the source from which the conclusion is quoted. Here it is shown that although the source is listed, the user should also check the information obtained in this way, since in the academic environment a source such as Wikipedia or youtube.com is not considered a source where the data is valid (at least according to Czech practice), because it does not have to undergo peer review. The near future of using artificial intelligence in decision support with the use of chatbots for the benefit of soldiers in general seems real. The issue of the military is a large number of data, information and documents having the character of sensitive information (this is information that is not provided to the general lay public) up to classified information. However, the mentioned chatbots work with information available in a publicly available environment and with the fact that the chatbots do not directly verify the reliability of the information for the time being. It is assumed that the authors who compiled the resources guarantee the correctness of the content both in terms of quality and quantity. The idea of creating an equivalent of one of the tested chatbots (Fig. 1) for decision support in a military environment is feasible, but under the condition that:

- can work in a closed, isolated and non-public environment (data cloud);
- the cloud will contain verified and valid data, documents and files;

- the issue of licenses for the use of commercial chatbots in the military environment will be resolved;
- or a national system (for example - TOVEK) will be used for a specific military environment, which will undergo appropriate certification;
- the chatbot will have to process data and files also stored in distributed data warehouses;
- access to public resources (on the Internet) will be handled through a gateway that will have firewall properties.

Soldiers generally work with data, information, documents and files that are generally not publically available. They are sensitive or classified. Therefore, it is necessary all sources of data, information and documents make available in closed and secured, authorized environment, i.e. in a private cloud. The implementation of some tool with the characteristics and behaviour of a chatbot should be handled as a licensed commercial tool that undergoes a reliable and secured review, or it should be developed ad-hoc according to the requirements of the military. The decisive criteria for the choice of the implemented option will be the financial issue of acquiring such a tool, as well as the result of the process of certification, conducted by authorities of the Czech Republic, which are responsible and guarantees information security in the army or the state.

The use of the cloud as a data source for a chatbot in the military assumes that the data in the cloud is verified, and the responsible arbitrator or department will certify the factual accuracy of the data, in which the data and information will not be inaccurate, unverified and unchecked. So-called Data and Information Validation will be performed.

In the case of choosing the option that the chatbot tool will be obtained as a commercial product from an international environment, it will be necessary, as stated above, to review it in terms of compliance with national and international rules established for information security, and of course with the consent of the owner - provider license.

The same procedure should be applied also in the event that a commercial but locally developed tool is implemented for the needs of the military.

The chatbot should also be conceived as a tool being able to read data and information from sources that are not included in the cloud, but are available in other army (or department of the army) repositories, as well as in coalition repositories and clouds.

The requirement that the chatbot search and assemble the outputs of requests from public sources cannot be omitted, as commercial chatbots are currently used (e.g. the tested COPILOT or GEMINI). In such a case, however, access to public resources will only be possible through a two-way gateway. And the gateway should be so-called asymmetric, which means it should check that the request for information and data is a small data set and the response would be a large data set. It would be appropriate for requests for information and data to be checked for selected keywords that should not occur in a private environment.

In Fig. 2 (Military Chatbot model) shows a model of the use of artificial intelligence potentially usable in the army, which can realize the above requirements placed on a chatbot, will allow access to resources available in the public space and public resources, as well as to private resources. At the same time, users can use data, files, etc. available in the so-called cloud. The cloud, as a centralized solution for storing data and files, can also simplify the solution to the security issues of valid and verified data and files against their unsolicited modification into the form of fake news, their deletion, etc.

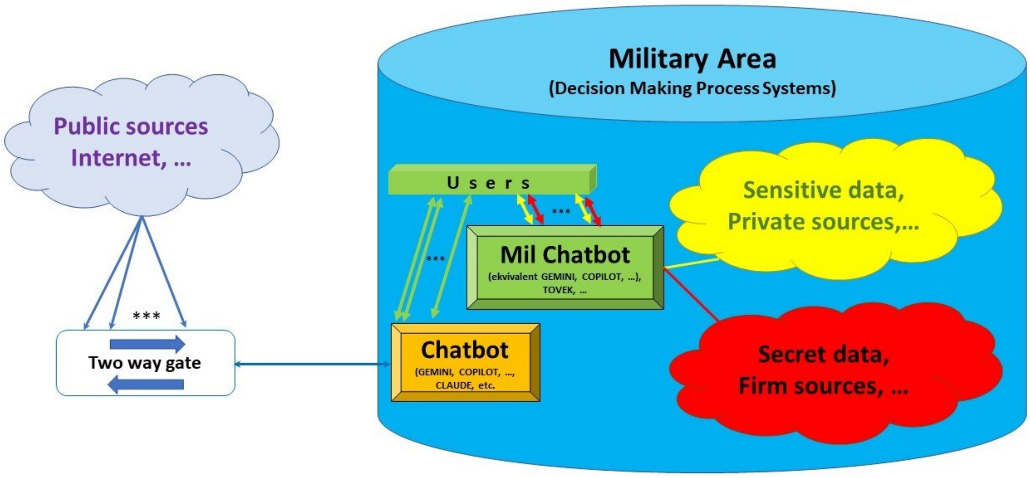

Fig. 2 Military Chatbot model (*Source: own*)

Chatbots which are able to detect fraud attempts can also be used in this environment (e.g. SCAMIO, see scamio.bitdefender.com). Especially when working with publicly available data, it is really useful for users to check whether the mail they received or the attachments in it are not fake, or whether the URL address is dangerous or not.
The practice also describes a state where artificial intelligence does not discuss with the user [11]. This situation should not occur in Military Chatbot.

3.2. Another Possible Use of Artificial Intelligence in the Military

Training of soldiers is perceived as a process consisting of education, individual training, collective training and exercises [12]. Artificial intelligence can be applied to all areas of training. In the field of training, it is mainly a virtual reality environment and a constructive simulation (a means of training staffs to conduct a battle or an operation).

Artificial Intelligence in Training Soldiers

The use of AI in teaching in a civilian environment currently dominates language training in almost any language. The created algorithms and means for communication in a foreign language between a student and a teacher are in their own way already perfect enough that students in the skill of using a foreign language in written or verbal form can be smoothly transited from the skill of a beginner to the skill of a professional. Both translators (Google, DeepL, etc.) and resources based on communication robots (chatbots) are available in public sources. From a practical point of view, it can be also stated that communication robots can be accompanied by a graphic form of an avatar in the form of a known teacher, colleague or a synthetic form of an unknown person. However, this possible solution runs into the legislative framework, where a specific person should at least express his consent to the use of a graphic form of his person in a communication robot.

Soldiers who go through the established system of career growth can (and already use) current algorithms of artificial intelligence implemented in communication robots, graphic systems for processing progress works (seminar work, ...), diploma these and other qualification documents. Here, however, it is important that in such an environment soldiers are not only users of the work that artificial intelligence has created for them, but that they understand the created content and, above all, know how to use it in practice. For this, it is necessary that the system of education of soldiers has control mechanisms, processes and authorities set up, which will have to evaluate the extent to which the soldier knows, understands and can apply the studied issue. In the same way that a list of sources appears at the end of a processed answer in more advanced communication robots, a system that will perform a so-called plagiarism check can work in a similar way.

An important aspect of the use of artificial intelligence in the training and education of soldiers is the protection of training and education systems from disinformation, so-called fake news. If training and education systems using artificial intelligence are in a closed and controlled system with verified and valid data, this threat can be almost eliminated (only the internal administrator or user of the systems can be a threat). If, in particular, the educational system is based on the possibility of using hybrid resources (publicly available - the Internet, or resources that do not carry classified information, but provide so-called sensitive information), it is necessary to strictly separate the two systems organizationally, technically and operationally, and soldiers must learn to work in such a hybrid environment. Lessons and examination procedures aimed at recognizing such information are also likely to be part of the soldier's training.

The education of soldiers, especially soldiers with a university education, should also be reoriented depending on the changes in the military environment and military technology. The gradual transition to the use of autonomous systems, combat and other robots requires a partial change in the content and scope of knowledge of soldiers and technical means in general. Even the army will have to gradually move to the environment caused by industrial revolution No. 4 (the application of informatics, cybernetics and automation), which will also change the overall content of the military. Soldiers will need to interact safely with an autonomous system, a warehouse or repair robot, a robot that works with dangerous substances (explosives, radioactive, chemical or biological substances and materials) will have to perform so-called imitation learning of robots and autonomous systems. Soldiers will have to respond and implement so-called leadership issues in a military environment, and therefore they will have to understand and know what a robot with a certain degree of artificial intelligence will do and why it does it.

New construction equipment and technologies that are incorporated into so-called 3D printing cannot be left out. In a way, the military environment creates the conditions for the implementation of so-called dark factories (spaces where devices work without lighting), where the so-called production of components, their parts and elements as well as systems of military equipment and technology will be carried out at the customer's premises (soldiers they will produce themselves if necessary). Soldiers will therefore have to have the knowledge and skills to draw the required parts, assemble a prototype, etc., because v cannot rely on the fact that the given part will be delivered to him from a non-military environment at the required time. Even the activities connected with the implementation of 3D printing in the military environment should be the subject of changes in the content of the teaching.

Artificial Intelligence in Individual Training of Soldiers

In a virtual simulation, artificial intelligence would complement or completely replace the so-called SAF (Semi-Automatic Forces) system, which in virtual (crew) simulators replace other virtual simulators in the functions of enemy forces, superior forces or forces in cooperation with the unit being trained. This proven solution would be given a higher level of quality, because a suitable and properly constructed algorithm would create conditions through a deep learning system where a simulated adversary reacts to the behaviour of trained units, where artificial intelligence can recognize undesirable stereotypes in solving tactical situations of unit commanders or combat vehicle crews. What form training could take in such conditions can be demonstrated on the ALPHA project (USA) [3], where learned artificial intelligence was implemented in the flight simulator, against which the pilots conducted air combat. Of course, the declared state that all the fights were lost by the real pilots can be taken with a grain of salt, because the conditions of the air fight and the functionality of the aircraft simulator were not published.

Artificial Intelligence in Collective Military Training and Joint Exercises

A similar approach can also be chosen in the means of so-called constructive simulation (ModSAF, OneSAF Testbed Baseline, OneSAF, WASP, etc.), when in particular the enemy's synthetic units work according to SAF (Semi-Automatic Forces) modes, but supported by artificial intelligence (for now, the UI in these simulations systems is not implemented). A possible solution would also be the use of artificial intelligence with simulation systems designed especially for conducting so-called war games (see below Artificial intelligence and decision support). A trained artificial intelligence would create the conditions and resources of the enemy in a wargame, while maintaining the desired attributes of the wargame, but at the same time it would observe possible stereotypes of the players' solutions to their own forces and thus learn how the enemy would use them. Certain elements of artificial intelligence are implemented in the SWORD (MASA Group) simulation system, but the ability of the simulator to modify the behaviour of entities in deep learning mode is not available for now.

Commanders and staffs should be prepared for situations where artificial intelligence implemented in weapon systems (e.g. drones, but also combat vehicles and tanks) supports so-called swarm behaviour in the performance of combat tasks. It must be assumed that artificial intelligence is likely to create new tactics in conducting offensive combat or in defence. This conclusion follows from the practical assumption that weapon systems will use so-called networking (see: CHIP 05/2024, Magazine about digital technologies, Volume 34, (Czech mutation), p. 20. ISSN:1210-0684) to coordinate the joint activity of units in battle.

Artificial Intelligence as a Military Decision-Making Process Support Tool

Commanders' decision-making support (MDMP - Military Decision-Making Process) is an inherent part of the commander's and his staff's work to accomplish the combat task. After receiving it, there is a phase of analysis on how to perform the given task in known and assumed conditions. The subsequent development of variants of the given task (CoA - Course of Action) and their testing is the subject of war gaming (WG - War Gaming). The war game is usually carried out using several methods (on maps, on plastic tables and in a version using holography) but also with the use of computer simulation.

Computer simulation is becoming an acceptable means of decision support (MDMP), especially in the phase of evaluation of variants (COA - Course of Action), where artificial intelligence is also starting to be used. Its outputs are available to the user if they evaluate individual variants, available in a relatively short time. For example, according to [13], artificial intelligence used in wargaming systems, it is stated that the evaluation of the chosen COA variants by the staff took a full 16 hours, while the CADET system needed only two minutes for this activity. More detailed information about data sources and artificial intelligence algorithms was (of course) not published.

Here, it is necessary to emphasize the requirement that the artificial intelligence implemented in the computer simulation can learn from previous exercises, but mainly from wars, operations and military activities, which are a source of lessons and experience for the elimination of advantages and errors that were recognized and identified in the past. Therefore, data from exercises performed with computer support (CAX - Computer Assisted Exercise) can also be used for learning.

Administrative Support of Staff Processes Using Artificial Intelligence

Routine activities in the creation and processing of documents, with which staffs and headquarters work usually have a given form and structure, can be supported and some of them automatically solved by AI. Reports, orders, methodologies, written preparations and a number of other military documents could thus be generated at least into a working version using artificial intelligence algorithms. Of course, a person will always be the last arbitrator to sign the document after the final review to make the document valid. The UI will (and already is) able to recognize which document it is. It's not just invoices, contracts and other documents. Documents that have a defined structure and are formalized are actually routinely used in the military environment. AI through learning and using metadata can significantly reduce the time needed for commanders and staff members to process documentation. In the same way, the UI can search for relevant data in stored documents. But even here it is true that the UI must learn this activity. Even so, a given document may not have the required content, even if it is formally processed in a given form. Such errors may arise when processing documents that are similar in terms of content, or the given document is an original. It also applies here that a person will be the decisive arbiter in the final content and formal form of the document.

Artificial Intelligence in Military Logistics

Artificial intelligence can arrange material on warehouse shelves. The current mode of material storage requires quite a lot of mental effort from employees when it comes to storing material by class, especially when replenishing it. Artificial intelligence can analyse the placement of material on warehouse shelves. A certain example can be the Goods Checker cloud service, which enables the material to be detected and recognized from images (photographs) of the location of the material in the warehouse, using machine learning and analysis of voluminous data. The algorithm minimizes the influence of human errors and mistakes and can increase the accuracy of information about the location of material in warehouses with different materials, in warehouses with different location, capacity, security, etc. A possible solution is presented by IBA Group with the Goods Checker solution (see: CHIP 09/2023, Magazine about digital technologies, Volume 33, (Czech mutation), p. 12. ISSN:1210-0684, and also at https://ibacz.eu/o-nas/profil-spolenosti/).

In addition to artificial intelligence, the solution to the implementation of virtual reality (full, extended, embedded) and quantum computers and their practical use is also coming to the forefront of the company's technological modernization. The combination of virtual reality and artificial intelligence in the military can be classified in the environment of diagnostics, maintenance and repair of technology.

Artificial intelligence can also increase the utility value of virtual reality, more precisely its clone - augmented reality. Augmented reality technologies can provide a look inside combat and other military equipment, ammunition and other material. Technologically, it is based on the possibility and functionality of holographic images, which are displayed on this device with the help of special iPad software (in the Czech Republic, the start-up Pocket Virtuality deals with this technology, details can be found at https://www.pocketvirtuality.com/ #home). Depending on the perspective which the user observes the diagnosed device or military equipment, the display device shows, for example, the structural elements of the given equipment, control elements, etc., depending on the direction in which the augmented reality camera and the technician's view are pointed. Even this UI application, like all those developed so far or already in use, places high demands on the computing power of the device (HW) in which the UI is operated.

Artificial Intelligence in Military Healthcare

Artificial intelligence is also being promoted in the healthcare sector, not only in routine administrative activities (processing of reports for health insurance companies), which limits the professional performance of doctors, but mainly in the diagnosis and recognition of non-standard objects in X-ray images or computer tomography. Implementation of such tools in the practice of military garrison and field hospitals and conditions of military trauma centres.

Health diagnostics, evaluation of X-rays and CT images, these are areas where artificial intelligence is already beginning to be used. X-ray images or CT image recordings, as basic diagnostic tools for obtaining views into places where a person "cannot see" and to detect "hidden" defects and anomalies in the human body, can be used to detect significantly faster with a high degree of certainty with the help of artificial intelligence. These technologies are structurally supported by computing resources with adequate computing power, as they must process high-resolution images.

Artificial Intelligence and Information Support Operations

A significant component of the conduct of operations in recent decades has been the use of STRATCOM and the conduct of PSYOPS and INFOOPS.

Strategic communication systems for commanding troops on the battlefield are and will be an inherent object of the enemy's interest in how to influence, disrupt or make impossible the fulfilment of the objectives of the operation. Transmitted intelligence information (image, text or video in both Off-Line and On-Line mode) can thus be deliberately modified with the aim of misleading the adversary. The current quality of artificial intelligence manages not only the modification of the source data file, but also the generation of new files about the non-existent state of the battlefield, which, however, can give the impression of reality. These are files with image data, voice data and video files. This can be used in conducting both PSYOPS and INFOOPS.

Deception is also a significant component of the military's activity in conducting combat activities. The process of misleading the enemy is carried out not only in the stage of conducting active combat activities, but also in the period of preparation for the performance of combat tasks. Here too, artificial intelligence can be used successfully, because it handles the work of creating or modifying documents, generating images, generating sounds and voices. AI can already generate or modify images, photographic images, video recordings or imitate the voice of a "famous person" and insert into this speech content that may not be true, may not be accurate, etc. The use of these technologies is certainly of interest to military experts in creating "Fake news". Public resources only do not provide resources or information about specific solutions, applications, implementations, and deployment conditions.

4. Conclusions

This article describes the possibility of using artificial intelligence in the segment of decision support for commanders. As a possible tool for this activity, the use of so-called chatbots appears (for now, the Chatbot /Chat robot combination is preferably used). In the abstract to the article, only one test question is presented, but total of 20 validation questions were asked, which the authors considered valid for reviewing the suitability of use for decision support.

The use of chatbots to support commanders' decision making and related administrative would be very beneficial in terms of time. It is important to follow information security policy. A possible way is to implement such chatbots in a proper way in the military environment or to develop completely new ones, being closed, protected, controlled, filled by verified and valid data, approved by relevant authority. In these terms, the information can be credible and reliable.

The implementation of artificial intelligence in the military, however, can no longer be a problem of only the military from a financial and moral point of view. It is necessary to develop the military's partnership with the academic, scientific and industrial sectors so that the requirements for the regular use of artificial intelligence in such a specific environment as the military are beneficial.

In conclusion, it must be stated that currently artificial intelligence does not have the ability that humans are endowed with, i.e. intuition, i.e. to predict what will happen on the basis of experience, knowledge and perception of the environment

(the world). But even here it is necessary to realize that intuition can disappoint. Even so, the human role is irreplaceable even with the "mass" deployment of artificial intelligence in all areas of society's life. The development of UI is very rapid indeed. Meta companies with OpenAI have already said that their language model LLaMA [14] will be able to not only carry out normal conversation, but also to actually think and plan. Reasoning and planning are considered activities that are a significant step towards achieving general artificial intelligence. It is assumed that such artificial intelligence will be able to perform tasks that are interconnected and will be able to predict the consequences of its actions.
Note. *This article has not been processed by any artificial intelligence (GEMINI, COPILOT, etc.).*

Limitations

The use of publicly available chatbots seems to be quite advantageous with respect to the speed of information retrieval. The problem, however, lies in the content and origin of the sources. The third wave of AI development (also known as enterprise AI), using large databases, utilizes data whose authenticity may not be verified and the validity of the information obtained may be doubtful.

Acknowledgements

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Analysis of the Dependability of Position Lights of Aircraft

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Abstract

This article focuses on position lights on the subsonic advanced light combat and trainer aircraft Aero L-159 Alca with an emphasis on the dependability of the position lights. Through long-term operation of the L-159 aircraft and continuous recording and reporting of faults, we are able to perform a comprehensive reliability analysis of lighting elements. Based on such observations, it is possible to create a reliability predictive model for lighting and signalling components, with the Poisson process being employed in this study. In addition, analysis and comparing failure rates can deal with the degree of criticality of the influence of position light failures on air traffic safety. The results of this study are crucial for enhancing understanding and safety measures in the area of dependability of lighting and signalling systems on modern military aircraft.

KEY WORDS: *aircraft, avionic, position light, dependability, reliability, failure rate, fault, prediction, Poisson process.*

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1.Introduction

Prediction of the technical condition of aircraft and its equipment is a significant requirement to ensure a high level of reliability of aviation technology and flight safety. The essential condition for dealing with the problem of the failure prediction is either the collection of data from the operation of the given component, or from the values of specific diagnostic parameters. Since data collection systems are common part of modern avionics systems, it is possible to use the principle of analytical estimation of errors based on the evaluation of output parameters. If it is not possible to find a suitable parameter (mileage or time until oil change, visual condition of a tire until its replacement, etc.) for the estimation of failure, the technical condition of the aircraft system or entity is evaluated only based on statistical prediction methods. [1]

Position lights are a mandatory part of any modern aircraft. Their purpose is to ensure visibility and safety during all phases of flight. In second section, we will focus on the importance of position lights and, related norms and standards. In addition, a brief description of the position lights on the selected aircraft type follows. A technological comparison of lighting elements will be conducted with focusing on design changes and innovations implemented on the new generation aircraft. [1] [2]

The most avionics faults on an aircraft are diagnosed and recorded by on-board monitoring systems. In the case of position lights, the failure is reported during an operational inspection (one-time, pre-flight, mid-flight, post-flight inspection) or during prescribed maintenance according to technical documentation of an aircraft. These inspections are carried out by the aircraft avionics engineers. It is therefore their responsibility to find and describe the fault and its cause, mission related consequences and fault mitigation. Recorded faults and failures their descriptions are collected in an integrated logistics system. Part of this registration system is the "aircraft maintenance" functionality, with specific agenda for "failure forms". All defects of lighting elements are listed here, together with all other faults and failures for all aircraft components. The collected data are analysed and process by the operator as well as provided to the aircraft manufactured for further analysis to allow them constantly improve safety and reliability parameters of each aircraft system in time.

To achieve a comprehensive dependability analysis of the position lights on the L-159 aircraft, we employed a robust methodology that involves the systematic collection, analysis, and processing of operational data. We consulted data entry and record keeping experts for data collection, which allowed us to minimize information bias in the data set. This

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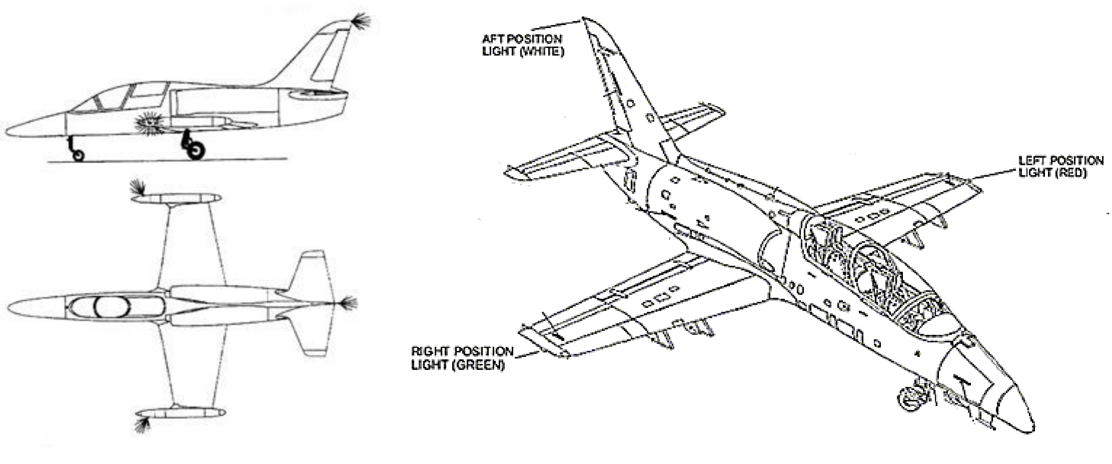
collaboration ensured that data were accurately recorded and systematically stored, increasing their validity and reliability for subsequent analyses. As a result, the risk of misinterpretation is greatly reduced. [3] As a result we achieve more precisely focuses on evaluating the probability of failure of these lighting components, considering the technological design of the aircraft's lighting systems. The analysis is grounded on empirical data derived from the operational use and maintenance records of the L-159 aircraft by the Czech Air Force.

By employing the Poisson process, we aim to develop a predictive model for the reliability of lighting and signalling components. This study is novel in its approach as it combines extensive real-world data with advanced statistical modelling techniques to enhance the understanding of the dependability of aviation lighting systems. The significance of this research lies in its potential to improve maintenance practices, spare parts planning and safety protocols for military aircraft. Through detailed analysis and comparison of failure rates, we can assess the criticality of position light failures and their impact on air traffic safety. The results of this study can be used for both the academic community and practitioners in the field of aviation safety and reliability.

2. Aircraft and Description of its Position Lights

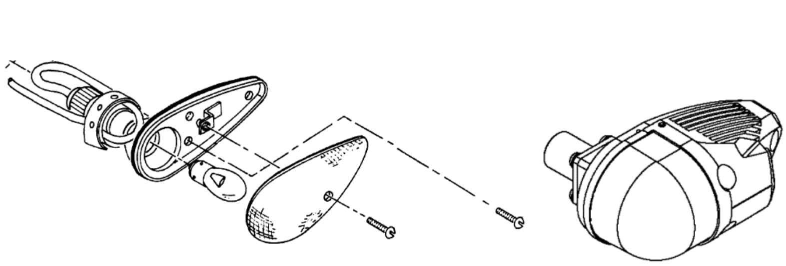
Position lights are crucial for ensuring the visibility and safety of aircraft during flight. In the past, incandescent lamps and low-pressure fluorescent lamps were commonly used in aircraft. However, recent advancements have led to the adoption of more advanced technologies such as electroluminescent lighting and liquid crystal displays. The development is increasingly focusing on the use of LEDs for lighting and signalling on aircraft due to their high visibility, reliability, and low energy consumption. [4]

The primary function of position lights is to indicate the presence of an aircraft and to determine its position and shape (Fig. 1). The L-159 aircraft (light, subsonic, fighter aircraft, single or double-seat aircraft with a wide range of missions) has three position lights on the outer surface of the aircraft. The white light is located in the highest part of the trailing edge of the rudder (vertical stabilizer or tail fin - Fig. 3). Another pair is located on the outer edge of the fuel tanks (Fig. 2). The right light is green, the left light is red. [5] The L-39NG aircraft (new generation double-seat turbofan- powered military trainer and light combat aircraft) has position lights located on each trailing edge of the wing and on the trailing edge tip of the vertical stabilizer. The colour distribution is identical to L-159, both following the standards of International Civil Aviation Organization (ICAO). [6]



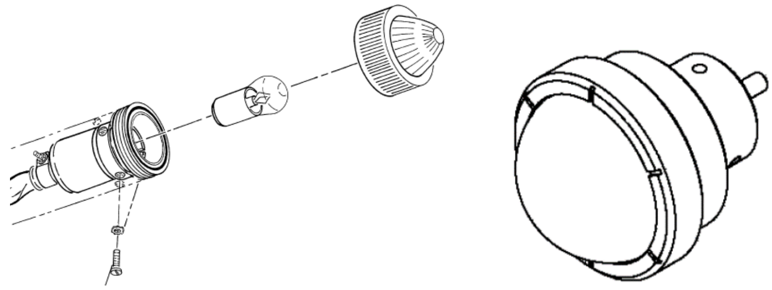
(a) (b)

Fig. 1. Placement of position lights [6] [7]: a) on the left L-159; b) on the right L-39NG)



(a) (b)

Fig. 2. Wing position light (red, green) [7]: a) old type on the left L-159; b) new type on the right L-39NG.



(a) (b)

Fig. 3. Rear position light (white) [7]: a) old type on the left L-159; b) new type on the right L-39NG).

Designing and implementing position lights (also known as navigation lights) on aircraft involves adhering to various international and national standards and regulations. These standards ensure that the lights provide the necessary visibility for the aircraft, aiding in the prevention of collisions by allowing pilots to determine the direction of other aircraft during night time and in conditions of reduced visibility. ICAO sets international civil aviation standards, including those for aircraft lights, through its Annexes to the Convention on International Civil Aviation (Chicago Convention). Specifically:

- Annex 6 (Operation of Aircraft): It includes general requirements for aircraft lights. [8]
- Annex 14 (Aerodromes): Although primarily focused on aerodromes, it also includes some standards that describe how aircraft lights should be visible from the ground. [9]

For civil aircraft operating within Europe, Europe Aviation Safety Agency (EASA) regulations also apply, which often mirror or adapt ICAO standards to the European context. In addition to international standards, individual countries may have their own specific regulations and requirements (NAA – National Aviation Authorities). Aircraft operators must ensure they comply with the regulations applicable in their country of registration and operation. While the specific requirements can vary depending on the aircraft type and jurisdiction, they generally include guidelines on:

- Colour: Position lights must be red on the left (port) wing, green on the right (starboard) wing, and white on the tail.
- Visibility Range: The lights must be visible from a certain distance, often several miles, and at specific angles to ensure they can be seen by other aircraft in the vicinity.
- Intensity and Flash Patterns: There are specific requirements for intensity and flash patterns to ensure they are conspicuous.
- Operation: Regulations specify when the lights must be operational, such as during night operations or when operating under Instrument Flight Rules (IFR).

All the above-mentioned requirements for the characteristics and conditions for civil aircraft position lights are incorporated into military defence standards with the help of individual military authorities. For Europe and the Czech Republic, these are bodies such as The European Defence Agency (EDA), the European Military Airworthiness Authorities Forum (MAWA) and the National Military Aviation Authority (NMAA). [10]

3. State of the Art

Current events on the defence and security scene of the Czech Republic are undoubtedly the ongoing modernization of the military technologies of the Air Force of the Czech Republic. Korecki et al. [11] discuss the importance of aircraft life cycle phase analysis and its relevance to financing and supply. Definition of the design and development phase, the production phase, the operation phase and the recycling and disposal phase. The Life Cycle Engineering (LCE) phases and the defining boundaries of the system are closely related to the following text.

Available scientific resources dealing with avionics data collection, reliability analysis of aircraft lights and display systems use traditional methods such as failure-free modelling and reliability prediction, but in addition, today's authors often use alternative models and methods to increase accuracy and applicability in real-world scenarios.

The importance of working with data in general and the methodology of this issue are described by Prakapienė and Prakapas. [3] Data accuracy is derived from a systematic process of data collection, analysis, interpretation and synthesis to provide timely and valid information for statistical and subsequent predictive models. Cheng et al. [12] introduced a novel fault diagnosis method for aviation general processing modules, utilizing prognostics and health management (PHM) technology to assess the health status of avionics systems, including lighting circuits. This approach integrates parameter acquisition, feature extraction, failure analysis, and system fault location to accurately diagnose faults. Gao, Li, and Dai [13] developed a fault prediction method based on an echo state network (ESN) for avionics, including lighting systems. Their approach, leveraging one-dimensional wavelet denoising and z- score standardization, significantly improves medium and long-term fault prediction accuracies. Tameh, Sawan, and Kashyap [14] proposed an optical, analogue, self-referencing, ratio-metric smart displacement sensor for avionics. Its design aims at enhancing the reliability of position sensing in lighting systems by mitigating power fluctuations. MacLean, Richman, and Richman [15] analysed the predictability of aircraft failures, including lighting systems, as they age. They applied a Poisson regression model to study unscheduled landings due to moderate mechanical failures, highlighting the impact of aging on system reliability. Samara et al. [16] introduced a statistical method for the independent monitoring of single sensors in aircraft, enhancing the reliability and safety of aircraft lighting systems. This approach addresses abrupt faults characterized by smaller time constants than those of the aircraft. Pandian et al. [17] critiqued traditional reliability prediction methods in avionics, suggesting that handbook-based prediction methods often lead to inaccurate results. They advocated for alternative approaches like physics-of-failure and data analytics for prognostics and systems health management. Furse and Safavi [18] demonstrated the feasibility of spread spectrum sensors for locating faults in aircraft wiring, including those affecting lighting loads. This technology promises significant advancements in identifying intermittent faults that impact lighting system dependability. Menu, Nicolai, and Zeller [19] discussed designing fail-safe architectures for aircraft electrical power systems, emphasizing the critical role of reliable power supply in ensuring the functionality of position lights and other safety-critical components. Mesgarzadeh, Söderquist, and Alvandpour [20] highlighted the challenges posed by silicon aging on the reliability of avionics systems, including lighting controls. As Complementary Metal–Oxide–Semiconductor (CMOS) technology scales down, aging accelerates, necessitating considerations for longevity in design.

This review underscores a multidisciplinary approach to enhancing the dependability of aircraft position lights, incorporating fault diagnosis, predictive maintenance, and innovative sensor technologies. The integration of advanced diagnostics and probabilistic modelling offers promising pathways for improving not only the reliability and safety of aviation lighting systems but improves the general safety of aircraft operation overall.

4. Data and Methods

The information system of the Air Force of the Army of the Czech Republic is used as a data source. It collects and stores all records of faults and failures and other operational data of the fleet. The collection and processing of data is therefore carried out thanks to this monitoring platform. We use this data source for our statistical analysis and predictive methods. The mentioned system for operational data acquisition is a military information logistics system used for official purposes of the Czech Army, for this reason the data are not published in their entirety, but only partial samples are demonstrated (see Table 1).

Table 1.

Partial data sample from operation of L-159 aircraft

A/C	Date of failure	Flight hours	Flight hours between failures	Flight hours between failures	Colour of position light	Type of position light
No.1	13.06.2013	225:19:34	225:19:34	225.33	WHITE	incandescent lamp
No.1	14.02.2014	264:26:26	39:06:52	39.11	WHITE	incandescent lamp
No.1	17.01.2017	431:45:13	167:18:47	167.31	WHITE	incandescent lamp
No.1	15.02.2017	437:20:13	5:35:00	5.58	WHITE	incandescent lamp
No.2	20.03.2012	267:33:43	267:33:43	267.56	WHITE	incandescent lamp
No.2	21.07.2015	483:52:47	216:19:04	216.32	WHITE	incandescent lamp
No.2	23.07.2015	491:30:39	7:37:52	7.63	WHITE	incandescent lamp
No.2	20.08.2015	516:26:08	24:55:29	24.92	GREEN	incandescent lamp
No.2	01.09.2015	526:25:15	9:59:07	9.99	WHITE	incandescent lamp
No.2	03.11.2015	535:04:02	8:38:47	8.65	WHITE	incandescent lamp

First, we use standard methods of descriptive statistics to describe the main characteristics of the data. Then, we use a Poisson process to develop probabilistic model based on operational data statistics in order to model failure rates of the position lights on the aircraft. If we have information about failure rates (e.g., how many times a position light fails per one flight hour), we can use this process to model and predict reliability parameters of individual components. However, it is important to consider the specifics of the given system and to prepare and filter appropriate data. R software is used for our data processing. [21] [22]

A Poisson process is a model used to describe events that occur independently at a constant average rate over time. In the context of our data, where the number of failures and the time between failures are known, we can use a Poisson process to model the number of failures over time, more precisely the probability of occurrence of failures.

$$p(x) = \lambda e^{-\lambda x}$$

Assuming that λ denotes the average aircraft failure rate per determined time, we obtain its estimate using the maximum likelihood method. [23] [24]

$$\hat{\lambda} = \frac{n\ (total\ number\ of\ failures)}{t\ (total\ operating\ time)}$$

In order to calculate the failure truncated two-sided confidence interval for λ, we use the Pearson χ^2 distribution, where n is the total number of failures and t is the total operating time. [25]

$$\left(\frac{1}{2t}\chi^2_{\frac{\alpha}{2}}(2n);\ \frac{1}{2t}\chi^2_{1-\frac{\alpha}{2}}(2n+2)\right)$$

Mean Time Between Failures (MTBF) is a key reliability metric that encapsulates the average interval during which position lights operate without failure. It is a key metric for maintenance planning, providing an aggregated view of component durability and functional availability. To explore the statistical spread and assess the consistency of MTBF across the fleet, the variance was examined. This measure of spread reveals the heterogeneity within the dataset, highlighting potential variability due to a variety of operational factors such as different usage patterns, maintenance practices or even different environmental conditions that the fleet may encounter. Other basic statistical data and results are also presented. [25]

In conjunction with these indicators and the exponential distribution, the chi-squared and goodness-of-fit test were employed to test the hypothesis that the observed frequencies of failure intervals conformed to a theoretical distribution, often assumed to be an exponential distribution in reliability studies for components such as position lights. This parametric test compares the empirical distribution against an expected frequency distribution and yields a p-value. It is the probability of observing the computed test statistic, or a more extreme value, under the null hypothesis, assuming the null hypothesis is true. A high p-value suggests that the observed distribution is not significantly different from the expected one, indicating the empirical data consistency with the assumed theoretical model. [26]

The main statistical methods and tools used to analyse data from fleet operation and position light failure rates include: Boxplot, which provides a visual representation of the distribution of time between failures for individual aircraft, highlighting the median, quartiles, and outliers, thus enabling quick identification of data deviations and variance. The analytical tool ANOVA (analysis of variance) was utilized to compare mean values across different groups of aircraft, aiding in identifying statistically significant differences in light failure rates between aircraft types. The step function of cumulative count of failures and the cumulative step distribution function allowed us to visualize the accumulation of failures over time and assess the frequency of occurrence of failures, which is crucial for maintenance planning and operational optimization. Finally, a histogram with the probability density function of the exponential distribution was applied to verify the assumption that the time between failures follows an exponential distribution, which is common in reliability theory and enables modelling and prediction of failures based on stochastic processes. Together, these methods provide a comprehensive view of the dynamics of failures, and their utilization is essential for ensuring a high level of operational reliability of the individual aircrafts as well as the whole fleet availability. [27]

5. Results and Discussion

As a first step, we will present the results of basic statistical data for the entire fleet and also for one selected aircraft from the fleet as an example.

Entire fleet:

- Average time between failures (MTBF): 223.85 hours
- Median time between failures: 141.49 hours
- Variance: 55.444.53 hours²
- First quartile (Q1): 28.93 hours
- Third quartile (Q3): 341.50 hours

Aircraft No.1:

- Average time between failures (MTBF): 109.33 hours
- Median time between failures: 103.21 hours
- Variance: 10.837.53 hours²
- First quartile (Q1): 30.73 hours
- Third quartile (Q3): 181.82 hours

Figure 1 presents a boxplot displaying the time between failures of position lights for individual aircraft. Each box represents a single aircraft, and the height of the box indicates the interquartile range of time between failures, excluding extreme values.

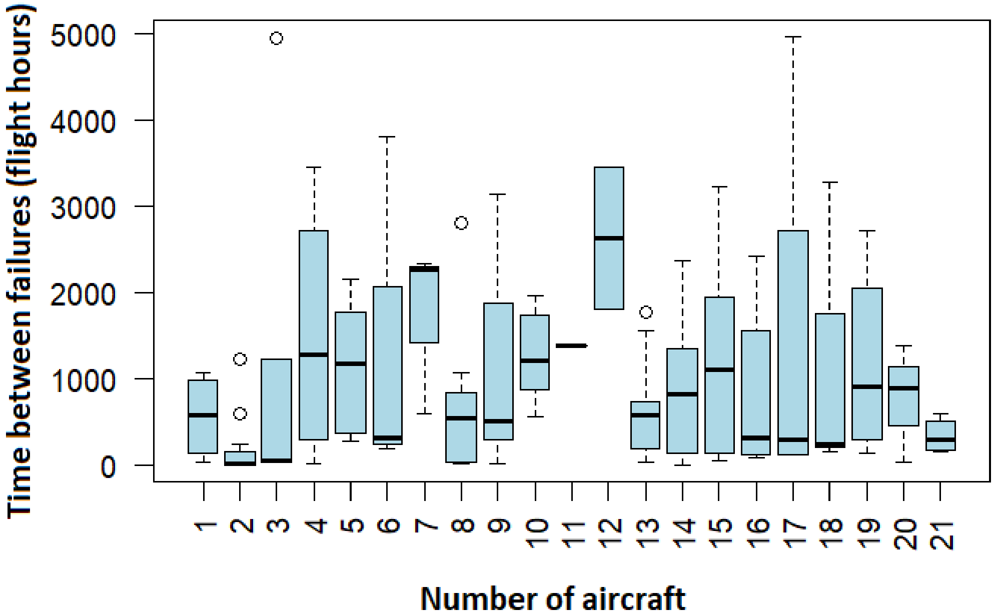


Fig. 4. Boxplot for time between failures of position lights

From the Figure 4, it is evident that some aircraft exhibit a very wide range of times between failures, which may indicate inconsistent reliability. There are notable extreme values for some aircraft that could require further investigation (why there was such a long or short interval between failures). The medians vary, suggesting that the average time between failures differs among aircraft. A boxplot graphically displayed the distribution of data points in groups based on quartiles and outliers, which are key pieces of information that can be formally tested using ANOVA. The results of the ANOVA test are summarized in Table 2.

Table 2.

ANOVA table with aircraft (A/C) being a factor (df stands for degrees of freedom)

Source	**df**	**Sum of Squares**	**Mean Squares**	**F-statistic**	**p-value**
Factor (A/C)	20	2.30×10^{7}	1149899	0.935	0.546
Residuals	87	1.07×10^{8}	1230306		

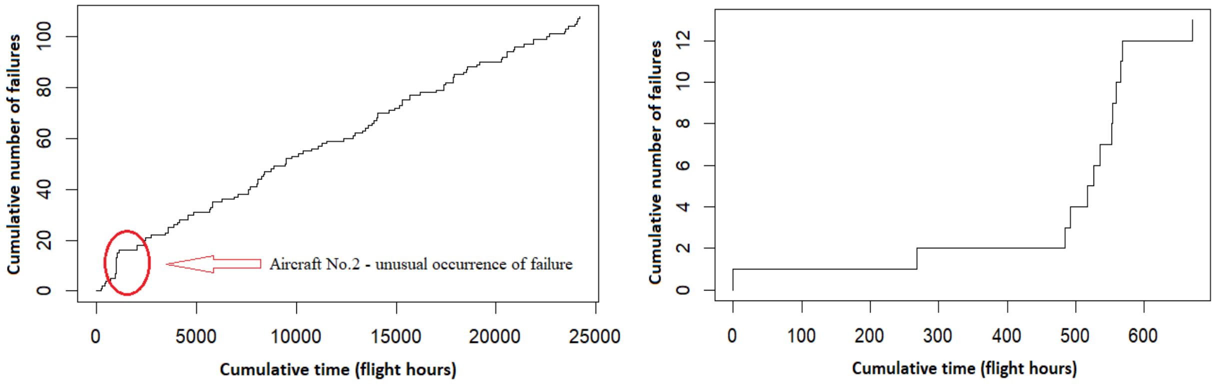
The F-statistic value of 0.935, accompanied by a p-value of 0.546, suggests that the observed variation in time between failures across the different aircraft in our fleet does not significantly deviate from the presumed equality of means. It can be concluded that there are no significant differences between groups of aircraft in the times between failures.

Therefore, we can continue in our analysis. Assuming that the occurrence of the failures follows the homogeneous Poisson process, we employed the Maximum Likelihood Estimate (MLE) method to estimate the parameter λ, representing the average rate of failures per unit of time (i.e., per one hour of flight). To determine the confidence interval for λ, we utilized the Pearson χ^2 distribution allowing us to better understand the variability of the λ estimate. The point estimate of the failure rate is.

$$\hat{\lambda} = \frac{108}{24176.25} = 0{,}004467$$

Calculated the confidence interval for λ with 95% confidence level is following: (0.003664526; 0.005393422).

In our analysis, we also generated a step cumulative plot based on the data obtained from the fleet of the aircraft. Result can be seen on the left panel of Figure 5. The shape of the counting process function is more or less linear with one exception at the beginning, which is cause by one of the aircrafts. Aircraft No.2 had a very unusual occurrence of position light failures during service (see the right panel of Figure 5). However, this anomaly does not influence the overall behaviour of the failure occurrence in the entire fleet.



(a) (b)

Fig. 5. Position light failures during service: a) step cumulative graph of the number of failures over time of the fleet; b) step cumulative graph of the number of failures over time of nonstandard occurrence aircraft No.2.

Testing the homogeneous Poisson process, we take a look at the inter-arrival times of the failures, which should follow the exponential distribution with parameter λ estimated earlier. Graph of an empirical cumulative distribution function (Fig. 6) provides a key perspective on the distribution of intervals between failures within our aircraft fleet. The red curve of the estimated exponential distribution function aids in understanding that the idea of homogeneous Poisson process is correct.

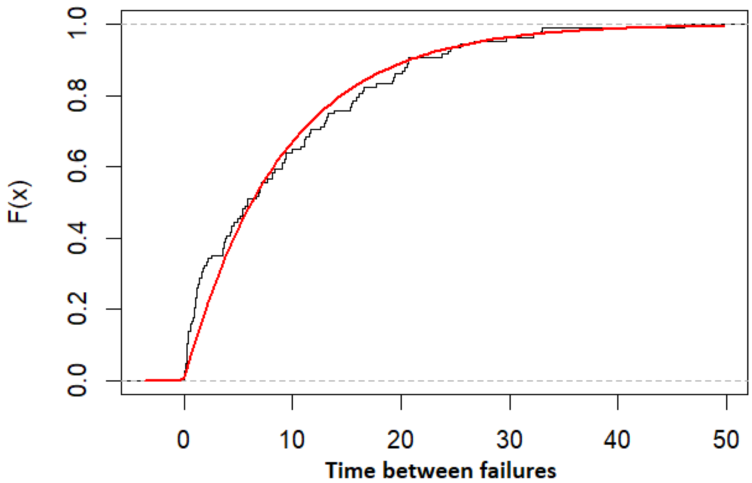


Fig. 6. Empirical cumulative distribution function (black curve) for time between failures for whole fleet and distribution function of the estimated exponential distribution (red curve).

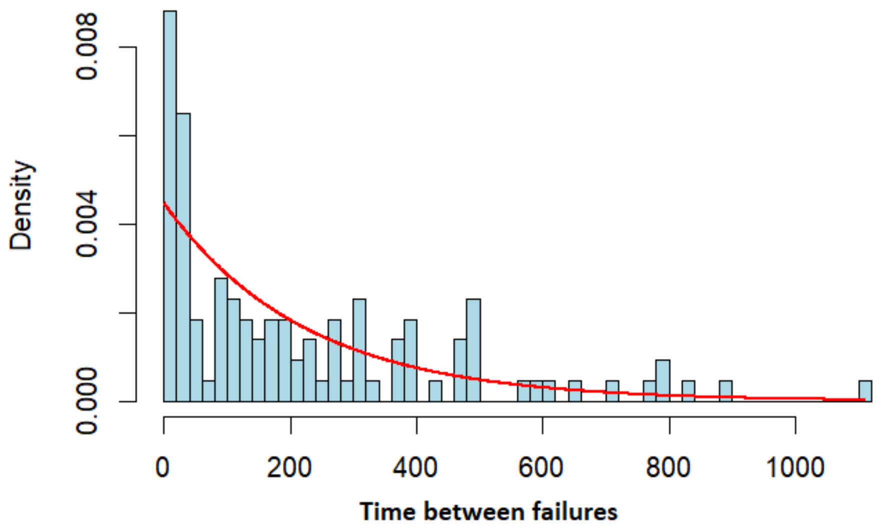


Fig. 7. Exponential distribution probability density histogram.

The exponential distribution probability density histogram (Fig. 7) provides evidence supporting the use of the exponential model to characterize the intervals between failures in our fleet. High agreement with the theoretical distribution indicates the random nature of failure occurrence, which is a key assumption for predictive maintenance and reliability planning.

Next, we support the visual result by testing the hypothesis that interval times between failures comes from the exponential distribution.

Chi-squared test:

- **X-squared (χ^2) = 25.309** (differences between expected and observed frequencies)
- **df = 18** (degrees of freedom)
- **p-value = 0.1166** (p-value greater than 0.05 implies that there is no reason to reject the null hypothesis)

Goodness-of-fit statistics

- **Kolmogorov-Smirnov statistic = 0.1452544** (lower values suggest a better fit), p-value = 0.02098
- **Cramer-von Mises statistic = 0.4335717** (lower values indicate a better fit), p-value = 0.05881
- **Anderson-Darling statistic = 3.6910957** (higher value suggests that the data in this area does not conform well to the expected distribution), p-value = 0.01241

In the context of our analysis, these tests suggest that the data have an acceptable level of agreement with the assumed theoretical distribution.

To find the probability of a given number of events in a period of time (MTBF = 223.85 hours), or the probability of waiting until the next event occurs, we need to analyse in detail the graphs of the Poisson probability function (Fig. 8) and the exponential distribution (Fig. 7), respectively.

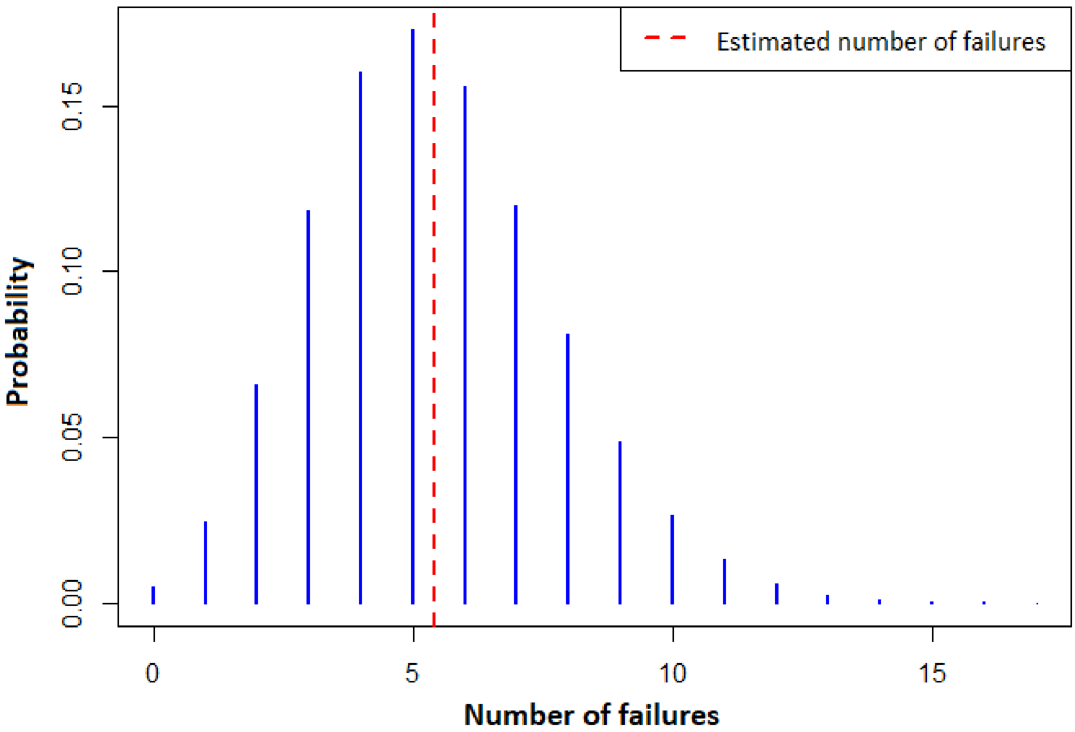


Fig. 8. Poisson process for probability of the number of failures in 1 year.

From the long-term observation of the annual raids of the fleet, an average raid in 1 year equal to 1647 flight hours was calculated. The probability function of the Poisson distribution plotted in Figure 8 shows that for our fleet the most likely number of failures in a year of operation is around the number 5, here the probability is 0.17282 (17.28%). This suggests that most of our aircraft have a relatively low number of failures, which is a positive indicator of operational reliability and maintenance efficiency. The dashed red line serves as an indicator of the number of failures with the highest probability of occurrence (5.4 failures per year). This is an approximated value based on the Poisson process calculated in software RStudio. However, this is only an approximation, as the discrete function does not allow us to use numbers other than integers. The occurrence of higher numbers of failures is significantly less likely, indicating that extreme events are not typical of the operation of our fleet. For example, the probability of 10 or more failures occur below the threshold of 0.02624 (2.624%) and less.

6. Conclusions

This article addresses the reliability of position lights on training and light combat aircraft L-159 Alca and attempts to statistically predict their future failure rates. Readiness of aviation technology is an area of critical interest in both civil and military aviation contexts. In civil aviation, discussions primarily focus on economic and safety aspects, whereas in military aviation, the emphasis extends to the continuity of pilot training and the associated security of the national airspace. Position lights play a vital role in aviation as they ensure the visibility of the aircraft and define its shape during flight. A malfunction in these lights would not comply with the aviation safety regulations, thereby compromising the safety of air traffic. Furthermore, since position lights remain illuminated throughout the flight, they are suitable for analysis based on flight hours, which eliminates the need to adjust the operation time of the diagnosed object over the flight duration.

In addition to processing and statistical analysis of data over the long operational period of this aircraft type, a cornerstone of this scientific article is the prediction of the number of failures per year. It was therefore necessary to determine the average flight hours of the fleet per training year from long-term operational data. Although options for predicting failures per month of operation, per average time of a single flight, or using the number of operational days instead of flight hours were considered, these measures would not have been sufficiently informative or relevant for appropriate prediction using the Poisson process. Statistical insignificance was also evident in examining the failure-free operations of individual aircraft separately, due to the small number of failures per aircraft. These numbers of failure are in the order of single digits.

It is also worth noting that the transition from incandescent bulbs to LEDs was carried out gradually as part of the modernization of this type of aircraft. The possible aim was to compare the reliability of both types of lighting and to confirm the expected higher reliability of LEDs. Unfortunately, the modernization took place only in recent years, and the period of LED usage did not provide enough diagnosed failures to be statistically utilized. In the future, based on observations of LED position lights and the results achieved, it may be possible to model a predictive reliability plan or determine the level of risk associated with this component failure. As part of a long-term initiative, experimental testing and measurement using highly accelerated life testing are being considered, and the evaluated results will be compared with incandescent lighting. [28] Future research may also explore predicting the location of faults based on empirical observation. The information system from which data is obtained offers not only the timing of fault detection but also the location. It could therefore be estimated whether it is better to focus on inspections (one-time, pre-flight, mid-flight, post- flight), or prescribed maintenance after certain flight hours or periodic maintenance after certain days of the equipment's life.

Even though the research is focused on relatively old but proven production technology and maintainability, the achieved results can serve as a benchmark or guide for evaluating modern, optimized types of aircraft lighting. In general aircraft operators can use research results to determine fleet maintainability or to identify potential operational problems. These results can help determine whether certain aircraft require improvements or changes in maintenance and whether some failures are too frequent and require additional attention. Based on the findings, the operator or manufacturer can optimize the intervals for prescribed maintenance of the aircraft or set an appropriate frequency for inspections focused on position lights. It is also possible to prepare the logistical support of the fleet based on the expected number of failures to prevent undesirable logistical delays. All this leads to more precise predictive analysis of the safety and reliability of lighting and signalling components for effective planning of the relevant spare parts and maintenance tasks while maintaining a high level of operational availability of the fleet.

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Quantum Technology and its Role (Not Only) in the Strategic Concepts of Central European States – Mapping Study

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Abstract

Quantum technologies represent a new agenda that has the potential to fundamentally change the security environment on a global scale. Countries or groups of countries that adopt these technologies before others will be at an advantage. The aim of the authors was to provide an overview of the current status of creating conditions for the development of quantum technologies in selected Central European countries (Czech Republic, Slovakia, Austria, Hungary and Slovenia). The study maps the conceptual, organisational and technical situation in this area, focusing on the five North Atlantic Treaty Organisation member states and the European Union. As a result of the investigation, it is found that the complexity of quantum technologies requires cooperation at two levels. The first level is undoubtedly cooperation between the state sector, scientific organisations, the defence sector and multinational companies. The second level is cooperation between individual states or within international organisations. Regarding the security aspects of these technologies, cooperation based on North Atlantic Treaty Organisation and European Union is crucial. Ensuring technological superiority in the coming years is a big challenge for the United States of America, resp. North Atlantic Treaty Organisation and the European Union.

KEY WORDS: *Central European States, cryptography, education, European Union, North Atlantic Treaty Organization, military defence, public policy, quantum technology, security, threats*

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1. Introduction

The contribution is devoted to the emerging, but even more relevant, the strategic grasp of the quantum issue (including the North Atlantic Treaty Organization quantum strategy). The authors map the positives (added value) of the emphasis on this agenda and the weaknesses resulting from the delay in this issue. Attention will also be paid to the quantum capacities of the individual Central European countries, as Czech Republic, Slovakia, Hungary, Austria and Slovenia (including the relevant strategic documents and its possible personnel, organizational and financial coverage).

In relation to the issue, both the approach of individual countries and the priorities of relevant international organizations (especially North Atlantic Treaty Organization and European Union) are being monitored. In this context, is it possible to claim that the European Union focuses more on technology as such, with the security dimension of the topic being left behind?

In this context, the content and diction of existing strategic-conceptual documents will be monitored, as well as the related external constructive-critical comments, especially from the private sector environment.

The period after 2010 to the present is covered, with the fact that, in relation to all individual countries, as many identical variables as possible are monitored, which will enable a subsequent comparison.

In relation to the topics, open sources are used only. Although this aspect can be perceived as limiting, it is also a prerequisite for publishing a study in itself.

2. Quantum Technologies – Approaching the Topic

Quantum technologies are a broad and diverse category of technologies that use the phenomena of quantum physics [1].

In quantum computers, pulses do not play a key role, but subatomic particles such as electrons or photons.

A quantum bit, a qubit, is a quantum analogue of a classical information bit. While a classic bit can only take on the value 0 or 1, a qubit can represent multiple values or states at once. In other words, a quantum computer can perform multiple calculations simultaneously, not necessarily sequentially (like a traditional computer). Thus, quantum computing shows the potential to outperform traditional computers due to much higher computing speeds [2].

Quantum computers can also use entanglement, a phenomenon that binds two or more qubits together so that their states are correlated. Any quantum manipulation of one of the entangled qubits generates an immediate effect on the other entangled qubits, regardless of the distance or barriers between them [3].

Quantum technology will, with a high probability, become, next to artificial intelligence, the most important emerging technology for general use. Quantum computing can bring enormous progress in science, including currently unsolvable logistical or logical problems [3, 4].

3. Core categories of Quantum Technologies

Quantum technologies can be divided into several main categories. Each of these generates impacts on information, intelligence, surveillance, reconnaissance, and cyber operations relevant to security and defence. In general, it is possible to state that quantum technologies will not introduce fundamentally new weapons, as was the case with nuclear and laser technologies, but rather will improve current sensing, communication and computing capabilities [3]:

a) Quantum computing

This is the use of quantum systems to perform calculations based on quantum logic and algorithms. Quantum computers can perform parallel and probabilistic calculations that allow them to solve certain problems faster and more efficiently than classical computers. Despite the misconception that the exponential increase in processing speed will affect and take over all tasks intended for classical computers, quantum computers will be particularly effective at breakthroughs in certain highly complex and demanding computational problems. Examples of such problems are quantum crypto-analysis (breaking most asymmetric encryption schemes commonly used to encrypt e-mail, voice and video, data transmissions and remote access), faster search, faster solution of linear or differential equations, quantum optimization (logistics, investment portfolios, or new drug designs) and quantum machine learning. Quantum technology can help solve complex and large-scale optimization problems, including resource allocation and decision-making, which are important for planning and executing military operations [1].

b) Quantum networks and communications

Quantum networks and communications aim to transmit quantum information (qubits) across different channels, such as optical lines, or in free space [1, 3].

- Quantum communication may enable quantum cryptography. Quantum cryptography can provide a higher level of security and authenticity than conventional asymmetric encryption (public key cryptography) because it can detect and prevent any eavesdropping or tampering by exploiting the properties of quantum physics. Quantum communication can enable quantum key distribution, which is a protocol that allows two parties to share a secret key using quantum states and measurements and classical communication. This technology is already commercially available to some extent for use with optical fibers.
- Quantum communication may enable quantum digital signatures, which allow a message to be signed using quantum states and measurements.
- Quantum communication can improve metrology, i. e. measurement using quantum states, to achieve higher precision than classical methods.
- Quantum communications can help improve the collection, dissemination, and protection of sensitive and intelligence information, as well as its situational awareness and operational effectiveness.
- Quantum communications can enable remote sensing, which is the use of quantum systems and protocols to detect and measure physical properties and phenomena such as distance, temperature, pressure, or magnetic fields without disturbing the system or environment.
- Quantum communication can enable quantum teleportation, which is a protocol that allows two parties to transfer a quantum state from one place to another using entanglement and classical communication.
- Laser communication offers high-speed data transfer ensured by quantum communication.

A next-generation quantum network, called a quantum information network (QIN) or quantum internet, is distinguished by its ability to distribute entangled qubits. QIN will offer more security-related services such as secure identification, location verification, and distributed quantum computing. The biggest obstacle to QIN implementing is the need for a reliable quantum memory to store quantum information for synchronization and distribution in a network with many intermediate nodes. In practice, the introduction of QIN can realistically be expected after 2030.

c) Quantum simulation

Quantum simulation is the use of quantum systems such as atoms, photons or electrons to simulate and model other quantum systems such as molecules, materials or fields. Quantum simulation can use quantum algorithms to perform calculations and measurements on quantum systems. Quantum simulation can be applied in various fields such as chemistry, physics, biology and engineering (simulating the behaviour of molecules for chemical and pharmaceutical research, development of new materials, etc.). It can help to understand and design complex and dynamic systems, such as molecular structures, chemical reactions, material properties and physical phenomena, which are relevant for research, development, testing and technology evaluation [1].

d) Quantum sensing (imaging)

This is a subfield of quantum optics that is active (a signal is emitted, and its reflection detected). The principle behind quantum sensing is the more precise measurement of various physical variables, such as magnetic or electric fields and biological magnetic signals, gravity gradients, rotation acceleration and time. Improved time measurements can be used for more accurate clocks (used by many current technologies), quantum inertial navigation, underground and undersea exploration, more efficient radio frequency communication, etc. This allows detection of metallic or other objects creating local magnetic anomalies, such as mines, improvised explosive devices, and camouflaged vehicles. This can also serve as an alternative method of underwater navigation (supposedly able to detect a submerged submarine from space). Quantum gravimeters are intended for underground surveillance systems and are being tested to detect underground structures such as caves, tunnels, bunkers or missile silos. Quantum imaging systems can be used in any weather, day or night. Quantum sensing can provide accurate and reliable information without relying on external signals such as GPS. Quantum sensing can also provide high-resolution images and provide detailed and accurate information about the composition, structure, and state of matter and energy of the monitored objects [3].

Quantum radar is a quantum imaging system that works similarly to classical radar, but at the level of individual photons. The principles of quantum radar and quantum light detection (lidar) have already been successfully demonstrated in laboratories. However, the effectiveness of the solution as a whole is still very uncertain. Using a quantum sensor with a useful degree of accuracy is unlikely, as sufficient spatial resolution will result in insufficient sensitivity. On the other hand, some quantum sensors are expected to be tested in field conditions in the coming years, around 2028 [2, 3].

e) Post-quantum cryptography (PQC), also known as quantum-resistant cryptography

PQC is sometimes seen as a subcategory of quantum communication but is also often considered a separate category. Until now, information security was guaranteed by the mathematical complexity of encryption itself and the secure transmission of encryption keys. With the advent of quantum computers, the performance of which will make it possible to break encryption keys, it is necessary to find new ways of transmitting information that are resistant to cyber-attacks. The solution to such a problem is the transmission of encryption keys using quantum technologies. The concept itself is not necessarily related to quantum physics but is based on the development of contemporary asymmetric cryptography. This type of cryptography relies on more advanced mathematics that is more difficult to calculate, even for quantum computers. As such, the concept can be seen as a software/hardware upgrade of existing systems. Even this concept cannot be seen as completely secure, as new classical or quantum cryptanalytic attacks may occur. Nevertheless, tools falling under this definition will likely become available in the foreseeable future. [3, 5].

4. Unavailability of Quantum Solutions

All quantum systems are extremely fragile, and many can only be used at temperatures close to absolute zero (about -273°C). The slightest disturbance (heat, electromagnetic fields and moving air molecules) leads to loss of quantum information or sensitivity in quantum sensors. Some scientists predict that these obstacles will be overcome within the next 20 years. However, this speculative timeline is largely tied to the amount of financial and human resources allocated to this challenge. Quantum computers are likely to be too expensive to serve smaller groups of cybercriminals. Their pioneers will likely be large technology companies and research institutions – and variously motivated nation states [3, 4].

5. A New Concept of Deterrence? Rethinking Traditional Paradigms

Quantum technologies could have significant implications for nuclear deterrence, conventional forces, and cyber defence as they could create new vulnerabilities and asymmetries [1].

Some actors may gain access to quantum technology while others may not. This could create new challenges for the posture of the armed forces as well as for their strategic and operational capabilities. Quantum communications may also undermine existing norms and frameworks, such as the International Telecommunication Union and the Outer Space Treaty, which regulate the use of the electromagnetic spectrum and outer space. This could create new conflicts and require new agreements and regulations to ensure the peaceful and responsible use of quantum communication. Ensuring the security of information and communication is one of the key issues for the running of the state. A country is secure only if it can protect information at the level of state institutions and its security forces, the health system, financial institutions, air traffic control, energy production and distribution, or transportation systems and logistics [5].

Anyone who assumes that the quantum threat is not a current challenge because quantum computing is not currently viable may be very wrong [4].

In October 2019, for example, Google announced the construction of a 53-qubit system, called Sycamore. He was able to calculate a proof in 3 minutes and 20 seconds confirming that the numbers generated by the random number generator are indeed random. The same task would take today's most powerful traditional computers about 10,000 years [2, 4, 6–8].

The People's Republic of China subsequently announced that it had a solution called Zuchongzhi with 66 qubits. In 2015, Prime Minister Xi Jinping explicitly designated quantum communication as a national strategic technological project where major breakthroughs to be achieved by 2030. Beijing is willing to allocate enormous resources to gain world leadership in quantum and other emerging technology fields. The total spending of the People's Republic of China on this agenda is estimated to be more than 2.5 billion USD per year after 2017, which is probably far more than the investment of the rest of the world combined [4, 9, 10].

This forced the Euro-Atlantic countries to take the subject seriously and invest accordingly. After all, history says that states capable of mastering the technology that gives them an edge in signal intelligence tend to be the winners in military conflicts as well. For example, the Allies were able to break the Enigma cipher that Nazi Germany relied on. London then kept its lead secret for decades to continue monitoring the communications of the Warsaw Pact countries [2, 11].

If anyone manages to build a fully functional quantum computer, much of conventional cryptography will fall apart. Quantum computing may disrupt some existing cryptographic systems being used to secure and encrypt data and communications. This could compromise the collection, dissemination and protection of sensitive and intelligence information.

As already stated in the text, quantum sensing can enable the discrete and remote detection and measurement of physical properties and phenomena such as temperature or magnetic fields. This could completely reshape the secrecy capabilities of any military and civilian activities. Military operations in all physical environments – on land, at sea, in the air, in space – rely on a variety of similar information technologies and networks that power the global economy. A systematic vulnerability in the cyber domain would become a systematic vulnerability in all domains. Classified information could be collected, changed or deleted. Personal, financial, legal, logistical and operational data could be manipulated to affect tactical and strategic operations. Malware could be installed at will to enable espionage or disrupt critical infrastructure.

With the prospect of a cryptographically significant quantum computer seemingly only a matter of time away, cybercriminals and geopolitical adversaries alike are rushing to obtain sensitive encrypted information that cannot be read today – so that it can be decoded once quantum computers become available.

Decrypting data encrypted by existing technologies will enable unprecedented visibility of highly valuable data. If the West were to lose the quantum computing race to rivals such as the People's Republic of China, the loss would be significant [4].

Cryptographic attacks can also negatively affect the economy and competitiveness. Quantum computers will increase the likelihood of intellectual property theft. Transport, energy distribution or communication systems will be particularly vulnerable. Disinformation could be spread from the secure accounts of senior officials, increasing the credibility of fraud efforts [8].

In relation to the issue, there is a very interesting mention of the creation of a new concept, which at the time of nuclear deterrence was called the **delicate balance of terror**. A new variant of the Cold War, apparently along the lines of the People's Republic of China versus the Euro-Atlantic states, may be based on the assumption that the mastery of quantum technology, capable of disrupting the functioning of an adversary's society, will be undesirable to the extent (assuming immediate retaliatory reaction) that the contending parties these eventualities they will really leave it as a weapon of the last judgment – and it will not be deployed.

The quantum threat to cyber security is an example of a self-fulfilling prophecy. The more convincing the prophecy of doom, the more determined its potential victims try to delay the disaster. In other words, states take this challenge so seriously that the most dangerous eventuality is unlikely to occur. So, there are reasons for cautious optimism that countermeasures are maturing faster than the threat. The quantum threat must be taken seriously, and that is precisely why it may never materialize. Given the pervasive importance of cyberspace, systematically compromising cybersecurity would be a strategic concern of the first order. History is full of expectations of technological transformation that never materialized. The race between offensive and defensive measures is as old as war itself. The balance between offense and defence at any given time depends on organizational and geostrategic context, not just technology. Scientific principles and technical feasibility limit the strategic and operational art of the possible. Technical trends set the boundary conditions for any potential **window of opportunity**. However, this window usually changes as individual actors start to create new weapons and to find new ways to use them [12].

A strategic swing would occur if one country acquired such a capability and kept this fact secret for several years or more. Other countries would not realize that everything, from their weapons systems to financial transactions, is vulnerable during this period – including historical records (encrypted communications collected by the adversaries and preserved in anticipation of obtaining this very capability). Attackers have an incentive to keep their progress secret because revealing it can prompt defenders to patch or reconfigure the respective systems. This represents a new "Sputnik moment". Whoever acquires this technology first will also be able to cripple traditional defences and manipulate the global economy [12, 13].

6. Approaches of Individual Monitored Actors to the Mentioned Agenda

In examining the varied approaches to this agenda, we observe distinctive strategies adopted by major entities such as the United States of America, the North Atlantic Treaty Organization (NATO), and the European Union.

6.1 United States of America and the North Atlantic Treaty Organization

When it comes to the activities of the North Atlantic Treaty Organization in the monitored area, it is crucial to see the pivotal role played by the United States of America in this regard:

- In 2016, the National Institute of Standards and Technology began the process of standardizing post-quantum cryptographic algorithms, aware of the rapid development of quantum computing and its potential impact on information security [56].
- In 2018, the White House released the National Strategic Review for Quantum Information Science. The National Office for Quantum Coordination, interconnecting 14 government agencies, was launched [14].
- In December 2019, the National Quantum Initiative Act passed, foreseeing an annual investment of at least 240 million USD in the development of quantum technologies [4].
- In 2022, the Quantum Cybersecurity Preparedness Act passed, setting the perspective for the migration of government information to post-quantum cryptography. The document envisages completion of the transition by 2035, ideally by 2030 for the most sensitive data [4, 15].
- In 2023, the National Cybersecurity Strategy identified protection against quantum cyber attacks as a national strategic goal [16].

North Atlantic Treaty Organization's nuclear deterrence is based on the principles of credibility and accountability. At the same time, it depends on safe and reliable command, control and communication systems, as well as on effective and resilient defence systems [1].

The Alliance also for this reason recognized the importance and potential of quantum technologies, and has taken some steps to address them, such as the Science for Peace and Security Programme, the Innovation Hub, and the Emerging and Disruptive Technologies Roadmap [17, 18, 19].

In February 2021, the defence ministers of the member states approved a strategy to promote a coherent approach to the development and deployment of dual-use technologies, with quantum-enabled technology being one of the nine technology areas promoted in the strategy. At the summit in 2021, a concept called the Defence Innovation Accelerator for the North Atlantic (DIANA) was introduced, also including the dimension of quantum technologies. DIANA consists of a network of test centres and accelerators across member states where innovators develop new technologies to address pressing security challenges. An example of such a workplace is the "Deep Tech Lab – Quantum" in Copenhagen, focusing on the financial return of quantum solutions [3, 20].

Secretary-General Jens STOLTENBERG called for the development of a transatlantic quantum community that harnesses the power of this critical technology for security. He emphasized the importance of closer cooperation between the public, private and academic sectors and the acceleration of responsible innovation. Speaking at the Copenhagen Quantum Conference 2023, STOLTENBERG said: "*NATO has always adapted and embraced new technologies to keep our people safe. With the rapid proliferation of disruptive technologies, we need to adapt further and faster than ever before, including in the quantum domain… We need to ensure that these technologies work for us – not against us… We need to ensure that the Alliance is "quantum ready" and "capable of integrating the right technologies into our capabilities and protecting against adversary use*" [20].

The North Atlantic Treaty Organization's Quantum Strategy, issued on November 28, 2023, states, among others, the following [21, 22]:

- Quantum technologies represent a potential revolution in the world of innovation and can be game changers in security, including warfare. It offers possibilities that far exceed the technologies that are currently available. It is necessary to ensure that the Alliance is prepared for this technological development.
- This topic needs to be closely monitored, along with other key trends represented by artificial intelligence, biotechnology and human enhancement,[2] hypersonic technologies, energy and propulsion, new materials and next-generation communication networks.
- Many of these technologies are already partially used in the private sector and have become subject to strategic competition. The Alliance must therefore support and lead collaboration with industry in the development of a transatlantic quantum technology ecosystem.
- Mastering these technologies will represent a strategic advantage – and not mastering them a strategic weakness. It is necessary to prepare the Alliance and individual member states to defend against the use of quantum technologies by their adversaries and competitors. It is equally important to detect and block potential related incidents in cyberspace.

[2] The authors are preparing a separate study on the topic in the future [23].

- Innovations are expected to help advances in cryptography, develop high-speed lasers to improve satellite connectivity, and improved 3-D imaging sensors in underwater environments.
- This requires investment coherence, cooperation between allies in technology development opportunities, as well as the development and protection of a skilled workforce. It will also require the development and deployment of critical supportive technologies…
- Strategic competitors and potential adversaries can also take advantage of disinformation opportunities by creating public distrust in the use of quantum technologies – similar to what happened in the case of 5G networks (according to the motto, "if we can't do something technically ourselves, we will try to install in the adversary's public that their homegrown advanced technologies are more harmful than beneficial…"). Allies will seek to pre-empt and counter any such efforts through strategic communications [24].

Some other recommendations and proposals of the Alliance for quantum technologies are, for example [1, 3]:
- Establishing a dedicated quantum technology office to coordinate and oversee all quantum activities and initiatives within the Alliance and among its allies and partners.
- Investing in research and finding opportunities to accelerate development and reduce related costs.
- Developing a quantum technology roadmap that would outline the vision, goals and priorities of the Alliance and allies and partners regarding quantum technologies.
- Enhancing its own quantum technology capabilities by investing in quantum research and development and deploying quantum technologies within its missions and operations.
- Enhancing technology education and training through the development and implementation of quantum technology curricula and courses and technology workshops and seminars for its employees and partners.
- Ensuring the development and implementation of quantum technology standards and regulations.
- Establishing and enforcing quantum technology rules for communication, information, and cyber systems.
- Ensuring quantum technology ethics and responsibility by developing and implementing quantum technology principles and guidelines, including the establishment and application of technology oversight and review mechanisms.
- Establishing goals and standards to support development and ensure interoperability.

6.2 European Union

For the European Union to thrive as a global competitor in quantum technology, it must protect access to sensitive government or personal data, or any data relevant to its technological and economic growth. The efforts that need to be made in this area go beyond the individual investment and research capacities of member states, and therefore there is a need to combine efforts and collaborate [25, 26].

To a certain extent, the European Union rather follows up and responds to the initiative steps of the United States of America (which it elaborates or adapts to the European environment). Union standardization processes follow the processes formulated by the National Institute of Standards and Technology. The whole concept is often mentioned as the connection of four levels [27]:
- Ultra Secure Connectivity Program from 2022 [20].
- Union scientific research initiative European Union Quantum Flagship; EUQF [28].
- Research projects within Horizon Europe [29].
- European quantum communication infrastructure (EuroQCI), an initiative that aims to build a secure quantum communication infrastructure that will span the entire space of the European Union member states. Quantum key transfer requires a very specific quantum communication infrastructure, which member states have committed to build within the EuroQCI initiative. EuroQCI is the Union's flagship project, with the aim of ensuring secure communication until 2027. All member states are signatories to this project, which in 2021 recorded the first interstate quantum-secure communication (100.5 km) between Trieste, Ljubljana and Zagreb. The EuroQCI concept, consists of several phases [1, 8, 30]:
    - Test phase, where there is an effort to operate various quantum lines via optical cables and ideally also with quantum satellites. This is a task for universities and other research platforms.
    - Educational phase, when possible, users will be introduced to the possibilities and functioning of quantum technologies.
    - Real deployment of quantum networks (assuming operation up to the SECRET level). This is the task of state agencies, or some certified operators and companies.

At the same time, coordinated prevention of "harvesting attacks" (theft of data for later decryption) is necessary. To support and expand the geographical scope of EuroQCI, the European Union approved the Union Secure Connectivity Program in 2022, concerning the development of the space segment for EuroQCI, the IRIS2 space constellation, built on the GOVSATCOM infrastructure. When completed, IRIS2 could become the flagship of the space program, along with the Copernicus and Galileo projects. In November 2019, member countries of the European Space Agency pledged to support the Space Systems for Safety and Security program, including a quantum component [31, 7, 32, 33].

However, according to critics, the EuroQCI concept distracts policy makers from paying attention to the fundamental challenges in relation to cyber security. The EuroQCI concept is intended to secure government communications and critical infrastructure but does not necessarily prevent incidents that disrupt other areas of cybersecurity, such as private supply chains [14, 8].

The challenges posed by quantum computers to European cyber security may seem distant, but the European Union's ability to detect, protect, defend and recover from them in the future starts with taking the necessary mitigation measures now. Therefore, a quantum cyber security program is essential for Europe's economic security in a rapidly evolving geopolitical environment and it is in the Union's interest to act swiftly [8].

In July 2021, for example, the European Union published a proposal for new anti-money laundering rules. They also include the creation of a new platform (Anti-Money Laundering Authority, AMLA), based on the cooperation and mutual support of the financial analytical units, as well as new requirements for cryptocurrency transfers. A separate problem that concerns all digital services is the long-term security of electronic communication between clients and banking entities. A possible risk comes from the introduction of quantum computers that can break current encryption methods. New technologies can be used/abused in stock market trading. This will probably happen as early as 2026 [34, 35].

The recommendations for the European Union, which result from the above statements, can be summarized as follows [8]:

- Create a quantum transition action plan that outlines clear goals and timeframes and monitors the implementation of national post-quantum encryption transition plans.
- Establish a new expert group within the European Union Agency for Cybersecurity (ENISA) with seconded national experts to exchange best practices and identify obstacles to transition to post-quantum encryption [14].
- Assist in prioritizing the transition to post-quantum encryption to respond to emerging vulnerabilities. Some – but not all – Member States are already taking steps to combat these emerging threats using available tools.
- Facilitate political coordination between the European Commission, and individual member states, national agencies for cyber security and the European Union Agency for Cybersecurity, with the aim of determining related technological priorities.
- Facilitate technical coordination at Union level, with the aim of addressing research gaps in quantum-safe technologies.

7. Individual Member States of the European Union

National quantum strategies are usually documents that define strategic goals in the field of quantum technologies, both security and economic. They usually include aspects such as the support and growth of a national quantum ecosystem, self-independence/self-sufficiency for specific technologies (for example, the establishment of a national quantum computer) and security strategic goals, where the transition to quantum-resistant encryption or quantum key distribution can be defined [36].

At least 12 Member States present national quantum strategies in the form of direct state-led science and research programmes. However, as of 2023, only a few member states have published plans to combat emerging quantum threats, and even fewer have initiated steps to mitigate them, such as Germany [37]. The cyber security budget and the number of specialists available allow only limited expectations regarding the mitigation of emerging threats [80].

Croatia, Cyprus, Greece, France, Lithuania, Slovakia, Slovenia, Sweden and Finland have agreed to cooperate with the other member states of the European Union to develop a quantum communication infrastructure (QCI) in Europe. In June 2019, the representatives of the mentioned states signed the initiated declaration of cooperation. The signatories, together with the European Commission and with the support of the European Space Agency, are going to explore the development and deployment of the European QCI over the coming years. Ultimately, it would connect sensitive public and private communication assets across the European Union [7].

Several countries, including **Austria** and **Slovenia**, participated in the project within the **European Defense Agency**, which is focused on the military use of quantum technologies. The project was led by France and focused on the following areas [38]:

- Fully autonomous positioning and timing for military platforms.
- Secure communication for Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR).
- Quantum network of sensors for synergic connection.

7. Case Studies Concerning Selected Member States of the European Union

In relation to the countries monitored in more detail, there is an effort to at least indicatively mention key milestones, related strategic documents and the most relevant workplaces in relation to the monitored area. If possible, mention will be made regarding practical results, with an emphasis on the area of defence.

7.1 Czech Republic

The Czech Republic conducts remarkable research in a number of areas related to quantum technologies, but the connection between research and practice shows shortcomings. The fact that basic research is dominant here is related to funding opportunities, i.e. mainly from the Grant Agency or various infrastructure projects [39].

The Tensor Ventures fund has invested about a million dollars in the American start-up QC82, which develops quantum technology. In the future, however, they may be beneficial in the discovery of new drugs, materials, and help in energy savings or emission reduction [40].

The LUMI-Q project of the IT4Innovation company (national quantum computer) [41, 42] should be mentioned. The transfer of quantum keys between individual cities has also already taken place in the Czech Republic. The transfer was successful between Ostrava, where the academic organization CESNET and IT4Innovations computer centre joined the event, and Těšín. It is envisaged to build another quantum infrastructure with connections to Austria, Poland, Slovakia and Germany [9, 43, 44].

In February 2022, the Czech Technical University announced cooperation on projects dedicated to artificial intelligence, quantum technologies and other fields, with other platforms, including parts of the North Atlantic Alliance (DefSec Innovation Hub, Supreme Allied Commander Transformation). In doing so, a project mapping the physiological effects of methods of cognitive (**disinformation**) influence on individuals was explicitly mentioned [45, 17, 46].

Applied research mainly in quantum communications is reported by the University of Technology in Brno (NESPOQ project) [47].

In the field of education, there is an inter-faculty field at the Czech Technical University [48].

However, despite the mentioned activity, the **quantum ecosystem is a relative weakness of the state**. There are few start-ups in the country, among which Quantum Phi is the most visible, whose main content is consulting and advisory activities [39, 49].

The Quantum Day event was dedicated to efforts to link capacities in this scientific field, but the related results are ambiguous [50].

Transnational players such as IBM, Microsoft or Tensor Ventures are also active in the Czech Republic. However, most of the activities of the domestic academic sphere are apparently concentrated in the area of basic and not applied research (Palacký University). For the purpose of coordinating the involvement of domestic actors in national and international quantum projects, the National Initiative for Quantum Technologies was established, but its activities apparently stagnated around 2020. The initiative is linked to a roadmap that describes activities at individual workplaces. Some plans look promising, but many have not been translated into applied form, let alone commercially successful results [9, 51–53].

The vision of the reform of the transfer of knowledge and technology, mentioned in the text of the Program Statement of the current government, is related to the topic. According to the prime minister, the country must try to gain a strategic advantage in many relevant fields, since quantum technologies are not explicitly mentioned [54, 55].

The National Office for Cyber and Information Security resisted the task in the mentioned area for about a year, until the government assigned it to it through an official resolution. However, the state lacks experts in this field anyway [56–59].

When **Minister of Defence** Jana ČERNOCHOVÁ presented the priorities of the Ministry of Defense of the Czech Republic for the year 2022, the key word was modernization. "*We want to complete key modernization projects. Autonomous combat systems, **quantum technology**, biotechnology and artificial intelligence must be key for us"* [60].

7.2 Slovakia

The Government of Slovakia in collaboration with private sectors and academic institutions, has initiated several projects aimed at developing quantum computing, sensing, and cryptography solutions [61, 62]. These efforts are supported by strategic partnerships within the European Union, notably participating in the European Union Quantum Technologies Flagship program [28], which facilitates the development of quantum technologies across the Europe.

The main coordinator of the project is the Institute of Physics of the Slovak Academy of Sciences, which plans to build the southern and northern branches of the national quantum communication layer in the coming years. Other involved institutions are the Comenius University in Bratislava; Department of Electrical Engineering of the Slovak Academy of Sciences; Institute of Experimental Physics of the Slovak Academy of Sciences and the International Laser Centre [5].

Slovakia used the experience of the recent quantum transmission of encryption keys between Vienna and Bratislava as well as cooperation with various European research institutions. Slovakia received funds from the Digital Europe program, launched by the European Commission at the end of 2021. This is how part of the supporting quantum communication layer of the future European quantum internet was built. The project is part of the innovation plan under the auspices of the Ministry of Investments, Regional Development and Informatization of the Slovak Republic. The uniqueness of the proposed approach is also the creation of own experimental-technological expertise in the field of quantum technologies in the direct involvement of national scientific teams, students and private companies [63, 64].

In January 2023, the Slovak Quantum Communication Infrastructure (skQCI) European Union project was launched. Its main goal is to build a quantum communication infrastructure that will connect 12 academic institutions from across the country. In addition, connections with neighbouring countries or quantum transmission of encryption keys using satellites arise. The creation of a highly efficient photon detector is planned, to be tested in the created communication infrastructure with a wide spectrum of use, practically in every field of quantum technologies [5].

The national strategic research agenda for quantum technology [65] is being shaped by Slovak National Centre for Quantum Technologies (QUTE). QUTE long-term strategic vision is to prepare Slovakia for the quantum industry. The QUTE Centre has been instrumental in establishing an environment that boosts Slovakia's capacity for competitive and excellent research and innovation in quantum technology. As a contributing member of the QUTE Centre, the Slovak Academy of Sciences is involved in several key initiatives: [66, 5]

- Developing an educational program [66] and founding eduQUTE, an international training centre.
- Establishing iQUTE, a virtual institute of quantum technologies that consolidates various research teams.
- Building the quantum communication infrastructure, netQUTE, as part of the EuroQCI European initiative, and developing a single-photon detector tailored for netQUTE's requirements [67].

In addition to local research hubs, Slovakia benefits from its collaborations with international entities and neighbouring countries. These partnerships help in sharing knowledge, joint research initiatives, and in securing funding for expansive projects that further the defence-oriented quantum research [68, 69].

One of the most compelling applications of quantum technology in defence is in the realm of quantum cryptography. Slovakia is involved in the development of quantum key distribution systems (QKD), which provide theoretically unbreakable encryption for secure military communications [65].

Another significant area is quantum sensing, where research teams are working on quantum radar and other sensing technologies that could potentially detect objects invisible to conventional radar systems. These technologies are crucial for surveillance and reconnaissance missions, providing a tactical advantage in defence operations.

Despite the promising developments, the road ahead for quantum technology in Slovakia's defence sector faces several challenges. These include high investment costs, the need for specialized human capital, and the rapid pace of global quantum technology advancements, which Slovakia must keep up with. Furthermore, ethical considerations and international regulations on quantum technologies in warfare need continuous attention [70, 71].

7.3 Austria

Austria is one of the countries where quantum research is developing the most. Success in this field is evidenced by the fact that Austrian quantum physicist Anton ZEILINGER received the 2022 Nobel Prize in Physics. Rainer BLATT founded the Institute for Quantum Optics and Quantum Information in Innsbruck already in 2003 [72].

Important activities in this field in recent years include, for example, The Austrian Quantum Technology Initiative in 2016. Austria launches the national research ad development funding programme for quantum research and technology with a budget of 32,7 million EUR over 2017-2021 [73].

In 2021, Austria launched the Quantum Austria research campaign. This is an initiative of the Federal Ministry for Education, Science and Research. Austria is investing 107 million EUR into expanding quantum research and technologies using the Next Generation European Union recovery and resilience plan funds [74, 75].

Other important documents in this area include Austrian Research Infrastructure Action Plan 2030, which focuses on expanding research infrastructure and participating in European and international large-scale research infrastructure. The strategy is to strengthen Austria's international position in this area [76].

In Austria, several institutions are devoted to quantum technology. The Vienna Centre for Quantum Science and Technology (VCQ) undoubtedly belongs to the essential institutions in Austria, and it is one of the largest quantum hubs in Europe. There are integrated 31 research groups from the University of Vienna, the Technical University Wien, the Austrian Academy of Sciences, and the Institute of Science and Technology Austria [77].

In December 2023, Austria’s cluster of excellence for quantum sciences was launched. It comprises more than sixty research groups in Innsbruck, Vienna, Linz, and Klosterneuburg [78].

The QCI-CAT consortium is building the Austrian national project of the European Commission initiative EuroQCI. It is a team made up of scientists from five universities, major industrial partners and with the support of relevant ministries. The consortium brings together a mature ecosystem of technology suppliers, integrators and operators, and finally end users, which will enable the project to carry out its activities as close as possible to the actual operation of secure quantum communication networks. The project aims to adopt modern encryption technology for highly secure communication between public authorities. In addition, new technological approaches, such as the combination of post-quantum encryption, are being researched 79–81].

The association Quantum Society Austria was founded in 2022 in Vienna, Austria. A platform brings together experts of various levels in the field of research and practice [42].

Austrian Institute of Technology is part of the QUARTZ consortium, which is developing the quantum key distribution satellite system and service architecture. This includes the service, underlying technologies, and ground-based end-to-end testing. The technologies will also be used in security and the military. Other international institutions from Germany or the Czech Republic participate in the project. The Austrian Armed Forces are also involved in this project, with aim to use quantum technologies, especially in cyber defence, digitalization and autonomous systems [82].

Austria is cooperating with People’s Republic of China on quantum technologies even though, for example, the United States of America are trying to eliminate China's approaches to these technologies. In 2017, Austrian and Chinese scientists created a quantum communication link between Beijing and Vienna using the Mozi satellite. This satellite was also used to connect People’s Republic of China and Russian Federation in 2023 [83].

7.4 Hungary

Hungary has been among the first European countries with a programme for quantum technology. The first flagship programme was Hungary Quantum Technology – HunQuTech (2017-2021). Hungary also became a member of the European Union's Quantum Flagship, a large-scale initiative launched in 2018 that involves developing quantum technologies across Europe over a ten-year period (funded under Horizon Europe) [84, 85, 28].

In 2020, Hungary launched the National Laboratories programme [86]. National Laboratories are conceived as knowledge centres and scientific hubs in areas with high potential for the national economy. National Laboratories are dynamic, institutionalised, collaboration-based arenas of discovery and experimental research that open up new, international dimensions and enable the social, economic and environmental utilisation of research results. As a key vehicle for international collaboration in quantum technologies in Hungary, QuantERA plays a crucial role in coordinating and funding research projects that span various aspects of quantum technologies, including quantum communication, quantum simulation, quantum computation, and quantum sensing. QuantERA not only amplifies Hungary's presence in the global quantum technology scene but also aligns with the country's broader goals of enhancing its scientific and technological infrastructure [67].

The Quantum Communication Infrastructure (QCI Hungary) project, officially known as the Deploy Advanced Quantum Communication Infrastructure in Hungary, is a significant initiative under the European Union's Digital Europe Programme, aimed at establishing a robust quantum communication infrastructure across Hungary. The overarching goal of this project is to integrate Hungary into a larger pan-European quantum network, enhancing the country's technological infrastructure and its position within the European Union's strategic communications framework. QCI Hungary seeks to connect Budapest, with three other major cities (Győr, Nagykanizsa, and Szeged) laying the groundwork for potential future expansions into neighbouring countries (Austria, Slovakia, Slovenia, Croatia, and Romania). The infrastructure within Budapest will include a metropolitan quantum network designed to serve multiple applications, supported by commercially available quantum key distribution (QKD) systems [68].

Through these efforts, QCI Hungary aims not only to advance quantum communication technology but also to secure a leading role for Hungary in the European quantum landscape, enhancing both national security and technological prowess.

7.5 Slovenia

The Ministry of Public Administration of Slovenia promotes the concept that the European Union must remain a global superpower when it comes to investing in quantum technologies. The country declares an effort to make new technology to be safe and serve society as a whole, both in space and on Earth [60].

One of Slovenia's key strategic documents is the Digital Slovenia 2030 Strategy, which is devoted to developing quantum technologies [87].

In 2019, Slovenia signed the Declaration on Cooperation Framework on Quantum Communication Infrastructure [88].

In 2021, Slovenia, together with other countries, signed the Quantum Future Declaration. This initiative aims to achieve the same level of quantum technology cooperation as developed Western European countries by fostering cooperation on these technologies between countries that have not yet made significant progress in this area [89].

In 2021, a demonstration of quantum communication between three countries took place: Italy, Slovenia and Croatia. It was Encrypted audio-video communication among Trieste, Ljubljana and Rijeka [90].

In May 2023, Google launched quantum tech centre in Ljubljana. The centre is devoted to research, but also educational activities. For example, students can carry out their PhD research in the most advanced quantum laboratories, mostly across Europe [91, 92].

Important research centres in quantum technologies include the Jozef Stefan Institute, Faculty of Mathematics and Physics, University of Ljubljana. The Institute mainly deal with quantum-enhanced devices and their applications in quantum computing, quantum simulations, quantum communication, and quantum metrology [93].

University of Ljubljana in general is working on a project called the Slovenian Quantum Communication Infrastructure Demonstration. The project addresses the implementation of a quantum network between research and government organizations in Slovenia. In addition to the technological focus, the project also focuses on preparing experts and training key personnel [94].

8. Results of the Investigation

The topic of quantum technologies may very soon represent a nemesis for modern civilization. It is in the interest of the Euro-Atlantic states not to fall behind in this area, including related military use. Any recommendations in the monitored area imply the need to invest considerable resources and acquire qualified personnel, which is very difficult at a time when there are a number of parallel social ties.

The complexity and comprehensiveness of quantum technologies require cooperation on two levels. The first level is undoubtedly the cooperation of the state sector, scientific organizations, defence and multinational companies. Without the connection of these entities, it isn't easy to imagine achieving positive results. As we have already shown in the mapping of the individual states of Central Europe, cooperation is already intensively underway. The second level is cooperation between individual states, resp. cooperation within international organizations. With regard to the security aspects of these technologies, cooperation based on North Atlantic Treaty Organisation, or the European Union is crucial. Ensuring technological superiority in the coming years is a big challenge for the United States, resp. North Atlantic Treaty Organisation and the European Union.

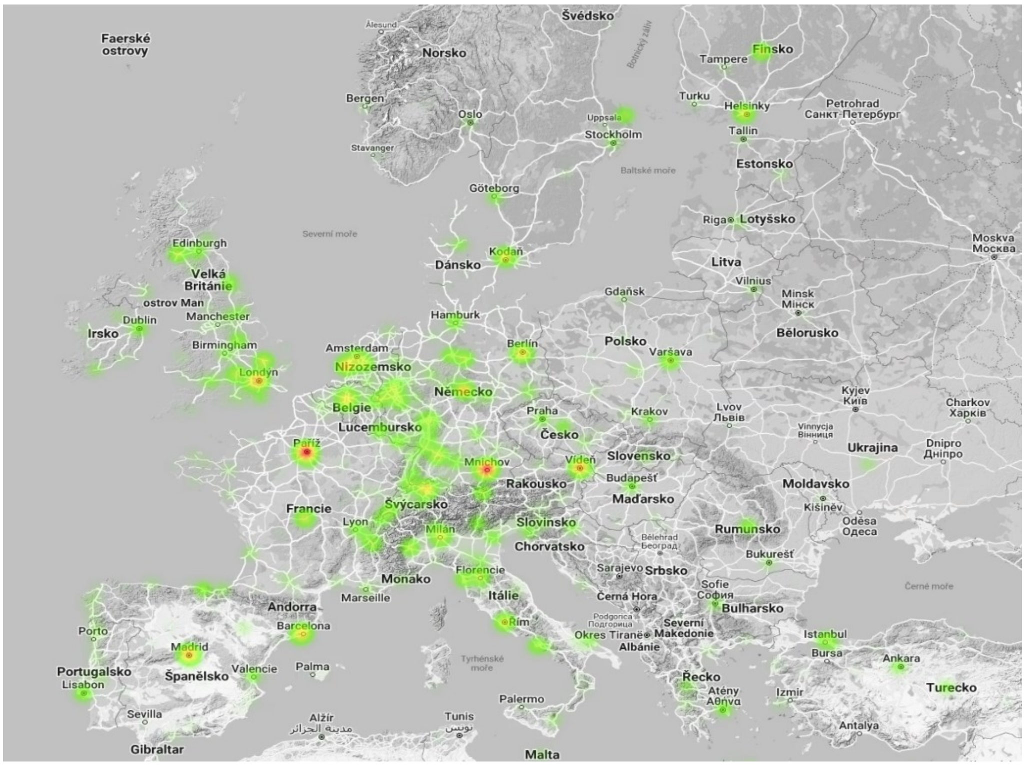

Fig. 1. Gradually focused heat map regarding the distribution of capacities for solving tasks related to quantum technology according to the European Union Quantum Flagship platform [94].

Fig. 2. Gradually focused heat map regarding the distribution of capacities for solving tasks related to quantum technology according to the European Union Quantum Flagship platform [94].

On the other hand, the effort to join forces within international organizations is reaching its limits, when some member states of the European Union and the North Atlantic Treaty Organization on the other side even today see the potential for cooperation with the People's Republic of China or even the Russian Federation in the field of quantum technologies. In several places, there is mention of the phenomenon of disinformation, for which quantum technologies represent a much greater opportunity – regarding its creation, dissemination and targeting, than for its suppression. Separately, the topic of quantum technologies is mentioned regarding the development of new drugs or in estimating the development of the economy (stock prices), which are again agendas with a high degree of potential abuse. In this respect, quantum technologies also bring many societal risks and will gradually become a significant topic.

Gradually focused heat map regarding the distribution of capacities for solving tasks related to quantum technology according to the European Union Quantum Flagship platform [94] is presented in Fig. 1. and Fig. 2. It is obvious that the observed five countries are in this respect, with the exception of Vienna, rather peripheral [95].

9. Conclusions

Quantum technology represents a relatively new solution, the anchoring of which at the level of states and relevant international organizations represents a very pressing challenge, especially in light of the sharp deterioration of the international security situation. Central European countries are significantly involved in this area and are achieving interesting results in it. Mastering the issue can thus be a decisive advantage in the event of a possible conflict, or rather play a role in the related deterrence. On the contrary, failure to master the topic can become a significant weakness, degrading the potential of a certain actor's security system.

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The Gray Zone and Its Place in Security Environment

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Abstract

In the space between "peace and war", which is called the gray zone in international relations, state actors operate with the intention of achieving their interests without the use of military force. The term "gray zone" defies categorization as well as framing, which would establish an international legal framework and, if crossed, could trigger a legitimate response from the international community. Power actors such as the United States of America (US), the Russian Federation (RU) or the People's Republic of China (CN) operate within the gray zone space. Given the ambiguity of the term, the possibilities for conducting activities within the gray zone are also expanding in an increasingly sophisticated manner.

KEY WORDS: *security environment; war; hybrid warfare; gray zone.*

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3. Introduction

The current development of human civilization is very dynamic, changeable and many times also highly turbulent. Significant changes are taking place in almost all areas, spheres, or sectors of human society. The field of security and defence clearly belongs to them (Ivančík, Nečas, 2023). As the global and regional security environment evolves, as the security situation evolves, so do the ways of waging war and the view of war as such evolves. Currently, state actors will not achieve their geopolitical objectives only using military force (Varecha, 2019). Its direct use requires a large amount of personnel, special military equipment and financial resources. Even if they are allocated and used for a particular military campaign, the objective of the campaign may not be achieved and may result in unforeseen consequences (Bartosh, 2021; Hrnčiar, Kompan, 2023). For this reason, the actors involved try to achieve their goals also through the use of various non-military means (Ivančík, 2021).

In 2013, the Chief of the General Staff of the Armed Forces of the RU; Army General Valery Gerasimov, at a presentation entitled "The Value of Science Is in the Foresight: New Challenges Demand Rethinking the Forms and Methods of Carrying Out Combat Operations", stated that modern armed conflicts are "conducted through the integrated use of political, economic, informational and other non-military means that rely on military power." (https://www.ndc.nato.int). The main objective of the presentation was to highlight the crucial role played by military science in understanding the current situation. One of the main ideas was that the role of non-military means has increased in achieving political and strategic goals. In many cases, their effectiveness exceeds that of weapon systems (Varecha, 2018; Käihkö, 2021).

The domains, spheres or dimensions of war in which actors can operate are also expanding (Panwar, 2017). They seek to achieve their objectives without entering into a direct military confrontation with the adversary. To do so, they employ a wide range of different means across domains of interest, thus expanding the spectrum of security threats. Due to constant technological developments and expanding capabilities, individual actors are conducting their activities in an increasingly sophisticated manner. In the context of the evolution of modern warfare, the concept of a "gray zone" representing the space "between peace and war" has emerged.

Despite the efforts of authors and institutions working in the field of the military, there is currently no unified definition of the term "gray zone". In September 2015, the US Special Operations Command published "The Gray Zone," which states that "the security challenges in the gray zone that exist outside of a formal state of war present new complications for US policy and interests in the 21st century. We have well-developed vocabularies, doctrines and mental models to describe war and peace, but the numerous gray zone challenges in between defy simple categorization" (United States Special Operations Command, 2015).

The US Special Operations Command introduced the term gray zone to "refer to activities, actions, or conflict in the space between peace and war" (Shenefield, 2022). The former commander of US Central Command (CENTCOM) US Army General retired (Ret.) Joseph L. Votel described this space as one "characterized by intense political, economic, informational and military competition or rivalry that is by its nature stronger than conventional steady-state diplomacy, but short on conventional warfare" (Votel, Cleveland, Connett, Irwin, 2016).

The different types of campaigns carried out within the gray zone are now numerous and are all considered to be elements of soft power. They are differentiated into instruments of national power, which incorporate diplomatic, informational, military, and economic instruments, and instruments of national security policy characterized as financial, intelligence, and law enforcement (Troeder, 2019). The director of the US Army's Joint Intermediate Force Capabilities Office (JIFCO) Colonel Wendell B. Leimbach and Principal Deputy Director Susan D. Levine stated in their 2021 publication that the gray zone is an area where a variety of operations are conducted on a daily basis, where "state actors employ a range of activities that do not amount to armed conflict ... through proxy elements that destabilize regions without identifying who is responsible" (Leimbach, Levine, 2021). The intent is to achieve the actor's intended goals without triggering a conventional war, such as annexation of the Crimean Peninsula by RU. It is also a space where state actors carry out dangerous activities. Leimbach and Levine pointed to the example of vessels approaching US Navy vessels on the high seas close enough to exploit this as part of their domestic propaganda. Such activities can escalate to an international crisis (Leimbach, Levine, 2021).

The US congressional report states that "competitors" are likely to use "covert and gray zone tactics to evade the traditional US military response" (House Armed Services Committee, 2020). A 2019 Science Board study states that in order to ensure US Armed Forces military dominance, the US "must be more aggressive in the gray zone" by building "a set of unique military capabilities in multiple domains to counter adversaries´ regional military advantages and force them to consider the costs of their activities" (Defence Science Board, 2019).

One of the other authors, who deals with the issue in question, is a candidate of military sciences of the RU, an expert in military diplomatic analysis, a teacher and researcher Colonel Ret. of the Armed Forces of the RU Alexander A. Bartosh. In 2021, Bartosh depicted the gray zone as a battlefield of hybrid warfare. The emergence and use of this concept in operational planning should be considered the most important factor determining the strategies of next-generation military conflicts. Such a radical transformation of the classical concept of the "battlefield of war" has occurred in the context of the impact of breakthrough information and communication technologies. As well as in connection with the creation of new areas of interstate confrontation in cyberspace and universe space, or domain, respectively, as well as the significant weakening of the competence of organizations ensuring international security in preventing negative developments. Bartosh said that potential adversaries of the RU are aware of this and are focusing on introducing new methods of unconventional warfare to help them carry out their policies. Both military and non-military means are being applied without individual actors resorting to large-scale military operations. In this context, Bartosh sees the issue as "that the armed struggle remains the central axis of war, while everything else is grouped around it forming a complicated hybrid system within, within which confrontation develops in different spheres of human activity: socio-economic, administrative-political, and cultural-philosophical" (Bartosh, 2021).

The characteristics of the non-linear and uncertain current operating environment are largely contained in the so-called gray zone. Bartosh argues that the activities conducted in the gray zone involve a version of the US strategy of coercion and deterrence built on modern hybrid warfare technologies. Operations of a similar nature help to compete with other states while staying below the threshold of conventional warfare, as well as activities that could provoke an international response. Preventing escalation in the gray zone is a line or 'threshold' limiting the objectives, scope and tools used in an operation that could reach a level, where the United Nations (UN) could respond, based on UN General Assembly Resolution 3314 of 14 December 1974 on the "Definition of Aggression", where Article 4 of the Collective Security Treaty of the Collective Security Treaty Organisation, or Article 5 of the North Atlantic Treaty Organisation (NATO) could be applied. Equally, a conflict whose dimensions could reach a harsh response, especially in the form of more severe economic sanctions, also constitutes a 'threshold' (Bartosh, 2021).

4. The Concept of Gray Zone

In connection with the development of the security environment, the term "gray zone" has been coined. The term was characterized in an official document in 2010, specifically in a Japanese (JP) document entitled National Defence Program Guidelines (Takahashi, 2019). The document describes the issue of the gray zone as the fact that, in addition to regional conflicts arising from ethnic and religious disputes, there is an increasing number of gray zone disputes, i.e., conflicts in which territory, sovereignty and economic interests are at stake, while at the same time not escalating into war. (https://japan.kantei.go.jp)

The issue became more prominent in the following years. In 2014, for example, the "gray zone" was mentioned in the context of a possible incident regarding the islands in the East China Sea that are under the administration of JP. JP officials stated that the JP preferred to discuss and request clarification of the respective roles of the US and JP in the event of a suspected incident. They stated this in the context of less extensive systematic military activities supported by the CN that posed a threat to the security of JP. In this context, Professor Narushige Michishita argued in 2014 that US policymakers will have to walk a fine line and must try to strike a balance between maintaining credibility, deterrence and avoiding over-involvement (Kubo, Sieg, Stewart, 2014).

In the same year, the term "the space between peace and war" was used in a statement by the then US President Barack Obama. This space was depicted as a space that is not empty. The context of the President's statement implied that the US must not rush into military operations without thinking through the implications in relation to achieving strategic objectives and continuing to engage in a particular space after the use of armed forces (Schadlow, 2014). In 2015, the term "gray zone" has already started to appear in several publications and documents of US armed forces, e.g., the aforementioned publication "The Gray Zone" published by the US Special Operations Command.

Strategies implemented within the gray zone are not new, 500 BC. Sun Tzu' in the work "The Art of War" stated that "to subdue an adversary without fighting is the height of skill" (Tzu, 1963). In the of 400 BC period Kautilya, an advisor to the first king of the Mauryan Empire, suggested the deployment of agents, assassins or murders, the use of disinformation, deceptive activities and the weakening of ties between united adversaries in order to create an opportunity for their king (Troeder, 2019). The tactic of exploiting the gray zone has been displayed in a number of conflicts in the past, including the Cold War.

As Bartosh said, the gray zone represents a battlefield of hybrid warfare. The term hybrid warfare was first used by Thomas R. Mockaitis in 1995. He portrayed hybrid warfare as a combination of counterinsurgency and conventional operations (Babbage, 2019). Subsequently, in 1998, Robert G. Walker used the term in the context of assessing the operation of the US Navy units (https://apps.dtic.mil). A broader outline of the concept in question was given by publications by Frank G. Hoffman and James N. Mattis in 2005. The first attempt to define hybrid warfare was attempted in 2007 by Hoffman: "Hybrid warfare encompasses a range of different modes of warfare, including conventional capabilities, irregular tactics and formations, terrorist acts including indiscriminate violence and coercion and criminal insurgencies" (https://www.potomacinstitute.org).

Naturally, the definition, or framing, as well as the understanding of hybrid warfare have evolved over the ensuing years by various authors as well as institutions. For example, US Army officer Timothy B. McCulloh in 2012 expanded the issue of hybrid warfare to include seven principles (https://apps.dtic.mil). Jānis Bērziņš a member of the National Defence Academy of Latvia (LV) expanded the understanding of hybrid warfare to include implications for LV security policy. In his publication, he cited Colonel Ret. of the Armed Forces of the RU Sergei G. Chekimov and Lieutenant General Ret. of the Armed Forces of the RU Sergei A. Bogdanov, who in 2013 illustrated the 8 phases of the next generation warfare (Bērziņš, 2014).

Colonel Ret. R. Ivančík and Colonel Ret. P. Nečas say that "in the case of a hybrid war, it is a way of conducting a modern armed conflict - a conflict that does not start with a shot and certainly not a declaration of war, a conflict in which the attacked society does not even know at first that it has been attacked and is at war. It is a dynamic combination of military, political, diplomatic, economic, humanitarian, diverse, terrorist, and criminal activities carried out by state and non-state actors, regular and irregular formations, using propaganda and the implementation of information, cyber and psychological operations" (Ivančík, Nečas, 2022). The issue of hybrid warfare is also elaborated in dozens of other studies defining various principles, phases, etc.

In 2014, when the annexation of the Crimean Peninsula by the RU took place, hybrid warfare was immediately associated with Gerasimov's speech in 2013. This issue also became one of the points of the 2014 NATO summit in Wales. Hybrid warfare became synonymous with RU and was considered a security threat by the West. The developments in question have turned the term of "hybrid war" into an ambiguous concept, with the constant threat of the so-called "reinvention of the wheel". The malleability makes the term useful in political and public debates; the lack of precision of the concept makes it impossible to use it for scientific purposes. The absence of a precise definition can result in hybrid warfare saying everything and nothing at the same time, which can also prevent a better understanding of contemporary warfare as well as the way it is waged (Käihkö, 2021).

5. Gray Zone and Security Environment

The departure from an order in which diplomatic and political means in particular have gradually relegated war to the background of the historical process is a particular feature of modern military-political thought, which has been shaped over centuries. According to the Director General of the Russian International Affairs Council, Andrei V. Kortunov, war is increasingly penetrating the fabric of global politics with its own logic, special thinking, its own principles and priorities. Carl von Clausewitz's statement that "war is the continuation of politics by other means", might sound today likes a mirror version of "politics is the continuation of war by other means". The triumph of the war paradigm over politics and diplomacy cannot but cause concern about the direction in which the modern world is heading (https://russiancouncil.ru).

For some, this may raise questions, so where is the new approach to war manifesting itself? Doctor of Military Science Lieutenant General of the Armed Forces of RU Alexandr V. Serzhantov, Candidate of Military Sciences Major General of Armed Forces of RU Alexandr V. Smolovy and Candidate of Military Sciences Colonel of Armed Forces of RU Alexandr A. Dolgopolov characterized such an approach in seven points (Serzhantov, Smolovy, Dolgopolov, 2021):

1. Increasing the number of actors participating in the war. The main and only actors in classical war are sovereign states. Modern military conflicts lack the characteristics of a unified organized force, or whole, and involve a variety of diverse actors that are not affiliated with the state, such as paramilitary groups unrelated to the regular armed forces, private military companies, mercenaries, and others. The participation of new actors in conflicts also determines the novelty of strategies aimed at prolonging the stalemate, harming the adversary from a moral or public opinion point of view, demoralizing the adversary or reaching a point where the conflict is no longer bearable.

2. Active seizure of the so-called uncontrollable space as well as its use against the opponent in all possible ways. Such space is understood as physical space, i.e., land, sea and air, where a certain "vacuum" appears due to the weak state or complete absence of influence in this environment.
3. Transitional alliances that are made between states and non-state actors with the intention of achieving certain ad hoc objectives. Such short-term alliances are concluded with actors with whom, on the one hand, there is useful cooperation and, on the other hand, they can carry out activities that the State cannot. Alliances of this kind are unclear and hidden from the point of view of transparency and are often formally denied at state level.
4. Changing the area of warfare. In the modern mode of warfare, the main area of warfare becomes the information domain, in which the consciousness of the population and its mentality is the object of efforts. Targeting the domain in question helps to reformat collective consciousness, falsify or distort world history and national culture and create a fifth column, i.e. a group of covert sympathisers or supporters of an adversary who engage in espionage and sabotage activities, thereby undermine national solidarity. In the event that regular armed forces retain their psychological stability and combat power but lose the support of the public as well as the state authorities, they are doomed to defeat. An equally important area of modern warfare is the political and economic sphere. The economy of the target state by the aggressor can be "bled" due to mismanaged and ineffective programs, which can steer the state into internal political chaos, the lowering of its political status and the decline of the economy and thus of the military power itself.
5. Changing priorities of confrontation types. In the classical warfare, the emphasis was on the use of regular armed forces as well as military-force methods of warfare, while other types of confrontation remained secondary. The role and importance of indirect methods of confrontation are currently increasing, consisting mainly of subversive, guerrilla, as well as non-military (information, economic and other) activities. The increased priority of informational methods of confrontation, mainly their impact on the population and members of the armed forces, represents a very important element. The use of such methods helps to change the mindset of society as well as the very attitude towards the adversary. The discovery of new means designed to influence confrontation participants represents the changing priorities of confrontation. A concrete example can be found in the emergence of the Internet. In the information domain, it is generally used to shape people's thinking and opinions regarding world events. This has resulted in an exponential increase in the use of the information domain in current confrontations. The use of military-power methods is also changing, whereby armed forces are increasingly used under the pretext of peacekeeping activities, deployed to address various crises or support humanitarian operations.
6. Changing the order of means that are used in confronting an adversary during different phases of the war. In classical warfare, military-force methods were applied from the beginning of the war to its end and across all its phases. The modern method of warfare depicts the armed clash between the entities participating in the war as an element that moves to the final phase. The intention is to consolidate the success achieved in the war. The emphasis in the initial stages is on the use of non-military means.
7. A changed spatio-temporal model of war, specifically in the use of hybrid methods that break the boundaries of individual stages of war. As a result, the initial phase is not clearly depicted, as opposed to the use of elements of armed combat or armed clash.

The war between the State of Israel (IS) and the Shiite Islamist movement Hezbollah (Lebanese Republic of Lebanon - LB), also referred to as the 'Second Lebanon War' in the IS and the 'July War' in the LB in 2006, is an example of the change in approach to the way war is fought. Hezbollah used guerrilla methods to achieve its objectives, as well as an underground network of tunnels that prevented the IS armed forces from exploiting its strengths, i.e. the activities of the IS land forces and air forces. They obtained up-to-date information through the access they gained to IS communications networks and the mobile phones of the personnel of IS armed forces. These were then also used for a massive propaganda campaign around the world (Gabrielsen, 2013). IS officials, on the other hand, provided limited information to the media, allowing Hezbollah to control the information battlefield. When civilian casualties were killed in Hezbollah attacks, they used their control of the information environment to undermine international support for IS.

Hezbollah's priority means of coercion was shelling the northern part of IS. The aim was to make daily life unbearable for the people of IS in order to improve Hezbollah's domestic standing in the context of a demonstration of its military power. Hezbollah operatives carried out these attacks on a daily basis, averaging the firing of approximately 130 rockets per day, and on the last day of the war, IS was hit by 250 rockets. Towards the end of the war, Hezbollah began to achieve strategic effects through rocket attacks (Gabrielsen, 2013).

When we look at the steps that the IS and Hezbollah have used to achieve their goals in the war in question, we can see their divergence as well as the change in the way the war has been waged in "practice". The IS sought to achieve its objectives in a largely conventional manner, with the IS air force playing a significant element in the IS's strategy. Hezbollah, on the other hand, has focused on the psychological aspect through constant shelling and has also exploited its superiority in the information environment. It thus used the space in which it could prevail over the adversary and thereby achieve its intended objectives.

Doctor of Philosophical Sciences Colonel Ret. of Armed Forces of RU Yuri A. Brychkov, Doctor of Military Sciences Colonel of the Armed Forces of RU Viacheslav L. Dorokhov and Candidate of Philosophical Sciences Lieutenant Colonel of the Armed Forces of RU Grigory A. Nikonorov stated in their publication that it is necessary to focus on the search for and development of asymmetric and indirect methods of warfare (Fig. 1.). In the publication, the authors stated that by analyzing armed conflicts over the last 200 years, the weaker side has been able to win 30% of all asymmetric wars.

History confirms that the forces of the stronger actor succeeded in the early stages of war when they conducted their activities against the regular forces of the weaker actor (Brychkov, Dorochov, Nikonorov, 2019).

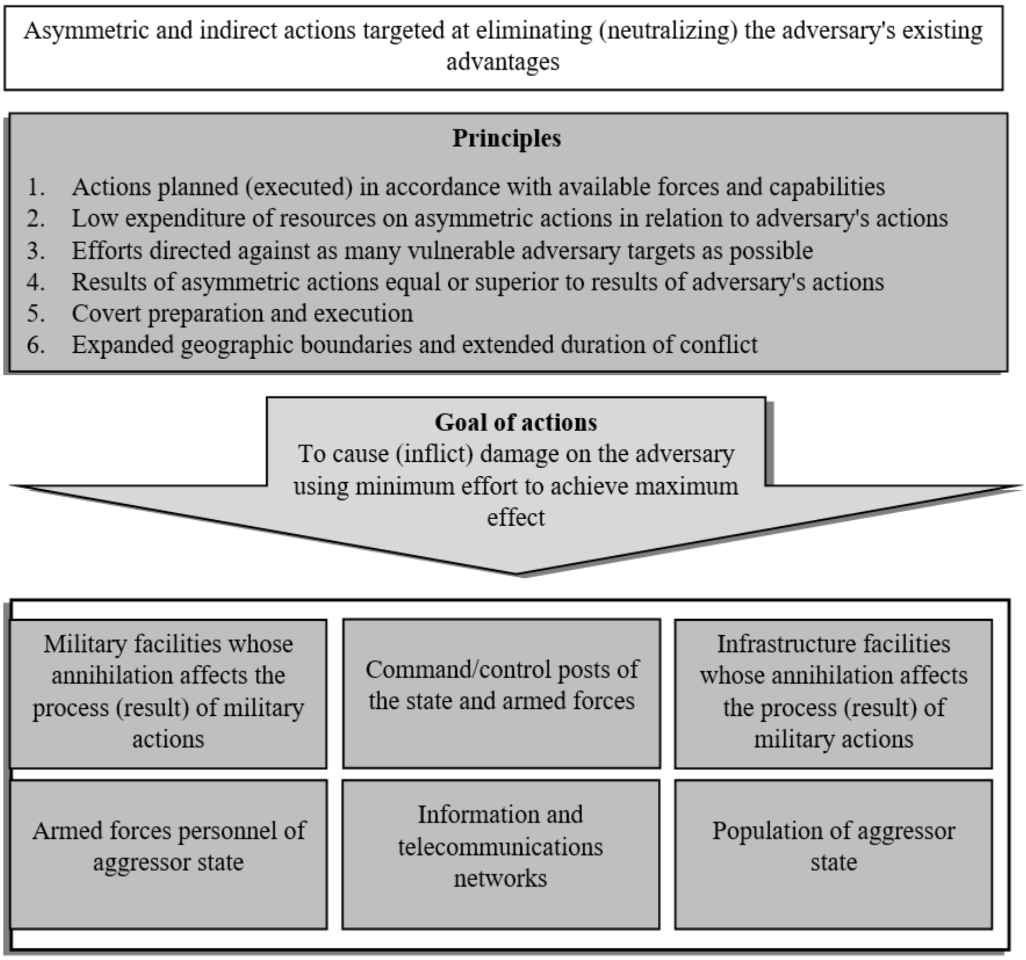

Fig. 1. Asymmetric and indirect methods of warfare
Source: Brychkov, Dorochov, Nikonorov, 2019

In 2021, Leimbach and Levine produced a publication in which they discussed the so-called Intermediate Force Capabilities (IFC). The term IFC is a non-doctrinal term that evolved from the US Department of Defence (DOD) program called Non-Lethal Weapons (NLW). The term is primarily associated with law enforcement, conjuring up images of rubber bullets and similar devices. The term IFC is future-focused and more accurately describes a range of capabilities beyond traditional NLW that are currently achievable through advanced technology. Current and emerging technologies provide the tools that will enable the US armed forces, working with allies and partners, to control the scope and pace of escalation (Leimbach, Levine, 2021).

The 2018 US National Defence Strategy states that "our goal is a Joint Force that has a decisive advantage for any likely conflict, while remaining capable across the full spectrum of conflict" (Department of Defence, 2018).

To maintain this decisive advantage, joint forces need, in addition to the use of lethal means themselves, a set of IFC tools that include non-lethal weapons as well as other such tools. IFCs capabilities will enable proactive measures when armed force presence alone is insufficient to deter harmful activities or when the use of weapon systems is neither desirable nor appropriate (Leimbach, Levine, 2021).

The continuing conduct of combat operations around the world in the 21^{st} century shows us that change remains a constant in the practice and in the conduct of war itself. Through various national security strategies, defence strategies, other assessments from a strategic perspective, analyses by think tanks, universities and other institutions, it is recognised that the conduct of war in the current century is significantly different from the past. The status of a state that is in a binary state of peace or war is increasingly unlikely. As a result, binary responses to US adversary activities consisting of taking no action or using a significant number of lethal weapon systems are inadequate. The changing elements of nature of 21^{st} century warfare underscore the need for policymakers to commit to the development of IFCs to support current and future war-fighting requirements (Leimbach, Levine, 2021).

The US National Defence Strategy stated that, the US DOD has rightly focused on developing weapon systems to deter potential adversaries. These systems are an important deterrent to conflict itself, but the state must also be able to compete with and deter activities that are not traditional armed conflict. Former Chairman of the US Joint Chiefs of Staff, General Ret. Joseph Dunford noted in 2018 that US adversaries recognize their dominance, so they avoid crossing the line into armed conflict. They have learned that they can manoeuvre very close to that border without consequences. In Joint Doctrine Note 1-19, this is referred to as "competing below the threshold of armed conflict" within the "Competition Continuum" (Joint Chiefs of Staff, 2019). It is also referred to as the gray zone, as it captures the essence of the fact that global conflict is rarely defined in black (total war) or white (peace) (see Fig. 2.). IFC capabilities are tailored to provide joint forces with options within the gray zone (Leimbach, Levine, 2021).

The US National Defence Strategy describes an alternative view of the historical pattern of peace and war and describes a Competition Continuum that consists of 3 parts (Fig. 2.).

Fig. 2. Competition Continuum
Source: Leimbach, Levine, 2021

The figure provides a useful construction to highlight the concept of the gray zone. If the black area of the images represents high intensity conflict and the white correlates with peace, then the rest of the operational environment and/or competitive continuity are gray. It is also an area in which US competitors operate and often outnumber US forces (Leimbach, Levine, 2021).

In their publication, Leimbach and Levine argued that the modern warfare is forcing political leaders to adapt to a reality that requires understanding that a multitude of lethal weapon systems must be complemented by other options. Like war, the approach to warfare itself must evolve, "if we stop refining, expanding and improving our profession, we risk becoming more obsolete, stagnant, and defeatist" (Leimbach, Levine, 2021).

Conclusions

During his 2013 presentation, Chief of the General Staff of the Armed Forces of the RU Gerasimov stressed that the new concept in which war is being waged leads to logical questions: "What is modern war? What should the army be prepared for? How should they be armed?" The construction and development of armed forces in the long term will be determined by the answers to these questions, and to do this it is necessary for those involved in military planning to have a clear idea of the forms and methods of use of force (Gerasimov, 2016). The deployment of a significant number of armed forces units (conventional forces) along with modern weapon systems is, on the one hand, financially demanding, and on the other hand, it may not guarantee the achievement of the desired objectives. State actors are aware of these facts and focus their efforts on introducing new methods of unconventional warfare.

The concept of hybrid warfare, which first appeared in 1995, has become a paradigm of warfare, including ways of waging war; 19 years have passed since then. The essence of the concept was a change in the approach to warfare and the expansion of conventional capabilities to include a range of economic, informational, diplomatic, and other means. The term hybrid warfare has not had a unified definition since its discovery, despite the fact that the concept has been described by a number of authors and institutions. Apart from the fact that the malleability of the term is useful in various discussions, a possible consequence of the absence of a precise definition may be that the term speaks of everything and nothing at the same time.

The beginning of the use of the term gray zone in the 21st century can be dated back to 2010. This concept, as well as its characteristics, has achieved a certain shift. Military leaders, strategists, institutions, etc. published a number of publications and perspectives on how to understand and operate in this space. They are reacting to the change and development of the modern way of conducting warfare and are trying to grasp the space of the gray zone so that they can cover it and achieve their stated objectives within it.

The gray zone strategy implies active activities of states (coalitions of states) with the intention of creating the desired situation in the administrative-political, financial-economic and cultural-philosophical spheres of the designated target state, several states or the entire region to achieve its destabilization and collapse (Bartosh, 2021; Kompan, Hrnčiar, 2024). The essence of the strategies carried out in this space, which are aimed at achieving set goals or winning over an adversary without achieving a direct military confrontation, are not a new idea (Jurčák, Marek, 2022).

The operational environment of the gray zone is the space "between peace and war". Like the concept of hybrid warfare, the term gray zone has no unified definition. The UN does not currently have a defined gray zone, nor does it have any legislation published on its website that defines or frames the issue in any particular way.

In the security strategies of the V4 countries in the period 2010-2023, the notion of gray zone appears as follows, the Security Strategy of the Slovak Republic of 2021 does not define the notion of gray zone, the same is the case with the Security Strategies of the Czech Republic of 2011, 2015 and 2023 and the National Security Strategies of the Republic of Poland of 2014 and 2020. In the National Security Strategy of Hungary of April 2020, there is the concept of gray zone. It refers to a way of waging war that does not know the boundaries between peace and war, which leads to situations that are below the threshold of conflict, do not meet the definition of war and is difficult to assess (Government of Hungary, 2020).

The inconsistency between the term depicting the space "between peace and war" is also represented by the fact that in many publications it is referred to as a "gray zone" or a "grey zone", even though the context of the terms is the same. As

Bartosh stated, the space of the gray zone, including operations in this space, can be characterized as a hybrid warfare battlefield and should be considered the most essential element that determines the strategies of new generation of conflicts. Nowadays, wars are aimed at controlling the space, be it economic, ideological or mental, as well as maintaining a state of chaos and unending conflict among citizens.

The limits of hybrid warfare are not defined in terms of morality or space. In this context, security is affected from a global perspective and the threat in individual states is increased. It also call for the development of relevant countermeasure concepts, which should be based on the boomerang rule, i.e. the diametrical shift of the threat vector from the target of impact to the source of generation (Serzhantov, Smolovy, Dolgopolov, 2021). We can see that the political, diplomatic as well as economic means that once sidelined war now constitute a distinctive feature of modern military-political thought. The paradigm of war is part of the modern or contemporary world. In this context, there is a need for continuous refinement in the conduct of the approach to war to avoid stagnation. Operating in new domains, namely the cyber and space domains, have expanded the capabilities of actors to operate on multiple 'fronts'. This may result in achieving even greater ambiguity in achieving their objectives, as well as weakening the organisations that provide international security.

Currently we see that there are several places or areas of instability in the world, such as Ukraine (UA), the Republic of Belarus, the Syrian Arab Republic, the Republic of Iraq, the Libyan state, as well as maritime border disputes, or an area such as the Arctic, where individual actors are trying to expand their influence and status by operating in the gray zone. The issue of the gray zone is addressed by experts mainly in the field of security studies. Representatives of the US, respectively the West, the RU but also the CN are dealing with the gray zone and trying to make the best use this space to their advantage, which shows its importance.

From the ongoing development processes, across all domains, risks and insecurities arise, which deepen the volatile contours of modern armed conflicts, which have a hybrid character (Bartosh, 2021). Thus, this requires the continuous development and implementation of relevant strategic documents by state actors, regardless of whether their substance is offensive or defensive in nature (Bartosh, 2021).

As a result of continuous technological developments, the emergence of the concept of hybrid warfare, its constant expansion in its definition, the expansion of the domains in which actors can operate (Jančo, Kompan, 2023), the characterization of the gray zone that constitutes the battlefield of hybrid warfare and in which state actors are increasingly operating a more sophisticated manner, we can conclude that the concept of the gray zone and its evolution blurs more than it explains. As part of this, we can expect state actors to continue to exploit this space, and to do so in a more sophisticated manner. A number of studies have been published in academic and policy research in this context. In several of them, RU representatives are portrayed as experts who will achieve the desired results at minimal cost while making it impossible for the adversaries to respond effectively. How well the RU can operate in a gray zone is also up for reconsideration, as it has resorted to the direct and extensive use of conventional forces on the UA despite having operated in a gray zone there for years (Cohen, 2022).

Certain issues arise with examining the issue of the term gray zone within an international law framework. The applicability of the gray zone is not uniform; actors have to vary certain elements to achieve their interests, e.g., on the basis of geographical distribution. In the context of the use of the gray zone space by the RU, the US, or another power, it is difficult to evaluate the success of the operation because the gray zone is not defined or framed. Assessing its success and/or effectiveness may vary based on the perspective of the conflict actors. The actor operating within the gray zone may have a different perspective on the results achieved than the one against whom the activities are carried out.

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Strategic Communication's Role in Eliminating Disinformation's Impact in Time of Current Geopolitical Challenges

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Abstract

The article presents strategic communication as one of the tools used to counter disinformation, especially during global security challenges, which undoubtedly includes the fight against disinformation. Disinformation has recently become a significant global security challenge that individual states must face. In this context, individual states and international organizations are looking for practical tools to eliminate the effects of disinformation campaigns. Strategic communication undoubtedly belongs among these tools. Nevertheless, strategic communication has several advantages compared to other approaches, such as restrictive measures or educational activities based on critical thinking. The advantage of strategic communication is that we choose the topics we want to communicate ourselves and the methods and tools for their dissemination. In this way, we will avoid several negative effects, such as deepening the polarization of society or cognitive dissonance. Attention is paid to the institutional security of strategic communications. Creating an "ecosystem" that would mainly operate outside state institutions appears to be effective. This contribution aims to present the optimal strategic communication model and its pillars. Another effort is to present the so-called "strategic communication ecosystem," its mission, and its role in the fight against disinformation.

KEY WORDS: *Polycrisis, Disinformation, Fight Against Disinformation, Strategic Communication, Behavioural Nudging, "Ecosystem"*

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1. Introduction

Disinformation has become a phenomenon today and is the subject of discussion. The COVID-19 pandemic started the so-called infodemic, which meant that the information space was filled with different narratives. In connection with the COVID-19 pandemic, the war in Ukraine, and the financial and energy crisis, the world has entered a period of so-called polycrisis. Polycrisis means great danger, which can even result in a war conflict [6]. The polycrisis, or several parallel crises, brought another wave of disinformation narratives, which are associated with the war in Ukraine, the energy or financial crisis, migration, etc. European Commission President Ursula von der Leyen said that risks like disinformation and societal polarisation are very serious as they can limit our capabilities to deal with other challenges. In a special address at the World Economic Forum Annual Meeting 2024, she mentioned that this is not the time for polarisation but for rebuilding trust [10].

Disinformation, manipulation of facts, and other influence operations thus pose a great danger to society's stability and citizens' trust in democratic principles and official authorities. There is no doubt about the seriousness of this situation. Recent revelations of activities around the pro-Russian Website Voice of Europe are concrete evidence of interference in the European Parliament elections. The Czech intelligence services revealed a network that was involved in the spread of Ukrainian propaganda in Europe. According to the Czech intelligence services, money was provided to politicians in the Netherlands, Belgium, Germany, France, Hungary and Poland in exchange for spreading Russian propaganda. In Poland, for example, it is being investigated very intensively [15].

Disinformation thus represents a new security challenge that has been talked about for many years. The information space thus represents a new battlefield. This phenomenon is specific because it blurs the boundaries between the purely military and civilian spheres. For this reason, it is urgent to find solutions that will be applicable to the whole society. Thus, society's resilience becomes one of the key challenges for ensuring national defence.

The key question remains: How can disinformation narratives and depolarization of society be eliminated? There are several approaches to eliminating the spread of disinformation narratives, from restricting and shutting down websites to educational campaigns and developing critical thinking.

The mentioned activities have their limits, especially in times of crisis. Restrictions can lead to even greater polarization of society, education, and the development of critical thinking, which is a long-term issue. For this reason, strategic communication is an effective tool in eliminating disinformation narratives. The goal of this contribution is not only to present strategic communication but also to analyze to what extent the Czech Republic can use it to build a resilient society facing global risks.

2. Strategic Communication and Behavioral Nudging: Tools for Countering Disinformation in Crisis Situations

As we have already indicated, several approaches exist to eliminate disinformation narratives. Each approach has its advantages and limitations. Let's introduce them step by step and show how effective they are.

One of the very often mentioned tools for combating disinformation is critical thinking. Developing critical thinking is not a one-time task but a daily commitment. It involves the systematic analysis of information, the ability to recognize its validity, analyse arguments, and avoid misleading content. This process includes logical reasoning, integration of evidence, and cross-referencing with other sources. Moreover, critical thinking necessitates introspection, where individuals examine their beliefs, admit mistakes, and show a willingness to correct them [2].

Psychologists and scientists who study the influence of human behaviour and decision-making processes believe that critical thinking is a relatively insignificant part of solving everyday situations compared to human spontaneity. Critical thinking relies on rational thinking, which predominantly engages the conscious brain system two, making up just 5% of brain capacity, while emotions and intuition control the remaining 95%. It is generally known that disinformation narratives primarily use emotion, which guarantees their success. In everyday life and when dealing with common situations, people do not make decisions rationally but subconsciously based on predefined patterns of behaviour. Factual argumentation is based on so-called heuristic approaches, which we use when problems seem familiar to us and, therefore, we no longer need additional information. In everyday life, we make decisions based on so-called cognitive bias. However, disinformation uses just cognitive bias. These "mental shortcuts" that usually break the rules of logic make us easy to manipulate [8]. Critical thinking does not 100% guarantee that people will not succumb to disinformation.

The development of critical thinking is possible through educational initiatives. Effectively setting up educational activities containing information and digital skills requires a longer period, and its results will manifest only in a longer time horizon. In other words, rationality plays a minor role in everyday decision-making and problem-solving. While developing critical thinking in the form of educational activities is essential, it does not guarantee that the "consumption" of disinformation will decrease since disinformation is not based on rationality but on emotions. As stated above, emotions are essential in people's everyday decisions (see Fig. 1).

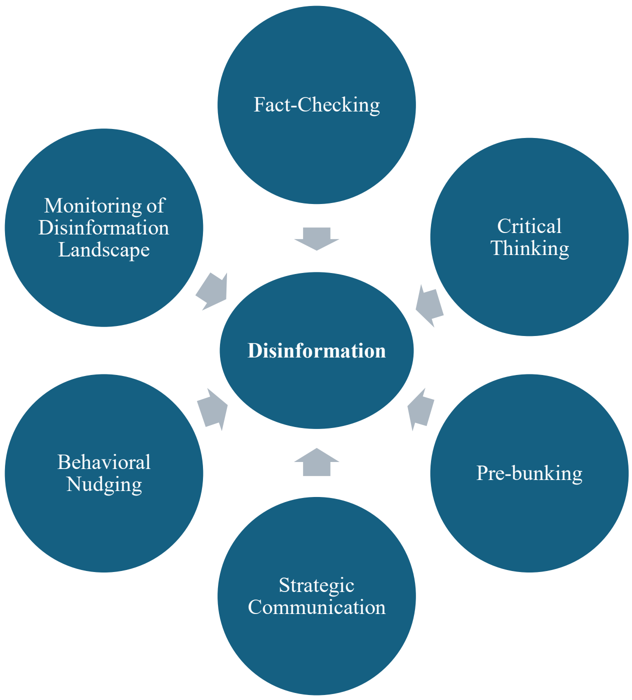

Fig. 1. A system of tools for countering disinformation narratives. Created by author.

Another approach is fact-checking. Fact-checking goes hand in hand with critical thinking. Fact-checking is one of the primary and first methods to uncover disinformation. However, fact-checking is more of the domain of journalists, politicians, and scientists. It is the very optimistic assumption that the average reader will check every article after reading it to see if it is true. However, the role of fake checking must be considered precisely because it is a crucial method by which we can analyse disinformation narratives. Currently, several platforms are dedicated to debunking disinformation narratives. These platforms should primarily be used by journalists, politicians, scientists or opinion makers, all those who are significantly involved in shaping [3].

Along with the fact-checking method, monitoring individual disinformation narratives and campaigns is essential. Practical tools have been developed in this regard, and several companies or platforms are dedicated to this. As an example from the Czech and Slovak environment, we can mention companies such as Semantic Vision, Gerulata, or the Czech Elves platform. Campaign monitoring is important, especially when setting up a strategy to eliminate disinformation narratives. We need to know and understand the information environment and its dynamics to develop the right plan.

Another method associated with fact-checking and critical thinking is various forms of pre-bunking. Google began using this method, which is called vaccination against disinformation. This method searches for and detects in advance possible errors and flaws in arguments or claims that could be spread as disinformation. This will increase the likelihood that people will be guided by facts and correct information and not fall victim to manipulation [7].

Strategic communication and behavioural nudging are another tool for countering disinformation narratives. Strategic communication is an active form of combating disinformation. Compared to the approaches mentioned above, which are oriented towards individual attitudinal changes, strategic communication and behavioural nudging rely more on behavioural changes. This aspect is crucial for us, especially when dealing with a crisis. Especially in times of crisis, when we need to act very quickly, we have to use tools to persuade the population to do what we want them to do, regardless of whether they fully identify with them. It is generally known that people rarely change their attitudes, and when they do, it is over a long period of time [9].

On the other hand, this does not mean that we should give up on other approaches. Critical thinking, as well as fact-checking or monitoring disinformation narratives, plays a key role in the resilience of the population's resistance to disinformation narratives, it sets us a real mirror of the situation in which we find ourselves. The disadvantage, especially with critical thinking, is the time frame when we get results over a more extended period. Other methods require a certain level of expertise that the general population does not possess. Strategic communication, together with behavioural nudging, thus appears as a flexible tool, especially in times of crisis when we have to take quick measures.

3. Summarizing the Essence of Strategic Communication: Supporting Goals and Gaining Support

Strategic communication is one of the most discussed topics in the Czech Republic. In 2021, the Czech Republic adopted the National Strategy for Countering Hybrid Impact and subsequently the Action Plan for the National Strategy for Countering Hybrid Impact. In 2024, a government coordinator for strategic communication was appointed [14]. However, there is still a discussion on how to tackle this issue and create an effective and functional system.

Strategic communication is not a new phenomenon, but historically, it has related to the existence of organizational units of different levels. Paul A. Argenti, Robert A. Howell, and Karen A. Beck define strategic communication as a tool for promoting a company or firm's overall strategy and thus strengthening its position [1].

According to Haseeb Tariq, strategic communication can be understood as an in-depth process that considers who we are talking to, why we are talking to them, how and when we will speak to them, what form the communication content should take and what channels we should use to share it [16].

In book Information War from 2017, Karel Řehka discusses strategic communication as a complex communication process that tries to plant a specific message in the target group's mind, while all messages sent must be coherent and mutually supportive. Such communication can subsequently change people's behaviour, which is the desired goal of strategic communication [12].

In security [5], for example, strategic communication is understood as:

- "integrated communication"; that is understood as an umbrella term for any communication aimed at achieving a goal, and thus including different disciplines;
- communication conducted at the strategic level of the organization's management; clearly distinguished from the tactical and support level of communication;
- communication conducted in the context of military and national power;
- an alternative name for the discipline of public communication.

Strategic communication has a wide range of definitions; for this reason, it refers to various communication activities that are not strategic communication in themselves but can be part of it, such as crisis communication or public relations. If we summarize the individual definitions, we can conclude that strategic communication, on the one hand, is intended to support the goals that we are trying to achieve, whether it is a private or societal subject. We must convince individuals of the correctness of our goals and efforts so that they identify with them and support them. If we were to give a specific example, if we want people to vaccinate us, we have to convince them that this step is correct. In this regard, we do not have time to educate people about what vaccination will bring them and to what extent it is safe or not. Another example is

Ukraine's support. In the Czech Republic, there are different opinions on whether to continue supplying weapons to Ukraine or to create pressure to conclude peace at any cost. In this situation, explaining the essence of the problem is less effective, but the goal is rather to focus on what the support mentioned will bring us and what impact it will have. Another topic that strategic communication can cover is the motivation of the population to actively participate in the defence of the country, whether by joining the armed forces or active reserves.

4. Understanding Behavioural Nudging

An important part of strategic communication is behavioural nudging, i.e. "pushing" or "pushing" towards certain behaviour. The nudging theory was described by Richard H. Thaler and Cass R. Sunstein in their publication Nudge: Improving Decisions about Health, Wealth, and Happiness [13].

Nudging is used mainly in marketing and economics, but this is not the case. We can also see the use of nudging in politics and other social spheres. In 2010, David Cameron's UK government created The Nudge Unit. The name "Nudge" is based on the book above by Richard Thaler and Cass Sunstein. The Nudge department has worked on various policy areas, such as encouraging people to pay their taxes on time or increasing organ donation. This centre played an irreplaceable role during the COVID-19 period [11]. France has also created a similar centre. Eric Singler created this centre in 2013. Eric Singer is among the world's recognized experts in behavioural nudging. Centre played a significant role in the fight against COVID-19, in particular [4]. Why is behavioural nudging an important part of strategic communication? In general, it can be said that it is a persuasive tool that creates a positive message. Above all, it can be effective in communicating sensitive topics that can cause a negative reaction in society. Examples can be mentioned topics such as Covid-19 or the war in Ukraine.

5. The Main Steps for Creating a Strategic Communication System

We will try to create an optimal model of strategic communication based on the approaches mentioned above. This is not an ideal model but rather a line of thinking we should follow when creating it.

Creating a strategic communication system is not a simple process. It consists of several steps. Let's introduce them briefly (see Fig. 2).

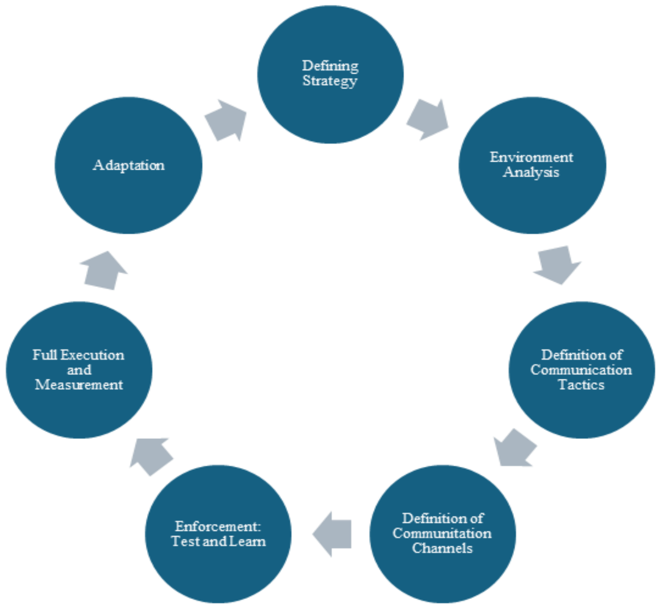

Fig. 2. A system of Strategic Communication. Created by author.

The key questions are how to set up a strategic communication system and the key activities:

1) The **planning process** must undoubtedly begin by defining a long-term but achievable goal. If we were to give a practical example from the time of Covid-19, a defined goal would be a high vaccination rate for the population.
2) The cornerstone of our strategy is a comprehensive **understanding of the current state**, encompassing both the internal and external environment. This environmental analysis is crucial, as it includes an assessment of knowledge, target groups, communication spaces, expenditures, and relevant topics, providing a solid foundation for our strategic planning process.
3) The following steps involve defining **communication tactics** based on the target audience we want to influence. If we were to use Covid-19 as an example again, the different ways of communicating with the older and younger populations would be important.
4) The next step is defining effective channels and **Touch Points.** This communication matrix, which specifies messages, media and touch points, is essential for effectiveness, considering the different impacts of the same

message in different contexts. We will use other Touch Points for the younger target group and others for the older, etc.
5) The implementation phase involves **testing and learning, optimizing communication** formats for different environments, and fine-tuning the media mix for various population groups.
6) Once we have optimized the communication and media mix, we embark on **full implementation**. This phase is marked by continuous measurement of key metrics, which serve as our compass, guiding us to verify the extent to which we have achieved our set goal. This data-driven approach ensures we stay on track and make informed decisions. If metrics prove insufficient for strategic goals, adjustments are made to ensure alignment with overall goals.
7) If we verify that the metrics are functional, we enter the **adaptation phase,** when the strategic communication system fulfils our goals. What is important is how we will measure communication effectiveness and what we will consider success. For example, indicators can include the population's awareness of the need to wear masks or the percentage of the population that has been vaccinated.

The effectiveness of strategic communication in influencing behaviour depends on several factors:

1) Scope of interventions, or reaching a broad part of the audience or our target group. Sometimes, we don't have to focus exclusively on the entire population, but only on a selected group.
2) Hit frequency emphasizes the need for frequent and successful content delivery. The point is that frequent repetition of the message better reaches the audience's awareness.
3) The third factor, quality and relevant content, plays a key role in attracting attention. Its timeliness is essential, underscoring the importance of your role in creating impactful content.
4) "Flooding the media space" is, in essence, about gaining the dominance of our communicated narratives over the narratives of disinformers.

6. The Need to Create a Strategic Communication Ecosystem

Setting up the system, especially who will implement and support strategic communication, remains a key issue. What should be its institutional and personnel provisions? If strategic communication is exclusively provided by the state administration, it may be perceived as government propaganda.

Table 1.

Strategic Communication Ecosystem

Know-how	**Organizations**
Data experts	State Institutions
Behavioural / Nudge experts	Incubators / start ups
Marketing experts	Think Tanks
Social media experts	Ad / PR agencies
Journalists	NGOs
Designers	Bureaucrats & politicians
Creatives	IT & Data experts

At the same time, an overall strategic communication system needs to be created over time and not dependent on one election period. One way is to create and support an "ecosystem". Under the ecosystem, we can imagine institutions, experts, and know-how. The advantage of the ecosystem is its timelessness. Most of the elements of this ecosystem are outside state institutions, thereby declaring a certain independence. The ecosystem consists of two pillars (see Table 1). One of the pillars is know-how, which is carried by experts in communication and marketing, as well as designers, journalists, and creatives. The second pillar is institutions, not only state ones but also non-governmental organizations, think tanks, IT companies, etc. However, we must perceive the system set up in this way as a natural element of our efforts. Its possible institutionalization could lead to its less effectiveness, while at the same time, it could give the impression that it is ultimately a system supporting state or government propaganda.

7. Conclusions

There is no doubt that disinformation has become a major global security challenge. Central and Eastern European states are exposed to extensive disinformation campaigns and influence operations, especially by Russia. In this regard, they are logically looking for ways to counter these campaigns and eliminate their impact. Fighting disinformation and eliminating its impact on society has become a significant challenge for national security. Restrictive methods are less effective and can be perceived as an attempt to limit freedom of speech, which is a very sensitive topic in post-communist countries. Other approaches related to education and the development of critical thinking require a more extended period. For this reason, strategic communication is an effective tool. What is essential, however, is the creation of a concrete system of strategic communication based on its individual pillars, which we have presented. In the Czech Republic, as well as in the countries of Central and Eastern Europe, we are at the beginning of the whole process. We are gathering experience not only from the states that have this system in place but also from our experience so far, which has been gained from the period of COVID-19 and from facing Russia's disinformation campaigns. If we were to mention the situation in the Czech Republic, so far, many of the measures mentioned in the strategic documents have not been effectively implemented. Currently, our system lacks an institution that would coordinate the entire process. However, the Czech government is starting to address this problem. The appointment of a government coordinator of strategic communication is the first concrete step.

On the other hand, the key steps in creating an overall system are still ahead of us. It will be important to define the topics to be communicated and the tools and methods of communication. The next step is to create an effective ecosystem in which a wide range of experts and scientifically recognized capacities will need to be involved. Creating an ecosystem is key, especially to gaining societal trust in communication activities.

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Security Strategies of the Visegrad Group Countries in the Current Security Environment

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Abstract

The aim of this article is to analyze the security strategies of the individual Visegrad Group countries in the context of current security threats, considering the development of the global geopolitical situation. The security strategies, fundamental to the governmental approaches of the Czech Republic, Slovakia, Poland, and Hungary, serve to secure national safety and can be utilized to protect the population and defend sovereignty and territorial integrity. The security strategies of these nations are subjected to a comparative and multicriteria analysis. Criteria were established based on the security documentation of the European Union and the Security Strategy of the Czech Republic, the latter being the most recent strategy from 2023 among those compared. Within the established criteria, weights were assigned using the Fuller's method. Through multicriteria analysis employing the weighted sum method, a ranking of the Visegrad countries was determined in terms of the content of their security strategies relative to the current security situation in the Euro-Atlantic space.

KEY WORDS: *security strategy; Visegrad Group; threats; European security strategy; security environment; comparison.*

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1. Introduction

In the international security environment, currently undergoing a significant transformation aimed at restoring the influence of major powers, substantial changes are taking place. The concepts of security and security strategy are highly pertinent in the current geopolitical context. The security environment within the European Union has been continuously evolving, often dramatically, in recent years [1]. Therefore, it is crucial to actively and correctly respond to these changes and challenges by identifying and analysing new threats and the often-unacceptable risks they pose. Suitable, timely, and effective measures must be adopted to address these issues [2].

A security strategy is a foundational document that outlines a government's approach to ensuring national security and can be directed towards safeguarding the population and defending the sovereignty and territorial integrity of the country [3]. It is one of the key documents that should contain essential information and evaluations of the security environment, the direction of security policy, and the security interests of the country. Additionally, it should identify the most significant threats to these interests and determine how the state will confront them to ensure national security [3], [4].

The aim of this article is to analyse the approaches of selected countries towards national and citizen security, comparing the priority directions in security within the context of current global events. The issue of state security within the European Union is examined from the perspective of the main directions in the European Union Security Strategy [5], [6] and the security strategies of the Visegrad Group countries, namely the Czech Republic, Slovak Republic (Slovakia), Republic of Poland (Poland), and Hungary. The article evaluates the extent to which the current Security Strategy of the Czech Republic [7] and other Visegrad countries are prepared to address security threats.

A comparison of individual key elements [8] of the security strategies of the Visegrad countries will allow for an assessment of the security threats, objectives, and interests of each state [3], evaluate the readiness of security strategies to current security threats in the environment of the ongoing war conflict in Ukraine, the recent Covid-19 pandemic [4], and other current security threats.

2. Comparative Countries

The selection of countries from the Euro-Atlantic area was based on the shared historical and political experiences of the chosen states. The four selected countries included three post-communist nations in Central Europe. The Czech and Slovak Federal Republic, Hungary, and Poland formed a group of states that sought economic, political, and cultural cooperation in Central Europe following the collapse of the bipolar world. During a joint meeting in the northern Hungarian town of Visegrad on February 15, 1991, representatives of the Czech and Slovak Federal Republic, Hungary, and Poland agreed on close cooperation in political and trade matters with the aim of ensuring regional stability and coordinating their approaches in these areas [2], [3], [9].

The process of forming the Visegrad Four into a group of four independent states was completed as a result of the dissolution of the Czech and Slovak Federal Republic on January 1, 1993. The signing of the declaration on close cooperation among Central European countries on their path to European integration led to the establishment of a successful Central European initiative. Among other goals, this initiative aims to influence and respond to security risks arising from global developments in recent years [2]. The locations of the individual countries within Europe and the European Union are shown in Fig. 1.

The declaration does not explicitly mention foreign security cooperation but anticipates the establishment of a comprehensive democratic social order in each state, based on fundamental human rights and freedoms, spiritual and cultural traditions, and respect for moral values [9]. The Visegrad Four developed cooperation, coordination, and consultations not only among themselves but also in their joint approach to relations with other countries. It can be said that all Visegrad Four countries uniformly regarded regional security as a fundamental prerequisite for their continued democratic development [2].

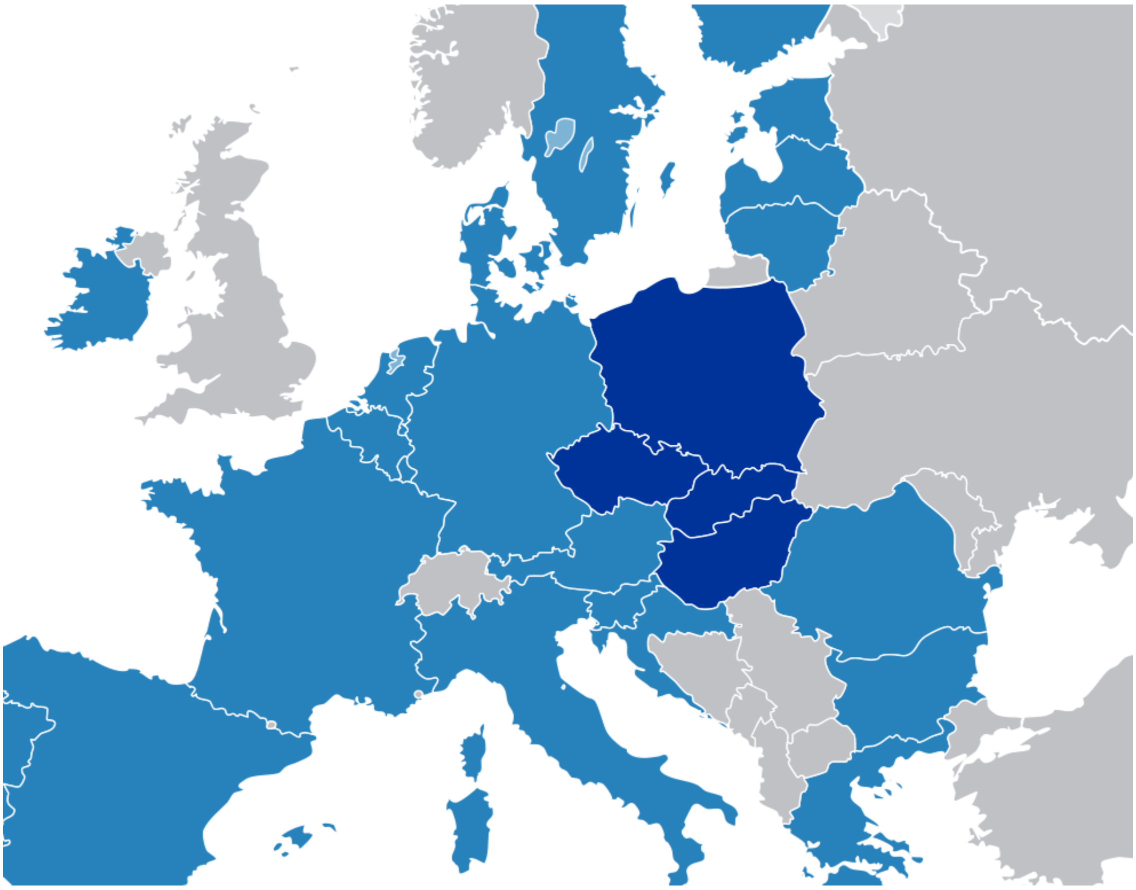

Fig.1. The location of the Visegrad Four countries within the European Union. Author: CrazyPhunk, Wikimedia

3. Aspects of the Security Strategy of the Czech Republic

According to the constitutional order of the Czech Republic, the government is responsible for the implementation of security policy. In 1998, the National Security Council was established as an advisory and working body of the government by Constitutional Act No. 110/1998 Coll., on the Security of the Czech Republic. It consists of the Prime Minister and other appointed members of the government. The National Security Council does not have any executive powers by law; instead, it prepares proposals for measures to ensure the security of the Czech Republic based on the government's mandate. For this purpose, it has six permanent working committees: the Civil Emergency Planning Committee, the Defence Planning Committee, the Intelligence Activity Committee, the Committee for the Coordination of Foreign Security Policy, the Internal Security Committee, and the Cyber Security Committee [10].

The Constitution of the Czech Republic and the Charter of Fundamental Rights and Freedoms establish the scope and limits of the functioning of security forces and all state authorities, which can exercise state power only within the extent defined by law. The Charter of Fundamental Rights and Freedoms sets certain restrictions on individual rights and freedoms in cases where it is necessary in a democratic society to avert serious threats to state security or to maintain public order. Restrictions on fundamental rights and freedoms of individuals are closely linked to the declaration of crisis states, which are regulated by Constitutional Act No. 110/1998 Coll., on the Security of the Czech Republic and Act No. 240/2000 Coll., on Crisis Management [4], [7].

The Security Strategy of the Czech Republic [7] is developed by the Ministry of Foreign Affairs and approved by the government. The current Security Strategy was adopted in 2023, marking the sixth conceptual document in the field of security (previous concepts were from 1999, 2001, 2003, 2011, and 2015). In order to ensure the security interests of the Czech Republic, this document includes statements that directly respond to current developments in the international environment. This security strategy introduces so-called areas of strategic concern to the citizens, focusing on various security domains and their assurance. Compared to previous versions, this strategy is highly proactive, with the greatest attention devoted to Russian aggression and China's power tendencies, identified as the most serious threats. According to the current Security Strategy, these are the most significant threats [7].

The Security Strategy emphasizes the necessity of the Czech Republic's involvement in collective defence and attaches significant importance to alliance relationships, which are to remain crucial for the country in the coming years. A notable aspect of the current strategy is its consideration and response to new threats that were not accounted for in the previous 2015 version [10]. The Security Strategy addresses the security environment comprehensively, with all its components being much more elaborated than in previous versions. This Security Strategy highlights the involvement of individuals in ensuring security, emphasizing that citizens of the Czech Republic should not merely be consumers of security, taking it for granted, but should also actively engage in it and recognize the importance of contemporary security threats [4], [7], [8].

4. Aspects of the Security Strategy of the Slovak Republic

The Slovak Republic, under its 1992 Constitution, is established as a parliamentary and representative democracy, where the government, as the main executive authority, is primarily responsible for the country's internal security policy. The National Council of the Slovak Republic, as the representative of the legislative power, holds oversight authority over the intelligence services and the police [11].

The Security Council of the Slovak Republic serves as an advisory body to the President during times of war. In peacetime, its primary tasks include creating and implementing the security system, assessing the security situation in Slovakia and abroad, fulfilling international security commitments, preparing proposals for government measures to maintain security and prevent crisis situations, and proposing solutions for arising crises. The handling of these crises during declared states of emergency is governed by the National Council of the Slovak Republic Act No. 42/1994 on the Civil Protection and Constitutional Act No. 227/2002 Coll., on State Security at the Time of War, State of War, State of Emergency, and State of Crisis. The Security Council has several working committees at its disposal: the Foreign Policy Committee, the Defence Planning Committee, the Civil Emergency Planning Committee, the Intelligence Services Co-ordination Committee, the Cybersecurity Committee, the Energy Security Committee, and the Hybrid Threats Committee [12].

The Security Strategy of the Slovak Republic [11] was developed by the Ministry of Defence of the Slovak Republic in 2021. It was subsequently approved by the government and then submitted for approval to the National Council of the Slovak Republic. This document marks the fourth security strategy since the establishment of the Slovak Republic, with previous versions issued in 1996, 2001, and 2005. The Security Strategy notes that global security has deteriorated in many respects, directly impacting the security and resilience of Slovakia [13]. Based on the assessment of the security environment, the strategy formulates the security policy of the Slovak Republic and defines its objectives, methods, and tools for implementation in a manner that creates conditions for the security, stability, prosperity, and development of the Slovak Republic and its citizens. The Security Strategy of the Slovak Republic identifies the North Atlantic Treaty Organization (NATO) as the best option for ensuring the state's defence capabilities, and it designates the United States as a strategic transatlantic ally [11].

As part of the security environment analysis, the Security Strategy of the Slovak Republic emphasizes the low predictability of the international environment and the increasing importance of non-military threats, focusing on hybrid threats [13]. The strategy further distinguishes threats in a broader regional context, such as unresolved conflicts, instability, conflicts in Eastern Europe, the fragile stability of the Western Balkans, and instability in areas such as the Middle East. Among its security interests, it highlights energy, raw material, environmental, and food security. It emphasizes the building of reserves of strategic energy and non-energy raw materials, as well as other natural resources, identifying water as the main strategic resource [13], [14].

5. Aspects of the National Security Strategy of the Republic of Poland

According to the Constitution of Poland of May 2, 1997, which establishes the fundamental provisions on the functions of the state and the limits of public power, the President is the guardian of the constitution, state sovereignty, security, and territorial integrity. As an advisory body in matters of internal and external security, the President appoints and dismisses members of the National Security Council (Rada Bezpieczeństwa Narodowego). Members include the Speakers of the Sejm and the Senate, the Prime Minister (head of government), selected ministers, leaders of political parties, and others. Among them is the head of the National Security Bureau, who is responsible for strategic planning and the functioning of the integrated national security system [15], [16].

This office primarily assists the President in fulfilling tasks related to security and defence. It provides support for the National Security Council and conducts analyses of national security developments, prepares materials on national security matters, evaluates legislation in the field of security, and more. The real performance and oversight of security are the responsibility of the Council of Ministers, which, according to Article 146 of the Constitution, ensures the internal security of the state and public order, and maintains the external security of the state [9].

The foundational document for security policy in Poland is the 2020 National Security Strategy. The Council of Ministers submitted the draft security strategy, which is approved by the President upon the request of the Prime Minister. It was adopted as the sixth national security strategy since the dissolution of the Warsaw Pact in 1991 (previous strategies were from 1992, 2000, 2003, 2007, and 2014) [15], [16], [17]. The 2014 National Security Strategy was considered one of the most comprehensive compared to those of other Visegrad Group countries [9].

The development and implementation of the current National Security Strategy of the Republic of Poland [15] stems from the necessity to ensure that the state is capable of countering threats and addressing challenges arising from the evolving security situation that Poland faces [18]. It aims to seize opportunities to enhance the security of the state and its citizens, ensure its further development, and strengthen Poland's position on the international stage. Consequently, it takes into account the context of Poland's membership in NATO and the European Union [18], [19].

The National Security Strategy of the Republic of Poland focuses on reformulating the civil defence system and the population protection system as part of its objectives to ensure and increase the state's resilience and civil defence. The system should be universal, applicable both in urban agglomerations and in rural areas. The system is also intended to be flexible and continuously adaptable to changing challenges and threats. The national interests and strategic goals in the field of national security of the Republic of Poland are formulated in accordance with national values established in the Constitution of the Republic of Poland [15].

The provisions of the National Security Strategy of the Republic of Poland are further expanded upon and incorporated into national strategic documents concerning the national security and development of Poland.

6.Aspects of the National Security Strategy of Hungary

The Fundamental Law of Hungary (Magyarország Alaptörvénye – the constitution) states that the government is responsible for security. The government is the general executive body and is to exercise all functions and powers not explicitly assigned by the Fundamental Law or by law to another body. The Fundamental Law of Hungary defines the basic framework for the activities of the police and national security forces. The police are primarily to serve in the prevention and investigation of criminal acts, the protection of public safety, and the safeguarding of state borders. The national security forces are tasked with protecting the independence and lawful order of Hungary and promoting national security interests. The activities of both the police and national security forces are governed by the government [20].

As part of the security processes, the Hungarian government established the National Security Cabinet (Nemzetbiztonsági Kabinet), which serves as its advisory body for strategic and political direction in national security. In 2011, the Working Group for National Security (Nemzetbiztonsági Munkacsoport) was established as an advisory interdepartmental body of the National Security Cabinet. Its main tasks include the exchange of information, coordination of operations, operational cooperation, execution of specialized tasks, and proposing security measures to the government.

Following the dissolution of the Warsaw Pact in 1991, Hungary, unlike the other Visegrad Four countries, developed its Principles of Security Policy (1993, 1998) and subsequently, Security Strategies (2002, 2004, 2012). In 2002, Hungary adopted its first historical Security Strategy. The 2004 Security Strategy responded to Hungary's entry into the European Union, and the 2012 Security Strategy responded to Hungary's accession to NATO and the adoption of a new constitutional law—the Fundamental Law of Hungary [21].

On April 21, 2020, the Hungarian government adopted the Hungarian National Security Strategy titled "A Secure Hungary in a Volatile World" [22], which was a response to the deteriorating security environment in Europe (the annexation of Crimea, destabilization of Ukraine, and crises at the borders of the European Union). The fundamental principles of the Hungarian National Security Strategy are contained in the Fundamental Law of Hungary and have remained unchanged over the years. The strategy is based on national values that are to be protected, the fundamental interests of the country, and the challenges, risks, and opportunities it faces [22].

Within the security strategy, visions of the nation in the context of security, fundamental values, Hungary's security environment, basic interests, main security risks, and strategic objectives were defined. In conclusion, comprehensive tasks and means for achieving these goals are defined. One possible response to the development of the security environment is the establishment of defence cooperation, which will strengthen the stability of our region at the military level. The Hungarian National Security Strategy defines the defence industry as a key segment of state security [9].

As Hungary is on the outer border of NATO, the European Union, and the Schengen Area, it places significant emphasis on international cooperation. This is reflected in the emphasis on the common political and economic interests in Central Europe and in actively strengthening cooperation with both NATO and European Union member states, as well as with the Visegrad Four countries and through bilateral cooperation with other regional partners [22].

7.Research methodology

Based on methods of comparison and multicriteria analysis, the content of the security strategies of the individual Visegrad Group countries is evaluated. Fuller's method was used to determine the weights of the criteria [23]. For the multicriteria analysis, the weighted sum method was utilized [24].

The criteria were defined based on the Global Strategy for the European Union’s Foreign And Security Policy [5], [6] in comparison with current security threats and the Security Strategy of the Czech Republic [7], which is the most recent among the assessed security strategies. The following criteria were established:

- k_1 – regional conflicts,
- k_2 – proliferation of weapons of mass destruction,
- k_3 – disruption of cooperation in international communities,
- k_4 – hybrid threats,
- k_5 – terrorism and organized crime,
- k_6 – cybersecurity,
- k_7 – energy security,
- k_8 – natural and anthropogenic disasters,
- k_9 – large-scale migration,
- k_{10} – spread of infectious diseases,
- k_{11} – environmental degradation.

Table 1.

Assessment of criteria using Fuller's method [23]

Criterion k_i	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8	k_9	k_{10}	k_{11}	Sum S_i
k_1	-	0	0	1	0	0	1	1	1	0	1	5
k_2	1	-	1	1	1	0	1	1	1	1	1	9
k_3	1	0	-	1	0	0	0	1	0	1	0	4
k_4	0	0	0	-	0	0	1	0	0	0	1	2
k_5	1	0	1	1	-	0	1	1	1	0	1	7
k_6	1	1	1	1	1	-	1	1	1	0	0	8
k_7	0	0	1	0	0	0	-	1	1	1	1	5
k_8	0	0	0	1	0	0	0	-	0	0	1	2
k_9	0	0	1	1	0	0	0	1	-	1	0	4
k_{10}	1	0	0	1	1	1	0	1	0	-	1	6
k_{11}	0	0	1	0	0	1	0	0	1	0	-	3

To perform a multi-criteria analysis of the content of security strategies of individual Visegrad Group countries using the weighted sum method, a criterion matrix was constructed, as shown in Table 1. This matrix shows the results of comparing the importance of the criteria using the weights calculated according to Fuller's method. All criteria were designed to be maximization criteria. The proposal for the evaluation of each criterion is provided in the text. The calculation using the weighted sum method is then carried out based on Formula 1 [23], and the results are presented in Table 2.

$$w_i = \frac{S_i}{\sum_{i=1}^{n} S_i} \tag{1}$$

where:
w_i is the weight of the i-th criterion, i ∈ {1, 2, …, 11},
S_i is the sum of the relative importance evaluations of the i-th criterion.

The weight values determined using the Fuller's method are:

- $w_1 = 0{,}0909$
- $w_2 = 0{,}1636$
- $w_3 = 0{,}0727$
- $w_4 = 0{,}0364$
- $w_5 = 0{,}1273$
- $w_6 = 0{,}1455$
- $w_7 = 0{,}0909$
- $w_8 = 0{,}0364$
- $w_9 = 0{,}0727$
- $w_{10} = 0{,}1097$
- $w_{11} = 0{,}0545$

8.Multi-criteria analysis

A comparative study of the security strategies of the Visegrad Group countries was conducted using a multi-criteria analysis with the weighted sum method [23]. The established criteria were set as maximization criteria. The evaluation of the criteria was based on whether they were included in the security strategy of the respective countries and whether the issues represented by these criteria were adequately addressed in their security strategies.

Criteria setting:

0. The issue is not addressed in the security strategy of the respective country or is only mentioned marginally. This rating also applies in cases where the criterion cannot be evaluated.
1. The issue is sufficiently addressed in the security strategy of the respective country and is given adequate attention.

In Table 2, the results of a multi-criteria analysis are presented. The weights of the criteria were calculated using Fuller's method. Evaluations of the alternatives for each criterion were determined based on the consensus of the authors. The multi-criteria analysis itself was conducted using the weighted sum method.

Table 2

Multi-criteria analysis

Criteria	Weight (rounded)	Czech Republic	Slovakia	Poland	Hungary
Regional conflicts	0,0909	1	1	0	0
Proliferation of weapons of mass destruction	0,1636	1	1	0	0
Disruption of cooperation in international communities	0,0727	1	0	0	1
Hybrid threats	0,0364	1	1	0	1
Terrorism and organized crime	0,1273	1	1	0	1
Cybersecurity	0,1455	1	1	1	0
Energy security	0,0909	1	1	1	0
Natural and anthropogenic disasters	0,0364	1	0	0	1
Large-scale migration	0,0727	1	1	1	1
Spread of infectious diseases	0,1091	1	1	1	1
Environmental degradation	0,0545	1	1	0	0
Weighted sum		1	0,8909	0,4182	0,4546
Rank		**1.**	**2.**	**4.**	**3.**

9. Conclusions

In the introduction, it was stated that the security strategy is the fundamental document outlining the government's approach to ensuring national security. Based on a multi-criteria analysis conducted with a proposed set of criteria and calculated weights of importance for each criterion, it was determined which countries of the Visegrad Group have the most comprehensive security strategy according to the degree of fulfilment of each criterion relative to the current security environment.

The Security Strategy of the Czech Republic [7] was rated the highest because it encompassed all the established criteria. A distinct advantage of this security strategy is that it was developed and approved in 2023, making it the most recent security strategy among those evaluated. Additionally, the Czech Republic's security strategy addresses issues such as the protection of critical infrastructure and the development of the population protection system, along with other areas of security interest that were not specified in the criteria. In response to the war conflict in Ukraine, significant emphasis is placed on identifying Russia as the greatest immediate threat and also as a long-term direct security threat. Similarly, Russia is mentioned in the National Security Strategy of Poland [14], which, based on the evaluation criteria, ranked last among the Visegrad Group countries.

The second highest-rated security strategy is the Security Strategy of the Slovak Republic [11]. It addresses most of the topics evaluated by the criteria, but it only marginally deals with issues related to disruptions in cooperation within international communities and the problems of natural and anthropogenic disasters. Significant emphasis is placed on current threats, and for this reason, historically recurring solutions to natural and anthropogenic disasters may have been relegated to the background of interest. The strategy mentions violations of international law by Russia, but at the same time, Russia is considered a strategic partner in addressing international threats. Given that the Security Strategy of the Slovak Republic was approved in 2021, before the onset of the conflict in Ukraine, this stance may be revised in the future.

Based on the evaluation, Hungary's National Security Strategy [22], approved in 2020, was ranked third. The strategy addresses, beyond the evaluated criteria, primarily economic crises, unexpected military attacks on its territory, including those with weapons of mass destruction, and thus the building of defence and protection systems. However, these criteria were not selected for evaluation. It also pays significant attention to issues of cyber and energy security, and environmental damage, but it only defines these matters in the context of threats and does not elaborate further in the document. Therefore, in the evaluation matrix, these criteria were marked as unresolved.

Within the evaluation of the individual security strategies of the Visegrad Group countries, more detailed research in this area will be necessary when all the countries update their security strategies in response to the war in Ukraine and the current security situation in the Euro-Atlantic space. It should also be noted that the evaluation was conducted solely from the authors' perspective on the issue, and the decision-making process was influenced by personal opinions. Consequently, no strategic significance is attributed to the results in the context of security assessments within the Visegrad Group and the European Union. This is not a critique of the states' level of preparedness in the area of security.

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The Positioning of Terrorism Issues in the Contemporary World and Its Perception from the Perspective of Czech Republic Citizens

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Abstract

This study examines public perceptions of terrorism within the Czech Republic, focusing on the complexities of terrorist threats and the efficacy of counter-terrorism strategies. It highlights a significant disparity in the public's understanding of terrorism, with many relying on the internet and mass media which often fail to provide comprehensive and high-quality information. This superficial understanding is coupled with a low perceived personal threat, leading to insufficient coverage in local media and educational programs. The findings emphasize the need for public discourse and targeted information campaigns that not only improve understanding but also actively involve the public in educational initiatives. The study advocates for the integration of terrorism education into broader security training programs, underscoring the importance of historical and political contexts to fully grasp the multifaceted nature of terrorism. Recommendations include enhancing public awareness through community-based educational programs and public campaigns that encourage active participation and critical evaluation of information. By acknowledging terrorism as a global issue with local implications, this research underscores the urgent need for a societal approach to prevention and education, which can significantly bolster societal resilience against terrorism through increased public engagement and cooperation.

KEY WORDS: *terrorism, combating terrorism, security, international cooperation, Czech Republic*

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1. Introduction

In an era marked by rapid technological progress and globalization, terrorism stands out as a significant global threat. Its adaptability to new technologies and extensive reach makes it an unpredictable force that commands attention at both national and international levels. Terrorism not only impacts direct security but also reflects broader social and political dynamics that shape its evolution.

Historically, terrorism has adapted to different eras, indicating it is not merely a modern phenomenon. The Czech Republic (CR) perceives terrorism primarily through the lens of global events, despite facing a lower risk of direct attacks. This perspective influences local policy responses and public attitudes towards security, human rights, and civil liberties. Media portrayal, which often focuses on international terrorism, shapes the Czech public's understanding, possibly overshadowing local nuances. The advent of the internet and social media has transformed how terrorism and counterterrorism operate, facilitating the spread of ideologies and counteractive measures. However, unchecked online information can foster misconceptions about terrorism's nature and appropriate responses.

The post-September 11 era has intensified the dimensions of terrorism, with subsequent radicalizations and new terrorist organizations emerging. Recent global events, like attacks on Israel, underscore the persistent and evolving nature of terrorism. This introduction lays the groundwork for a deeper exploration of terrorism's perception and management in the CR, emphasizing a comprehensive approach that combines historical insight, technological advancements, and public engagement to enhance security and resilience.

2. Impacts of terrorism

Terrorism inflicts extensive damages across various facets of society, categorized into two distinct levels by Foltin and Řehák (2006): primary and secondary effects [1].

Primary impacts of terrorism

Primary impacts directly result from terrorist activities, including psychological trauma, and significant political, economic, and social repercussions. These impacts often align with the terrorists' objectives, disrupting daily life and instigating long-term trauma among survivors.

Politically, they can destabilize governments and lead to military responses, such as Israel's lengthy "Operation Wrath of God" following the Munich massacre in 1972. Economically, attacks like 9/11 had profound effects, severely affecting markets, and prompting expensive, long-term military engagements [2].

Secondary impacts of terrorism

Secondary impacts include media coverage that can unintentionally spread terrorists' messages and environmental or infrastructural damages. These effects can be categorized as immediate, like casualties or service disruptions, or later impacts, which evolve over time and affect political, economic, and societal structures.

Broader societal impacts

State structures: Government responses to terrorism are proportional to the attack's severity, involving significant political decisions that affect national security and civil liberties.

Economic sphere: Terrorism causes direct infrastructure damage and long-term impacts on market stability and investor confidence. Countries reliant on tourism face severe economic downturns due to terrorism.

Human psyche: Terrorism causes widespread fear and anxiety, leading to changes in social behaviour and an increase in mental health disorders.

Infrastructure and environment: Attacks cause significant environmental damage, affecting biodiversity and ecosystems.

Tourism and travel: This sector, crucial for some national economies, suffers long-term declines in tourist numbers after attacks.

Understanding the varied impacts of terrorism and crafting responses involves emergency preparedness, long-term security planning, economic resilience strategies, and mental health support. International cooperation is crucial in shared intelligence, coordinated security measures, and unified aid strategies, highlighting the need for a proactive and comprehensive approach to counterterrorism [3].

3. Current state of terrorism as of 2023

Since 2013, the Global Terrorism Index (GTI), crafted by the Institute for Economics & Peace (IEP) using data from Terrorism Tracker and other sources, has provided an annual comprehensive overview of global terrorism trends. The GTI tracks nearly 66,000 terrorist incidents from 2007 through 2022, offering a detailed analysis of the patterns and shifts over the last decade. In 2022, the GTI reported a 9% decrease in terrorism-related deaths, totalling 6,701, marking a 38% decline from the peak in 2015. This reduction is reflected in a nearly 28% decrease in the number of attacks, down from 5,463 in 2021 to 3,955 in 2022. Excluding Afghanistan, which remains the most affected country for the fourth consecutive year, the global death toll would increase by 4%.

The deadliest terrorist groups in 2022 included the Islamic State (IS) and its affiliates, al-Shabaab, the Baluchistan Liberation Army, and Jamaat Nusrat Al-Islam wall Muslimeen, with IS being the most lethal for the eighth consecutive year. In 2022, IS was responsible for the highest number of attacks and deaths among all groups. Despite significant decreases in terrorism between 2015 and 2019, the number of countries experiencing deaths remained relatively stable from 2020 through 2022, ranging from 43 to 42 countries. This represents a decline from 2015, when 56 countries reported terrorism-related deaths.

The number of countries with increasing and decreasing terrorism-related deaths in 2022 was roughly equal, with 25 countries reporting fewer deaths and 24 reporting increases. Terrorism dynamics have shown minimal overall change in recent years, but significant fluctuations have occurred in specific regions like Niger, Myanmar, and Iraq. Notably, the lethality of terrorist attacks increased in 2022, with an average of 1.7 deaths per attack, up from 1.3 in 2021.

The Sahel region of Sub-Saharan Africa has become a new epicentre of terrorism, accounting for more deaths than South Asia, the Middle East, and North Africa combined in 2022. Over the last 15 years, terrorism in the Sahel has increased by over 2000%, with 43% of global terrorism-related deaths occurring there in 2022, compared to just 1% in 2007. The political volatility in the Sahel, marked by multiple coups since 2021, has exacerbated this trend. Contributing factors include water mismanagement, food scarcity, ethnic polarization, rapid population growth, foreign interventions, geopolitical competition, pastoral conflicts, the rise of Salafist ideology, and weak governance. Burkina Faso and Mali were particularly concerning, accounting for 73% of the Sahel's terrorism-related deaths and 52% of all such deaths in Sub-Saharan Africa in 2022. Both countries saw significant increases in terrorism, with deaths in Burkina Faso rising by 50% to 1,135 and in Mali by 56% to 944. The violence in Burkina Faso also spread to neighbouring countries, with Togo and Benin experiencing their worst GTI scores to date (see Fig. 1).

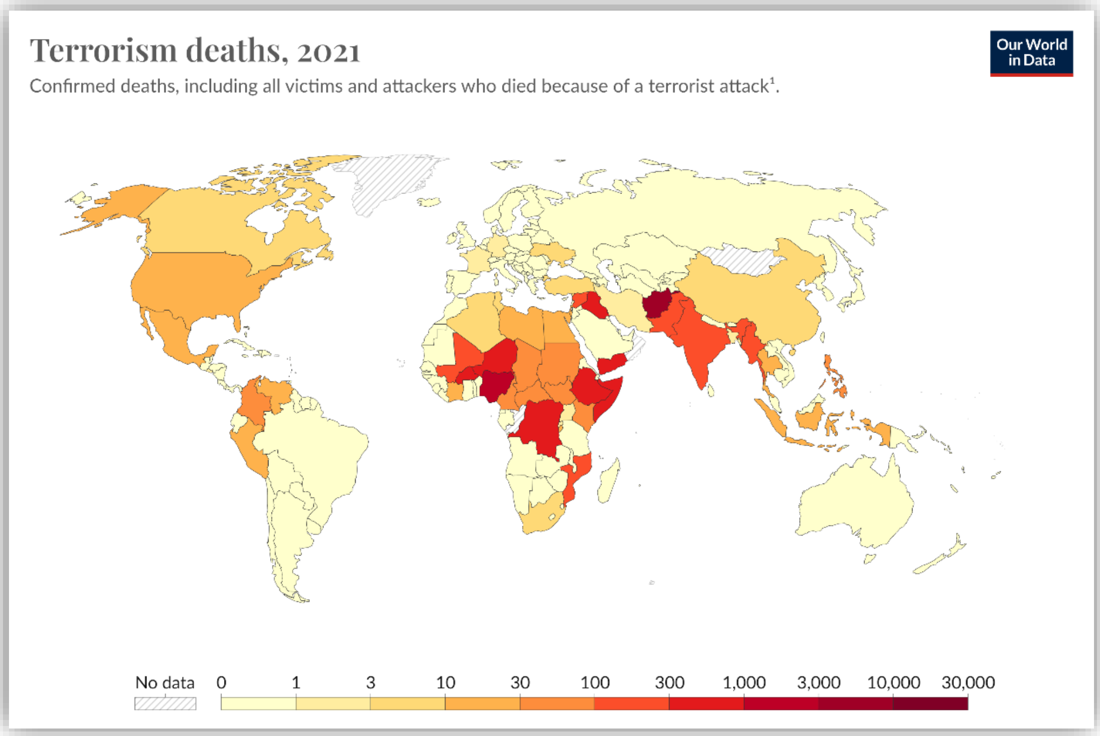

Fig. 1. Terrorism deaths in 2021 [5]

North America showed the most significant regional improvement in the GTI score, while Sub-Saharan Africa saw the greatest deterioration. North America consists of the USA and Canada, neither of which has a high GTI score, yet it is the only region where no country has a zero GTI score.

In the West, the number of attacks has been declining since 2017, with 40 attacks recorded in 2022, a 27% decrease from 55 in 2021. However, the number of deaths doubled from nine in 2021 to 19 in 2022, with 11 occurring in the USA. This increase marks the first rise in Western terrorism-related deaths since 2019. In Europe, Islamist extremists carried out two attacks in 2022. The USA recorded just eight attacks, none attributed to any known terrorist group. The UK reported only four attacks and no deaths, marking the first year without terrorism-related deaths since 2014. Germany recorded its lowest number of attacks since 2015.

The use of drones in terrorism is an emerging trend, with groups like IS, Boko Haram, and Houthi rebels utilizing this technology. Currently, 65 non-state actors can deploy drones that can travel up to 1,500 kilometres, potentially carrying out targeted assassinations or holding biological weapons. Drones require minimal training and are highly accessible, representing a significant shift in how conflicts are conducted [4].

4. Combatting Terrorism

Terrorism is a complex, pervasive threat that transcends borders, cultures, and religions, posing a significant challenge to global security and international stability. Nations worldwide respond to this threat by employing a variety of methods and resources aimed at eliminating terrorism through rigorous, well-coordinated efforts both domestically and internationally [6].

One of the cornerstone strategies in the fight against terrorism involves the use of intelligence services. These agencies play a crucial role in the pre-emptive identification and disruption of terrorist plots. Operating largely out of the public eye, intelligence services collect and analyse vast amounts of data on potential threats. Their effectiveness is evident from the substantial decrease in successful terrorist attacks since the intensified intelligence activities following September 11, 2001. Reports indicate that numerous major attacks have been thwarted due to enhanced intelligence cooperation globally [7].

Counterterrorism units within various nations specialize in direct action against terrorists. These highly trained tactical teams engage in both preventive and responsive actions to mitigate terrorist threats. Their activities include hostage rescue, assault operations on terrorist hideouts, and neutralization of imminent threats. The units are equipped for rapid deployment and are skilled in close-quarter combat, ensuring they can respond swiftly and efficiently to terrorism incidents, minimizing casualties and maximizing the safety of civilians and infrastructure [8].

The broader strategy also includes legal and political measures such as prosecuting terrorists, isolating states that sponsor terrorism, and applying international pressure to reduce support for terrorist activities. These efforts are supplemented by promoting robust international cooperation among countries through various treaties and alliances to enhance collective security measures against terrorism [6].

An essential aspect of counterterrorism is the need for cooperation among international intelligence communities. Effective sharing of intelligence is crucial but often hampered by concerns over the security and political implications of disseminating sensitive information. The international community continuously works towards improving mechanisms for sharing intelligence without compromising the operational security of nations involved.

Furthermore, the fight against terrorism is supported by specialized research and analytical work provided by think tanks and research institutions. These organizations, such as the RAND Corporation and the International Centre for Counterterrorism, conduct in-depth studies on terrorism trends, terrorist psychology, and effective countermeasures. Their research helps refine counterterrorism strategies and policies, ensuring they are based on accurate, up-to-date information and tailored to the evolving nature of global terrorism [9].

Military involvement in counterterrorism is complex and often controversial. While the military's role is traditionally focused on external threats, their capabilities in logistics, heavy weaponry, and strategic operations make them an invaluable asset in countering severe terrorist threats. Countries vary in their use of military forces in domestic counterterrorism roles, with some incorporating specialized military counterterrorism units into their national security framework [10].

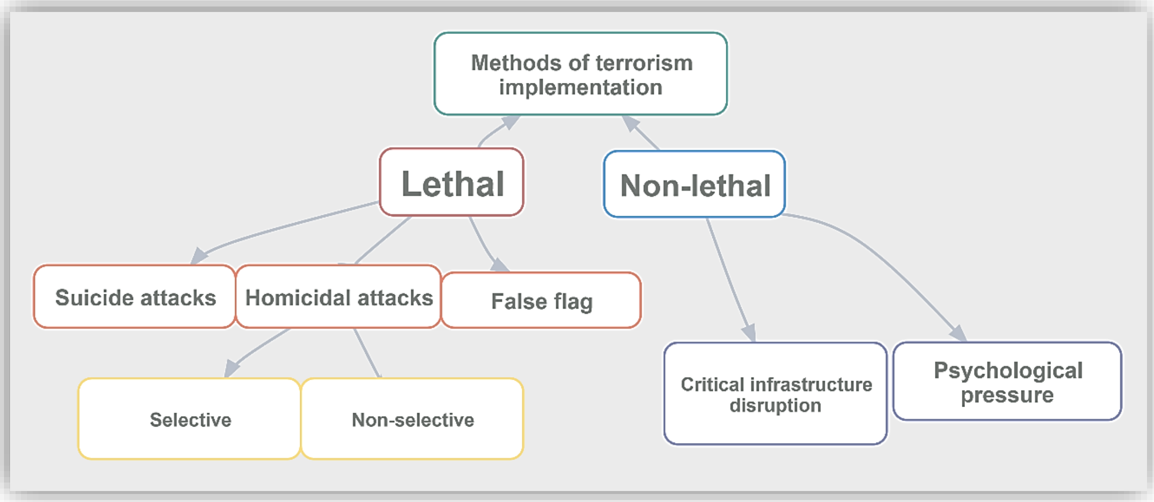

Fig. 2. Methods of terrorism implementation [1] [fig. source: own]

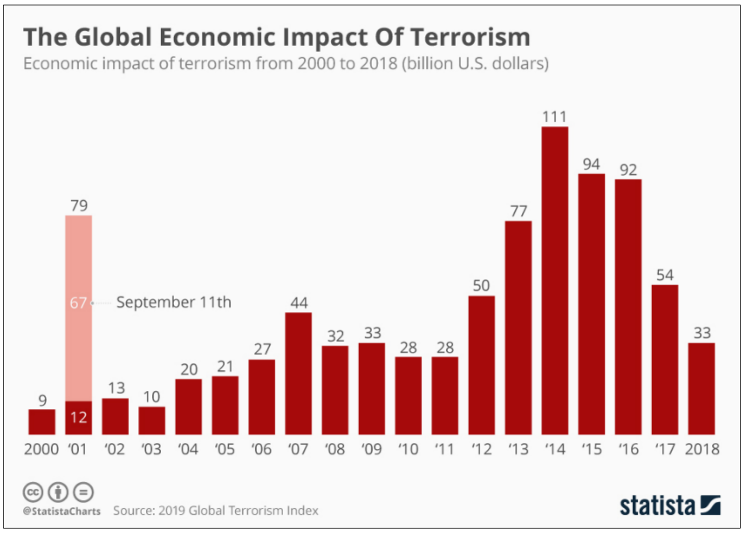

Fig. 3. Economic impact of terrorism between the years 2000 and 2018 [12].

5. Description of the research investigation

The quantitative study initiated in 2023 with a thorough examination of academic literature and online resources on terrorism, laying a solid theoretical groundwork and providing a comprehensive summary of current knowledge in the field. Following this theoretical groundwork, a detailed and systematic questionnaire focusing on terrorism's critical aspects was crafted. Data gathering was executed via a standardized online survey using Survio.com, streamlining the collection process from a broad respondent base. This phase spanned 50 days, with 198 participants. The online method was chosen for its quick distribution, anonymity for participants, and immediate data processing capabilities, emphasizing sample diversity to enhance result representativeness. The statistical software R was employed for data analysis, facilitating the examination of categorical variables through contingency tables and the $\chi2$ independence test. This approach, conducted in 2023, yielded a quantitative evaluation of variable relationships, identifying statistically significant patterns. The findings provided a nuanced understanding of terrorism and its perception within the study's demographic, condensing the research process and insights into a focused examination of terrorism's multifaceted impact and public perception.

6. Discussion of Results

In the framework of the survey, 26 distinct questions were formulated. However, for the purposes of the article, we have elected not to include all the findings but to focus more closely on those that we subjectively perceive as the most significant or those that most distinctly delineate the positioning of terrorism issues in the contemporary world and its perception from the perspective of Czech Republic citizens.

In the initial part of the survey, respondents were asked if they had ever encountered the term "terrorism". A very positive finding is that 99% of all respondents have at some point in their lives come across the issue of terrorism, although the specific level of awareness and the quality of information acquired can only be estimated. A total of 122 respondents were able to capture the fundamental essence of terrorism at least partially in their responses, indicating a certain degree of understanding of the issue. The introductory set of questions also included a prompt for respondents to identify the general definition of terrorism from provided options. A total of 171 were able to determine the correct version, which confirms that despite the lack of a comprehensive overview of terrorism issues, perhaps in formal education, the public is familiar with the basic connections that assist in estimating the correct definition, comprising a list of what terrorism truly entails. This positive result may also be influenced by the current highly publicized situation in Israel and Gaza, which indirectly encourages the public to seek more information.

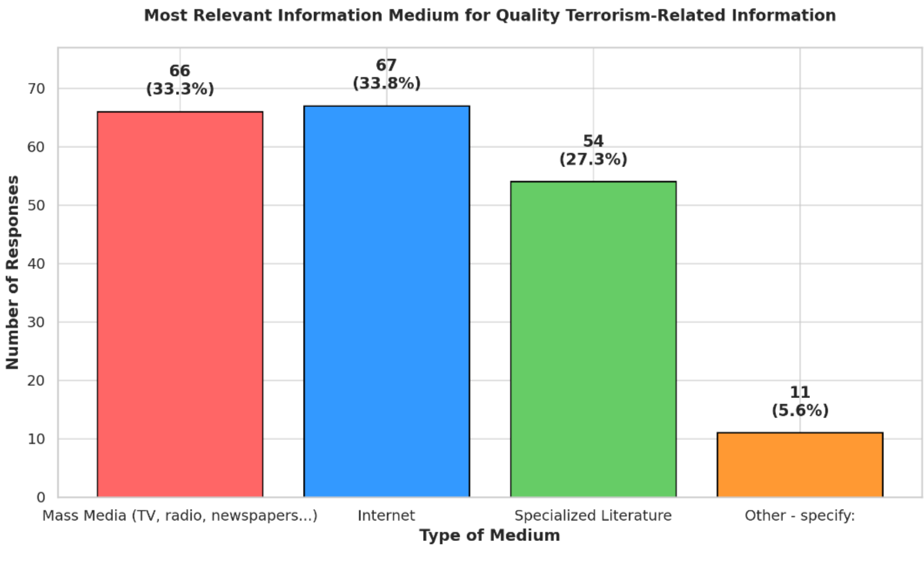

Fig. 4. Preferred sources for quality terrorism-related information [source: own]

Most respondents tended to search for suitable and relevant information through mass media or the internet, with scholarly literature ranking third. This shift to the virtual environment is understandable given the broader trend towards digitization of information. However, from my own literature review, I observed a significant difficulty in finding sufficient current domestic book resources on terrorism, as well as appropriate studies discussing current trends. Sources created before the events of September 11, 2001, often depict terrorism differently than the more numerous sources from several years after. Over time, the frequency of new publications has decreased, possibly due to the low incidence of terrorism in our area, which might foster a societal view questioning the necessity of engaging with this topic. Foreign authors discuss terrorism more extensively, and their works are more accessible online, which is beneficial as these sources are also readily available to the public on the internet.

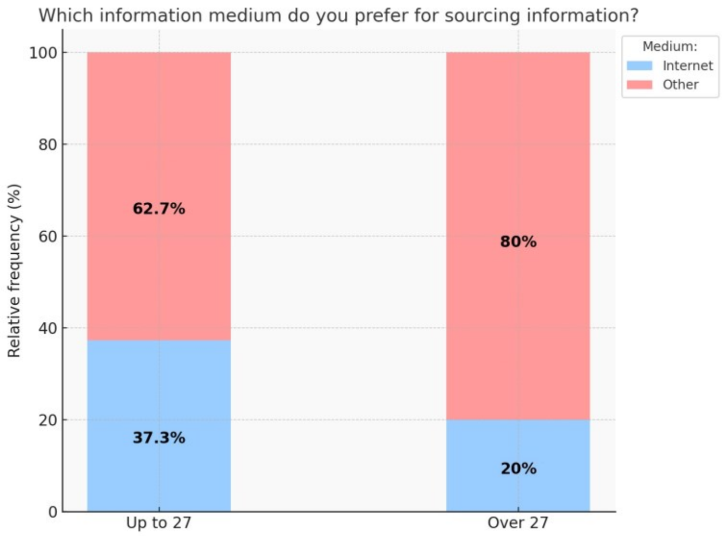

Fig. 5. Information medium preference by age for sourcing information [source: own]

Interestingly, statistics show that the younger generation, particularly those under 27, more frequently uses the internet to find relevant sources. This not only underscores the significant role of the online environment as a primary information source but also presents an opportunity to specifically target this younger demographic through their preferred medium. This tailored approach could enhance the dissemination of information and education on terrorism, ensuring that younger individuals have access to accurate and insightful content about this critical global issue.

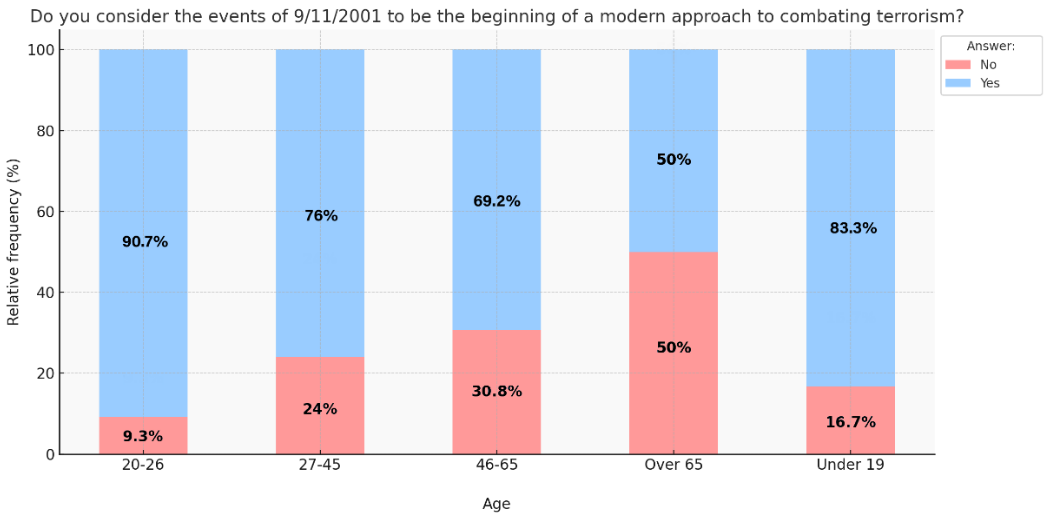

Fig. 6. Perceptions of 9/11 as the start of a modern approach to combating terrorism by age group [source: own]

The survey highlighted significant awareness of specific terrorist attacks among respondents. The events of September 11, 2001, stood out prominently, recognized by 92.4% of the participants, underscoring its lasting impact on public consciousness. Following this, the 2015 bomb attacks in France were acknowledged by 83.8% of respondents, reflecting the recency and prominence of these events in the media. Interestingly, the hijacking of a Boeing 747 in 1985 was also well-remembered, mentioned by 51.5% of respondents, demonstrating its enduring recognition in discussions on terrorism.

A particularly insightful aspect of the findings was the correlation between respondents' ages and their perceptions of terrorism. Younger respondents, especially those aged 20-26, were the most likely to view the September 11 attacks as a pivotal moment that marked the beginning of a contemporary approach to counterterrorism, with 90.7% affirming this view. This agreement noticeably declined in older age groups. This trend suggests that younger individuals, who may not have lived through earlier significant terrorist events, perceive the influence and consequences of such incidents differently than older generations, possibly due to the different contexts in which they were educated about these events.

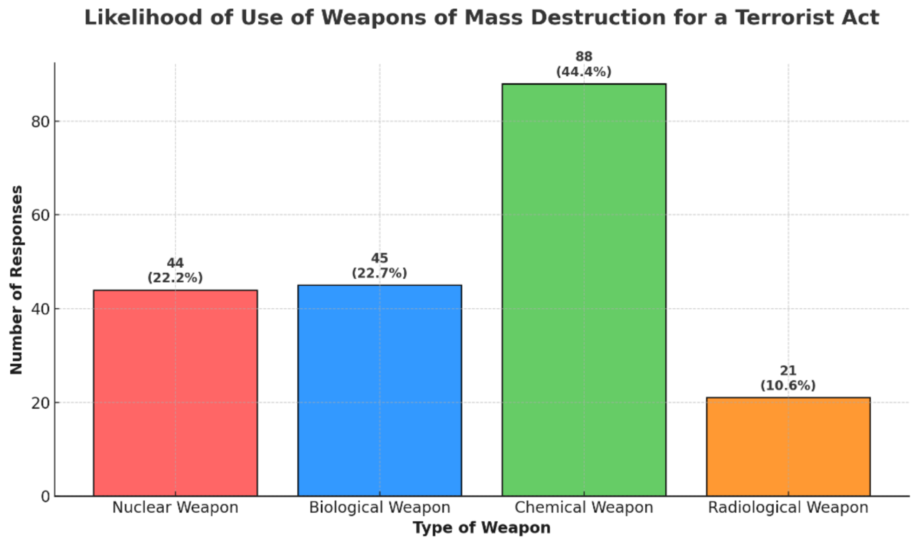

Fig. 7. Perceived risks of WMD use in terrorism by weapon type [source: own]

The most alarming scenario in terrorism involves the use of weapons of mass destruction (WMD), with a survey revealing that chemical weapons are perceived as the most probable type, chosen by 44.4% of respondents. Closely following are nuclear and biological weapons, which nearly match chemical weapons in perceived likelihood. Radiological weapons, on the other hand, are considered the least likely by respondents, possibly due to their lower impact compared to other types.

Chemical and biological weapons are particularly concerning because they require only a small amount to inflict massive casualties, combining high fatality rates with significant psychological impacts. Despite the complex nature of manufacturing these weapons, the presence of a black market and available expertise make it feasible for well-supported terrorist groups to acquire and deploy them.

Nuclear weapons, while representing the pinnacle of WMD in terms of potential damage, are seen as less accessible to terrorist groups due to the substantial financial, technological, and material hurdles involved. This perspective is echoed in the academic debates and studies about the feasibility of nuclear terrorism. For instance, Matthew Bunn in 2006 estimated a 29% probability of a nuclear terrorist attack occurring over the following decade. His model highlighted the serious but manageable risk, although, fortunately, no nuclear terrorist attacks have materialized to date [12].

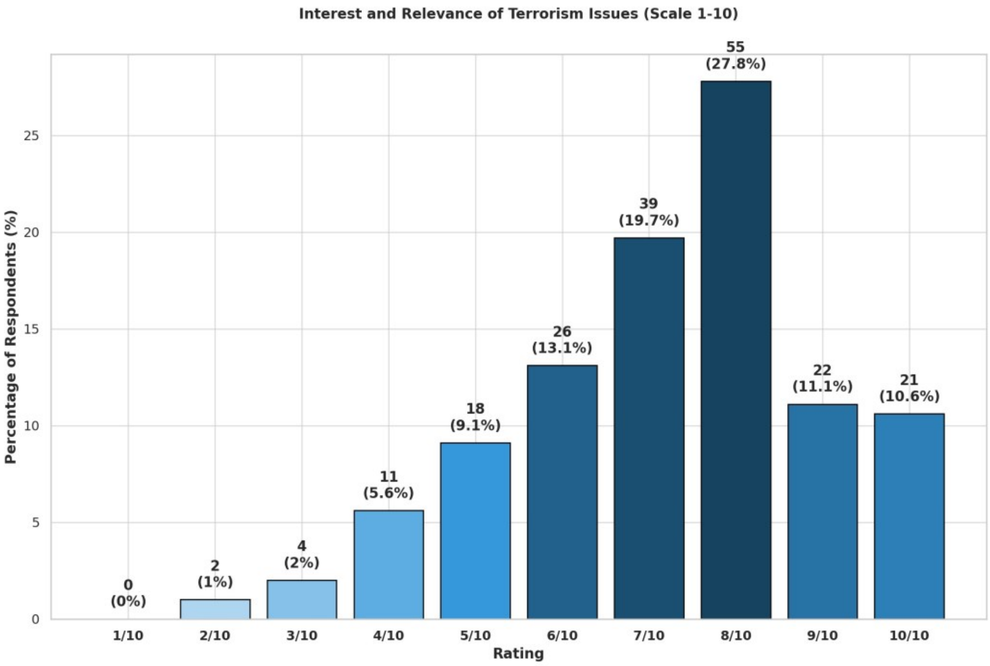

Fig. 8. Public interest and concern for terrorism issues on a 1 to 10 scale [source: own]

The survey explored how respondents perceive terrorism as an interesting and current topic. None of the respondents considered the topic to be uninteresting or outdated; instead, 21 respondents (10.6%) rated terrorism as very current and interesting. To simplify the analysis, the data were aggregated into three categories:

- 1-3 for 'Not Relevant',

- 4-7 for 'Relevant',
- 8-10 for 'Highly Relevant'.

Although respondents concurrently viewed the threat of terrorism as unlikely in the Czech Republic, this finding is positive in the sense that citizens do not underestimate the threat. It is important to note that this score may have been influenced by the ongoing conflict in Ukraine at the time of the survey. Given that the research was conducted just before significant events in Israel and Gaza, it is plausible that the score might be even higher today, likely falling into the 'Highly Relevant 'category.

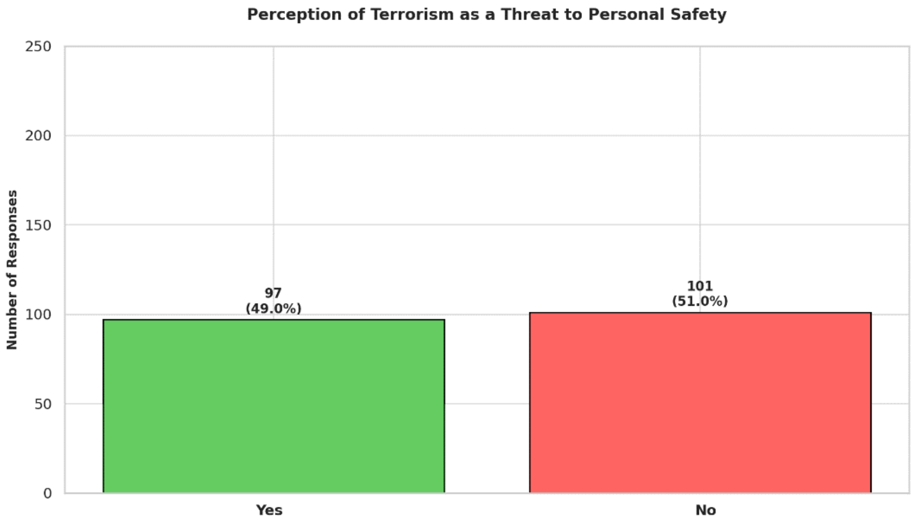

Fig. 9. Public opinion on terrorism as a personal safety threat [source: own]

The survey also probed whether individuals perceive terrorism as a threat to their personal safety. The responses were nearly split, with a slight majority, 51%, indicating they do not see terrorism as a threat, compared to 49% who do. This finding suggests a notable divergence in public perception, which may be influenced by the nearly absent direct experience with terrorism within the Czech Republic. Many citizens might view terrorism as a distant issue, occurring beyond their national borders and not affecting their immediate environment. Despite this local sentiment, an overwhelming 86.9% of respondents acknowledged terrorism as a global issue, implying an understanding of its potential impact on an international scale. Additionally, the prevalent view of terrorism as a remote problem might reflect a certain underestimation of the issue. The absence of traditional attacks on Czech soil does not eliminate the need for vigilance and preventive measures, underscoring the importance of maintaining awareness and preparedness even in perceived low-threat environments.

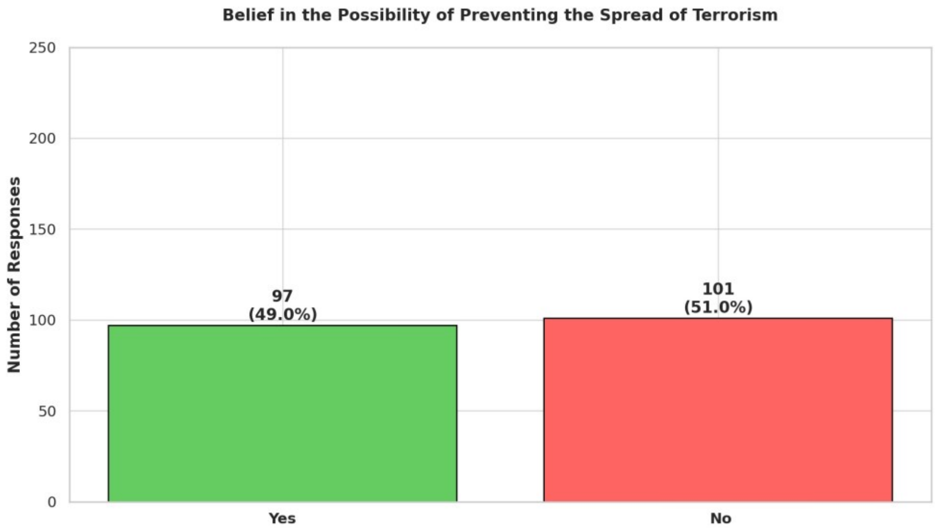

Fig. 10. Survey responses on the feasibility of preventing terrorism spread [source: own]

The issue of terrorism spread and its potential financing by individual states has been relevant for several decades. Over half of the respondents (51%) believe that the spread of terrorism cannot be prevented, and 77.3% perceive that there are states that support terrorism. Those respondents acknowledging the existence of such states more frequently held the view that it is impossible to prevent the spread of terrorism. Eradicating the threat of terrorism is not feasible soon if there are entities intentionally supporting terrorism.

A significant 77.3% of all respondents agreed on the existence of states that deliberately support terrorism. Countries most frequently identified by respondents as supporters of terrorism included Russia, the USA, Iran, Afghanistan, Iraq, and China. Russia resonated the most among respondents, which can be attributed particularly to a relatively recent resolution passed by European Parliament members, designating Russia as a state sponsor of terrorism due to deliberate attacks by the Russian military on civilian targets in Ukraine. Countries like Iran, Iraq, and Afghanistan have a long history associated with the occurrence and support of terrorism, which is why they are often listed on official state sponsors of terrorism lists. This historical context contributes to their frequent identification by respondents as states that support terrorism.

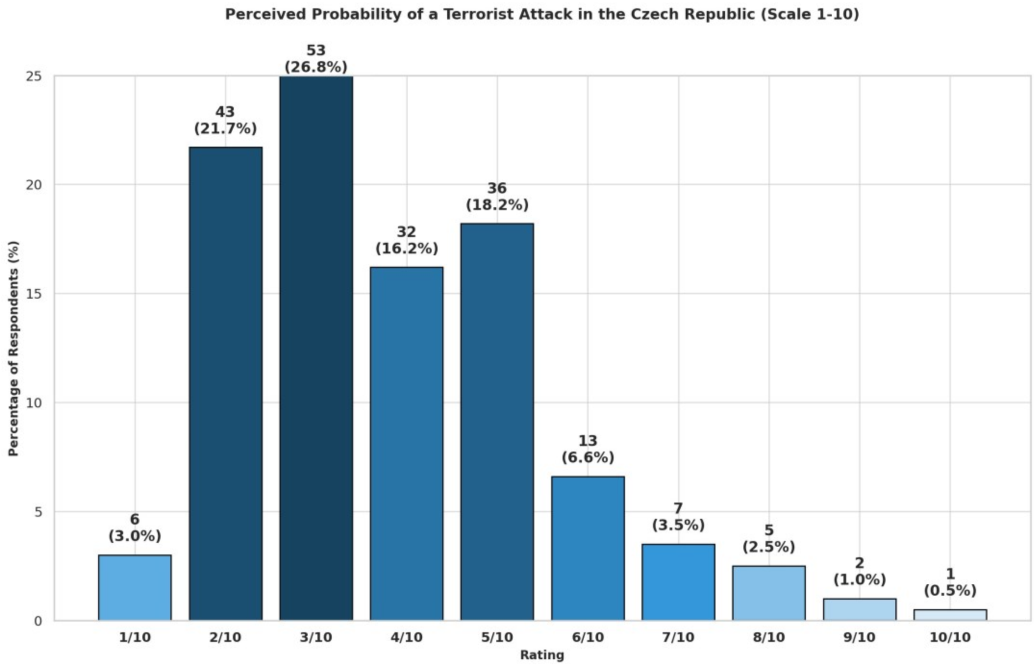

Fig. 11. Perceived risk levels of a terrorist attack in the Czech Republic (Scale 1-10) [source: own]

Respondents were asked about their perception of the likelihood of terrorism occurring within our territory. Extremes were rarely chosen; only six participants believed it completely improbable, and a single respondent (0.5%) saw it as extremely likely. This could reflect the Czech Republic's history of never being the target of a traditional terrorist attack. While many incidents in history might display characteristics of terrorism, they are often confused with actual terrorist attacks. To date, the Czech Republic is one of the few European countries that has not experienced a verified terrorist attack, influencing the public's belief that terrorism is not likely to happen locally. The average response rated the likelihood at 3.8/10, which would be possible to categorize as "unlikely”. It would also be interesting to map perceptions over a longer period after the outbreak of the war conflict in Israel and Gaza, to determine whether increased global tensions could influence a higher concern score.

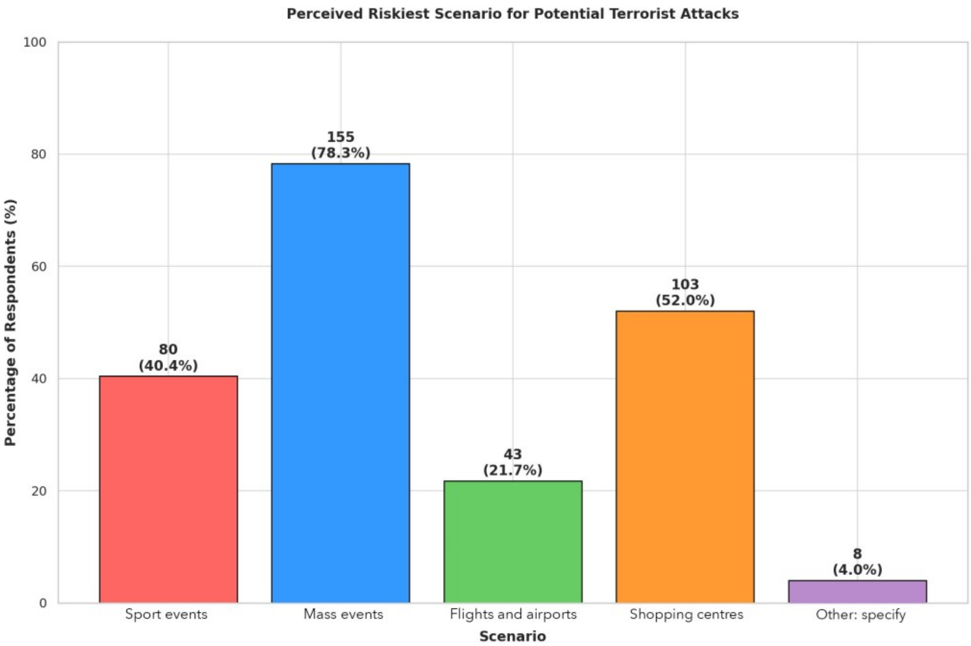

Fig. 12. Public perception of the most vulnerable settings for terrorist attacks [source: own]

Terrorism as a topic not only influences people's thinking but also serves as a determinant in their decision-making processes. Many respondents indicated that the presence of terrorism significantly influences their choices of travel destinations abroad; 60.1% of responses reflected this concern. Additionally, respondents identified mass events in squares (78.3%), shopping centres (52%), and sports matches (40.4%) as locations with the highest perceived risk of terrorist attacks. Such events require considerable respect and appropriate enhancement of security measures to mitigate the potential occurrence of terrorism.
Furthermore, it was observed that those who perceive terrorism as a threat to their personal security are also more likely to consider the risk of terrorism when planning their travels abroad. This correlation suggests that the perceived threat of terrorism significantly shapes individual attitudes towards safety in public spaces and international travel decisions.

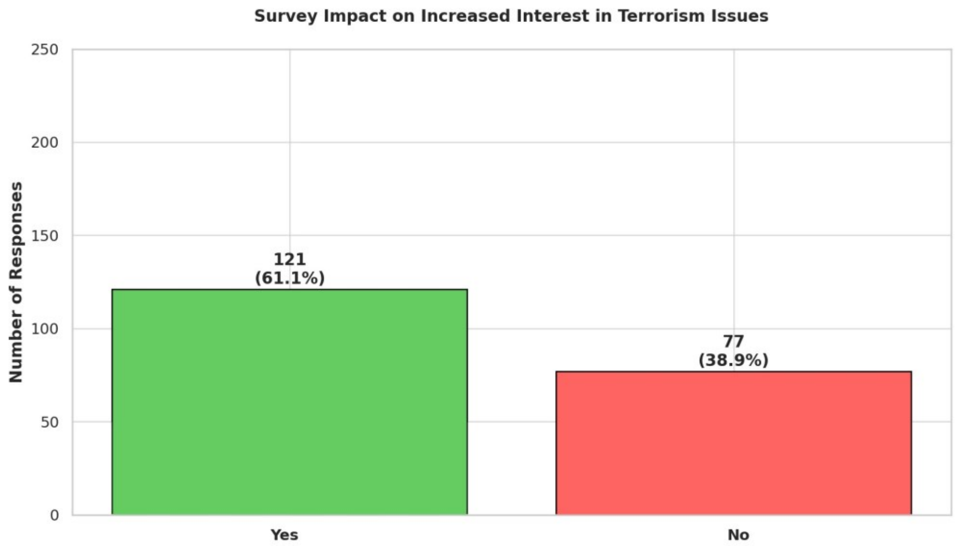

Fig. 13. Effect of survey participation on interest in terrorism topics [source: own]

We firmly believe that awareness and understanding of terrorism, especially its comprehensive treatment within educational systems, is insufficient. For example, terrorism is not adequately addressed in schools. Consequently, we also hoped that participating in the survey would at least partially increase respondents' interest in terrorism issues. It was very encouraging to find that, according to the final, twenty-sixth question of the survey, 121 respondents (61.6%) indicated that completing the questionnaire could enhance their interest in terrorism.
Thus, it can be modestly suggested that encouraging respondents to complete the questionnaire not only provides them with basic information but also fosters a deeper interest in the topic and greater engagement in seeking out quality, verified information.

8. Conclusions

Based on the obtained results, the implementation of extensive awareness programs and educational initiatives is recommended to inform the public about the risks, prevention, and protective measures associated with BW. It is imperative to enhance media coverage of the BW topic, support the integration of relevant information into school curricula, and develop targeted media campaigns aimed at expanding public awareness. Furthermore, strengthening international cooperation and transparency within control mechanisms is proposed to increase public trust in the effectiveness of international agreements. The creation of a unified online platform providing access to verified information and resources on BW could significantly contribute to demystifying the topic and increasing public awareness. Additionally, it is crucial to incorporate this issue into awareness and educational programs within the broader context of weapons of mass destruction. This approach can significantly contribute to overall public awareness of risks and protective strategies in the current security situation.

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Contemporary Civil-Military Relations

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Abstract

Civil-military relations are still an under-researched area in relation to the existence and deployment of armed forces. However, it is the factor that significantly influences the management of the state and the use of relevant power tools, including the armed forces. The aim of this paper is to carry out research of the fundamental factors affecting the establishment, deployment and control of armed forces. The research was carried out using the methods of analysis, synthesis, comparison, abstraction, deduction and prediction. It was found that in democratic states there is a legislative framework for the establishment, deployment and control of armed forces. However, each state has its peculiarities. Their mutual understanding is important especially in multinational operations. This can help in reducing differences of opinions and in achieving both political synergy and military interoperability. This paper can assist both civilian and military officials in understanding their place in civil-military relations and their competencies in managing the armed forces.

KEY WORDS: *civil-military relations, democratic control, professional control, military personnel*

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1. Introduction

The roles of civilian leaders of the state and senior military leadership evolved during the history and currently are formulated in the legislative documents. This relationship has implications for the effectiveness of strategic decisions in pursuance of national interests. The military is more than simply a tool to its civilian principals.

Friction between the military establishment and its civilian leadership is not a contemporary phenomenon. The debate concerning civil-military relations has been a fundamental issue for long time and surely in the future it will be as well. Tension between members of the military and civilian leaders existed, exist and will exist. Especially it was visible in the post-communist states in which democratization processes took place. The Central and Eastern European states have put in place the core institutions and practices of democracy, and this is reflected in civil-military relations in these states. This was, among other things, requirement for their accession to the NATO and the EU. The basic signs of friction between the political leadership of the state and the military leadership of the armed forces are also visible in the ongoing conflict in Ukraine. It is probably one of the reasons why there was a change in the position of Chief of the General Staff of the Armed Forces of Ukraine.

The members of these organizations are currently using and planning to use military force in the future. This trend poses fundamental questions about the use of military force in world politics and the relationship between civilian political leaders and the military in shaping when and how force is used.

The intention is to provide a comprehensive and comparative overview of the approaches used in the application of civil-military relations in achieving goals at the strategic, operational and partially tactical level. The author's effort is to achieve a comprehensive view of the considered issue with an emphasis on use in democratic states and organizations.

The author draws on the existing mostly western literature on civil-military relations. The literature used includes, for example, the works of Cottey [1], Krupski [2] or Rapp [3]. The literature cited covers the general topic broadly enough and from different perspectives (e.g., military and/or civilian role in governance, etc.) and was therefore chosen by the author as a starting point. Other authors also deal with issues of civil-military relations. Elischer [4], Dudzevičiúte [5] and Petraitis [6] focus on the specific environment in which civil-military relations apply. This creates good conditions for comparing different approaches to the mentioned issue. Pantev [7] describes basic principles and standards of democratic control of the security sector which is also very fruitful to understand investigated context.

The work of the American author Huntington [8] can be perceived as a capstone work, covering the issue of the position of the soldiers in the state. It brings a critical view at the processes of security and all actors involvement to it including elected representatives of citizens, who play an important role in the civil-military relations. Literature by authors such as Gray [9] and Lynn [10] is useful for understanding the long-term development process of civil-military relations in the context of armed conflicts and wars.

Works by authors such as Balsys [11], Rana [12] and Steed [13] are significant precisely in relation to the military representatives of the essence of the matter. The mentioned authors illustrate it with several examples. Some of the mentioned examples are rather individually processed in the literature and therefore it is necessary to look for a wider context for the use of own research findings. That is the reason why it is necessary to solve the raised problem and pay more attention to it. It is necessary to find a general connection of the rules valid for large players to the conditions of small states. There are, for example, in Central Europe, a large number.

The aim of this paper is to carry out research of the fundamental factors affecting the establishment, deployment and control of armed forces. Due to the theoretical framework of the paper, empirical-analytical methods were used to achieve the goal. Subsequently, synthesis was used. Main functions of the chosen approach were description, classification, abstraction and typology. When processing individual parts of the text, the analysis of the achieved theoretical knowledge as well as empirical conclusions were applied. These were subsequently generalized, and deductions and partial predictions were made.

The supporting methodological approach was the use of a combination of theoretical knowledge and practical experience of the author, using sociological and psychological approaches that were, are and probably will be used in the issue of civil-military relations.

2. Establishment of Armed Forces

The armed forces (AF) are a specific formal social organization that uses armed violence in the interest of the entity that created it and uses it to pursue its political goals. This means that the AF is an instrument of power, and it is not an implementer of power that could decide its size and deployment.

The creator and user of the AF can be:

- the state represented by the highest bodies of state (legislative and executive) power,
- an insurgent organization that acts as a body of the state power (de facto, by rising against the legal government for political reasons, effectively controlling part of the state territory and establishing an independent government power in it - essentially a government) and fighting the central government,
- an international organization that, because of an international agreement of an intergovernmental nature, establishes a joint AF of the contracting parties or disposes of a dedicated part of the AF of the contracting parties.

The specificity of AF consists in the fact that, under the conditions of their legitimate use (decision on their use in accordance with the constitution of the relevant state and the UN Charter) and compliance with the principles of international humanitarian law, it is a legal instrument of armed violence. This means that, subject to compliance with the stated conditions, their members are authorized to kill or injure enemy AF members in battle, damage and destroy their military objects and material.

The AF of a sovereign state was and currently still is one of its basic institutions. As a result of fundamental changes in the security environment, their nature, structure and functions may change, but their main mission remains. The AF is still irreplaceable, the most important and the strongest instrument of the state ensuring its independence, territorial integrity and the integrity of state borders. On a foreign policy scale, they represent the basic symbol of its sovereignty and are the main guarantor of its subjectivity under international law. It is expected that the modern AF will be formed as an institution with strategy, military doctrine, training, education, organization, equipment operations, and tactics to achieve decisive military results [9].

The AF can generally have the following character [14]:

- regular AF,
  (permanent, organized and acting according to military regulations)
- irregular AF.
  (insurgent armed formations that is under the command of persons responsible for the insurgent organization for the actions of their subordinates and it is subject with an internal disciplinary system)

In this case, the term regular AF becomes synonymous with the term armed forces. Some states consider the term army to be synonymous with the term armed forces. For some countries (especially in the Anglo-Saxon environment), this can cause misunderstanding because they perceive the term only as ground forces, i.e. one of the basic components of the AF. Some militarily strong states perceive the term army in the meaning of a military formation made up of two or more army corps. For that reason, it is appropriate to prefer the term armed forces in general.

The AF of the democratic states is a legal instrument of the state power. The basis of their establishment in a democratic state is usually the constitution of the respective state. The definition of the mission, main tasks and basic structure of the AF of the relevant state is subsequently defined in a special founding law. For example: in the case of the USA, it is United States Code Title 10 [15], in the case of the Czech Republic it is Zákon č. 219/1999 Sb. o ozbrojených silách České republiky (Law No. 219 of 1999 about Armed Forced of Czech Republic) [16], in case of the Slovak Republic it is Zákon č.321/2002 Z.z. o ozbrojených silách Slovenskej republiky (Law No. 321 of 2002 about Armed Forces of the Slovak Republic) [17]. The specific situation is in Great Britain, where the parliament adopts a law on the AF every 5 years based on the Bill of Rights from 1689 (1689 Bill of Rights) [18], which allows in peacetime to maintain a standing army only with the express consent of Parliament.

3. Personnel of Armed Forces

The AF of a democratic state is a state institution with a priority purpose of applying legal armed violence against the aggressor. Consequently, the current conflicts between state and non-state actors, which is asymmetric in nature, are even more difficult for regular conventional forces to consider whether and how to use the deadly potential at their disposal [19]. The development and use of non-lethal weapons is also a consideration [20].

Through its activity, the AF produce a public asset, which is the assurance of sovereignty and territorial integrity. Based on the above, the AF can be perceived as a production entity that needs adequate human, material and financial resources for its activity.

The AF human resources are referred to as the AF personnel. By this term, we understand the sum of persons who are included in the organizational structure (either peacetime or wartime) of the AF. The AF human resources are created by military and civilian personnel.

3.1. Military Personnel

The military personnel are the main personnel component of the AF. The term "member of the Armed Forces" is synonymous with the term "soldier" in its general meaning. It refers to a person performing military service in uniform, armed and materially equipped in accordance with functional and rank classification.

The essence of the rank hierarchy is the enlistment of soldiers into rank categories: enlisted, non-commissioned officers, and officers (including generals). The officer corps is the key military personnel for organizing the activities of the AF. Accordingly, it is destined to perform command and control functions and in all militarily advanced states it is made up of professional soldiers.

Members of the AF in the categories of enlisted and non-commissioned officers are mostly direct performers of combat and non-combat activities and are partly commanders of the smallest military units. The long-term trend is to reduce the number of other soldiers to one officer. This phenomenon can be explained primarily by the increase in the share of officers in the exploitation of modern weapon systems and by the increase in the number of smaller, independently operating units under the command of junior officers.

In addition to rank classification, the enlistment of military personnel into active duty and reserve soldiers is also applied. Depending on whether it is professional or conscription AF, all soldiers in active duty are professional soldiers, or part of them are professional soldiers and part of them are soldiers performing compulsory military service. The nature of the AF affects the creation of mobilization reserves. The advantage of professional AF is the lower need for financial resources for the training of soldiers in active service, but the lower number of reserves. On the contrary, the advantage of conscription AF is a relatively high proportion of reserve formation, but with a higher frequency of personnel training and thus a higher need for financial resources.

Skills, health, education, and training can by evaluate as the key factors of the concept to create military personnel. The broader view can include emotional intelligence, work experience, employee well-being, and loyalty to the institution, as well as the social and cultural characteristics. These characteristics are also important for military human capital, as they help to reveal its potential and fulfil an important national duty [5].

To adapt military personnel to the modern conditions of civil-military relations, we must focus primarily on officers in active duty. It means to handle the context of warfare, and another thing is what share of it will be civilian and military matter. It is necessary to perceive that it is not focused only on the development of "uniformed" personnel, but also civilian personnel to ensure the comprehensive security of population at the national, regional and local levels [21].

Activities in power struggle belong to three areas:

- the use of political/diplomatic tools,
- the realization of intelligence/special operations,
- the deployment of the armed forces.

A classical power struggle with the use of foreign affairs, intelligence with hidden activities and uniformed military services is reflected in this hierarchy. The actors of the power struggle have different interests. They are determined to use force, whether military, political or economic, to achieve them [22]. Military power depends not only on manpower, weapons, or resources, but success on the battlefield lies in the mind of soldiers. Military capability depends on personnel with the right qualifications in the right job when we need them there [5].

The main feature of value is that personal interests become more important for individual. This feature is also connected with individual perception of your own place in the community or institution. Nowadays individual needs are higher than collective commitment. The standards and expectations which rise from institution become inconsistent with service perception of contemporary officers. Aspect of individualism in collective values propagating military institution leads to ambivalent situation. Modern society's structure and social diversity are factors that might become one of the most important challenges for national defence security and policy of personnel in Western countries. Institutional officer's identity remains crucial for national defence tasks implementation because defence tasks always require specific values, attitude and beliefs. Nowadays convergence of civil-military relations might be challenging. Contemporary society trends that are specific with such features as individualistic, hedonistic, liberal values suggests plausible identities foundation for armed forces individuals. Traditional, demanding institutions values become difficult to accept for nowadays officers [11].

Comprehensive use of civilian and military instruments or the creations of new "complex units" under civilian command/control are encouraged. Especially officers must also perceive their place in civil-military relations in this regard [12].

3.2. Civilian Personnel

Civilian personnel are an additional component of AF, which is assigned exclusively to job positions that are not related to combat activity. These are mainly logistical and administrative positions performed outside the area of combat deployment and teaching positions in those military schools that are part of the AF. Such predetermination of the job positions of civilian personnel results from the Geneva Conventions I to IV from 1949 and the additional protocols I and II from 1977 [23]. It follows from their content that only military personnel with the status of "combatant" can participate in armed activities.

According to Article 44, paragraph 4 of Additional Protocol I to the Geneva Conventions, a member of the AF has the status of a combatant on the condition that he complies with the obligation to distinguish himself from a civilian by his clothing (obligation to wear an identification mark visible from a distance) and by publicly carrying a weapon during any military activity. In compliance with these conditions, the combatant:

- has the right to actively participate in hostile activity,
- is entitled to violent acts (killing or injuring combatants of the other side, damaging or destroying military objects and material) if his violent acts do not violate international humanitarian law, his actions have the character of an authorized activity and do not lead to criminal liability,
- represents a legitimate target of attack by enemy combatants,
- has a legal right to the status of a prisoner of war.

On the other hand, from the content of Article 51 of Additional Protocol I to the Geneva Conventions, it follows that a civilian who engages in armed activities loses the right to protection (immunity from attack) and becomes a legal military target. The articles mentioned above are binding on the signatory states of the Geneva Protocols in all cases of international armed conflicts in which they participate, either as direct actors or as a third party (for example, when participating in operations with a UN Security Council mandate to enforce peace). When the AF is deployed in non-combat operations (for example, stabilization or assistance), international humanitarian law does not limit the participation of AF civilian personnel in these activities.

Despite this, the use of civilians (not only AF civilian personnel) is calculated not only in non-combat operations but also in warfare. There are two major reasons for use of civilians in the warfare. One is the fact that they are where the battles are taking place. This is only increase in the future as cities grow even larger and population continues to explode. The second is that there is an innate weakness for higher-tier soldiers seeing death or harm done to an innocent. These two combine to make the use of civilians a very low-risk, high-profit area [13].

Security can contain military, environmental, economic, societal and political sector, or it can be appended by informational, or even also energy sector. It is a subject of discussions [24]. In any case, the military is represented in it, in combination with many others that are of a civilian nature. The challenge is how to connect the mentioned sectors, to determine the overall responsibility as well as the share of responsibility in individual sectors. Preparing military and civilian personnel to work in risk management is a challenge for educational institutions, especially at the university level [25] [26] [27].

4. Position of the Armed Forces in the Structure of the State Institutions

The state stability is given by many factors such as the political system, military capabilities, law enforcement, social and economic stability of the country [28]. Military capabilities undoubtedly occupy an important place in the entire mentioned system. The position of the AF depends on several factors, among which the character of the state in terms of the applied form of government (authoritarian or democratic state) dominates. It determines the position of the AF in the system of state bodies and the applied principles of supervision over the activities of the AF.

Most states have a military as a highly organized, well trained and armed force maintained by them and authorized to play an adequate role in the statehood. In democracies, a principle of a civilian control over the military prevents it from gaining too much influence but one knows examples of military becoming in lead (military junta) and, as an extreme case, dominative and fully influencing all areas of statehood. Historically those extreme cases with the military penetrating "all and everything" are known under a "military state" name [6].

Identifying the position of the AF in the system of state institutions means clarifying the role of the AF in the performance of state functions, i.e. on the performance of activities by which the state realizes its mission. For the state to be recognized by the international community as a sovereign power authority that directs the actions of the population on its territory through law and with the use of power, it must have a system of executive power bodies with the ability to perform the basic functions of the state. Among them is the security function that ensures the security of the state as a whole and its citizens. The security function is complex in nature and its integral part is also the defence function of the state performed with the aim of:

- prevention of the emergence and organized management of a crisis caused by the violation of sovereignty and territorial integrity because of military aggression,
- prevention of the use of armed violence by other state and non-state entities against the vital interests of the respective state.

The main implementer of the defence issues of the state is usually the Ministry of Defence. The main executive institution of the Ministry of Defence is the AF, which operates under the direct subordination of the Ministry of Defence. Usually it acts as a political-strategic, conceptual, standard-setting and administrative body around creation and implementation of defence policy and military-political management of the AF. At the same time, it does not solve the military-professional matters of the AF.

Finding the border between the military-political and military-professional part of AF management is a real challenge for those dealing with security and especially military matters. The challenge is also what kind of persons are in civilian positions (it means in the military-political part) in the mentioned processes. They can be civilians who have a civilian education and have never served in the AF. As a result, they do not have the appropriate experience or knowledge of how military units are working. Their advantage is that they are e.g. experts in security, economy, law, etc. as well as not being encumbered by their ties to the military environment. However, they can also be civilians (former soldiers) who have a military education and served in the AF. Thus, they have the appropriate knowledge and experience of how military units are working. The challenge lies in what ratio of civilians with military experience and without military experience to use in these processes. Even more so because they are all led by persons who emerged from democratic elections and for them the management of the Ministry of Defence is a political matter.

It is in the above-mentioned areas that the space for self-realization of soldiers is offered after the end of their military career. The military must actively prepare for transitions in civilian leadership. Politicians and civilian appointees will require greater involvement at the beginning of their terms. This is not a burden; it is an opportunity. Higher engagement at the onset must have an aim of aligning goals with the newly elected or appointed civilian principals. The fact that many civilian principals now have very little military experience makes this even more important. The military must actively engage its leaders and receive guidance. There is no need to frame threats. Military leaders must understand that their issues may be only one of many national interests their leaders are trying to address [2].

5. Democratic Control of Armed Forces

Democratic Control of Armed Forces (DCAF) means the management, supervision and control dimension of the instruments used in connection with the existence of the AF. DCAF belongs among the basic attributes of civil-military relations in democratic states. The need to deal with civil-military relations, or to codify some of their attributes, dates to the 19th century and is related to the emergence of mass armed forces, the professionalization of the officer corps, and the gradual separation of this professional group from civil society.

During the 20th century, democratic control emerged as a doctrinal principle of the relationship between the political bodies of a democratic state and its AF, which defines the indivisible responsibility of the political leadership of the state for strategic decision-making on the construction, development, use of the AF, as well as their resource provision. During the Cold War, especially in the Eastern Bloc, the question of DCAF was not given special attention. The key topic was the question of the potential use of the AF of NATO states in a possible military confrontation with the AF of the Warsaw Pact states. After the end of the Cold War, this question became a dominant topic, especially in connection with the transition of the former communist states to the Western model of democracy. As part of this process, it was necessary to make fundamental changes that would rid the AF of both their subordination to one political party and their privileged position among state institutions in their resource provision [1].

The question of DCAF became critical in connection with the decision of the NATO authorities to include mentioned issue among the determining conditions for joining the Alliance. Paradoxically, even though the Alliance emphasized the DCAF, it did not have a universal model for the application of it. Its creation became the subject of research not only within the Alliance but also in the scientific workplaces of various international security organizations. Democratic civilian oversight of the AF and the entire sector of security, including intelligence are of crucial importance in the process of democratic consolidation of the transition countries. Effective functioning of the security sector turns into a major feature of the democratic society [7].

Since the last two decades, we can see strong difference between Russian and Western attitude to the civil-military relations. Russia is witnessing growing its military involvement into all statehood areas while modern forms of civil-military relations are visible in the Western countries. Today, differently from a majority in the Western countries, Russian military organization remains a follower of Prussian military organization and continues using its culture and philosophy [6].

In both, the idea is to create the homeland and to achieve this through relaying on country's history and tradition. It is promoting by similar state values and virtues (loyalty and devotion to the state, a common-sense patriotism) and proposes efficiency, austerity and discipline to achieve this. A closer look taken at it, we can see difference in democratic and bureaucratic approaches.

Russian system can be characterised as a division of labour, a clearly defined organisational hierarchy, detailed rules and regulations including a way of working, a personnel selection, carrier policies and impersonal relationships in the organisation. All these characteristics are so well presented, imbedded and followed in Russian military organization.

On the other side, the purpose of DCAF is to apply such a principle of relations between the political representation of the state and the AF, which is intended to prevent the risk of a military coup and, on the other hand, to prevent them from becoming a liberal organization without strict military discipline. DCAF also ensures that the AF will not be abused in the political struggle for power in the state, i.e. to promote the party's power ambitions. When applying DCAF, it is essential that their functional parameters are preserved and that they can fulfil the tasks for which they were created and while they do not have the opportunity to threaten the democratic principles of the society for which they were intended. A balance must be achieved between political and military-professional intentions in the use of AF [10]. Therefore, the debate over the civil-military relationship inherently involves discussion about how these two actors interact [2].

The subjective definition of civilian control presupposes a conflict between civilian control and the need of military security. This was generally recognised by adherents of civilian groups who commonly asserted that continued military insecurity made civilian control impossible. Steps necessary to achieve military security are thus viewed as undermining civilian control. On the other hand, the effort to enhance civilian control in the subjective sense frequently undermined military security. If civilian control is defined in the objective sense, however, no conflict exists between it and the goal of military security. Indeed, just the reverse is true.

The question is what conditions are likely to maximize military professionalism and objective civilian control. The answer depends upon the relation between the two levels of civil-military relations. On the power level, the key issue in the power of the officer corps relative to civilian groups within society. On the ideological level the key issue is the compatibility of the professional military ethic with the political ideologies prevailing in society. On the one hand, criteria are needed by which to measure military and civilian power. On the other hand, some notion is required as to where the professional ethic fits into the spectrum of political opinion [8].

The creation of the national security policy is decisive in the mentioned relations [3]:

- there is rarely clear policy guidance,
- the process is iterative rather than linear,
- political decisions are rarely timely,
- mutual trust is not automatically conferred and is the result of personal relationships built over time,
- civilian and military leaders need each other,
- the civil-military divide neglects strategy.

The application of the principle of political control over the AF is visible even in dictatorial regimes, where the political representation of the state is not a product of the democratic electoral system, but the dictates of the ruling party. Special case is in countries in which the AF continue to dominate the political system. Governments can use the AF to contain riots or protests. In functioning democracies, the police perform this task. Situations in which governments resort to the AF to quell riots and protests indicate either that these riots and protests ran out of control, or they point to the autocratic nature of the incumbents [4].

Although there is no universally valid model for ensuring DCAF, there are generalized principles of democratic control, the content of which is:

a) Constitutional (legal) guarantee of the subordination of the AF to the political bodies of the state with a clear definition of the constitutional bodies' competence of the legislative and executive power in political management matters of the AF. It represents a process in which the constitutional bodies, within the scope of their competence, decide on the use of the AF, on the allocation of resources (human and financial) for the needs of the AF, and within the defined scope they control their activities. In individual states, there are differences in the competence of the parliament, the head of state and the government in the cited matters, and it is basically defined in accordance with the power traditions and political culture of the respective states. For example, fundamental differences in the powers of the president and the government stem from the applied system of governance (state with presidential or parliamentary democracy).
b) Combined representation of civilian and military personnel in the structure of the Ministry of Defence with a predominance of civilian personnel in conceptual and management positions, including the position of Minister of Defence. The purpose of this measure is that the solution of military-political matters such as the AF profiling was the responsibility of civilian management staff, and military personnel acted more in the role of advisors. Such allocation of competences is intended to prevent uncritical, military-biased opinion in the cited matters. An important prerequisite for the application of this principle is the stabilization of civil servants in key management positions and their managerial competence. The possible inclusion of lay people in management positions (in matters of the AF functioning) creates the possibility of promoting incompetent opinions and realizing their ambitions at the expense of the AF through their legally guaranteed management competences. They can thus create prerequisites for a serious

reduction in the functionality and efficiency of the AF. It is possible to counter this by introducing a system of military-theoretical training of civilian employees to the extent that corresponds to the requirement that the manager knows the object of management to the extent that corresponds to his management competencies.

c) Parliamentary supervision over the development and the deployment of the AF to ensure the legitimacy of the AF. The principle of "parliamentary supervision" is based on the basic principle of democracy, which is the right of citizens to control the exercise of state power. Citizens exercise their authority over public affairs through elected representatives who have the duty to control how power institutions are created and used. Accordingly, the parliament is the most important subject of democratic control of the AF. For this purpose, the parliaments of democratic states have created special bodies in the form of a specialized committee for the affairs of the AF. Parliamentary supervision over the development and the deployment of the AF is generally based on the scope of Parliament:
    - approve the state budget, check its implementation,
    - decide on the declaration of war if the state is attacked or this results from obligations from international agreements on joint defence against attack, and after the end of the war on the agreement of peace,
    - express consent to send the AF units out of own territory,
    - express consent to the presence of foreign AF units on own territory.

d) Maximum transparency of the AF and their accessibility to the media represent important elements of the process of building trust between civil society and the AF. In this process, a significant role is played by the periodic publication of the so-called "White Papers on Defence". It is an analytical-conceptual document in which, based on a rigorous analysis of the current state of defence assurance and the AF readiness, the principles, direction, priorities and basic guardrails for the further development of the defence sector are defined. In this context, the "White Paper on Defence" represents a source of data for defence planning and, at the same time, a tool for communication between the Ministry of Defence and citizens. By its nature, it has the ambition to gain the understanding and support of the wider professional and lay public for the tasks and needs of guaranteeing the defence of the state, including the development of the AF.

After the end of the "Cold War", the issue of DCAF became part of the complex transformation of the AF of both "traditional" democratic states and post-communist states. The mentioned transformation manifests itself:

- strengthening the political-military nature of the Ministry of Defence and respecting the autonomy of commanding bodies in military-professional matters,
- changes in the mission of the AF by adding a "peace-making mission" in the form of establishing peace, building peace and maintaining peace to the traditional "war mission" in the sense of achieving victory over the enemy in a general war. Developmental trends in the global security environment indicate that the importance of the "peace-making mission of the AF" will increase and the importance of their traditional mission will stagnate or decline in proportion to the decrease in the probability of the outbreak of war between sovereign states,
- structural changes in the sense of an overall reduction in the number of soldiers and basic types of military equipment, together with overall professionalization and the generation of new, non-traditional capabilities such as civil-military cooperation capability (CIMIC), which is frequently applied in the entire spectrum of peace operations,
- technical and technological progress in armaments (introduction of new sophisticated types of armaments and information technologies into the AF).

International security organizations, in an endeavour to unify the democratization efforts of member states, have adopted several initiatives in which they encourage a democratic approach to the creation and use of AF and identify general norms and procedures in the field of their democratic control.

A general overview of the initiatives of international organizations in the field of identifying standards of democratic control of AF is presented in Table 1. Despite their insufficient enforceability (absence of sanctions for violations), they have an undeniable benefit in unifying the views of member states on the issue of mechanisms for ensuring DCAF.

Table 1.
Initiatives of international organizations in the field of DCAF

Organization	Focus of the initiative	Contained in document
UN	A call to the UN member states to encourage the development of democracy by, among other things, guaranteeing that the AF will remain subordinate to the democratically elected civilian government	UN General Assembly Resolution 55/96 on promoting and consolidating democracy (2000)
	Recommendation to UN member states to apply exhaustively defined principles of democratic control of the AF, police and other security forces	Human Development Report 2002
OECD	Detailed specification of politically binding standards of democratic control of military, paramilitary and	Code of Conduct on Politico-Military Aspects of Security (1994)

	security forces as well as intelligence services and police	
NATO	The Partnership for Peace (PfP) program, in which one of the five objectives is to ensure democratic control of the AF	Partnership for Peace Framework Document (1994)
EU	The Copenhagen criteria for joining the EU include Legal responsibility of the AF, police and security services	Agenda 2000, § 9

Source: own work

The most important of the mentioned initiatives can be considered the OSCE initiative contained in the document "Code of Conduct on Politico-Military Aspects of Security" published in 1994. This politically binding document concerns not only the democratic control of the AF, but all intervention institutions of the security sector (police and other armed security forces).

The Table 2 identifies a set of standards of democratic control, which can be divided into international standards (applied at the level of the signatory states of the Code) and national standards applied at the level of the AF.

Table 2.
Basic international and national standards in the field of political-military aspects of security

International standards	National standards
Application of the principle of solidarity - support for joint response if agreed standards and principles are violated	Political management and control of the AF and the armed security forces of the state should be carried out through constitutionally elected bodies with democratic legitimacy
The maintenance and use of the AF must be in accordance with international law, i.e. in accordance with international agreements regulating numbers of the AF, ways and means of conducting armed conflict and the protection of victims of these conflicts	Limiting spending on armaments, the defence budget approved by law, transparency and public access to information about the AF
Maintaining the military potential within the limits of military sufficiency for the need of individual or collective defence	Consideration in laws and regulations of the rights and obligations of military personnel, ensuring the exercise of human rights and freedoms by military personnel in accordance with service requirements
Application of democratic principles of decision-making about the military capabilities of the state	Political neutrality of the AF, adoption and application of measures against accidental or unauthorized use of the AF
Deployment of the AF on the territory of other states only with their consent and in accordance with international law	Deciding on the use of AF to ensure national security in accordance with the constitutional framework

Source: own work

The "Geneva Centre for Democratic Control of Armed Forces" plays a particularly important role in the field of consulting services. It is an international organization founded in October 2000 on the initiative of the Swiss government, operating in accordance with Swiss laws. 61 countries of the world are represented in the "foundations", including Switzerland. The governing body of the foundation is the DCAF Board with about 100 experts. They collaborate with international organizations, such as the UN, NATO, AU, EU, and OSCE [29].

The centre collects information and conducts research to identify problems, collect experience and propose best practice in the field of democratic control of the security forces. Through practical work programmes, the centre provides its expertise and support to all stakeholders, particularly governments, parliaments, military institutions, international organisations, non-governmental organizations and academics.

6. Conclusions

It was found that in democratic states there is a legislative framework for the establishment, control and deployment of the AF. Civil-military relations must be linked to security and to democratization. However, each state has its peculiarities. Their mutual understanding is important especially in multinational operations. This can help in reducing differences of opinions and in achieving both political synergy and military interoperability.

Security is a complex issue in democratic states as well as in the states with some form of authoritarian regime. Security in this context implies the only (external/national defence) role for the military in democratic and dual (internal/public safety and external/national defence) role for the military in authoritarian regime. In transition states with weak civilian control, discussion of these roles runs the risk of challenging the status quo, in the absence of specific attempts to reduce the armed forces' role in internal policing. Coups d'état or undue military pressure on the government could result.

Accordingly, a more propitious setting for civilian control of the armed forces must be consciously built. There is tension between the need to have the military focus on its mission of external security (notably where history and constitutional provision press the armed forces into internal security activities) and the need to have the military fill the gap where government capacity to deliver services or maintain internal security is low.

This paper can assist both civilian and military officials in understanding their place in civil-military relations and their competencies in managing the armed forces. The concept of civilian control of the professional military in the democratic states is strongly given. The concept of the subordination of the military to civilian control ensures the continued adherence of democratic principles. Mentioned principles produce impassioned discussion on both (military and civilian) sides. The primary question in the past was: what pattern of civil-military relations to create. Nowadays primary question is where the balance between impact of civilian nonprofessional decisions (in military point of view) and impact of military professional influence to political decision makers is.

Small countries (such as Slovakia) can learn several lessons from global players efforts to create functional civil-military relations. While conceptual and legal frameworks for civil-military relations in some small countries have been taken over and adapted for one's own needs, they need to be fully implemented and tested. Some additional efforts are required for better delineation and coordination for all stakeholders to the civil-military relations. Social awareness of the importance of creating firm rules requires more attention. The preparation of military as well as civilian personnel working in defense sector is particularly important. Extremely important is also preparation of civilian decision-makers who are part of mentioned processes only for short time (election period).

Despite some predictions, it is not certain which direction civil-military relations will take. Only the future will tell whether the military-professional aspect will be strengthened and respected when setting strategic goals, or whether the aspect of political responsibility will be more enforced. It appears that the evaluation of the mentioned aspects will be a never-ending process and further research is needed.

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The Impact of the War Conflicts on Residential Childcare: A Survey into Czech Children's Homes

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Abstract

The paper's main aim will be to present the research results that mapped the reflection of current war conflicts on the situation in Czech children's homes. We investigated whether ongoing war conflicts are changing the population of children in these institutions and to what extent children's homes are prepared to meet the needs of children from war zones. We worked with a qualitative research design based on close contact with the research setting. We have identified several areas that require attention. In particular, these are issues of religion and socio-cultural norms. We have also identified the need to significantly strengthen the training of teaching staff in the area of skills for working with children traumatized by war and refugee experiences.

KEY WORDS: *children's home; social-legal protection; trauma; special educational needs.*

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1. Introduction

The explosions of war do not only tear up battlefields; they also tear up families. The most vulnerable members of our societies, children, suffer from war [1;2]. Although children should be guaranteed the protection guaranteed by international conventions [3], many families prefer to send their children to the relative safety of a foreign country. It has been demonstrated that separation from parents profoundly impacts a child's psyche [4;5]. Studies have repeatedly confirmed that the experience of war-induced separation has a massive effect on children's psychology and development [6;7]. The issue of children displaced abroad by war in their homeland is extremely relevant in today's geopolitical situation. In our globalized society, the changes caused by armed conflicts affect us all [8]. As soon as a child enters the territory of the country of destination, he or she is subject to that country's socio-legal protection legislation [9]. In many cases, the child is placed in an institutional setting.

The paper's main aim will be to present the results of a unique research that mapped the reflection of current war conflicts on the situation in Czech children's homes. We investigated whether ongoing war conflicts have an impact on the composition of children in these institutions and to what extent children's homes are transported to meet the needs of children from areas of war conflict. This issue is minimally elaborated in the Czech space; the responsible ministries need in-depth analyses. We focused our research on the area of special educational needs, the area of socialization of newly arrived children in the Czech school environment, and the area of social interaction of children with experience of war conflicts with children from the intact population.

We divide the paper into two main sections. First, a brief introduction to the social and legal protection of children in the Czech Republic will be necessary, as this is a crucial sector for children coming from war zones. We will then present the research design of our qualitative research. In the second part of the paper, we describe the research setting and present a unique case study. We then describe the research findings. In the discussion, we outline recommendations for practice and finish the paper with a conclusion in which we appeal to experts to pay more attention to the issue of children coming from war zones and their stay in residential childcare settings.

2. Child Protection

The fundamental child protection legislation in Czech Republic is Act No. 359/1999 Coll. on Social and Legal Protection of Children, which introduced new perspectives and new services to help vulnerable children. Socio-legal protection of the child means ensuring the child's right to life, to his or her favorable development, to parental care and family life, to the child's identity, to freedom of thought, conscience, and religion, to education, and employment. Also, it includes the protection of the child from any physical or mental violence, neglect, abuse, or exploitation [9]. Child protection, which is a broader concept than socio-legal protection, thus encompasses the protection of a wide range of rights and legitimate interests of the child and is therefore regulated in different branches of law and legislation of different legal forces [10]. Social and legal protection does not only apply to Czech citizens, but also to any children who are present on the territory of the Czech Republic. If a child finds him/herself in a situation where social protection intervention is needed, the procedure is as follows.

The social workers of the child welfare authorities first check whether there is a person responsible for the child's upbringing in the Czech Republic, and if they are unsuccessful, they begin to address the child's situation. They must find out the age, name and nationality of the child. In some cases, where the child does not have an identity document, the authorities have to base their decision on the stated age and register the child as a stateless foreigner. The Child Protection Authority also establishes the contacts and initials of the child's legal guardians, relatives and details of extended family [11]. If the unaccompanied minor alien is not an applicant for international protection, the municipal authority of the municipality with extended competence is obliged to immediately inform the competent embassy and the Office for the International Protection of Children in Brno. The municipal authority of the municipality with extended competence shall discuss with the embassy the way of connecting the unaccompanied alien minor with his/her parents or other persons responsible for the child. If it finds that there is no person responsible for the child's upbringing in the Czech Republic and that it is not possible to hand the child over to the care of the parents or other close persons, the social worker submits to the district court a proposal for an interim measure placing the child in an institution of institutional upbringing. In the case of an alien child with a language barrier, such a child is placed in the Institution for Alien Children in Prague.

The Institution for Alien Children is a state organization managed by the Ministry of Education, Youth and Sports, which works in the system of residential childcare. The Institution for Alien Children takes into its care children of foreign nationality who find themselves in the territory of the Czech Republic without the accompaniment of their parents or other persons responsible for their upbringing. It also receives children whose parents are in prison or custody, and there is no other person in the Czech Republic who could care for them. Children who are themselves criminals, educationally unmanageable, or children for whom other forms of outpatient assistance have not been effective are also placed here. They may also include abused, exploited, and trafficked children.

The Institution for Alien Children accepts children aged 3-18 years on the basis of a court decision - on a precautionary measure, on institutional childcare or on protective childcare. The facility also accepts children for so-called voluntary diagnostic stay, which is the only form of stay in the facility that does not have to be supported by a court decision. In this case, the child is admitted on the basis of a contract between the establishment, the parent, and the child for a two-month voluntary stay. During this period, a comprehensive diagnosis of the child is carried out (psychological, special-educational, educational, medical and socio-legal). At the end of the stay, the child returns to the care of the parents, and the facility recommends further forms of work with the child. In cases where no other solution to the situation is available, the child is placed in a children's home. The child may remain there until the age of majority, i.e. until the age of 18. If the child is still studying, the stay in the children's home can be extended until the age of 26.

3. Research Design

We are utilizing a qualitative research approach that has demonstrated efficacy in prior studies [12]. Qualitative research methodologies have the potential to significantly enrich the contemporary inclusive paradigm [13]. Our initial data collection employs semi-structured interviews and participant observation, with interviews being the predominant method in qualitative research [14]. Notably, researchers have a shifting perception regarding the interview process, emphasizing the need for researchers to reconcile their personal involvement with their professional stance [15].

We contend that an actively engaged researcher yields more dependable results than a passive researcher [16]. As qualitative researchers, we maintain close contact with the subject group, investing significant time within the research environment [17]. This proactive involvement mitigates respondent distrust, particularly in close-knit communities like the children’s home we study. Our research design comprises two levels. The primary stage involves conducting interviews, observations, and analyzing pedagogical documentation for initial data collection. Subsequently, the gathered information undergoes grounded theory methods and phenomenological interpretive analysis. The research methodology is regularly reviewed and tailored to meet current research objectives, utilizing a variety of instruments and techniques to respond flexibly to the research context and targeted population. Continuous refinement and integration of new research tools and methods contribute to the ongoing improvement of our research methodology. We view research as a dynamic and continuous process, necessitating suitable research tools and methods. Research objectivity is paramount. Given the potential for bias inherent in qualitative research due to the researcher's presence, we emphasize objectivity and utilize triangulation. Triangulation involves subjecting our findings to scrutiny from other research methods or researchers [18]. Using triangulation of research methods, we enable our qualitative research approach to obtain information based on a solid scientific foundation.

In this research, we have a unique opportunity to utilize several in-depth case studies. Case studies are highly effective research tools, particularly valuable for investigating complex issues in real-world scenarios. The frequent use of case studies in qualitative inquiry presents challenges, which can be mitigated through precise language and careful research design [19]. Additionally, our prolonged presence in the research environment enables us to operate within the linguistic code of the target group, providing our qualitative research with deep insight into the issues under study. It was necessary to take into account the sensitive areas associated with the war experience, which has a crushing impact on children's psyche [20;21;22]. Because these are highly vulnerable children, our research strictly adheres to data protection principles and takes into account the ethical aspects of conducting research with at-risk children.

4. Researched Environment

We're researching the children's home environment. Children's home is an institution for the provision of residential childcare. In the Czech Republic, children's homes are the responsibility of the Ministry of Education, Youth and Sports. The examined children's home is located in Prague, Czech Republic. This children's home consists of seven family groups with a total capacity of 54 children. It is a standard children's home intended primarily for children without serious behavioural problems. The vast majority of children come from families that can be described as pathological [23]. In recent years, there has been a slight change in the age distribution of new arrivals, with an increase in older children. There has also been a marked increase in the number of new arrivals requiring psychiatric care. The ethnic composition of children is also changing. Currently, children from Kazakhstan, Slovakia, Venezuela, Ukraine, Yemen and Morocco live in the Klánovice Children's Home.

Our research has confirmed pathological family environments as an essential common feature for children in children's homes [24]. The exception is children who come to the children's home as refugees. In the case of these children, we have not observed any pathological behaviour patterns in their original families, the vast majority of them are children from stable families. The refugees can be divided into two groups: economic refugees and refugees from war conflicts. Our paper will focus specifically on children who have found themselves in a children's home environment due to the ongoing war conflict in their home country.

5. Course of Research

It would be illusory to believe that the war conflicts occurring in distant foreign countries do not concern us. The children's homes are proof that even a distant war has an impact on our society. Over the years, we have seen children from the conflict areas of Chechnya and Syria in children's homes, and in the last year, there has been an increasing number of children from Ukraine. We could go on with a list of other areas, such as Afghanistan or Yemen. Moreover, children from all these war-torn corners of our planet can find themselves in the environment of a Czech children's home. For our research, we worked with two children. They were a Ukrainian girl from the Zaporizhzhia region and a young man from Yemen. Due to the need for privacy, we will not use identifiers that could lead to the children's identity being broken. Both children were informed about our research plan and gave us their consent. We obtained additional information from the educational staff of the children's home; we also spoke with the social worker and worked with available documentation. We worked with documentation not only from the field of education but also with medical records and documents related to social and legal protection. We recognized the need for an interdisciplinary approach [25;26] and an inclusive perspective on the studied issue [27].

The research interviews and documentation analysis took place between January and March 2024. Because the author of this paper is employed as an educator in the children's home under study, we were able to spend a considerable amount of time in the research setting. Another advantage of our prolonged presence was that the children did not perceive us as researchers. Therefore, their responses were much more open than possible with an outside research intervention. We are well aware of the limitations of our research. A major limitation of our research is the difficulty of generalizability, as we studied only a limited sample of children. Another significant limitation is that we have focused on highly personal areas of children's lives that are by default understood as difficult to generalize. Given the relatively short time that the issue of children from war zones in children's homes has been an issue, further and especially longer research in this area will be needed. Therefore, we are preparing a series of additional studies in which we will examine the exact numbers of children from war conflict areas in Czech institutional facilities.

6. Case Study

Both children came to the children's home from the Institution for Alien Children. Their initial special education and social diagnostics were carried out here. Based on the recommendation of the Institution for Alien Children, the children were placed in the Klánovice Children's Home. They both attend secondary schools. As far as school performance is concerned, both have very good results. The Ukrainian girl is currently taking online distance learning and completing her final year of high school in Ukraine. After passing the final exams, she plans to apply for nostrification of her Ukrainian qualification, which will allow her to apply to a Czech university. The boy is studying the final year of a vocational apprenticeship. After graduation he plans to apply to university. Both of them adapted very well in the children's home, there were no disciplinary problems. The girl is very withdrawn; she does not communicate much with other children. The boy, on the other hand, is popular and sociable among the other children. Both children come from stable family backgrounds. They keep in regular contact with their families and make use of social networking opportunities. The pedagogical staff contacted assess both children in a positive way.

7. Findings

Thanks to the qualitative approach, we obtained several insightful findings. The findings from the children were compared with the results of interviews with teaching staff and the records in the educational documentation. We coded and then categorized the results into several key categories.

Language: The Ukrainian girl had no significant difficulties acquiring the Czech language. After a few months, she was able to communicate without any problems; only a slight accent remained. Slavic languages are difficult to acquire, especially for newcomers from Arabic-speaking countries. We were even more surprised by the Yemeni boy who, after a very short time, mastered the basics of communication in Czech. The level of communication is sufficient for his social and educational needs.

Religion: The boy is a practicing Muslim. As there have been Muslim children in the past at the Klánovice children's home, the staff was prepared for the needs arising from his faith. We were able to provide halal food but also ensured sufficient privacy to allow the boy to pray regularly. We also contacted non-profit organizations that work to address the issue of integration. We provided training for the teaching staff. This was very important because the Czech Republic is, by default, a very secular country where public awareness of religious issues is deficient.

Interpersonal relationships: Both children repeatedly mentioned missing contact with their original environments. We noted their tendency to be involved only with individuals of their cultural group. This is understandable, but it can lead to exclusion from other children in the children's home. Regarding the joint activities organized by the children's home, the Yemeni boy was mainly involved in football tournaments, while the Ukrainian girl tended to avoid such activities. For both children, we observed a significant tendency to predefine one key teaching staff member of the children's home.

Cultural differences: It was interesting to find out to what extent both children adore their native countries. In both cases, we noted their assertion that the school system in Yemen and Ukraine is better than in the Czech Republic. Another intriguing finding was related to the children's views on the political situation in the world. The opinion of the Ukrainian girl on the war in her homeland was accepted by the educational staff of the children's home without issue. However, we observed a discrepancy between the Ukrainian girl and children with Russian roots. The debates of the Yemeni boy on the situation in the Israeli-Palestinian conflict were interesting. The boy stated that in the predominantly pro-Israeli Czech environment, he was confronted several times with outright disagreeable reactions.

8. Conclusions

During our research, we observed no difficulties in the interaction between the Ukrainian girl, Yemeni boy, and other children living in the Klánovice children's home. In other words, it may seem that both children have no issues. Both have quickly acclimatized, rapidly acquired the Czech language, and are successful in school. This fact is, of course, positive, but these achievements may divert the attention of the educational staff of the children's home from serious problems that are not immediately apparent. The fact that children do not show signs of psychological problems does not mean that they do not have them. It is, therefore, our duty to be aware of these specifics and strive to provide maximum support for these children.

Our research activities have outlined several areas that Czech children's homes must urgently address. There will be a significant need to strengthen the language competencies of pedagogical staff. Basic language requirements should include fluent English and at least one other Slavic language. In addition to language proficiency, there will be a need for intensive training of pedagogical staff in religious matters. Czech educators will need to accept the fact that religious questions are of significant importance for practicing Muslims or practicing Orthodox Christians. We will need to prepare the Czech system of children's homes for the future; we must prepare for the arrival of children who will be forced to leave their homes due to further armed conflicts. We must recognize the complexity of the situation faced by children coming from war-torn areas and ensure conditions that enable them to cope with their challenging life circumstances.

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Approaches to the Population Sheltering in Selected Countries in Relation to Threats and the Security Environment

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Abstract
The aim of this article is to analyze the approaches of the Czech Republic, Poland, Austria, Germany and the United States of America to the issue of sheltering in the context of current security threats with regard to the development of the geopolitical situation. The article defines the basic methods of sheltering, types of shelters with regard to related normative legal acts and other documents, their current technical state, the capacity of shelters and the structure of threats for which sheltering is used, current initiatives in the field of sheltering and information support for the population. Variants of approaches to sheltering within individual countries are subjected to comparison and multi-criteria analysis. The output of the multi-criteria analysis is the order of alternative approaches to the sheltering of the population compiled on the basis of the proposed criteria, including a verbal assessment for the purpose of interpretation and contextualization of the findings.

KEY WORDS: *population sheltering; threats; security environment; comparison; multi-criteria analysis, Saaty method*

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1. Introduction

More than ever, security has become a global issue. Significant changes can be seen in the international security environment, which is undergoing an extensive process of transformation aimed at restoring the influence of major military powers. In parallel with this change, natural and anthropogenic disasters are also intensifying, and the vulnerability of the population to them is growing. A key task to minimize the loss of civilian life is the management of shelters. The construction of protective infrastructure for population sheltering took place mainly in European countries during the Cold War. The altered security environment following the Cold War frequently led to a reassessment of civil protection and shifted the focus towards a different threat structure, including floods, terrorism, and biological threats. The issue of sheltering has been neglected in many states, as concerns about direct military threats have diminished. Concurrently, the potential for utilizing shelters in response to other threats has not been fully explored [1]. As a result of the evolving geopolitical situation, there arises a challenge to reassess the approach to sheltering [2].

While previous works have examined sheltering approaches in individual countries in the past, there is a need for comprehensive comparative analysis across multiple nations in the context of the current, rapidly evolving security environment. This study meets this demand by conducting a multi-country comparison of population sheltering approaches in the Czech Republic, Poland, Austria, Germany and the United States. By employing comparison via multi-criteria analysis and verbal assessment for the purpose of interpretation and contextualization of the findings, this research provides valuable insights into the relative strengths and weaknesses of different national approaches.

The practical problem this research aims to address is the need for updated sheltering policies that are responsive to both traditional and emerging threats. Many countries face challenges such as aging shelter infrastructure, unclear responsibilities for shelter maintenance, and public uncertainty about sheltering procedures. By comparing national approaches to sheltering, authors can examine the main common features and differences, highlight beneficial initiatives, evaluate the strengths and weaknesses of various approaches at the national level, and provide a basis for potential improvements in the current state of population protection in the studied areas. The findings have practical implications for emergency planners, civil defense authorities, and policymakers seeking to optimize sheltering capabilities in an evolving threat environment.

The aim of this article is to analyze the approaches of selected countries to the issue of sheltering and to conduct a comparative study of these approaches. Through this analysis, the research seeks to identify best practices and innovative solutions that could be adapted to strengthen sheltering preparedness across different national contexts.

2. Selected Aspects of the Sheltering in the Czech Republic

The construction of shelters in the Czech Republic dates back to the establishment of the Civil Air Raid Protection under the responsibility of the Ministry of the Interior. The Civil Air Raid Protection was established on 11 April 1935 by the adoption of Act No. 82 Coll., on Protection and Defence against Air Attacks. One of the main tasks of the Civil Air Raid Protection was to provide a sufficient number of shelters for the civilian population. After the Second World War, the construction of shelters began in 1948 in connection with the political developments after February 1948. Shelters for the population began to be built, with a focus on sheltering against conventional weapons. [3]

A change occurred in 1958, when the Resolution of the Government of the Czechoslovak Republic of 15 January 1958, No. 49 on the Civil Defence of the Czechoslovak Republic, was adopted. From the beginning of the 1960s, shelters with increased resistance to weapons of mass destruction began to be built [4]. On 1 January 1976, the civil defence was transferred to the Ministry of Defence and the construction of shelters against weapons of mass destruction continued until 1989 [3].

After 1990, a transformation of civil defence was undertaken, focusing on contemporary non-military threats. The construction of new permanent shelters was suspended; however, those already under construction were completed, and maintenance was carried out on all existing shelters. During this period, shelters were constructed to accommodate 1.35 million inhabitants, representing 13.1% of the population [5]. In 1993, the term “civil protection” was officially introduced [6]. By the Resolution of the Government of the Czech Republic of 15 January 1993, civil protection was transferred from the jurisdiction of the Ministry of Defence to the Ministry of the Interior, specifically under the administration of the Fire Rescue Service of the Czech Republic.

Since 2000, population protection (including sheltering), has been legally established with the adoption of Act on the Integrated Rescue System [7]. According to this law, the sheltering of the population on its territory is ensured by the municipal office. The Concept of Population Protection until 2006 with the outlook to 2015 [8] stipulated that the fund of permanent shelters will not be further expanded from the state budget and that the costs of maintenance, inspections and operation of these shelters will be reduced [2].

In 2003-2004, surplus technology was removed from the shelters, and in 2006 financial support for the maintenance of permanent shelters was discontinued. Given the focus on non-military threats in population protection, further utilization of the Czech Republic's shelter fund was not anticipated, and to date, more than 70 % of the shelters (with a capacity for 667,000 people) [5] have been removed from the registry.

The Concept of Population Protection until 2013 with the outlook to 2020 [9] states that permanent shelters should not be relied upon in non-military emergencies and has emphasized the importance of improvised shelters [6], [10]. Suitable buildings and spaces for the construction of improvised shelters were to be selected by municipal authorities in cooperation with the Regional Fire Rescue Service during the planning phase. In the event of an escalating threat of war, the following would be utilized for the purpose of sheltering the population:

1. Functional permanent pressure-resistant shelters and protective systems of underground transport structures, or decommissioned permanent shelters suitable for reactivation to their original purpose,
2. Decommissioned permanent shelters not suitable for full reactivation to their original purpose and other selected spaces appropriate for conversion into improvised shelters. [9]

Due to heightened public interest in the location of shelters related to the war in Ukraine, the Ministry of the Interior initiated an inspection in 2023 of all registered permanent shelters with a capacity exceeding 500 people. The inspection was carried out by the Regional Fire Rescue Services, and the results are published on the website of the Fire Rescue Service of the Czech Republic [5]. This record is shared with municipalities, which also have access to the list of decommissioned shelters. The map of registered permanent shelters is freely accessible to the public in the Terinos application [11]. The registered permanent shelters have a capacity to accommodate 685,000 people, representing 6.3% of the Czech Republic’s population, with 70% of these shelters located in Prague [5].

The Concept of Population Protection until 2025 with the outlook to 2030 [12] emphasizes the importance of improvised shelters for population sheltering during an armed conflict [6]. The state will support only the maintenance and inspection of protective systems in underground transport structures and the shelter fund of selected university hospitals, which corresponds to approximately 50% of the shelter fund in the Czech Republic.

3. Selected Aspects of the Sheltering in the Republic of Poland

The foundational document of security policy is the National Security Strategy of the Republic of Poland from 2020, which includes the following among its goals for ensuring and enhancing the resilience of the state and civil defence: “*Redefine the civil defence system and the population protection system by making it universal, both within urban agglomerations, as well as in rural areas, focusing on building the capacity of the system to constantly adapt and respond to the changing challenges and threats. Develop a law comprehensively regulating the subject matter of civil defence*” [13]. The excerpt from the National Security Strategy of Poland shows that the Republic of Poland (Poland) is currently undergoing fundamental changes in the area of legislative regulation of the issue of sheltering. The issue of sheltering in Poland has historically fallen under the competence of the Ministry of National Defence, but in 1996 it was transferred to the competence of the Ministry of the Interior and Administration [14]. At present, the issue of sheltering remains the responsibility of the National Headquarters of the State Fire Service under the Ministry of the Interior and Administration [14]. The "*law comprehensively regulating the subject matter of civil defence*", as referred to in the National Security Strategy [13], is likely to evolve into The Law on the Protection of the Population and on the State of Natural Disasters (in original language: "Ustawa o ochronie ludności oraz o stanie klęski żywiołowej") [15]. However, the final form of this legal regulation, including any possible follow-up regulations, has not yet been fully determined. In its report [16], the Supreme Audit Office (of Poland) states that in the current situation arising after the adoption of new legislation in the field of national defence and before the adoption of the key Law on the Protection of the Population and on the State of Natural Disasters [15], there is basically no firm legislative regulation of the issue of civil protection (including sheltering).

In terms of protective infrastructure and permanent shelters, the situation in Poland is similar to the situation in the Czech Republic and some other European countries, except for some specifics. Most permanent shelters were built in Poland in the 1950s and 1960s in large cities and industrial centers. The shelters did not have very good pressure resistance and their construction was inefficient in terms of capacity-to-cost ratio. The current shelter fund of permanent shelters would provide shelter for a very small percentage of the population (about 4% or less). Most of the shelters are located in Warsaw. The actual equipment, durability and usability of the shelters are low. Currently, the construction of permanent pressure-resistant shelters is neither being carried out nor planned, and often, adequate maintenance of the existing stock is not performed [14]. This is confirmed by the Supreme Audit Office in its report [16], which points out the unsatisfactory condition of a large portion of the shelters.

The key document on sheltering in Poland is the 2018 Directive of the Chief of National Civil Defence and its annexes [17]. This Directive [17] contains, among other things, a classification and categorisation of the forms of shelters and shelter options for the population. It also contains various technical and functional requirements for protective structures (e.g. movement around the shelter, hygiene requirements, etc.).

An interesting initiative is that of the Polish government, which, through the State Fire Service, conducted an inventory of almost 235,000 buildings in 2022 to assess their potential for various forms of sheltering. The survey was conducted in response to the population's concerns following Russia's invasion of Ukraine and the related increase in public interest in the issue of sheltering [18]. According to the results of the inventory [18], Poland has a declared sheltering capacity for up to 49 million people, which is more than the population of Poland (population of less than 37 million people) [19]. Simplified categorisation (intended for the population) of shelters divides variants into shelters ("schrony"), hiding places ("miejsca ukrycia"), temporary shelters ("miejsca doraźnego schronienia") [18]. Based on the findings of [16], [17] and [18], it can be deduced that shelters and hiding places are different variants of shelters that together represent a capacity for less than 4% of the population, which confirms the figure given in [14]. Thus, more than 90% of the declared shelter capacity is comprised of temporary shelters. These are characterized as places that utilize the inherent protective properties of buildings, which, according to [16], are primarily intended for protection from weather events and lack distinctive protective or operational features.

As part of the information support for the sheltering, the map application "Schrony" [20] was created. The application enables users to search for shelters easily based on the aforementioned categorisation, depending on their geographic location. The application operates on the web and the authors have not identified an equivalent in the form of a mobile application.

4. Selected Aspects of the Sheltering in the Federal Republic of Germany

The construction of the protective infrastructure in Germany began as early as 1920 due to the need for civil air defense. The intensification of the construction of shelters began after the Second World War, and during the Cold War the variety of shelters also increased (in cellars, schools, underground parking lots and stations, hospitals, important operations, etc.). By the end of the Cold War, 2,000 public shelters had been registered. The largest systems had a capacity for up to 10,000 people [21].

The issue of sheltering was addressed by the Act on Construction Measures for the Protection of the Civilian Population [22]. However, the change in the security environment after the end of the Cold War led to a focus on modern threat scenarios (especially natural threats and terrorism) and caused the abolition of this law. Moreover, after the reunification of Germany (since 1990), no new shelters were built, and the existing shelters operated in the new federal states (especially in East Germany) were not even included in the concept of public shelters. [1]

To fulfil civil protection tasks, the federal government adopted the Act on Federal Civil Protection and Disaster Relief (ZSKG) in 1997, which defines the types of protective structures:

1. Public shelters ("Öffentliche Schutzräume"),
2. House shelters ("Hausschutzräume"),
3. Structural operational safety ("Baulicher Betriebsschutz"). [23]

The government also enacted the Act on the Establishment of the Federal Office of Civil Protection and Disaster Assistance (BBK) [24], which brought the issue of shelter within its jurisdiction. The Act on Federal Civil Protection and Disaster Relief was also reflected in the New Population Protection Strategy of 2002 and the overall change in approaches to population protection saw the abandonment of public shelters in 2007, which were subsequently phased out and decommissioned. [1]

In response to the gradual phasing out of public shelters that were owned by the federal states, options for purchasing shelters from the Institute for Federal Real Estate (BImA) were explored. In 2009, responsibility for their use was also transferred to this office. With effect from 1 September 2020, BImA has taken over their overall management and is therefore currently the central point of contact for all issues relating to public shelters. BImA's task was also to ensure the complete abolition of civil defence structures and, at the request of the owners of these structures, to abolish their obligations arising from civil defence requirements. [1]

Shelters in Germany were built according to a uniform concept and the structural requirements (construction and design principles) for public and private shelters [25] date back to the Act on Construction Measures for the Protection of the Civilian Population [22], from 1968 to 1996. Interestingly, public shelters were never designed to protect against direct hits from nuclear weapons. Therefore, in most cases, they provide only what is referred to as basic protection, namely, static resistance and mechanical stability, protection against radioactive fallout, effects of fire, and combat chemical agents, utilizing a filtration ventilation system designed for this purpose. Requirements for enhanced protection were particularly applied to protected workplaces [25].

In the current context of the war in Ukraine, the situation has changed. The federal government decided to review the reverse concept of public shelters, suspended their decommissioning until further notice, and, together with the federal states, conducted a complete inventory of the shelters that had not yet been decommissioned. Currently, there are 579 public shelters available (with a capacity of 477,593 shelter spaces, i.e., approximately 0.6% of the German population), which are very unevenly distributed across the country [26]. These shelters are not ready for use, as the focus of population protection and information is primarily on warnings and evacuation. The time and cost of reactivation depends on the level of protection the shelters are to offer, ranging from debris and fragmentation protection as the lowest level to protection from nuclear threats (CBRN protection) as the highest level of protection. In addition, BImA has proposed other measures aimed at increasing protective capacities, which are currently being evaluated. The findings of the inventory will then form the basis for further decision-making. [21]

In the event of armed conflict, protective infrastructure should ensure that every citizen has the right to access a shelter close to their residence, and that such shelters are readily available. These shelters can also be used during disasters and emergencies as emergency shelters. [21]

5. Selected Aspects of the Sheltering in the Republic of Austria

The origins of the building of protective infrastructure in Republic of Austria (Austria) were very similar to the situation in other European countries, in the context of the threat of the Cold War and the deteriorating security environment. Similarly, there have been changes in the approach to the issue of sheltering since the 1980s, especially with regard to a peaceful unified Europe.

According to the Federal Ministries Act [27], civil protection is the responsibility of the Federal Ministry for Digital and Economic Affairs for civil engineering matters related to civil protection and spatial and state planning, and of the Federal Ministry of the Interior for all other civil protection matters. However, the Austrian Civil Protection Association plays a key role in developing protective infrastructure, overseeing civil protection associations across all federal states. At the same time, it serves as the point of contact for the population and public institutions regarding individual crisis preparedness [1].

The individual federal states are responsible for the regulation of shelter construction and design, based on their respective building codes according to the general clause of the Federal Constitutional Law [28]. Within their jurisdiction, they are also authorized to regulate the maintenance and repair of shelters. However, there is no obligation to include the issue of sheltering in state regulations. Building protective infrastructure is thus approached in different ways. This fact is also evidenced by the significant differences in the number of shelters and their coverage among the individual federal states [3].

Moreover, there is no federal law or provision specifically addressing the construction and maintenance of shelters, except for certain cases like shelters in elevator or tunnel systems, or international regulations that primarily apply to wartime situations. Any obligations regarding the necessary construction measures for the construction of shelters are specified in the applicable building regulations [25].

The issue of sheltering is addressed particularly in relation to a possible nuclear accident. Information on emergency preparedness in the event of a radiation emergency is therefore provided to citizens. However, this guidance directs them to utilize their own (safety) flats by enhancing the natural protective properties of buildings and adhering to behaviour rules (iodine prophylaxis, temporary stays in closed and isolated spaces, food control, etc.) due to the necessity of (re)activating public shelters [29]. Overall, there are three options for protection:

1. Safety flat without built-in filter (“Sicherheitswohnung ohne eingebauten Filter”), offers temporary protection, requiring the insulation of all penetrations to ensure safety,
2. Security flat with built-in filter (“Sicherheitswohnung mit eingebautem Filter”) with air filtration and pressurisation using a special filtering device,
3. Basic safety room (“Grundschutzraum”) public shelter providing protection from fire, falling debris and external radiation. [29]

In Austria, only in certain cases are public shelters built for large populations. Mostly private shelters attached to the living quarters of buildings are used. The number of shelters and their technical condition is very difficult to determine due to the lack of records of shelters built in the private sector. However, it is estimated that in 1982 there were shelters in public buildings for about 60,000 inhabitants; by 1984 the number of shelters in public buildings had increased and provided shelter for 127,000 inhabitants. As for the total of all shelters (public and private), estimates in 1980 were about 250,000 shelter places, in 1984 about 350,000 places [30].

The current capacity of the shelters cannot be determined, as even official public sources vary significantly in their figures - according to source [31], shelter in Austria is secured for only 3% of the population, while according to source [32], there are 2 million shelter spaces available (approximately for 22% of the population). The government's approach to sheltering in response to recent changes in the security environment is not yet apparent from public sources.

6. Selected Aspects of the Sheltering in the United States of America

In the United States of America (USA), sheltering is an important part of protecting the population from a wide range of natural and anthropogenic threats. In the USA, the role of the state primarily involves providing methodological support for sheltering. Methodological assistance is provided in the form of expert guidelines and other documents, ranging from less extensive documents to comprehensive guidelines and methodologies that include detailed descriptions of shelter construction and suitable modifications of selected spaces. The implementation of sheltering is then carried out by the population and other entities (e.g., local authorities), using the methodological materials and in cooperation with the state, or other institutions at the national or local level. In certain cases, the role of sheltering in the USA overlaps with emergency survival for the population, and the activities of nonprofit organizations (such as the American Red Cross) play a significant role. [33], [34]

The issue of sheltering the population is part of comprehensive emergency management, which is based on the Robert T. Stafford Disaster Relief and Emergency Assistance Act and related regulations [35]. Primarily, the Federal Emergency Management Agency (FEMA), a part of the Department of Homeland Security, is responsible for overseeing sheltering activities and providing methodological support related to sheltering [33]. Examples of documents distributed by FEMA include:

1. Safe Rooms and Shelters [36],
2. Taking Shelter from the Storm [37],
3. Design and Construction Guidance for Community Safe Rooms [38],
4. Standards for Fallout Shelters [39],
5. Expedient Shelter Handbook [40].

Due to the decentralized nature of the issue and the wide range of shelter types, it is difficult to determine the capacity in relation to protective features and the technical condition of shelters in the USA. Part of the management and record-keeping of shelters is the National Shelter System, which contains a database of shelters using continuously updated data from the American Red Cross and other entities. [41]

However, even the National Shelter System is primarily intended for operational record-keeping and evaluation of shelter options (e.g. at the site of a disaster) and obtaining accurate data on total capacity is beyond the scope of this article. [41]

FEMA's website primarily recommends the following sheltering options to the population, although there are more sheltering options to consider:

1. Mass Care Shelters – collective sheltering (e.g., in the case of a hurricane) in a predetermined facility, directly linked to the emergency survival of the population.
2. Sheltering in Place – seeking shelter at one's current location, akin to the concept of "sheltering using the inherent protective properties of buildings" employed in the Czech Republic.
3. Stay-at-Home – sheltering within one's home, primarily as an anti-epidemic measure [42].

As evident from the lists above, the concept of sheltering in the USA differs from the commonly used approach to sheltering (e.g., in the Czech Republic), as it focuses on a broader spectrum of threats and includes variants of sheltering the population that may not always be considered part of the sheltering issue, depending on the specific approach.

FEMA also offers comprehensive informational support for population sheltering, including through its mobile application available on Android and iOS platforms [43].

In the USA, sheltering is also considered part of broader security measures, such as enhancing the resilience of businesses against a wide range of threats [44].

7. Research methodology

Based on the methods of comparison and multi-criteria analysis, approaches to sheltering within the selected countries are assessed. A quantitative pairwise comparison method, the Saaty method [45], is used to determine the weights of the criteria. The weighted sum method is used for multi-criteria analysis [46].

The scale shown in Table 1 was used to evaluate the relative intensity of importance *Sij* of the criterion in row *i* relative to the criterion in column *j* within the application of the Saaty method. The standardized weights of the criteria are then calculated as the geometric means of the individual rows divided by the sum of the geometric means of all rows.

Table 1.

Evaluation of criteria by the Saaty method – scale [45]

Intensity of Importance (*Sij*)	**Definition**
1	equal importance of criteria
3	moderate preference
5	strong preference
7	very strong preference
9	absolute preference
$S_{ij} = \frac{1}{S_{ji}}$	reciprocals of all scaled ratios that are entered in the transpose positions

For a multi-criteria analysis of the variants of each country's approach to sheltering using the weighted sum method, the criteria matrix shown in Table 2 was created. At the same time, Table 2 summarizes the results of the multi-criteria analysis using the weights calculated by the Saaty method. All criteria were designed as maximization criteria. The weighted sum method is partially modified compared to its usual approach. The standard procedure involves converting the matrix into a normalized criterion matrix prior to performing the weighted sum. This step typically serves to eliminate the mutual incommensurability of the criteria. Regarding the fact that only integer scoring scales with a unified point range of 1 to 3 are used for evaluation, this step is identified by the authors as redundant and omitted from the procedure. The design of the rating scales is proposed further in the text. The calculation using the weighted sum method is then based on Formula 1 [46].

$$h(Vi) = \sum_{j=1}^{k} w_j \cdot h_{i,j} \quad (1)$$

where: *h(Vi)* - the weighted sum of the sheltering approach evaluations (based on proposed scales for criteria) for the i-th country, $i \in \{1,2,\ldots,5\}$; w_j – weight of the j-th criterion, j ∈ {1,2,…,6}; $h_{i,j}$ - evaluation of the i-th variant based on the j-th criterion.

8. Results of Analysis

Multi-criteria analysis was performed using the weighted sum method and the following set of maximization criteria. The criteria were evaluated based on the scales outlined below.

The limits of the analysis can be seen in the subjective evaluation of the multi-criteria analysis by the authors. The results of the performed analysis may also be distorted due to a possible lack of relevant information, as some information related to the sheltering may be classified or otherwise unavailable to the public. Shelter capacities may also differ if some shelters have recently been removed from the register or, conversely, re-registered. Another limitation is the limited number of countries included in the comparison.

Legislation, standards and other guidelines:

1. The issue of population sheltering does not have basis in key legal statutes pertaining to national security, nor in subsequent and related regulations (such as methodologies, directives, guidelines, etc.), or they are so outdated that they cannot be followed. The evaluation also applies to cases where the criterion cannot be assessed.
2. Currently, the issue of sheltering does not have a firm, established basis within valid and effective legal statutes, but related regulations in a valid and effective form (e.g., methodologies, directives, guidelines, etc.) do exist in specific forms and can be followed. Alternatively, the issue of sheltering has a firm, established basis within valid and effective legal statutes, but related regulations (e.g., methodologies, directives, guidelines, etc.) in a specific, valid, and effective form do not exist.
3. The issue of sheltering has a firm, established basis within valid and effective legal statutes, and related regulations in a valid and effective form (e.g., methodologies, directives, guidelines, etc.) do exist in specific forms and can be followed.

Shelter capacity for the population in relation to protective characteristics:

1. Permanent pressure-resistant shelters can only accommodate a small percentage of the population, and the capacity of identified improvised shelters is also presumed insufficient to serve as a form of shelter for the remaining part of

the at-risk population. A significant portion of the population would have to rely on improvised sheltering (using the inherent protective properties of buildings) or other forms of shelter even in cases where these forms are not considered adequate (e.g., in the event of a nuclear threat). The evaluation also applies to cases where the criterion cannot be assessed.

2. It is anticipated that permanent pressure-resistant shelters along with identified improvised or permanent non-pressure-resistant shelters are capable of collectively accommodating the at-risk population in scenarios where this mode of protection is required (e.g., in the event of a nuclear threat), with the majority of the shelter capacity (>50%) being made up of improvised shelters or permanent non-pressure-resistant shelters. It is also assumed that the capacity of other methods of sheltering is adequate given the nature and severity of the threat.
3. It is anticipated that permanent pressure-resistant shelters and identified improvised or permanent non-pressure-resistant shelters are together capable of collectively accommodating the at-risk population in scenarios where this protection is required (e.g., in the event of a nuclear threat), with the majority of the shelter capacity (>50%) consisting of permanent pressure-resistant shelters. It is also assumed that the capacity of other methods of sheltering is adequate given the nature and severity of the threat.

Technical condition of shelters:

1. It is assumed that shelters do not undergo regular inspection and maintenance of technical elements essential for operational readiness and required protective features, nor are hygienic limits for population sheltering met or checked. The evaluation also applies in cases where the criterion cannot be assessed.
2. It is presumed that shelters are regularly inspected and maintained, and hygienic limits for population sheltering are adhered to or monitored. However, due to their ownership status (public vs. private shelters) or other uncertainties, it is not possible to determine their proportion relative to shelters that do not meet requirements for inspection, maintenance, and hygienic standards.
3. It is assumed that regular inspections and maintenance of technical elements essential for operational readiness and required protective features are carried out in shelters, and hygienic limits for sheltering individuals are met and monitored. The shelter is prepared to be operational within the planned timeframe.

Range of threats:

1. The approach to sheltering within the state is focused on protecting the population from the impact of a single type of threat (e.g., only nuclear weapons or only radiation accidents), or a very limited number of them. The evaluation also applies to cases where the criterion cannot be assessed.
2. Sheltering is considered as a form of protection for the population in relation to some other anthropogenic or even natural threats.
3. The approach to sheltering corresponds or is close to the general, comprehensive concept of sheltering according to Article 61 of the Geneva Conventions. Sheltering, when relevant, is implemented against a wide range of threats and is closely linked with other tasks, such as emergency survival.

Current initiative in sheltering:

1. The state's approach to sheltering does not show a significant initiative responding to changes in the security situation since the end of the Cold War. Sheltering as a measure of population protection is not a priority for the country. The evaluation also applies to cases where the criterion cannot be assessed.
2. The state's approach to sheltering shows a significant initiative that takes into account the changing security situation and evolving concepts of security after the end of the Cold War, e.g., in connection with the increasing risk of selected natural and anthropogenic threats (increased occurrence of selected extreme meteorological events related to climate change, developing terrorism in the 21st century, etc.).
3. The state's approach to sheltering shows a significant initiative responding to current trends (not older than 5 years) in the security situation (especially the military invasion of Ukraine by Russia).

Information support for population:

1. Information support is either not implemented or its role is negligible in terms of preparedness and response to adverse events. The evaluation also applies in cases where the criterion cannot be assessed.
2. There are partial, specific, identified, significant gaps in information support in the area of preparedness for the occurrence of an adverse event or in the area of response to an adverse event (e.g., informing the population for the purpose of coordinating sheltering in real-time).
3. Information support for sheltering creates a comprehensive system that functions in both preparedness and response to adverse events, utilizing modern technologies. No significant deficiencies are apparent.

Table 2.

Multi-criteria analysis

Criteria	Legislation, standards and other guidelines	Shelter capacity	Technical condition	Range of threats	Current initiative	Information support for population	Weighted sum	Rank
Weight (rounded)	0,1317	0,1843	0,1769	0,1559	0,1756	0,1756		
Czech Republic	2	1	2	2	1	1	1,4645	3.
Poland	2	1	1	2	3	2	1,8145	2.
Germany	2	1	1	1	2	1	1,3073	4.
Austria	1	1	1	1	1	1	1,0000	5.
United States	3	1	1	3	2	3	2,1020	1.

In Table 2, a multi-criteria analysis of the alternatives is presented—the weights were calculated using Saaty method, and the multi-criteria analysis itself was conducted using the weighted sum method. The evaluation of the alternatives for each criterion is based on a consensus among the authors.

Conclusions

On the basis of a multi-criteria analysis using the proposed set of criteria and calculated weights, the ranking of countries was determined according to the degree of fulfilment of the criteria.

The USA has become the highest-rated country primarily due to extensive methodological support for various types of sheltering, which is supplemented by a firm legislative framework. Additionally, the approach to sheltering in the United States is both modern and broad, specifically in terms of the threats against which it is designed. Furthermore, comprehensive information support is provided to the population. The United States is ranked highly despite the fact that some criteria could not be evaluated in comparison with European countries – namely, the shelter capacity criterion and the technical condition criterion. Shelter capacity cannot be evaluated, particularly because sheltering in the USA is carried out by a wide range of entities and obtaining unified data on shelter capacity exceeds the scope of this research. For a similar reason, the technical condition criterion also cannot be evaluated. It is also important to note that the comparison of shelter capacity and technical condition of shelters with European countries is problematic because the broad concept of sheltering in the USA likely includes capacities that, in countries such as the Czech Republic, would be considered as capacities for the emergency survival of the population. In the case of the USA, the current initiative criterion has not been fully met, primarily because fulfilling this criterion requires a key initiative that addresses recent changes in the security environment, particularly those related to the war in Ukraine. In the case of the USA, a key initiative was not identified. However, given the geopolitical status and geographical position of the USA, it can be assumed that the shifts in the security environment did not necessarily translate into pressure for changes in the sheltering approach and related initiatives in the USA.

The issue of sheltering within the European states included in the comparison has some common characteristics, especially in terms of the historical development of sheltering during the Cold War and the often problematic role of sheltering in contemporary times. Poland is ranked second in the multi-criteria analysis, mainly due to a major current sheltering initiative in relation to the Russian invasion of Ukraine in 2022, which led to an extensive inventory of premises and the development of information support tools for sheltering. Despite the fact that certain initiatives have taken place in other countries and that some sources, including Polish official sources (e.g. [18]), are rather sceptical about the results of the inventory and the state of sheltering in Poland, it is still probably the most extensive and substantial initiative in response to current security trends within the scope of this article. The only European country included in the evaluation that approaches Poland in terms of its initiative is Germany. However, according to the authors, at the time of writing this article, Germany has not yet made sufficient progress in addressing sheltering-related issues to consider its initiative in response to current trends as substantial. The Czech Republic ranked third in terms of the results of the multi-criteria analysis. In terms of sheltering, the Czech Republic does not stand out particularly among the other countries included in the comparison. In the criterion of the technical condition of shelters, particularly permanent shelters, the Czech Republic is rated slightly higher compared to Poland. As far as the criterion of legislation, standards and other guidelines is concerned, the Czech Republic has a more stable legal regulation, but methodological materials for sheltering are more up to date in Poland. Germany and Austria ranked fourth and fifth respectively. Germany scores higher in the case of the legislation, standards and other guidelines and the current initiative criteria, mainly due to the existence of more comprehensive legislation and the previously described initiative in the area of response to current security threats.

With the proposed criteria, differences between states were identified based on the rating scales. An exception is the shelter capacity criterion, which was rated equally for all states included in the comparison. For the European countries, this uniformity in ratings primarily stemmed from the low capacity of dedicated shelters, whereas for the USA, it was due to the inability to determine the sheltering capacity within the scope of the submitted article. The technical condition criterion was difficult to evaluate due to limited information about the actual state of the shelters and was probably the most prone to inaccuracies in the evaluation – in cases of uncertainty, the lower of the considered evaluations was awarded (e.g. in the case of Poland). However, the criteria shelter capacity and technical condition are associated with the highest weights of the criteria, which, in addition to expressing their importance, indicates the need to carry out more detailed research in the given area in relation to the abovementioned conclusions.

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Analysis of Migration in the Czech Republic and Security Challenges in the Context of the Current Geopolitical Situation

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Abstract
The article focuses on the analysis of migration in the Czech Republic from several perspectives. A portion of the analysis is dedicated to illegal migration in the Czech Republic, including its structure, main migration routes, and illegal transit migration. It also examines the administrative expulsion of foreigners from the territory of the Czech Republic during the period under review. A comparative study of migration status in relation to the war in Ukraine has focused on the number of refugees entering the Czech Republic, illegal entries, and legal residence of Ukrainian citizens in the Czech Republic, the impacts of migration on internal security and public order, and the state's approach to migration in connection with the refugee influx.

KEY WORDS: *migration routes; illegal migration; legal residence; administrative expulsion; internal security and public order; refugees from Ukraine; the Czech Republic*

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1. Introduction

Migration can be defined as the movement of individuals or groups, either within a region or country (internal migration) or to another country (international migration) [1]. Together with fertility and mortality, migration is a key element that influences the economy, culture, and society. It is a phenomenon inherent in the history of society, triggered by a range of factors (wars, deep economic crises, scarcity of resources, etc.). These are phenomena that cause fluctuations in society and induce a range of problems related to forced migration and the integration of refugees in the host country [2]. The Czech Republic was the first country of the Visegrad Group to extensively regulate migration (or immigration) since 2000 [3]. It similarly responded to the refugee crisis in 2015. However, the current war in Ukraine is causing continuous and extensive forced migration from Ukraine to Central and Western Europe, which significantly differs from the refugee crisis in 2015 [4]. This situation requires a response not only from individual states but also from European integration groupings. Therefore, on February 8, 2024, a preliminary agreement was approved to support the reform of the European Union (EU) asylum and migration system. The Common European Asylum System (CEAS) [5] should establish minimum standards for handling asylum seekers across the EU, as under the current rules, they are not uniformly treated across the EU. The aim of this reform is to create a common framework that addresses all aspects of asylum and migration management, enhances the efficiency of this system, and its resilience to migration pressures, eliminates factors prompting migration, and better supports the most affected member states.

The present article aims to analyze the legal aspects of migration in the Czech Republic, examine the evolution of migration in light of the situation before the war in Ukraine and currently during it, and outline the state's approaches to addressing illegal migration and the Ukrainian refugee crisis. The article provides a comprehensive and current perspective on illegal migration in the Czech Republic, presenting information in a form and scope previously unavailable in a single study. This research synthesizes multiple aspects of migration dynamics, including the latest statistical data, the impact of global events on the migration situation in the Czech Republic and the effects of policy measures on migration flows. By integrating these diverse elements, the study provides a nuanced understanding of the complexities of illegal migration in the Czech Republic, thereby advancing the scientific discourse in this field.

Data on migration and migration routes were primarily sourced from official documents of the Ministry of the Interior of the Czech Republic, statistics provided by Frontex, and documents from the European Commission's Directorate-General for Migration and Home Affairs.

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The migration analysis focuses on the period between 2013 and 2023, concentrating on absolute figures of migrant numbers for individual years. Migration data are analyzed in terms of both immigration to the Czech Republic and transit migration through Czech territory to neighboring countries. The article also broadly addresses the development, impacts, and resolution of the migration wave triggered by Russian aggression against Ukraine in the context of the Czech Republic and the EU.

2. Legal Aspects of Migration in the Czech Republic

Migration inherently involves both immigration and emigration, as each immigrant is simultaneously an emigrant. Unlike terminology commonly used in foreign professional literature and EU documents, the Czech legal framework does not employ the term "immigrant," instead exclusively employing the term "foreigner" [1].

The domain of illegal migration falls within the purview of the Foreign Police of the Czech Republic [6]. Additionally, the Analytical Centre for the Protection of State Borders and Migration (ANACEN), overseen by the Ministry of the Interior, assumes a significant role in monitoring and analyzing migration within the Czech Republic.

The conditions for foreigner entry into Czech territory are shaped by the Schengen Area. Czech state borders, internal to the Schengen Area, are generally accessible to foreigners at any point without border control. However, border controls are enforced solely at external Schengen borders, typically limited to international airports for flights originating outside the Schengen Area. Entry into the Schengen Area for third-country nationals is regulated by the Schengen Border Code [7]. According to this legislation, foreigners must provide proof of identity through valid travel documentation (as stipulated in § 108 and §177 of the Act on the Residence of Foreigners [6]) and undergo border control, which includes completing a border pass (as outlined in § 14 of the Act on the Residence of Foreigners [6]). Entry may be denied based on specific conditions:

1. Lack of a valid travel document, valid for at least 3 months beyond the intended departure date from the Schengen Area and not older than 10 years (excluding individuals under 15 years of age who are listed in the travel document of another person with whom they are traveling).
2. Lack of a short-term visa (if subject to visa requirements), or valid long-term visa, or valid residence permit.
3. Lack of documentation substantiating the purpose of one's stay.
4. Insufficient financial means for the duration of the intended stay and for the return to the country of origin or transit to a third country where their admission is guaranteed; or inability to obtain these means legally.
5. The foreigner is considered a threat to public order, internal security, public health, or international relations of the member states, or is listed in the Schengen Information System (SIS) as a person to be denied entry.

If entry to the territory is denied to a foreigner, they are obliged to return unless prevented by a serious illness or concern for their life. Subsequently, they are escorted back to the border crossing by the police. It is also important to note that the granting of stays in the territory of the Czech Republic falls entirely under the responsibility of the Department of Asylum and Migration Policy of the Ministry of the Interior of the Czech Republic, a responsibility assumed since 2011 when the Immigration Police Service transferred this issue to the ministry due to changes in the Foreigners' Residence Act.

In connection with the armed conflict in Ukraine, triggered by the invasion of Russian Federation forces, the Parliament of the Czech Republic issued a new law [9] regulating the conditions for granting temporary protection to displaced persons from Ukraine and its possible extension (in accordance with implementing decisions of the Council of the European Union [10, 11]), provision of accommodation and related services to persons granted temporary protection, assisted voluntary return, special rules for the provision of health services, and registration of vehicles with Ukrainian license plates. This temporary protection serves as an EU crisis mechanism, activated under exceptional circumstances in the event of a mass influx of persons, aiming to alleviate pressure on the national asylum systems of EU countries and provide collective protection to displaced persons, enabling them to enjoy rights including residence, access to the labor market, housing, medical assistance, social assistance, and access to education for children.

3. Migration Routes

Migrants utilize several routes to travel to Europe, including the Western Balkan route, Eastern Land Borders route, Eastern Mediterranean route, Central Mediterranean route, and Western Mediterranean route, see Fig. 1.

The Western Balkan Route began to gain attention around 2010 as the number of individuals illegally entering Europe began to increase. This route became particularly prominent in 2012 following the relaxation of Schengen visa requirements for countries such as Albania, Bosnia and Herzegovina, Serbia, Montenegro, and North Macedonia. Compared to the Mediterranean routes, this route is considerably safer due to the shorter distance migrants must traverse across the sea. The Western Balkans, due to its geographical location within EU member states, serves as a transit hub and key corridor for migrants heading to the EU, particularly from the Middle East, Asia, and Africa. Many illegal migrants who enter the EU via the Western Balkan route subsequently move to another EU country from the first member state they enter, resulting in a high number of detected illegal migrants and asylum applications in Europe [12]. Since 2015, when the EU recorded a record number of 764,033 illegal border crossings, the trend in illegal migration via the Western Balkan route has been decreasing. However, since 2019, the number of illegal migrants has begun to rise again [13]. In 2022, approximately 330,000 cases of illegal entry were detected at the external Schengen border, representing a 64% increase compared to 2021. The highest number of illegal entries since 2016 was also recorded. The Western Balkan route was the most burdened migration route to the EU in 2022. A total of 145,600 entries were recorded (a 136% increase). Illegal migrants primarily originated from the Middle East, traveling through Greece and North Macedonia or Bulgaria to Serbia. They then proceeded through Hungary to Austria or through Slovakia and the Czech Republic to Western Europe, especially Germany [14]. In 2023, the migration pressure decreased by approximately 31% compared to 2022 but remained at a high level. There was a high proportion of citizens from Syria, as well as Turkey and Afghanistan. The activity and aggressiveness of smuggling organizations also increased (traffic accidents, clashes with police, loss of lives). After security measures were implemented on Serbian borders at the end of 2023, the migration flow decreased and shifted to other migration corridors [15]. From January to April 2024, 7045 cases of illegal border crossings were recorded, primarily involving migrants from Syria (2698), Turkey (1897), Afghanistan (472), Iraq (250), and Morocco (228) [16].

The Eastern Land Borders route is particularly significant for foreigners arriving from Ukraine into Slovakia, Poland, the Czech Republic, Hungary, and Romania. The notable increase in the number of foreigners along this migration route was attributed to the Russian military aggression in Ukraine after February 24, 2022 [17]. The ramifications of this conflict extend beyond Ukrainian borders and significantly impact European nations, which have accommodated a substantial influx of refugees [18], primarily through this migration route. However, the Eastern Land Borders route is not solely utilized by refugees due to the mentioned war. A certain number of illegal border crossings were also recorded at the borders between Belarus and EU states (Lithuania and later Latvia and Poland), especially in 2021 due to the migration crisis in that region [19]. In 2022, a higher migration pressure was subsequently recorded at certain points along the Lithuanian and Polish borders. A total of 20,480 entry attempts were prevented [14]. Since 2023, migration pressure has slightly decreased; however, cases of entry prevention at the borders between Belarus and EU states continued to be recorded daily. The total number of illegal crossings of the eastern EU border in 2023 was 5,608. Initially, these were primarily citizens of Ukraine, followed by Syria, Iran, Iraq, and Afghanistan. However, since July 2023, there has been a sharp increase in the number of incoming migrants from African and Middle Eastern countries without valid documents at the borders between Finland and Russia. Many migrants unsuccessfully attempted to enter the EU from Belarus before arriving at the Finnish-Russian border [16]. From January to April 2024, 2,102 cases of illegal border crossings were recorded. In addition to migrants from Ukraine (1,918 individuals), Syria, Belarus, and Afghanistan [16].

The Eastern Mediterranean route is observed within the maritime borders of Greece and Cyprus or at the land borders between Greece and Bulgaria. It became the main migration route primarily in 2015 [20]. Migrants utilize this route when traveling to Central Europe, which passes through Turkey to Greece, southern Bulgaria, and Cyprus. In 2018, there was a significant increase in the number of migrants on this route heading towards Greece (a total of 49,158 individuals) [21]. Migration activity on the Eastern Mediterranean route remained high in 2019, especially in the second half of the year. The number of migrants arriving in Greece via this route in 2019 (74,348 individuals) was approximately 47% higher than in 2018 [22]. In 2020, the situation between Turkey and Greece became very tense due to the violation of the agreement established between these states. In the second quarter of that year, activity on this route was very low due to measures related to the COVID-19 pandemic [23]. Arrivals both by sea and land decreased. The most common countries of origin in that year were Afghanistan, Syria, and the Democratic Republic of the Congo [24]. However, migration along this route intensified in the following years. The number of migrants to Greece via the Eastern Mediterranean route since the beginning of 2022 reached 18,788 [17], exceeding the previous year's count of 8,803 individuals by 105% [25]. The total number of unauthorized migrants in 2023 reached 48,404 individuals [26]. In the first quarter of 2024, 17,315 cases of illegal border crossings were recorded. These mainly involved migrants from Syria (5,941), Afghanistan (4,948), Egypt, Turkey, and Eritrea [16].

The Central Mediterranean route has long been the busiest route across the Mediterranean. The route extends from the western part of Libya to mainland Italy or the island of Sicily. The journey continues through the inland regions of Italy to the borders with Austria and then to the migrants' final destinations. Studies indicate that the Mediterranean route is the most dangerous migration route, with a consistently high number of fatalities. Unlike other Mediterranean routes or the Western Balkan route, the Central Mediterranean route differs in the extensive representation of nationalities. Consequently, the main characteristic of this route is a wide spectrum of migrating individuals. The numbers of individuals arriving in Italy have significantly increased in recent years, despite measures taken to combat the spread of COVID-19. In 2021, nearly twice as many migrants arrived in Italy (66,752 individuals) [19] compared to 2020 (34,133 individuals) [24] and almost six times more than in 2019 (11,487) [22]. In 2023, a total of 157,314 individuals arrived illegally in Italy, roughly 50% more than in 2022 (105,131 individuals). Since the beginning of 2024, there have been 16,068 cases of illegal border crossings recorded. These mainly involved migrants from Bangladesh (3,400), Syria (2,501), Tunisia, Guinea, and Egypt [16].

The Western Mediterranean route, originating from North Africa, serves as a key pathway for migrants seeking entry into Spain, both by sea and overland. Its popularity has varied over the years, often influenced by border control policies. In 2018, it became the most utilized route to Europe, with nearly 64,427 refugees arriving in Spain, marking a 131% increase from the previous year [21]. However, in 2019, the number of illegal migrants decreased significantly, attributed to joint efforts by Morocco, Spain, and the EU (32,492 individuals, representing a year-on-year decrease of 50.3%) [22]. In 2020, there was a slight increase in illegal migration, totaling 41,925 arrivals in Spain, notably due to a surge in arrivals on the Canary Islands [24]. Throughout 2021, a total of 66,752 individuals arrived in Italy, with an additional 838 migrants arriving in Malta. In 2021, Libya was the main departure point for migrants heading to Italy, accounting for 47% of all migrants, followed by Tunisia (30%) and Turkey (19%) [25]. A significant increase in illegal migration was recorded in 2022 (a total of 105,131 individuals), almost 60% more than in 2021 [17]. The main departure points were again Libya, followed by

Tunisia, Turkey, Lebanon, and Algeria. In 2023, a 50% increase in illegal migration (157,314 individuals) was recorded compared to 2022 [26].

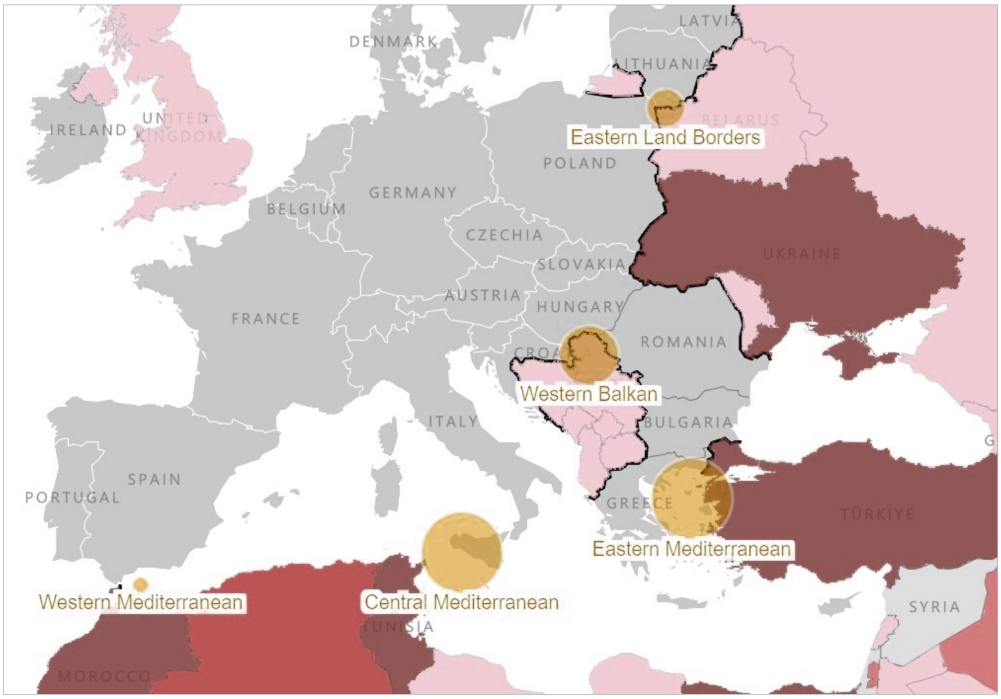

Fig.1. Migration routes to Europe [16]

Migration pressure along this route has significantly intensified since 2021. From January to April 2024, a total of 4,454 cases of illegal border crossings have been recorded, mainly involving migrants from Morocco (2,081), Algeria (1,379), Mali, and Guinea. For many illegal migrants (538 individuals), their origin is unknown [16] (see Fig. 1).

4. The Development of Illegal Migration in the Czech Republic

Illegal migration should be understood not only as unauthorized entry into the territory of the Czech Republic or its unauthorized departure but also as unauthorized presence in the territory of this state or residence contrary to the purpose for which a residence permit was issued. Until 2021, the highest annual number of persons within illegal migration in the Czech Republic was recorded in 2015 (a total of 8,563 persons, representing a year-on-year increase of 77.6%), largely due to the refugee crisis mentioned at the beginning of the article (see Fig. 2). From June 17, 2015, transit illegal migration also began to be statistically recorded within illegal residence (see Fig. 3) [20]. In the following year, illegal migration significantly decreased, but from 2017 onwards, the number of illegal foreigners in the Czech Republic began to slightly increase again. In 2019, a total of 5,677 persons were detected in illegal migration in the territory of the Czech Republic, of which 266 persons were involved in transit illegal migration (4.7%) [22]. In 2020, 7,093 foreigners were detected in illegal migration, the second-highest number since 2008. This was primarily due to the violation of protective measures related to the spread of the COVID-19 pandemic (a state of emergency was declared in the Czech Republic on March 12, 2020, and among the measures taken by the Czech government in this context was the temporary closure of state borders and the introduction of a ban on entry for foreigners into the territory of the Czech Republic) [24]. However, transit illegal migration increased almost twofold year-on-year (approximately 7% of the total illegal migration). The number of illegal entries into the territory of the Czech Republic continued to increase in 2021, reaching a value of 11,170 (a year-on-year increase of 157.5%). The main share was held by foreigners who again did not meet the conditions of stay set in connection with adopted anti-epidemic measures (primarily citizens of Ukraine). Transit illegal migration increased to 12% (1,330 persons) of the total illegal migration [19].

The situation in 2022 was entirely different. A record increase in total illegal migration was recorded, primarily due to an unprecedented number of illegal migrants transiting through the Czech Republic by land or intra-Schengen flights. A total of 29,235 individuals were detected in illegal migration in the territory of the Czech Republic, representing an increase of 161.7% compared to 2021 (18,065 individuals) [19]. Transit illegal migration reached 29,034 individuals, accounting for 99.3% of the total illegal migration in that year. Foreigners entered the territory of the Czech Republic without the necessary documents and mostly without travel documents, with the intention of reaching Germany (or other countries in Western or Northern Europe). Illegal entries into the Czech Republic were primarily by land from Slovakia. Taking necessary measures such as reintroducing border controls on the Slovak borders (more in the Chapter 6) significantly reduced the numbers of detected illegal migrants in illegal migration in the territory of the Czech Republic. Illegal migration across the external Schengen border (attempted or unauthorized crossing of the air border at international airports) accounted for less than 1%

of the total illegal migration (a 40% decrease compared to 2021). This mainly involved intra-Schengen flights from Greece, where foreigners traveled with irregular documents. The most frequently identified nationality of illegal migrants in 2022 (with a 71.8% share of the total number of individuals detected in total illegal migration) were Syrians, showing a significant year-on-year increase of 20,547 individuals. Ukrainian citizens, who reported to the relevant Regional Assistance Centers for Ukraine (abbreviated as KACPU, more in the Chapter 6) or to immigration police offices to legalize their previous illegal stay in the Czech Republic before the outbreak of armed conflict in Ukraine, constituted markedly lower year-on-year numbers of illegal migrants [14]. In 2023, there was a drastic decrease in illegal migration (13,898 individuals), with transit illegal migration accounting for 34% (4,742 individuals) and illegal migration across the external Schengen border accounting for less than 3% (368 individuals) [15].

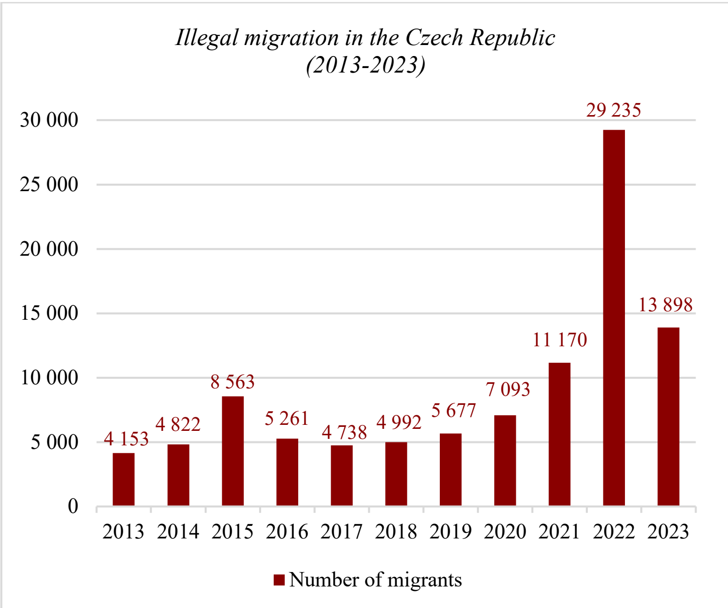

Fig.2. Illegal migration in the Czech Republic [14, 15]

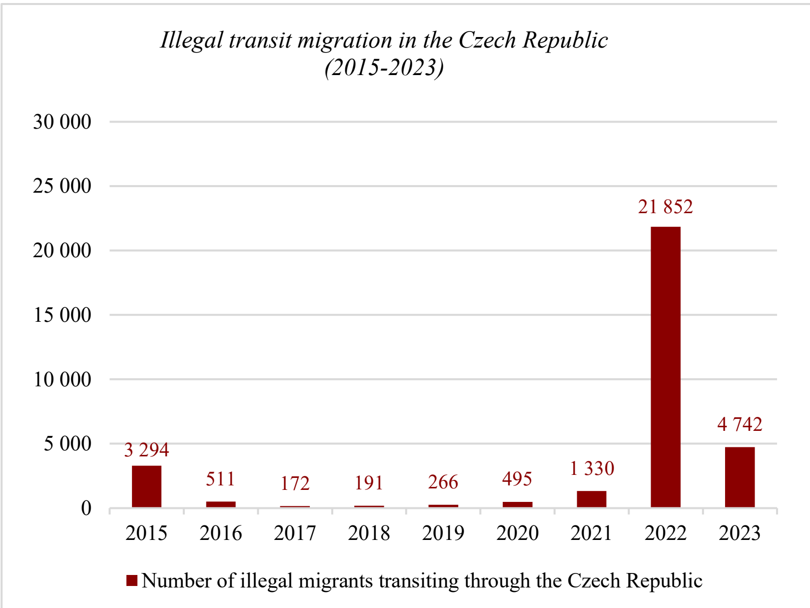

Fig.3.Illegal transit migration in the Czech Republic [14, 15]

A determining factor for many migrants in the Czech Republic is the institution of administrative expulsion. It involves the involuntary termination of a foreigner's stay in the country for sanctioning reasons, governed by the Act on the Residence of Foreigners [6]. The expelled individual is given a specified period to leave the country, during which entry into EU member states is prohibited, as determined by the Czech Police in the expulsion decision. The prevailing reasons for issuing decisions on administrative expulsion during the observed period (2013-2023) include violations of the residence regime, violations of the Employment Act, and non-compliance with decisions on administrative expulsion. The number of foreigners issued with decisions on administrative expulsion is recorded in the Foreign Information System (a non-public information system managed by the Foreign Police Service of the Czech Republic).

In 2013, decisions on administrative expulsion were issued to a total of 2,020 individuals. The largest group facing administrative expulsion comprised Ukrainian nationals (874 individuals), accounting for 43.3% of the total, followed by individuals from Vietnam, Kuwait, and Russia [27]. In 2014, decisions on administrative expulsion were issued to a total of 2,149 individuals (a year-on-year increase of 6.4%). The most represented group of foreigners were Ukrainian nationals (815 individuals, accounting for 37.9% of the total number of decisions issued), followed by nationals of Libya and Vietnam [28]. In 2015, a significant increase in the number of individuals issued with decisions on administrative expulsion was recorded (3,009 individuals, representing a year-on-year increase of 40%). This increase was primarily due to a higher number of decisions issued to Ukrainian citizens (1,243 individuals, i.e. 41.3% of the total number of such foreigners) and to nationals identified during transit illegal migration, especially Syrians and Vietnamese [20]. In 2016, there were 3,539 decisions on administrative expulsion, marking a 17.6% increase from the previous year. Ukrainian nationals dominated this group, totaling 2,045 individuals, accounting for 57.8% of the total decisions, followed by Moldovan and Vietnamese nationals [29]. In 2017, there was once more a notable rise in decisions on administrative expulsion, affecting 5,119 foreign individuals (a year-on-year increase of 44.6%). The decisions primarily targeted Ukrainian nationals (3,451 individuals), constituting 67.4% of the total, followed by Moldovan and Uzbek nationals [30]. In 2018, decisions on administrative expulsion were issued to a total of 5,713 foreigners (a year-on-year increase of 11.6%), most commonly to citizens of Ukraine (3,856 individuals, representing 67.5% of the total number of decisions issued), Moldova, and Vietnam [21]. In 2019, the highest number of these decisions issued during the entire monitoring period (2013-2023) was recorded, with a total of 7,067 foreigners subject to such decisions (a year-on-year increase of 23.7%). The most represented group of foreigners were Ukrainian nationals (4,631, accounting for 65.6%), followed by Moldova and Vietnam [22].

The decrease in the number of decisions on administrative expulsion occurred only in 2020, during the outbreak of the COVID-19 pandemic. A total of 6,385 foreigners were subject to this decision (a year-on-year decrease of 9.7%), most commonly citizens of Ukraine (4,233, accounting for 66.3% of the total number of decisions issued), Moldova, and Uzbekistan [24]. In 2021, there was a 21.9% decrease from the previous year, totaling 4,987 individuals facing administrative expulsion, comprising Ukrainian (2,718 individuals), Moldovan, and Syrian citizens. [19].

In 2022, there was a notable rise in both transit illegal migration and administrative expulsion of foreigners from the Czech Republic. A total of 6,449 foreigners faced administrative expulsion, marking a 29.3% increase from the previous year. Among them were 1,960 Ukrainian citizens (30.4%) and 1,382 Syrian citizens (21.4%), representing a more than fivefold year-on-year increase [14]. Alongside the decrease in illegal migration, there was also a decrease in the number of decisions on administrative expulsion in 2023 (5,240, a year-on-year decrease of 18.7%), however, a 154.8% increase was noted among Ukrainian citizens subject to decisions on administrative expulsion (3,034 individuals). Additional decisions were issued mainly to citizens of Moldova, Uzbekistan, and Georgia. The decrease among Syrian citizens was more than tenfold (111 individuals) [15]. Table 1 presents the numbers of foreign nationals most issued administrative expulsion decisions from the Czech Republic between 2013 and 2023, categorized by their country of origin.

Table 1.
Foreign nationals issued administrative expulsion decisions from the Czech Republic, 2013-2023 [14,19-22,24,27-30]

Country of foreign nationals	*Year*										
	2013	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022*	*2023*
Ukraine	874	815	1 243	2 045	3 451	3 856	4 631	4 233	2 718	1 960	3 034
Moldova	67	33	85	295	688	888	1 171	1 050	984	991	742
Russia	106	122	114	116	102	91	69	36	65	43	122
Syria	3	25	237	13	2	7	25	32	245	1 382	111
Georgia	22	15	11	7	18	50	120	121	123	214	135
Uzbekistan	49	43	48	75	179	107	122	125	99	213	137
Afghanistan	9	7	83	9	7	5	14	41	47	104	*
Turkey	13	15	20	16	15	22	19	25	41	434	*
Vietnam	180	152	135	117	114	96	157	116	93	191	94
Morocco	2	2	4	4	4	4	2	34	104	113	*

* *Note: no official data has been published yet*

5. Foreigners with Legal Residence in the Czech Republic

Regular growth in the number of foreigners residing in the Czech Republic occurred after the economic crisis subsided from 2011 onwards. In 2012, there were 438,213 foreigners recorded, with the following year seeing 441,536 foreigners (including 105,239 individuals of Ukrainian nationality, constituting 23.8%) [27]. As of December 31, 2014, there were 451,923 foreigners with legal residence in the country, comprising 251,342 individuals with permanent residency and 200,581 with temporary residency. Foreigners accounted for approximately 4.4% of the population of the Czech Republic. The largest representation was among Ukrainian nationals (104,388 individuals, constituting 22.3% of all registered foreigners) [28]. In 2015, there were a total of 467,562 foreigners legally residing (for longer than 90 days) in the Czech

Republic, representing a 3.5% increase compared to the end of 2014. Ukrainians accounted for 22.8% (106,019 individuals) [20]. In 2017, there were 526,811 foreigners legally residing (for longer than 90 days) in the Czech Republic, which is a 6.1% increase compared to the end of 2016 (496,413 foreigners). Once again, the largest representation was among Ukrainian nationals (117,480 individuals, constituting 22.3%) [29, 30]. Compared to 2016, the share of Ukrainian nationals from the total number of foreigners remained virtually unchanged (110,245 individuals, constituting 22.2%). As of December 31, 2018, there were a total of 566,931 foreign nationals registered in the Czech Republic, of whom 276,252 had temporary residency and 290,679 had permanent residency. A total of 131,709 individuals from Ukraine were recorded (23.2% of all registered). Among foreigners legally residing in the Czech Republic, citizens of third countries predominated (334,438 individuals, constituting 59%) over citizens of EU, European Economic Area (EEA), and Switzerland (232,493 individuals, constituting 41%) [31].

In 2019, a total of 595,881 individuals of foreign nationality were registered in the Czech Republic, with 295,197 having temporary residency and 300,684 holding permanent residency. Ukrainian citizens accounted for 24.4% (145,518 individuals) [32]. Despite the COVID-19 pandemic, the number of foreigners in the Czech Republic continued to rise. By the end of 2020, a total of 634,790 individuals of foreign nationality were registered in the country, including 165,654 individuals from Ukraine (26.1%) [33]. The number of foreigners in the Czech Republic further increased in 2021. As of December 31, 2021, a total of 660,849 individuals of foreign nationality were registered in the country, comprising 338,957 with temporary residency and 321,892 with permanent residency. Foreign nationals legally residing in the Czech Republic were mainly from third countries (429,881 individuals, constituting 65%), while citizens of EU, EEA, and Switzerland comprised the remaining portion (230,968 individuals, constituting 35%). Within legal migration for this year, 29.8% were Ukrainian nationals (196,875 individuals) [25]. In 2022, a significant year-on-year increase was also recorded among foreigners with permitted residency in the Czech Republic, by 159.4%, see Fig. 4. As of December 31, 2022, a total of 1,116,154 individuals of foreign nationality were registered, with 782,000 having temporary residency and 334,154 having permanent residency [14]. This substantial increase was primarily caused by the high number of Ukrainian citizens (particularly refugees due to the armed conflict in their home country).

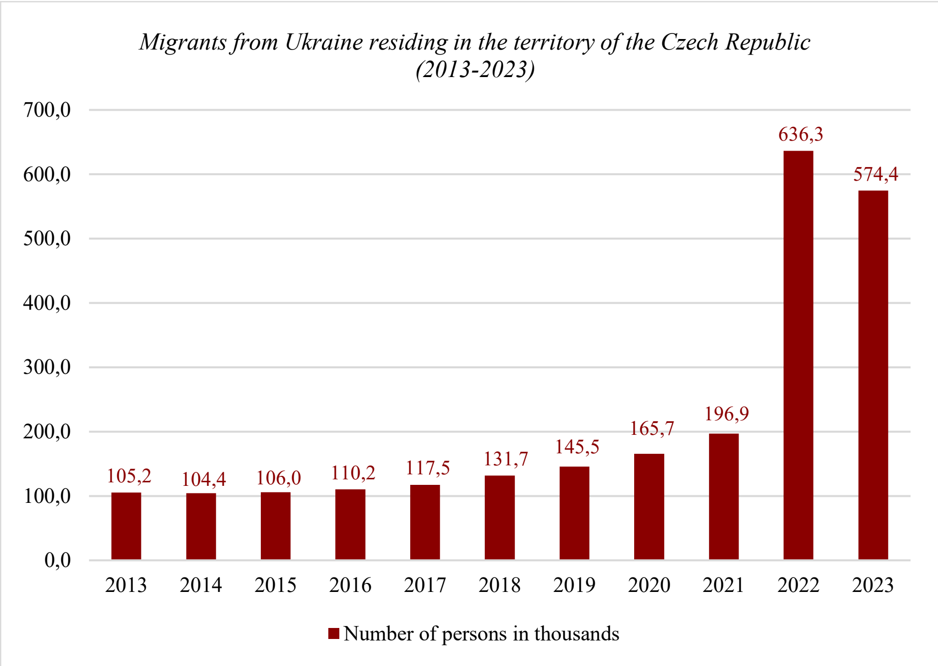

Fig.4. Ukrainian migrants residing in the Czech Republic [14,19-22,24,27-30]

Since the onset of Russian aggression in Ukraine, a total of 473,216 temporary protections were granted in the Czech Republic in 2022. Interestingly, the Czech Republic had the highest number of issued temporary protections in the EU in 2022 per capita. Among Ukrainian citizens, there was a year-on-year increase of 223.2% (636,282 individuals), constituting 57.0% of the total number of legally residing foreigners in the Czech Republic [17]. Among foreigners legally residing in the Czech Republic, citizens of third countries predominated (888,806 individuals, 80%) over citizens of EU, EEA, and Switzerland (227,348 individuals, 20%). By the end of 2023, a total of 1,065,740 individuals of foreign nationality were registered in the Czech Republic, with 341,111 having temporary residency, 349,995 having permanent residency, and 375,021 registered under temporary protection. The significant increase in the number of foreigners in the Czech Republic is primarily attributed to the granting of temporary protection to Ukrainian nationals (574,447 individuals, 53.9% of all registered foreigners in that year) fleeing the war in their country. Among foreigners legally residing in the Czech Republic, citizens of third countries predominated (836,044 individuals, 78%) over citizens of EU, EEA, and Switzerland (229,696 individuals, 22%) [26].

6. The Czech Republic's Approaches to Illegal Migration and Responses to the Ukrainian Refugee Crisis

The approaches of the Czech Republic to addressing illegal migration and responses to the Ukrainian refugee crisis are founded on the Migration Policy Strategy [34]. The main tools employed by the Czech Republic in the realm of preventing illegal migration include effective pre-entry controls, as well as return policies, cooperation with third countries, combating human trafficking, and the detection and rigorous punishment of organizers of illegal migration. Regarding unauthorized residence in the territory of the Czech Republic, the primary tool is primarily the monitoring of foreigners' stays.

In the fight against illegal migration and other transnational criminal activities, emphasis is placed on enhancing activities in controlling illegal crossing of both internal and external borders of the Schengen Area, including thorough cooperation with relevant foreign security forces. Members of the Czech Republic police are deployed in joint operations as part of cross-border and international cooperation efforts.

Continuous police cooperation with neighboring countries prioritizes border law enforcement, particularly through sharing analytical and operational information on foreigner movement and residence across state borders. Border officers implement joint measures aimed at enhancing monitoring of the development of migration routes for illegal migration through controls on designated road and railway corridors. Joint police and customs cooperation centers with neighboring states play a crucial role in this collaboration, especially in gathering information on specific individuals. Direct operational cooperation with the authorities of neighboring states (Slovakia, Germany, Austria, Poland) and Hungary is essential in combating illegal migration (human smuggling, fictitious marriages, abuse of work visas, etc.), cross-border criminal activities (theft of luxury motor vehicles, detection of distributors of narcotics and psychotropic substances, human trafficking, etc.). Further collaborations are established ad-hoc according to current needs. In 2019, a total of 765 joint patrols were conducted by officers of the immigration police departments of regional police directorates with units from neighboring states [22]. In 2020, only 226 joint police patrols were conducted, representing a significant 70.5% decrease compared to the previous year, attributed to measures taken in response to the COVID-19 pandemic [24]. In 2021, only 75 joint patrols were conducted, marking a further 66.8% decrease compared to 2020, mainly due to the ongoing COVID-19 pandemic, which significantly influenced the global migration situation in all its aspects. The execution of joint patrols was suspended or entirely canceled in most months of 2021[19].

In 2022, EU member states in the Western Balkans recorded the highest volume of secondary movements of illegal migrants since 2017. The heightened migration pressure was primarily attributable to a substantial number of migrants already present in the Western Balkans, with the open visa policies of Western Balkan countries also playing a significant role. In response to the aforementioned surge in illegal migration, increased activity of organized smuggling groups, and the worsening security situation reaching such intensity that alternative measures for ensuring public order and safety proved inadequate, the government of the Czech Republic decided to temporarily reintroduce border controls along the land border with the Slovak Republic (from September 29, 2022, to October 8, 2022) [14]. This decision is grounded in Article 28 of the Schengen Border Code [7]. The reimplementation of border controls was further repeatedly extended by the government (until February 4, 2023) in accordance with the provisions of Article 25 of this code. Since the outset of the reintroduction of controls, the implementation of measures involved collaboration between the Czech Republic Police and the Customs Administration, subsequently supplemented by active-duty military personnel [14]. In November 2022, the issue of increasing illegal migration from the Western Balkans was also addressed at a meeting of the interior ministers of the Czech Republic, Slovakia, Hungary, and Austria, emphasizing the need to harmonize the visa policies of Western Balkan countries with the EU. In its capacity as the Presidency of the EU Council, the Czech Republic led ministerial discussions within the EU-Western Balkans forum for justice and home affairs, focusing on enhancing cooperation in the Western Balkans regarding border management, operational partnerships against human trafficking, alignment of visa policies with the EU, and the necessity to continue developing relationships with Western Balkan partners [14]. On December 5, 2022, the European Commission presented the EU Action Plan for the Western Balkans [35], outlining operational measures to strengthen partnerships with Western Balkan countries. This partnership facilitates the alignment of local systems with EU standards and is crucial due to the perspective of Western Balkan countries' accession to the EU. In 2022, 466 officers of the Czech Republic Police were deployed in joint operations under the Bilateral Police Cooperation in Western Balkan countries. Officers operated in North Macedonia and Hungary, intercepting over 39,000 illegal migrants. In 2023, 299 officers were deployed, intercepting nearly 21,000 illegal migrants [15, 36].

As part of international cooperation, the Czech Republic Police also participates in operations conducted by the European Border and Coast Guard Agency (FRONTEX), which supports EU member states and Schengen associated countries in managing the external borders of the EU and combating cross-border crime. In 2021, the European Border and Coast Guard Standing Corps (EBCG SC) was deployed for the first time as a permanent unit, serving as the uniformed service and operational component of the EU, to which member states are obligated to contribute a specified number of personnel. The Czech Republic fulfilled its commitment, and its national team within the EBCG SC currently comprises 252 police officers. In 2022, a total of 161 police officers were deployed in joint operations under this unit, and in 2023, 146 police officers were deployed [15, 36].

Regarding the response to the Ukrainian refugee crisis, in 2022, the Czech Republic, along with the unity of EU member states, faced challenges in addressing the impacts of the Russian invasion of Ukraine and had to contend with significant migration pressure, which experienced rapid growth again after relatively calm years during the COVID-19 pandemic. A pivotal point of assistance became the discussion on the historic first activation of the Temporary Protection Directive [10], enabling EU member states to cope with the influx of newcomers. Following the offer of temporary protection to those fleeing the war in Ukraine, the EU and EEA countries recorded over 5 million registrations of this type of protection in the first quarter of 2023. The highest number of overall registered temporary protections as of December 31, 2023, was noted in Germany (1,251,245), Poland (954,795), and the Czech Republic (375,021). In the Czech Republic, a total of 581,077 temporary protections were granted from the beginning of the conflict (February 24, 2022) until December 31, 2023 [26]. From this perspective, the coordination of aid and discussions on financial support to the most affected member states at the EU level were also absolutely crucial. The Ministry of the Interior of the Czech Republic succeeded in negotiating financial assistance amounting to 670 million CZK from the Asylum, Migration, and Integration Fund [37]. Similar assistance was obtained by Poland, Slovakia, Hungary, and Romania [14].

The exceptional nature of the situation can also be seen in the deployment of Czech Republic Police officers to Slovakia during the peak of the refugee wave from Ukraine (March to June 2022). Four Czech police contingents totaling 210 officers were dispatched to Slovakia. Their primary tasks at the border crossings between Slovakia and Ukraine mainly included assisting with traffic coordination, migration flow management, providing support during identity document checks, and inspecting cargo spaces of transportation vehicles [36].

In the Czech Republic, Regional Assistance Centers for Ukraine (abbreviated as KACPU) were also established to aid war refugees. These centers provide administrative assistance through representatives from the Department for Asylum and Migration Policy, insurance companies, the Foreign Police, and interpreters [38]. Additionally, they offer humanitarian aid and all necessary provisions for accommodation. Simultaneously, the National Assistance Center for Assistance to Ukraine was established to coordinate integration and humanitarian activities in the regions. An official web portal (https://frs.gov.cz/) was also created for foreigners who wish to live or are living in the Czech Republic, providing information and forms for their legal entry and stay in the country.

Equally crucial were non-governmental non-profit organizations (diocesan and archdiocesan charities, integration centers, charitable foundations, regional branches of the Czech Red Cross, etc.), which implemented numerous projects to support the integration and adaptation of Ukrainian refugees in the Czech Republic.

7. The Impact of Migration on Internal Security and Public Order

Illegal migration is a phenomenon that can significantly threaten internal stability and security in destination countries. Therefore, addressing illegal migration is a crucial aspect of the Czech Republic's migration policy. The impact of migration on internal security and public order in the Czech Republic is evident from the necessity of temporarily reintroducing border controls along the internal Schengen border with Slovakia. This is not only due to increased activity of organized smuggling groups but also to growing aggression from smugglers, leading to traffic accidents, clashes with the police, and sadly, loss of life. The deterioration of the migration and security situation at the external borders of the Schengen area is also visible.

The influx of migrants into the Czech Republic, exemplified by the Ukrainian war crisis, has implications for its citizens. While a wave of solidarity emerged, accompanied by a long-term governmental initiative to support Ukraine, varying opinions on the extent and manner of assistance have surfaced. Research [39, 40] by the STEM Analytical Institute indicates that the Czech public tends to be conservative and resistant to change, reflected in their attitude toward migration. Only 53% of citizens view allowing Ukrainian refugees to stay in the Czech Republic as appropriate.

In recent years, resistance to immigrants has emerged as a significant threat to democracy not only in the Czech Republic but also in many countries, where it has undermined or could potentially undermine the proper functioning of democratic institutions [41].

A more restrictive immigration policy could potentially subject immigrants to unfair exclusion. However, it is also necessary to consider that immigration encompasses not only the process of settling migrants but also their interaction with the host society [41]. It is thus a two-way process, with subsequent integration of migrants entering various societal domains, including employment, education, health, civil rights, social welfare, and family [42]. On the other hand, if immigration were left unregulated, it could undermine democratic foundations or even lead to democratic failure. This presents a challenging ethical dilemma that cannot be easily resolved [43].

8. Conclusions

Migration represents a complex phenomenon with significant legal, economic, and societal implications. Migration routes to Europe are dynamic. The Western Balkan route remains the busiest, although there was a slight decrease in 2023. The Eastern Land Borders route is primarily affected by refugees from Ukraine. The Eastern Mediterranean route is experiencing an increase in activity following the COVID-19 pandemic-induced slowdown. The Central Mediterranean route, extending from Libya to Italy, is characterized by its diversity of migrant nationalities and continues to be the most perilous, with a consistently high fatality rate. Despite measures to combat COVID-19, this route has seen a substantial increase in migrant arrivals in recent years, with numbers in 2023 reaching 157,314, a 50% increase from 2022. The Western Mediterranean route, primarily used for entry into Spain, has experienced fluctuations in popularity influenced by border control policies. After becoming the most utilized route in 2018, it saw a significant decrease in 2019 due to collaborative efforts between Morocco, Spain, and the EU. However, migration pressure along this route has intensified since 2021. Each route has its specific challenges and trends that change depending on the geopolitical situation, security measures, and socioeconomic factors in migrants' countries of origin.

The dynamics of illegal migration in the Czech Republic have exhibited significant fluctuations over the past decade, influenced by various factors including geopolitical events, policy changes, and global crises. The year 2015 marked a peak in illegal migration due to the European refugee crisis, followed by a decline and subsequent gradual increase from 2017 onwards. The COVID-19 pandemic in 2020 led to a spike in illegal migration, primarily due to violations of pandemic-related border restrictions. However, the most dramatic change occurred in 2022, with an unprecedented surge in transit illegal migration, accounting for 99.3% of total illegal migration. In response to this situation, various measures were implemented, including the temporary reintroduction of border controls with Slovakia, participation in joint operations within the EU framework, and international cooperation. The implementation of border control measures proved effective in significantly reducing illegal migration numbers. In the current year, the Czech Republic faced increased migratory pressure, particularly in connection with the refugee crisis from Ukraine. The Czech Republic actively responded to the Ukrainian refugee crisis by providing temporary protection and establishing Regional Assistance Centers for Ukrainian. Many Ukrainians also took advantage of the opportunity to legalize their previous illegal residence in the territory of the Czech Republic. Despite this, Ukrainians constituted the largest group of foreigners issued with administrative expulsion orders (over 30% of the total number of decisions issued that year).

Coordination at the EU level played a key role, including the activation of the temporary protection directive and financial support for the most affected member states. Non-governmental organizations also played a significant role in supporting the integration of Ukrainian refugees. The Czech legal framework has been continuously adapting to the changing migration landscape, with EU membership and participation in the Schengen Area playing crucial roles.

The Czech Republic has experienced a significant transformation in its foreign resident population, largely due to the Russian aggression in Ukraine. In 2022, the country granted the highest number of temporary protections per capita in the EU, with 473,216 issued. This led to a dramatic increase in the Ukrainian population, which grew by 223.2% year-on-year, constituting 57.0% of all legally residing foreigners in the Czech Republic. By the end of 2023, the foreign national population in the Czech Republic reached 1,065,740, with a majority under temporary protection or residency status. Ukrainian nationals, fleeing the war, accounted for 53.9% of all registered foreigners. This influx has shifted the demographic landscape, with third-country nationals now comprising 78% of legally residing foreigners, compared to 22% from EU, EEA, and Switzerland. These figures underscore the Czech Republic's significant role in providing humanitarian support during the Ukrainian crisis. They also highlight the need for comprehensive integration policies and infrastructure to accommodate this rapid demographic change. The situation presents both challenges and opportunities for the Czech Republic in terms of social cohesion, economic integration, and long-term population dynamics.

In summary, illegal migration poses a complex challenge with far-reaching implications for the internal security and stability of destination countries. In combating illegal migration, it is necessary to focus on new trends in transit illegal migration and coordinate security measures across the entire territory of the Czech Republic. Facilitating legal migration enables the reduction of illegal migration and associated risks, including enhanced control and registration of incoming foreign nationals. Furthermore, within the context of international relations, it strengthens diplomatic ties between countries and promotes global cooperation in this field. The Czech Republic must strike a delicate balance between safeguarding its borders and democratic values while ensuring equitable treatment for legal immigrants. Effective resolution necessitates international cooperation, robust integration policies, and open dialogue with the public. Only a balanced approach to migration can ensure long-term societal stability and prosperity. The results of the conducted analysis can serve as a basis for the development and improvement of migration issue resolution in the future.

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War's Shadow: Exploring Multifaceted Strategies in the Politics of Fear

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Abstract

This study delves into the intricacies of approaching politics of fear in general, with a particular focus on Russia. The author unveils different approaches to defining the politics of fear and describes its various dimensions, including instrumental, discursive, emotional, socio-political, and psychological aspects of fear manipulation. Through the analysis of fear-based tactics targeting the opposition, elites, and regime supporters, the study uncovers the intricate strategies to maintain control and suppress dissent in Russia today. However, the author underlines that the politics of fear in Russia has its limitations. For the majority of the previously depoliticized society, the opposite politics of pacification is implemented.

KEY WORDS: *politics of fear, politics of pacification, political strategies, Russia's war in Ukraine, political repressions, social anxiety, dissemination of fear.*

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1. Introduction

The discourse surrounding the politics of fear in Russia is expanding, gaining significance, particularly in light of the ongoing conflict with Ukraine, which has not only affected Ukrainian territories but also impacted Russian citizens. Russian society appears divided into two distinct groups: those deeply entrenched in political affairs and the broader populace. For the former, a climate of fear dominates, stifling dissent and fostering caution. Conversely, the latter experiences a depoliticized environment, characterized by a politics of pacification [20] aimed at maintaining societal inertia.

Both strategies converge on a common goal: suppressing dissent to preserve stability, especially during times of conflict. This article delves into Kremlin policies targeting politically engaged individuals, analyzing the dynamics of fear in politics and its impact on Russian society. It also delves into the philosophical underpinnings of fear, highlighting its pervasive influence on individual and societal behavior.

It was the French author Michael de Montaigne who wrote "The thing I fear most is fear" [14]. Of course, the entire history of mankind is marked not only by the use of fear in politics but also by a desire to free itself from it [17]. The Russian political philosopher N.A. Berdyaev wrote about the phenomenon of fear: "Fear is the foundation of the lives of this world... The most terrifying people are those who are consumed by fear. Fear is destructive... it governs the world. Power, by its very nature, employs fear. Human society was constructed on fear. Therefore, it was built on lies because fear breeds lies... Fear always conceals the truth... it is connected not only to lies but also to cruelty... Not only are the masses ruled through fear, but the masses themselves rule through fear... Fear distorts consciousness and hinders our ability to know the truth" [4].

The above statements of the philosopher draw our attention to the fact that fear, as a negative emotion, is a constant companion of individuals and society. In everyday life, it manifests itself as an instinct for self-preservation from objectively existing threats. A significant portion of fears is generated by society. Fear, to the highest degree, is a political sentiment. However, we should emphasize that this feeling can arise in conditions of both real and imagined, illusory, and false dangers, but it is experienced as real. The quality of life in society depends on the intensity of this social sentiment [16].

The overarching aim of the article is to understand the current state of social sentiment in Russia and its implications for the country's future trajectory. Key questions addressed include the nature and measurement of the politics of fear, its utilization in Russian governance, and the populace's receptiveness to such strategies.

2. Theoretical Framework

While there is no single, universally accepted definition of the politics of fear, summarizing the existing views on the problem gives us an opportunity to identify five main methodological approaches that have been encountered in the academic literature. Each of these approaches attempts to analyze and understand the politics of fear through its unique focus and perspective.

These focuses and perspectives are:

1. The strategic and instrumental use of fear as a tool by those in power - Instrumental approach.
2. The ways in which fear is discursively produced, disseminated, and reinforced by the regime and other social actors - Discursive approach.
3. The affective dimension of fear and its impact on individuals and groups - Emotional approach.
4. The power dynamics, institutional structures, and societal conditions that are both shaped by the politics of fear and contribute to its production - Sociopolitical approach.
5. Individual and collective psychological processes that underlie the politics of fear - Psychological approach.

The instrumental approach is one of the most popular and widely discussed in the literature. It emphasizes the utilization of fear by those in power, focusing on its strategic and instrumental use to control and manipulate the public. The instrumental approach is frequently employed as a methodological framework for analyzing the politics of fear, particularly in the context of US society facing concerns such as terrorism and other external threats.

One of the most famous authors of this approach is the American professor Corey Robin. In his book "Fear: The History of a Political Idea" [17], he refers to political fear, that is defined as a fear experienced by people due to the potential harm to their collective well-being, such as fear of terrorism, panic stemming from rising crime, anxiety over a decline in morality, or intimidation by authorities or groups. Robin distinguishes political and individual fear and emphasizes that political fear originates in society or has social consequences. Individual fears, such as fear of flying or fear of spiders, are products of our own psychology and experiences that have minimal impact on others. In contrast, political fear arises from conflicts within and between societies.

Robin defines the politics of fear as the deliberate manipulation of fear by political actors to shape public opinion, maintain authority, and legitimize policies that would not otherwise be accepted. Fear, according to Robin, can be used to rally support, create divisions, and marginalize dissenting voices.

A one more prominent representative of the instrumental approach, an American political theorist and professor, Sheldon Wolin in his book "Democracy Incorporated. Managed Democracy and the Specter of Inverted Totalitarianism" [21] also examines a form of managed democracy and how fear is employed by political elites to justify the expansion of state power and curtail civil liberties in the United States.

He discusses the role of political elites, the influence of money in politics, the erosion of civil liberties, and the manipulation of public opinion through mass media. Wolin also analyzes the role of political parties, the impact of globalization, and the concentration of power in the hands of a few. As well as Robin, Wolin views the politics of fear as a mechanism employed by political elites to maintain and consolidate power in democratic societies.

A political theorist and former leader of the Liberal Party of Canada Michael Ignatieff has written extensively about the politics of fear. In his book "The Lesser Evil: Political Ethics in an Age of Terror," Ignatieff examines the ethical dilemmas and challenges posed by fear-based politics, particularly in the context of counterterrorism measures taken after the September 11 attacks in New York.

Ignatieff argues that the politics of fear involves the instrumental use of fear by politicians to justify exceptional measures and policies, often in response to perceived threats. He explores the trade-off between security and civil liberties and questions the extent to which fear should be allowed to shape political decisions. Ignatieff emphasizes the importance of balancing security concerns with the preservation of democratic values and individual rights.

We can conclude here that the instrumental approach focuses on the strategic use of fear by political actors in decision-making and the establishment of authority regardless of the type of political regime.

The discursive approach examines how fear is constructed and disseminated through language, discourse, and narratives. It analyzes the processes through which fear is discursively produced, spread, and reinforced by the ruling regime and other social actors. The highlighting of a discursive approach as an independent perspective is attributed to the ideas and viewpoints expressed in the works of Brian Massumi and Ruth Wodak.

Brian Massumi, a Canadian philosopher and the editor of the book "The Politics of Everyday Fear" [12], explores fear as a discursive construction that is mediated through media, rhetoric, and political narratives.

His main focus was on examining the widespread presence of fear-mongering mechanisms in American society, with a particular emphasis on the influential role of the media. The key objective was to highlight the tangible impact on individuals, the ultimate target of fear-inducing technologies. These technologies can be understood as power apparatuses designed to imprint habitual patterns, predispositions, and associated emotions—especially hatred—that contribute to the creation of social divisions, the preservation of hierarchies, and the perpetuation of systems of domination.

Massumi states that the nature of fear extends beyond being merely an emotion. Instead, it can be understood as the objective manifestation of subjective experiences within the context of late capitalism. Fear encompasses the way images and commodities exist, and it encompasses the self-generated impacts that arise from their circulation, even in the absence of a solid foundation.

Ruth Wodak, an acclaimed Austrian linguist and social scientist, has made significant contributions to the investigation of fear discourse from a discursive approach. One of her notable books that delves into this subject is "The Politics of Fear: The Shameless Normalization of Far-Right Discourse" [22]. In this book, Wodak explores the ways in which right-wing populist movements and politicians employ fear as a rhetorical and discursive strategy to gain support, shape public opinion, and advance their agendas. She examines case studies from various countries to illustrate the discursive techniques and ideologies utilized by these actors.

According to Wodak, fear discourse often involves the construction of "Otherness", where certain groups or individuals are portrayed as threats to society. This process contributes to the reinforcement of stereotypes, stigmatization, and the fostering of hostility and prejudice. Wodak emphasizes the need to critically analyze fear discourse and its underlying power dynamics in order to understand how it operates and to counteract its potentially harmful effects. Overall, Wodak's work underscores the significance of fear discourse as a tool of persuasion and control, shedding light on its role in shaping social attitudes, policies, and intergroup dynamics.

The discursive approach views fear as a socially constructed phenomenon that influences perceptions, beliefs, and behaviors, which aligns it with the instrumental approach. However, the discursive approach sets itself apart by specifically analyzing the technologies used to generate social fear, thus distinguishing it as a unique approach among others.

The emotional approach specifically delves into the subjective experiences, emotional responses and psychological impacts of fear in political contexts. It emphasizes the affective dimension of fear and its impact on individuals and groups.

Martha C. Nussbaum, an influential American philosopher, in her book "Political Emotions: Why Love Matters for Justice" [15], examines the specific types of emotions that are essential for citizens in order to uphold and maintain a just society or a society that strives for justice. Nussbaum focuses on the emotional dimension of politics and its impact on democratic societies. Among other emotions Martha C. Nussbaum examines fear and its impact on democratic processes and public discourse. She sees the politics of fear as an instrumentalization of fear by political actors to control and manipulate public sentiment. Nussbaum argues that excessive fear can undermine democratic values and inhibit rational deliberation, calling for the cultivation of alternative emotions such as empathy and love.

What distinguishes the emotional approach from other approaches is its emphasis on understanding the affective aspects of fear, including the emotional states, responses, and influences it generates. In summary, the emotional approach in the study of the politics of fear highlights the affective dimensions of fear and its influence on individuals and collective behavior.

The sociopolitical approach considers the broader social, political, and institutional factors that shape the politics of fear. It looks at power dynamics, institutional structures, and societal conditions to understand how fear operates and influences the relationship between the regime and different actors.

Talking about the representatives of this approach we should first of all mention Wendy Brown who is an American political theorist. In her book "Walled States, Waning Sovereignty" [5], Brown explores the phenomenon of walls and barriers erected by nation-states as a response to globalization and the perceived threats to sovereignty. Brown argues that fear plays a significant role in the justification and implementation of walled borders. She contends that the fear of losing control, the fear of cultural and economic insecurities, and the fear of transnational threats (such as terrorism and immigration) contribute to the construction of physical barriers.

Brown highlights how the fear is utilized by political leaders and governments to justify securitization measures, including the construction of walls. Fear is often employed as a tool to mobilize public support for these measures, presenting them as necessary for protecting national security, cultural identity, and economic well-being.

Another prominent representative of a sociopolitical approach is Arjun Appadurai, an Indian-American anthropologist and social theorist. His book "Fear of Small Numbers: An Essay on the Geography of Anger" [2] examines the dynamics of fear, anger, violence, and social conflict in the context of globalization, migration, and cultural encounters. Appadurai explores how the intensification of global interactions and the movements of people, goods, and ideas can create conditions of insecurity, fear, and resentment. He argues that these conditions can lead to the emergence of violence and anger, particularly when they intersect with issues of identity, ethnicity, religion, and nationalism.

Didier Fassin, a French anthropologist and sociologist, also has a number of writings that touch upon fear as it relates to issues of security, policing, and the management of populations. In his work "Enforcing Order: An Ethnography of Urban Policing" [7], Fassin examines fear as a mode of social control within the context of policing. He explores how fear is used by police forces to maintain order and control in urban environments.

Fassin also engages with the broader politics of fear indirectly in his work on humanitarianism, migration, and borders. In a book "Humanitarian Reason: A Moral History of the Present" [8], he examines the securitization of borders, the politics of asylum, and the management of populations in the context of migration. This work touches upon the use of fear in shaping immigration policies, border controls, and the treatment of migrants. Fassin's research primarily focuses on the ways in which fear operates within sociopolitical contexts, examining its manifestations in relation to power dynamics, social control, and the management of populations.

David L. Altheide's work on the politics of fear, titled "Terrorism and the Politics of Fear" [1], primarily falls within the sociopolitical approach as well. The scientist explores the role of fear in contemporary society, particularly in relation to the phenomenon of terrorism. He argues that fear has become a pervasive force in political discourse, media representation, and public perception, shaping the ways in which we understand and respond to acts of terrorism. He suggests that fear is strategically employed by political actors and media institutions to advance particular agendas, justify security measures, and maintain social control.

So, the sociopolitical approach views fear as a social and political phenomenon that is shaped by power relations, social structures, and broader socio-political dynamics. From a sociopolitical perspective, fear is not solely an individual psychological experience but is shaped and influenced by larger social forces.

The psychological approach delves into the individual and collective psychological processes that underlie the politics of fear. It focuses on cognitive, emotional, and behavioral aspects, examining how fear influences decision-making, attitudes, responses, and psychological well-being.

While the field of investigating the politics of fear from a psychological approach is vast and continuously evolving, there are several prominent scholars who have made notable contributions, serving as evidence of the significance of this approach.

Stanley Milgram, a social psychologist and professor at Yale University. In his book "Obedience to Authority: An Experimental View" [13], Stanley Milgram explores the factors that influence individuals' obedience to authority, even when it involves inflicting harm on others. Milgram's experiments involved participants who were instructed to administer electric shocks to another person (an actor) under the guise of a study on learning. The shocks were not real, but the participants believed they were. Milgram found that many participants were willing to continue administering shocks, even at high levels, when an authority figure instructed them to do so.

Milgram suggests that fear plays a role in this obedience to authority. Participants may experience fear of repercussions or punishment if they refuse to comply with the instructions. The presence of an authority figure, with their perceived power and legitimacy, can create a sense of fear and anxiety in individuals, leading them to obey even when it goes against their own moral judgments.

The second representative of this approach is a renowned psychologist and professor emeritus at Stanford University Philip Zimbardo. Zimbardo's Stanford Prison Experiment [23] highlighted how situational factors and power dynamics can lead individuals to engage in abusive behavior. His work provides insights into the potential role of fear and authority in the context of oppressive systems.

Zimbardo's Stanford Prison Experiment demonstrated how fear, both experienced by prisoners and induced by guards, played a role in shaping obedience to authority. The fear of punishment or retribution can lead individuals to comply with orders, even if they go against their personal values. At the same time, Zimbardo has discussed how fear of rejection or social isolation can drive individuals to conform to group norms. The fear of being different or ostracized can lead people to adopt beliefs or behaviors that align with the group, even if they may personally disagree. Zimbardo has explored the role of fear in deindividuation, which is the loss of self-awareness and individual identity in group situations. When individuals feel anonymous or part of a crowd, they may experience reduced fear of personal consequences, leading to increased aggression or risky behaviors.

Thus, the scientist has emphasized the potential for fear to be manipulated by authority figures or institutions as a means of control. The instillation of fear can be used to maintain power, discourage dissent, or foster obedience to those in positions of authority.

An American psychiatrist Robert Jay Lifton examines in his book "Thought Reform and the Psychology of Totalism: A Study of 'Brainwashing' in China" [11], the psychological processes and techniques used in totalitarian regimes to manipulate and control individuals' beliefs and behaviors. Lifton explains how totalitarian systems instill and exploit fear in individuals as a means of control. The regime creates an atmosphere of constant surveillance, uncertainty, and potential punishment, which induces fear and keeps individuals compliant. He discusses how the pervasive fear experienced within a totalitarian system can have profound psychological and social effects. It can lead to heightened anxiety, self-censorship, conformity, and the suppression of critical thinking. The author argues that fear is employed to break down individuals' existing beliefs, values, and sense of self, making them more susceptible to accepting the ideology and control of the regime.

Lifton also explores the transformation of fear within the totalistic environment. Initially, individuals may fear punishment or reprisal for non-compliance, but over time, their fears may shift to internalized forms, such as fear of betraying the ideology or fear of being ostracized by the group.

In addition to the previously mentioned scholars, it is worth noting the contributions of prominent researchers such as Hannah Arendt and Stanley Cohen in the field of studying the politics of fear using the psychological approach. Although not a psychologist by training, Arendt's work on totalitarianism and the banality of evil offers insights into the psychological dimensions of fear and conformity in authoritarian contexts [3]. Cohen's research on moral panics and the construction of public fears provides insights into the ways in which authoritarian regimes can manipulate and exploit public anxieties to consolidate power and control [6].

Thus, psychological approach first of all considers how fear can be exploited or manipulated by political actors to influence individuals' political behavior.

Overall, these approaches offer valuable insights into the multifaceted nature of the politics of fear, highlighting its strategic, discursive, emotional, sociopolitical, and psychological dimensions. By examining fear from diverse methodological perspectives, researchers can gain a deeper understanding of its role in shaping political dynamics and societal outcomes.

3. Data and Methodology

Methodologically, the study takes an interdisciplinary approach encompassing both content analysis [18] and critical discourse analysis [9] in order to understand what methods are used by authoritarian states in order to implement the politics of fear.

This study aims to illuminate the evolving discourse in Russian media during the first year of the war, spanning from February 24 to December 31, 2022. The research draws on a diverse array of sources, including Russian media, official documents, and speeches.

The dataset encompasses content from key information agencies and newspapers, as well as official documents and speeches from government figures. The selected information agencies, Ria Novosti, TASS, and Interfax, stand as pillars of the Russian media landscape, providing a broad perspective on the national narrative. Additionally, influential newspapers—Moskovsky Komsomolets, Kommersant, and the official newspaper Rossiyskaya Gazeta—contribute nuanced perspectives to the study.

Government documents, official communications, and speeches were extracted from the President of the Russian Federation's website (kremlin.ru) and the Ministry of Defence of the Russian Federation's website (stat.mil.ru). These platforms were chosen for their authoritative status and central role in disseminating information related to the Russian war in Ukraine.

The research design employed a multi-step approach to analyze the collected data comprehensively.

1. Scan Interfax Monitoring System. The Scan Interfax monitoring system facilitated a systematic analysis of the Russian media landscape. Relevant articles and messages were extracted using predetermined keywords. A total of 10,000 articles were initially gathered, with subsequent ranking by relevance. The top 2,300 articles were selected for further in-depth analysis.
2. NVivo Software Analysis. The selected articles underwent content analysis using NVivo software. This method allowed for the identification of patterns, themes, and sentiments within the media content, providing a deeper understanding of the narratives presented.
3. Critical Discourse Analysis. Employing critical discourse analysis, the study delved into extra-discursive behaviors of political actors. This approach enabled a nuanced exploration of the socio-political dynamics during the specified period.

4. Results

The analysis of the politics of fear in Russia reveals a complex and multifaceted landscape shaped by historical, social, and political factors. This section presents the key findings from the examination of various methodological approaches to understanding fear in Russian society, including the instrumental, discursive, emotional, sociopolitical, and psychological perspectives.

Table 1.

Three types of fear-based politics - targeting opposition, elites, and supporters

	Opposition	***Elites***	***Regime supporters***
Instrumental approach	Repressions	Coercion and Control, Patronage and Rewards, Co-optation and Fragmentation	Cultivation of Enemy Perceptions
Discursive approach	Othering and Marginalization	Cultivation of Loyalty and Dependence	Othering and Stereotyping, Symbolic Politics
Emotional approach	Self-censorship, Avoidance, Radicalization, Emigration, Psychological distress	Compliance and Loyalty, Self-Preservation	Dissemination of Fear (self-regulated emotion)
Socio political approach	Suppression of Dissent, Erosion of Democratic Space, Polarization and Divisions	Consolidation of Power, Fear-driven Compliance, Limited Autonomy and Independence	Justification of Repressive Measures, Social Pressure and Conformity
Psychological approach	Fear and Anxiety, Self-Censorship, Paranoia and Mistrust	Instrumental Rationality	Group Identity and Belonging, Cognitive Biases

In Russia, it's crucial to recognize three distinct dimensions of fear-based politics, each tailored to specific societal groups. Firstly, tactics target regime opponents, including activists and journalists. Secondly, elites are intimidated to prevent dissent within influential circles. Lastly, even regime supporters are kept under fear to ensure compliance. These strategies predominantly impact politically active individuals. By understanding these dimensions, we gain a more nuanced insight into the varied effects of fear-based politics across different segments of society.

By correlating the three types of fear-based politics - targeting opposition, elites, and supporters - with diverse approaches to defining it (see Table 1), we develop the following framework to enhance our understanding of the current situation and the strategies employed by the government to implement politics of fear in Russia.

In analyzing the politics of fear in Russia, it becomes apparent that one of the most conspicuous dimensions involves the treatment of the opposition. The opposition contends with a multitude of challenges resulting from the government's utilization of fear-based tactics. These challenges span diverse dimensions, each representing distinct approaches aimed at instilling fear and exerting control over dissenting viewpoints.

Instrumental approach in this case is represented by repressions. Repressions against opposition figures, such as criminal and administrative prosecutions, dispersal of protests, infringement of rights and freedoms, pressure on employees in the public sector, donors of NGOs, and students exemplify this approach. According to "OVD-Info"[24] from February 24, 2022, to December 23, 2023, criminal cases were initiated against 801 opponents of the war. Among them, 297 individuals were prosecuted under Article 207.3 of the Criminal Code of the Russian Federation ("dissemination of knowingly false information about the actions of the Armed Forces of the Russian Federation"), 140 under Article 280.3 of the Criminal Code of the Russian Federation ("discrediting the use of the Russian Armed Forces"), and 122 under Article 205.2 of the Criminal Code of the Russian Federation ("justification, propaganda, or incitement to terrorism"). Our analysis also reveals a significant number of mentions of cases involving court proceedings and prosecutions against I. Yashin [25], Y. Shevchuk [26], and others. These cases sent a clear message to other dissenters about the potential consequences of challenging the regime.

Discursive approach implements such strategies as othering and marginalization of opposition. The opposition is often portrayed as unpatriotic, foreign-backed agents seeking to destabilize the country. State-controlled media outlets frequently employ rhetoric that "others" opposition figures, depicting them as enemies of the state and the fifth column [27]. Such discourse serves to marginalize and delegitimize the opposition, making it easier to justify repressive measures against them.

Emotional approach is represented by self-censorship, avoidance, radicalization, emigration and psychological distress. The emotional approach highlights the affective dimension of fear and its impact on individuals and groups. In the context of the Russian opposition, fear manifests through various emotional responses and coping mechanisms. Many activists engage in self-censorship, avoiding certain topics or activities out of fear of reprisal. Others may become radicalized, resorting to more extreme tactics as a response to perceived threats. Additionally, some opposition members choose to emigrate to escape persecution [28], while others experience psychological distress, including anxiety, paranoia, and mistrust of others.

Socio-political approach reflects suppression of dissent, erosion of democratic space, polarization and divisions. The socio-political approach considers the broader social, political, and institutional factors that shape the politics of fear. Laws targeting "foreign agents" [29] and "undesirable organizations" [30] restrict the activities of civil society groups and opposition movements, stifling dissent and limiting political participation. Moreover, the deliberate fostering of divisions within society exacerbates tensions and reinforces fear among opposition members.

The psychological approach unveils anxiety, self-censorship, paranoia, and mistrust. The psychological approach delves into the individual and collective psychological processes underlying the politics of fear. In Russia, opposition members experience fear and anxiety due to the constant threat of surveillance, harassment, and violence. This fear often leads to self-censorship, as individuals refrain from expressing dissenting opinions or engaging in activism to avoid repercussions. Moreover, the pervasive atmosphere of fear fosters paranoia and mistrust among opposition circles, undermining solidarity and collective action [31].

Overall, the politics of fear in Russia target the opposition through a combination of repressive tactics, discursive marginalization, emotional manipulation, socio-political suppression, and psychological coercion. These approaches work synergistically to maintain the regime's grip on power and silence dissenting voices, perpetuating a climate of fear and intimidation.

However, the politics of fear extend beyond the opposition to target elites within the political and economic spheres. The government employs various strategies to influence and control elites, utilizing different approaches based on instrumental rationality, discursive manipulation, emotional appeals, socio-political dynamics, and psychological factors.

The instrumental approach concerning elites is reflected in coercion, control, patronage, co-optation, and fragmentation. This approach involves the strategic use of coercion and control, where the government employs threats, intimidation, and punitive measures to ensure compliance. The Speaker of the State Duma, Vyacheslav Volodin, even advocated for the dismissal of public sector workers who do not agree with the war in Ukraine: "Those who are supported by the state, and therefore by the people, and have betrayed it, should step down from leadership positions in budgetary institutions in the fields of culture, education, healthcare, and other sectors" [32].

Simultaneously, elites are enticed through patronage and rewards, offered lucrative business contracts, political positions [33], or legal protection in exchange for loyalty. The regime also fosters divisions among elites, fragmenting potential opposition and consolidating its power base.

Discursive strategy is focused on cultivation of loyalty and dependence by promoting narratives of national unity and stability. Elites are portrayed as integral to the country's prosperity and security [34], fostering a sense of obligation and loyalty towards the government. Through discourse, the regime reinforces the perception that cooperation with the authorities is essential for the common good, thereby maintaining elite support and compliance.

Emotionally, elites navigate a complex landscape of compliance and self-preservation, balancing loyalty to the regime with personal interests and security concerns [35]. Fear of reprisal, loss of status, or economic consequences [10] drives many elites to prioritize allegiance to the government, even at the expense of their principles or the welfare of society. The emotional appeal of self-preservation perpetuates the regime's control over elite circles.

From a socio-political perspective, the government's objective is the consolidation of power through fear-driven compliance and the imposition of limits on elite autonomy. Elites who challenge the regime risk losing their influence and privileges, compelling them to acquiesce to government directives to maintain their positions of authority. Limited autonomy and independence curtail elites' ability to challenge the regime effectively, ensuring their continued subordination to state interests. The Prigozhin affair can be considered a notable example of this phenomenon, especially his fate following the appraisal [36].

Due to psychological approach elites operate within a framework of instrumental rationality, weighing the costs and benefits of aligning with or opposing the regime. Fear of retribution, coupled with promises of rewards and protection, influences elite decision-making and behavior. Instrumental rationality dictates that elites will act in their self-interest, aligning with the government to secure their status, wealth, and security, thereby perpetuating the regime's control over elite circles. In the context of Russia, the politics of fear are also directed towards regime supporters, albeit with a different focus and set of strategies. The government employs a range of approaches to maintain support among its base and suppress dissent [21].

Utilizing the instrumental approach, the regime cultivates perceptions of external and internal enemies among its supporters. By framing opposition groups, dissidents, or marginalized communities as threats to national security or stability [25], the government reinforces the narrative of a besieged state. Supporters are encouraged to view themselves as defenders of the regime against purported enemies, fostering loyalty and solidarity in the face of perceived threats.

Through the discursive approach, the regime engages in othering and stereotyping to vilify dissenters and reinforce the superiority of its supporters. Opposition figures are depicted as unpatriotic, disloyal, or aligned with foreign interests, while regime supporters are portrayed as virtuous defenders of the nation united with the government and elite members [37].

Emotionally, the dissemination of fear is a key strategy employed by the regime to maintain control over its supporters. By instilling a sense of anxiety, uncertainty, or insecurity, the government fosters dependence on its leadership for protection and stability. By employing the politics of pacification [20] on one hand, the government simultaneously maintains a high level of societal anxiety [38] to manage these sentiments during times of war. These sentiments are then readily embraced by the populace, leading to their further spread and reinforcing a self-perpetuating atmosphere of fear. For instance, efforts to quell societal unease may involve promoting a narrative of imminent global conflict or the anticipation of a global warfare. This narrative suggests that the war is not exclusive to Russia's involvement in Ukraine but is a global phenomenon involving the entire world, with no escape from its reach. Moreover, the expectation of extensive warfare and the potential for nuclear conflict function as means for regime supporters to reassure themselves, implying that their circumstances and the dangers they confront are not exceptional [39]. Other global conflicts are intentionally exaggerated, like the situation in Israel-Palestine or the UK's involvement in Yemen. From a socio-political standpoint, the government employs repressive tactics and social coercion to ensure compliance among its backers. Any form of dissent or critique is swiftly met with legal repercussions, social isolation, or economic penalties, instilling a pervasive atmosphere of fear and conformity. Even if someone fails to perceive legitimate reasons for initiating war, it's imperative to recognize that once engaged, winning becomes paramount. Failure to secure victory jeopardizes the nation's future. Among regime supporters, apprehension regarding reparations, sanctions, and further humiliations intensifies [40]. Supporters, in turn, feel a strong sense of belonging and identity within their group, fostering unity and allegiance to the ruling regime [41]. Moreover, cognitive biases like confirmation bias and favoritism towards their own group influence their perceptions, further solidifying their support for the government's narrative and worldview.

5. Discussion

The analysis presented in this study sheds light on the intricate dynamics of mechanisms of politics of fear in Russia, highlighting its influence across various societal groups and dimensions. By examining the tactics employed by the government to instill fear and maintain control, as well as the responses of opposition, elites, and supporters, we gain valuable insights into the complex correlation between power, coercion, and manipulation within Russian society.

One of the key findings of this study is the multi-dimensional nature of fear-based politics. This understanding necessitates studying the politics of fear from different approaches. At the same time the politics of fear manifests differently across distinct segments of society. The tactics targeting the opposition, including repressions, discursive marginalization, and emotional manipulation, underscore the regime's relentless efforts to suppress dissent and stifle opposition voices. The systematic use of legal, social, and psychological mechanisms to instill fear among activists and journalists highlights the government's determination to maintain its grip on power.

Similarly, the strategies employed to influence and control elites reveal the regime's adeptness at leveraging patronage, coercion, and emotional appeals to secure loyalty and compliance. By offering rewards, fostering divisions, and exploiting fears of reprisal or economic consequences, the government effectively maintains the allegiance of influential

figures within political and economic spheres. The case of Vyacheslav Volodin's call for the dismissal of public sector workers critical of the war exemplifies the instrumental approach used to coerce compliance among elites.
Furthermore, the tactics employed to manipulate regime supporters underscore the regime's adeptness at cultivating a narrative of external threats and internal enemies to foster loyalty and solidarity among its base. Through discursive othering, emotional fear-mongering, and socio-political coercion, the government reinforces its narrative of national unity and stability, effectively silencing dissent and perpetuating a climate of fear.

However, despite the regime's concerted efforts to control the narrative and suppress dissent, this study also reveals cracks in its façade of power and control. The resilience of opposition activists, the emergence of alternative narratives, and the growing discontent among certain segments of society suggest that fear-based politics may not be sustainable in the long term. As the regime continues to escalate its repressive tactics, it risks further alienating its own supporters and exacerbating societal divisions. It leads us to an idea that the politics of fear is not the only strategy that is used by the Russian government to induce the state of societal inaction. It is also the politics of pacification that is implemented.

In conclusion, the findings of this study underscore the urgent need for a nuanced understanding of fear-based politics in Russia and its implications for governance, democracy, and human rights. By elucidating the strategies employed by the government to manipulate fear and control dissent, this study contributes to a broader conversation about the nature of authoritarianism and the challenges of democratic resilience in contemporary Russia.

6. Conclusions

The exploration of the politics of fear in Russia through diverse methodological approaches has provided a nuanced understanding of the intricate ways fear operates across different segments of society. This comprehensive investigation highlights the role of politics of fear in shaping power dynamics, influencing individual and collective psychology, and contributing to the broader socio-political landscape. The findings emphasize the regime's strategic manipulation of fear to consolidate power, control narratives, and maintain societal cohesion. As Russia navigates its future, understanding the multifaceted strategies employed in the politics of fear becomes crucial for envisioning scenarios that may either perpetuate or challenge the existing dynamics, ultimately shaping the trajectory of the country's political landscape.
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Impact of the War in Ukraine on Global Environmental Security

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Abstract

The article examines the environmental consequences of the Russian-Ukrainian war and their impact on global environmental security. The authors consider various aspects of the ecological consequences of the war, in particular, local ecological consequences manifested in the growth of carbon dioxide emissions, the increase of specific waste, the pollution of water; environmental challenges of post-war reconstruction; the connection between military actions and the threat of global warming. The authors emphasize that the ecological consequences of this war will be felt not only on the territory of Ukraine, but also far beyond the country's borders, both in the short and long term. It is concluded that in the short term, the full-scale war of Russia against Ukraine resulted in an energy imbalance and a global crisis, in the long term, such a shake-up of the system will be able to accelerate the development and transition to renewable energy sources and bring the world closer to climate goals and reduce dependence on supplier countries fossil fuel.

KEY WORDS: *Russian-Ukrainian war, environmental consequences of war, global climate change, goals of sustainable development*

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1. Introduction

Environmental pollution is the least obvious but very serious consequence of war that cannot be underestimated. The war made Ukraine even more vulnerable. In addition to economic consequences, destruction of infrastructure and forced migration, the war causes serious direct and indirect environmental consequences, in particular, pollution of air, water and soil, as emissions from explosions, fuel burning and other sources enter the air as a result of hostilities; the destruction of natural ecosystems, because as a result of hostilities, significant areas of forests, steppes, meadows and other natural ecosystems are destroyed or damaged, which leads to the disruption of natural processes, the reduction of biodiversity and the deterioration of the quality of the environment as a whole; spread of diseases and pests through polluted air and water; an increase in the risk of man-made disasters, since as a result of hostilities, numerous infrastructure facilities, including damaged or destroyed oil refineries, chemical plants, and other facilities that may pose a potential threat of an environmental disaster.

The ecological consequences of this war will be felt not only on the territory of Ukraine, but also far beyond the country's borders, both in the short and long term. The war has a negative effect on the planet's climate, in particular, due to the increase in the amount of greenhouse gases in the atmosphere, which were formed as a result of the burning of fuel and other energy sources during hostilities; deterioration of the quality of life of the population due to air, water and soil pollution; a decrease in investment in renewable energy sources, which may slow down the transition to clean energy and lead to further increases in greenhouse gas emissions.

Although today there is no universal methodology for determining the amount of emissions caused by military actions, the assessment of the amount of fuel consumed by the military and the amount of greenhouse gases produced as a result of military actions is a significant factor in the success of international climate policy and the achievement of the UN Sustainable Development Goals and The goals of the Paris climate agreement. The restoration of Ukraine's environment after the war will be a long and difficult process. This will require significant investment and international cooperation.

Ukraine has undertaken a number of environmental obligations, both at the national and international level, and is trying to fulfill them. The fulfillment of these obligations is one of the factors of the success of the euro integration policy of Ukraine and ensuring the sustainable development of the country.

Researching the impact of the consequences of Russia's war against Ukraine on global environmental security is a complex task due to several key factors, in particular, the lack of data and access to the territory, the complexity of the impact, the long-term consequences of military actions at the local and international levels, the complexity of assessing the extent of damage, political and social factors etc. Military conflicts often make it difficult to access areas for sample collection and observation. The presence of danger for researchers and destroyed infrastructure can significantly limit the possibility of conducting field research. The Russian-Ukrainian war affects ecosystems in many ways, including direct environmental destruction, water and soil pollution, forest fires, biodiversity loss, and more. Studying and disentangling these different influences requires an interdisciplinary approach and the use of different research methods. The environmental consequences of war can manifest themselves long after the end of the conflict. For example, soil and water contamination with heavy metals and chemicals can have long-term effects on human health and the environment. Tracking such consequences requires long-term research and monitoring.

This war has already led to changes such as population displacement, land use changes and infrastructure destruction. Assessing the real extent of environmental damage requires accurate and detailed data, which are not always available in conflict situations. Political instability and social problems associated with war can also complicate research. For example, Russian troops restricted the access of representatives of international organizations, such as the IAEA or the Red Cross, to the Zaporizhia NPP or to Ukrainian prisoners. Developing appropriate methods for assessing and modeling the environmental effects of war is a challenging task. This includes the use of geographic information systems (GIS), remote sensing, environmental modeling, and other modern technologies that require specialized knowledge and resources. In general, the study of the environmental consequences of the Russian-Ukrainian war is a multidimensional task that requires the synergy of various scientific disciplines, access to reliable data, and consideration of numerous risk factors.

2. Method of investigation

The issue of studying the impact of the war in Ukraine in the context of global environmental security is complex and refers to the interdisciplinary field of knowledge in international security, ecology, international relations, and political science. This determines the methodological basis of the research, which is based on the principles of objectivity, multifactoriality and systematicity. Therefore, for the study of the phenomenon of global environmental security as a component of military actions, using the example of Russia's armed aggression against Ukraine, the most justified method is, first of all, the interdisciplinary method of discourse analysis, because it allows you to answer the following questions: first, what local environmental consequences will Russia's war against Ukraine have ; secondly, what are the environmental challenges of Ukraine's post-war recovery period; thirdly, what are the global environmental consequences of the war in Ukraine and how will it affect global warming; fourthly, what environmental obligations Ukraine has undertaken and how it is able to fulfill them during a full-scale war.

The study of the impact of the environmental consequences of the war in Ukraine was conducted using a systemic approach and its component as a political analysis, which gave a holistic view of the environmental consequences of military actions at the regional and international level. The application of the method of analysis and synthesis made it possible to systematize environmental challenges, as well as to assess their short- and long-term consequences. The method of document analysis made it possible to determine the key components of climate policy at the level of the UN, the European Union and Ukrainian climate commitments.

The empirical basis of the work was the basic documents of the UN and the Council of Europe [14] on the main directions of international climate policy, official documents of the Ministry of Environmental Protection and Natural Resources of Ukraine and the Ministry of Regional Development of Ukraine [1, 3, 13], analytical materials of ChatamHouse and the National Institute for Strategic Studies [4, 8-11], as well as studies of Ukrainian international environmental organizations [5-7, 12].

3. Investigation Results

Local ecological consequences of Russia's war against Ukraine. The obvious consequences of military actions in Ukraine are the loss of life, the destruction of houses, the destruction of civil and military infrastructure, mass migration, the deterioration of the economic condition of countries and the living conditions of the population. At the same time, military actions pose a threat to the environment of the country where hostilities are taking place. Russian troops are taking deliberate actions that cause man-made accidents and threaten the environmental security of millions of people who live far beyond the borders of hostilities.

Fighting and the need to build fortifications lead to the destruction of forests and other natural ecosystems. A decrease in the number of trees, in turn, leads to an *increase in carbon dioxide emissions into the atmosphere*. A calculation made by international researchers shows that in the first year alone, the war in Ukraine caused about as many emissions as a country like Belgium during the same period - namely 120 million tons of CO2 equivalents.

Due to the destruction of buildings and infrastructure facilities, both directly next to the contact line and throughout Ukraine, very large volumes of dust and greenhouse gases enter the atmosphere, which pollute the air and affect climate change. Emissions of carbon dioxide and other harmful substances contributing to global warming have increased significantly. This is provoked, in particular, by fires in forests, settlements, and fields; burning of oil and gas storage facilities, factories, gas stations; use of inefficient diesel generators; destruction of military equipment in large quantities; the use of military equipment, in particular tanks and combat aircraft, which produce harmful gases as a result of their work, etc.

According to Chatham House, during the first seven months of hostilities, about 100 million tons of carbon were released into the atmosphere, the share of emissions caused directly by hostilities amounted to 19% from the total volume of emissions, with the largest part falling on fuel consumption by the Russian and Ukrainian troops. Another 15% of emissions were caused by frontline fires [1].

As a result of military operations on the territory of Ukraine, numerous detonation products of rockets and artillery shells are released into the atmosphere. When projectiles hit buildings and structures, fires occur, due to which dangerous combustion products enter the air - mainly nitrogen oxide, heavy metals and gaseous compounds. In addition, due to the occurrence of fires in natural ecosystems and the burning of crops, forests and forest strips, emissions of soot and gas-aerosol compounds occur. Greenhouse gases are also produced due to the combustion of fuel as a result of the operation of aircraft, heavy military equipment, and rocket launches. All this leads to the fact that harmful compounds enter the atmosphere and useful components are destroyed.

Since the beginning of the full-scale Russian-Ukrainian war, Ukrainian pyrotechnics neutralize hundreds of munitions per day in the combat zone and in the de-occupied territories. In the occupied and de-occupied territories, heavy military equipment is moved through the forests, military units are located in the forests and active combat operations are conducted. More than 40% of forest fires in Ukraine are caused by shelling. The total area of forests affected by the war is approximately 3 million hectares, which is almost 30% of all forests in Ukraine. In terms of size, it is like the area of the whole of Belgium. Another 1 million hectares of forest were damaged in the occupied territories. According to the independent anti-corruption center NGL.media, "Since the beginning of the full-scale war, the Russian invaders have completely destroyed more than 600 km² of forests in the occupied territories, the cost of which was at least 350 million USD" [2]. Constant shelling leads to numerous fires and, as a result, harmful emissions into the atmosphere. Thus, emissions of carbon dioxide into the atmosphere have already amounted to almost 70 million tons, including 54.7 million tons from forest fires, 979.5 thousand from the burning of oil products, 11.9 million tons from the burning of other objects.

All these pollutions have negative consequences and they are divided into three different groups: *meteorological, weather and climatic*. Meteorological effects from hostilities change the optical and physico-chemical characteristics of the atmosphere (turbidity, formation of gaseous and aerosol substances, etc.). When talking about weather and climate, we are talking about various gas-aerosol impurities, soil particles and other combustion products that cause condensation. In turn, it leads to an increase in cloud cover, more frequent precipitation (including acid rain), and an increase in thunder and thunderstorms. Dark rains, which can form if the core of condensation is soot, should not be excluded. Instead, the period of exposure of these products ranges from several hours to several weeks, until they are completely "washed out" from the atmosphere. Taking into account that currently explosions and shelling in some regions of Ukraine occur constantly, the process of emissions can drag on for months.

This war caused a dramatic increase in the volume of specific *waste*, including damaged and abandoned vehicles and equipment, shell debris, construction debris, and household and medical waste. Some of the waste is quite toxic, especially shell fragments, medical waste and construction debris containing asbestos and heavy metals. According to the Ministry of Environment, the volume of such waste has already reached a scale not seen on the European continent since the Second World War. On the territory of Ukraine, there is more than 325,000 tons of destroyed Russian equipment [3]. In addition, huge volumes of waste from the destruction of residential and transport infrastructure were created, which is a new challenge for the country. According to preliminary estimates of the Ministry of Development of Communities and Territories of Ukraine, Russian troops destroyed about 6,800 residential buildings. Only in the de-occupied territories of Kyiv, Chernihiv and Sumy regions, about 15.2 billion tons of waste was generated from the destruction of buildings and structures due to the actions of the Russian Federation. More than 200,000 cars and trucks destroyed in Ukraine during hostilities are now stored in specially designated places. The longer such waste remains on the territory of Ukraine, the more damage it will cause to the environment, polluting the soil, water, and air, as well as causing additional emissions of greenhouse gases, which will have a negative impact on global climate processes. At present, work has begun to clean the territories of destruction waste where possible. Thus, according to the report "Ukraine: rapid assessment of damage and needs for restoration" [4], 5% of garbage trucks, 17% of biogas plants, and 9% of sorting lines were destroyed and damaged in the country. Direct losses in the field of waste management - 95.36 million dollars. In the United States, the estimated cost of removal of construction debris and rubble is $320.7 million. USA, and the loss of profits of waste disposal enterprises is estimated at 11.9 million dollars. USA. Such calculations were made only for certain regions of Ukraine, including the territories of Donetsk, Luhansk, Kharkiv, Kyiv, and Chernihiv regions, but they make it possible to estimate the overall scale of potential losses in the entire territory of Ukraine. Given the fact that the post-war reconstruction of Ukraine should not copy the pre-war structure of the economy, which was based on fossil fuels, was inefficient and polluted the environment, scientific research aimed at creating favorable conditions for the introduction of effective trends and technologies for waste processing is of particular importance today wars for their reuse.

According to the experts of the National Institute of Strategic Studies, in the short term, for the effective management of war waste, Ukraine should focus on eliminating and reducing immediate risks to human health and the environment. The preparation and implementation of comprehensive environmental cleanup measures, especially related to the collection, safe disposal and management of huge amounts of military and other waste, will make it possible to reduce the immediate risks to public health. In the long term, the management of war waste should be subordinated to the task of developing an ecologically clean, "green" economy in Ukraine [5]. The problem of preventing ecological threats to the environment due to the Russian full-scale invasion requires special attention from domestic specialists and the world public. Today, those crimes against nature that take place in the combat zone are defined by experts as *ecocide* [6]. The largest of them is the explosion of the Kakhovskaya HPP dam, which occurred on June 6, 2023. This is the biggest man-made disaster in Ukraine since the explosion at the Chernobyl nuclear power plant. Aquatic ecosystems were the most affected by this ecocrime. The "Let's do i Ukraine" team, with the support of the Ukrainian Scientific Center for Marine Ecology, conducted three environmental missions last year to study the effects of the Kakhov disaster on water bodies. During the missions, water samples were taken from reservoirs, wells, as well as samples of bottom sediments from the Dnipro River, flooded areas, and the Dnipro-Buzka estuary. Samples from the Dnipro near Kherson, the Dnipro-Buzka estuary, the Black Sea near Ochakov, and samples from the Odesa Bay showed the same pollution structure. At all these stations, the content of petroleum products, toxic metals (zinc, cadmium, arsenic) and organochlorine compounds exceeds the maximum permissible concentrations. Metals such as zinc and cadmium are toxic to many species of aquatic organisms, especially at high concentration levels. The results of the research will also be used as part of criminal proceedings conducted by the Specialized Environmental Prosecutor's Office of Ukraine and the Main Investigative Department of the Security Service of Ukraine. Figure 1 shows the Kakhovskaya HPP a day before the dam destruction and a day after.

(a) (b)

Fig. 1 Kakhovskaya HPP on June 5, 2023, the day before the dam breach: (a) (left) and (b) Kakhovskaya HPP a day after the dam breach, on June 7, 2023 (right). Source: https://www.bbc.com

Water. Even before the start of the full-scale war, Ukraine had a shortage of water resources. In 2019, Ukraine ranked 125th among 181 countries in the world in terms of available drinking water reserves. According to experts, the southern, eastern and some central regions of Ukraine are already critically short of water reserves, and the drought of 2020 was one of the most severe in recent decades. It is clear that climate change will continue to worsen the water supply situation. Russian aggression became a significant challenge for agriculture due to soil pollution, destruction and damage of agricultural machinery, and constant shelling. According to calculations by the Kyiv School of Economics, the repair and replacement of the irrigation infrastructure alone in the affected regions will cost 225 million dollars. USA [7]. The occupiers' forced withdrawal of Dnieper water from the Kakhovsky Reservoir and its supply to Crimea in violation of technological requirements had a negative impact on water availability in the region. It is impossible to fully assess the losses, because the Kakhovskaya HPP was under occupation before its detonation. These losses are not compensated by natural hydration.

3.1. Environmental Challenges of the Period of Post-War Reconstruction of Ukraine

Emissions. According to estimates, the largest share of emissions will be caused by post-war recovery, when power plants, industry and buildings will have to be rebuilt. The construction sector, which uses a large amount of concrete, is generally one of the sectors with a very high level of greenhouse gas emissions.

Waste. International and European experience shows that it is possible to reuse certain types of war waste, destroyed objects and property. For example, after the Second World War, the reconstruction of Warsaw was accelerated by the use of materials that remained after the end of hostilities. In particular, undamaged whole bricks were reused, and construction waste was crushed into concrete. Today, in countries such as Denmark, the Netherlands, and Germany, builders are required to use a certain percentage of products from recycled waste. In the Netherlands, there has been a law for about ten years that prohibits the disposal of recyclable construction waste to landfills. Such experience is particularly important for Ukraine. Given the fact that the post-war reconstruction of Ukraine should not copy the pre-war structure of the economy, which was based on fossil fuels, was inefficient and polluted the environment [8], scientific research aimed at creating favorable conditions for the introduction of effective directions and technologies with processing wastes of war for their reuse. At the same time, in the short-term perspective, for the effective management of war waste, Ukraine should focus on eliminating and reducing immediate risks to human health and the environment, and conducting comprehensive measures to clean up the environment. In the long term, the management of war waste should be subordinated to the task of developing an ecologically clean, "green" economy in Ukraine.

Water. Even after the end of hostilities and restoration of the irrigation system due to climate change, the volume of fresh water in most river basins of Ukraine will continue to decrease. This means that the country's agriculture will constantly experience a shortage of water, and therefore it is critically important to adapt it to climate change, taking into account the decrease in water content of rivers and the issue of water security in the region. Therefore, water resources in Ukraine are threatened not only by the actions of the occupiers, but also by climate change. It is obvious that post-war reconstruction must take into account not only the consequences of hostilities and occupation, but also the negative impact of climate change. After the restoration of peace, it will be necessary to restore a controlled and technically correct water supply to the Crimean Peninsula. It will also need to be taken into account when rebuilding agriculture, in particular, irrigation systems, in order to ensure the Crimeans' need for water and have a minimal impact on the irrigation of fields in the regions dependent on the Kakhovsky Reservoir.

3.2. Global Environmental Consequences of the War in Ukraine and the Threat of Global Warming

The ecological impact of the Russian Federation's war against Ukraine is not limited exclusively to the territory of Ukraine. Inger Andersen, Deputy Secretary General of the United Nations, Executive Director of the United Nations Environment Program, said that "countries directly bordering Ukraine are aware that the war waged by the Russian Federation has a cross-border impact on nature" [9]. She believes that the pollution of the Black Sea, the Dnipro River or the air should cause concern for all those who could potentially be affected by such an impact, since forests run across the border, water flows into a neighboring country, water-bearing arteries are connected underground, the marine environment and winds are not subject to human control. This situation calls for additional research into cross-border impacts.

The war aggravated the issue of international food and energy security, in particular, due to periodic blockades of food exports from Ukraine through the Black Sea. Global energy independence, which is a prerequisite for international political security, has experienced significant challenges. Although EU countries are attracting additional resources to get rid of energy dependence on the Russian Federation, in the short term there is a risk of delaying or canceling actions to reduce their carbon footprints and return to fossil fuels. But on the other hand, military aggression is an argument for the gradual reduction of dependence on fossil fuels. With international help, post-war Ukraine can rebuild its damaged infrastructure and take a step forward to a more sustainable, cleaner, low-emissions future [1].

The biggest climate challenges for humanity in this century are the reduction of biodiversity, overpopulation and global warming of the planet, which leads to the mass extinction of species, the reduction of useful resources for maintaining a normal standard of living and threats to the existence of humanity. The war on the territory of Ukraine significantly increases the negative effect of these challenges.

Man has disturbed and changed the ecosystems of about 70% of the surface of our planet. Since the advent of agriculture, the biomass of terrestrial vegetation has halved, and 20% of its original diversity has been lost forever. Another 20% of all species are threatened with extinction within the next few decades. War accelerates the process of extinction because war destroys ecosystems - steppes and fields are bombarded with artillery, forests are burned. As a result, all this leads to the death of plants and insects typical for these areas, as well as large animals such as mammals and birds. The area becomes unsuitable for their existence, and new places are occupied by invasive, more aggressive species for which eruptions from explosions are a favorable place for reproduction, and for other plants such soil will be unsuitable, which will further accelerate the capture of our territory by harmful plants.

Another problem, which, at first glance, is not related to war, is the overpopulation of the planet. Of all the animal biomass on Earth today, the majority is represented by livestock (59%) and humans (36%), and only about 5% of this total biomass is wild mammals, birds, reptiles, and amphibians. By 2050, the world population is likely to increase to 9.9 billion. In the end, this will lead to a need for so many resources that our planet simply will not be able to satisfy it. According to experts, the war is directly related to the overpopulation of the planet, since the use and destruction of natural resources during military operations occurs much faster. The main "resource" in Ukraine in economic terms is soil. If earlier they were fertile, which was the reason for the active development of agriculture, now more than half of all territories in Ukraine are arable land. War directly destroys fertile soil as a resource because fertile topsoil cannot be formed on arable land. The most fertile soils - chernozems - are formed under perennial natural vegetation, and the shelling that takes place in the fields literally leaves "chemical burns" on the ground, since the explosion is a chemical reaction. Charges also contain heavy metals and sulfur, which accumulate in the environment and lead to various harmful effects, such as mutations. Therefore, in the context of war, "scorched earth" means not only fires, but it is an acid-scorched earth, when everything that lives in the soil, plants, seeds, roots, everything is burned in the acid. Therefore, resources, in particular, clean water, a habitable atmosphere, fertile soils are the result of the activity of living organisms that reproduce these resources.

Greenhouse gases formed on the territory of Ukraine as a result of military operations will directly affect global warming. The military is one of the largest emitters of greenhouse gases in the world. Due to the war, the military industry is growing, which is very energy-intensive and additionally emits greenhouse gases into the atmosphere. Such emissions will have significant climatic effects, because in terms of volume, they can affect entire regions in terms of several months to several years [10]. On the one hand, much data on fossil fuel consumption and carbon dioxide emissions from military equipment is confidential. On the other hand, many countries, including NATO and the EU, have announced plans to become climate neutral by 2050. The war in Ukraine may negatively affect these plans. During the UN Climate Conference COP27 in Egypt, the leaders of the EU countries emphasized that the climate transformation was complicated by the aggression of the Russian Federation against Ukraine, which led to huge human losses and caused damage to the environment. In the conditions of war, harmful emissions entering the air increase several times. For example, during fires that regularly occur in cities, industrial facilities and chemical plants due to shelling, a large amount of organic substances, black carbon, carbon dioxide and nitrogen dioxide enter the air, which harm the planet and significantly accelerate global warming. Forest fires also accelerate this process. According to estimates, more than 100,000 hectares of forests and grass ecosystems were destroyed by fire in the first year of the war. The area of fires continues to increase.

According to the UN, the war of the Russian Federation against Ukraine may disrupt the achievement of the goals of slowing global climate change and the Sustainable Development Goals, and the consequences of the war create a risk of destabilization of the world food and energy markets. The sharp increase in greenhouse gas emissions was caused by the accident and leaks from the Nordstream pipelines and emissions produced by long-haul aircraft over Asia after the imposition of sanctions against Russia. Damage to the Nord Stream pipelines created a 700-meter pool of boiling water in the Baltic Sea. According to estimates of German experts, about 300,000 metric tons of methane, one of the most powerful greenhouse gases [11], entered the atmosphere as a result of the emissions. Germany's Federal Environment Agency estimates that this amount of gas will have roughly the same impact on the climate over 20 years as the annual emissions of more than 5 million cars in the United States. However, these emissions mostly moved to other countries. In addition, the decrease in CO2 emissions in Europe due to the decrease in the use of natural gas and the energy crisis is almost completely offset by the increase in the use of oil, coal and liquefied natural gas. [12].

3.3. Environmental Obligations of Ukraine

In 2021, Ukraine voluntarily undertook to reduce greenhouse gas emissions. But as a result of Russian aggression, funds that were planned to be spent on energy efficiency, a green economy, renewable energy sources, the creation of new nature reserves and the preservation of species are now being spent on military actions, which experts define as wasted opportunities. The government of Ukraine admits that Russia's war against Ukraine is accelerating climate change and causing an increase in greenhouse gas emissions. The strategic goal of the country's post-war reconstruction is a clean and safe environment, compliance with the principles of the European Green Course, and the reconstruction of the economy according to the principles of sustainable development. To date, the Ministry of Environmental Protection and Natural Resources of Ukraine has finalized the Climate Law of Ukraine, which should cover all directions in the field of climate policy formation and implementation; completed work on a plan of measures to implement the updated Nationally Determined Contribution of Ukraine to the Paris Agreement. The ministry stated the importance of the discussion at the international level regarding the impact of the Russian-Ukrainian war on the climate, so that this issue is reflected in the annual reports of the Secretariat of the UN Framework Convention on Climate Change.

For Ukraine, an effective climate policy is directly related to the country's Euro integration policy and green reconstruction [12]. In the current difficult conditions, Ukraine continues to implement practical measures of climate obligations, in particular, the national system for monitoring reporting and verification of greenhouse gas emissions has been updated and improved; a pilot emissions trading system is planned to be launched in 2025 with a full launch in 2026, which will allow the country to join the European ETS; together with German partners, the Climate Office in Ukraine was opened as a platform for cooperation within the framework of the Paris Agreement and a tool for attracting investments for green reconstruction; Ukraine's readiness to participate in the carbon market was announced.

To update the issue of the environmental consequences of war and its consequences in the context of adaptation and overcoming the consequences of global climate change, Ukraine uses authoritative international platforms, in particular, the 28th UN Climate Change Conference, which became the largest in the history of UN climate conferences. Climate policy of Ukraine. Among the main environmental issues that became relevant due to Russian aggression, the "Aggressor refunds" initiative should be singled out - a mechanism for compensating the aggressor for damage caused to the environment and climate as a result of armed conflicts and the inclusion of this mechanism in the Paris Agreement [13].

4. Conclusions

Full-scale Russian aggression against Ukraine will have very serious negative consequences for the ecosystem of the country and the region, both in the short and long term. This war is taking place at a time of global climate change, which may also exacerbate negative climate trends. For Ukraine, the war is certainly an existential threat, but it also increases environmental degradation and creates new problems that may affect the global ecology of Europe and the world in the future. Since the beginning of the large-scale invasion of Russian troops into Ukraine, the state's environment has been under the constant destructive influence of new threats to environmental security. The active phase of hostilities in Ukraine due to Russian armed aggression, which negatively affects the ecological security of Ukraine and the countries of the region, can become one of the leading factors of climate change and disrupt the achievement of climate goals determined at the highest international level. In addition, the consequences of the war create a risk of destabilization of the world food and energy markets. While EU countries are raising additional resources to break their energy dependence on Russia, there is a risk of a return to fossil fuel dependence, narrowing the window of opportunity to limit global temperature rise. On the other hand, although in the short term the full-scale war of Russia against Ukraine resulted in an energy imbalance and a global crisis, in the long term such a shake-up of the system could accelerate the development and transition to renewable energy sources and bring the world closer to climate goals and reduce dependence on fossil supplier countries fuel. The global ecological consequences of the war in Ukraine are complex and multifaceted. They affect all aspects of life on the planet, from people's health to the state of the climate. In order to minimize the negative consequences of the war and promote the restoration of the environment, it is necessary to take comprehensive measures at the international level. It is important to understand that the environmental consequences of the Russian-Ukrainian war may be felt for decades, and some of them may be irreversible. Therefore, combating climate change and restoring damaged ecosystems are among the most important tasks for all of humanity.

5. Limitations

Emissions caused by military operations in peacetime and during hostilities have only been partially investigated. Given the fact that such emissions can reach hundreds of millions of tons of CO2 per year, a more thorough assessment of the direct and indirect climatic consequences of war is necessary. This requires including all wartime emissions in the global tally of greenhouse gases. At the same time, today there is no standardized procedure for measuring greenhouse gas emissions by armies, and military emissions are excluded from the Paris Agreement on climate protection. Therefore, the introduction of new approaches and the creation of methods for calculating environmental damage from military actions and their impact on global climate change remain relevant. The research challenge is that, on the one hand, greater transparency can strategically weaken armies, but on the other hand, establishing common standards for assessing the environmental consequences of military actions should contribute to the successful implementation of the European "New Green Deal."

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Cross-Cultural Comparisons for the Analysis of Disinformation in a Geopolitical Context: Case of Ukraine

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Abstract

Cross-cultural comparisons are a valuable tool for analysing disinformation in a geopolitical context due to the increasing interconnectedness of the world and the spread of information across different cultures and societies. By examining how disinformation campaigns manifest and are perceived in various cultural contexts, researchers can gain insights into the underlying motives, tactics and effects of such campaigns.
Disinformation has become a systemic challenge to society due to a combination of disruptive technological, political and sociological transformations of social spheres in a very short period. In addition, the geopolitical zeitgeist, which focuses on the vulnerability of democracies to structural changes in the security order and the risks of global interdependence, reinforces the tipping point effect.

KEY WORDS: *Cross-cultural comparison, geopolitical context, disinformation, war, information.*

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6. Introduction

Cross-cultural comparisons are a valuable tool for analysing disinformation in a geopolitical context due to the increasing interconnectedness of the world and the spread of information across different cultures and societies. By examining how disinformation campaigns manifest and are perceived in different cultural contexts, researchers can gain insights into the underlying motives, tactics and effects of such campaigns.

Disinformation has become a systemic challenge to society due to a combination of disruptive technological, political and sociological transformations of social spheres in a very short period. In addition, the geopolitical zeitgeist, which focuses on the vulnerability of democracies to structural changes in the security order and the risks of global interdependence, reinforces the tipping point effect.

Disinformation, mis- or misleading information, is an ever-developing phenomenon, that affects a large share of the public. Driven by the digital age, it is mainly spread online by state and non-state actors which complicates the battlefield by necessitating the inclusion of personalization techniques within the tactical arsenal. There are numerous classification systems in existence, if we are to evaluate disinformation from an ideological point of view, it would be tough to distinguish between misinformation and differently slanted interpretations due to the indefinability of truth within historical or opinion-based topics [2].

1.1. Background of Cross-Cultural Comparisons

The very concept of how people understand and respond to disinformation is different from one individual to another. Cross-cultural researchers state that different people's perceptions about events that pose traditional questions constitute various "truths" and can be mutually unintelligible to one another. In particular, communication as one type of crucial information factor of influence is particularly receptive to influences of social and cultural self-learning–cognition and information processing among people of different societies. Political communication systems and traditions are themselves different depending on the country, which is expressed in the different types of communication as control forms, audiences, and political actors of possibilities and restrictions that can be implemented.

The development of the Internet has led to the rapid spread of disinformation, thereby giving rise to what has been termed an 'information warfare'. Disinformation is a specific type of false and misleading information that is spread, without any formerly contained intentions in mind, for ideological, political or economic manipulation. The more the Internet and related electronic media products and services provided opportunities to access disinformation, the more they became tools of informational influence and the so-called propaganda-building strength. According to recent studies, people who receive news primarily through social media express higher levels of concern about ever-increasing disinformation than those receiving news from other sources [3]. Two of three individuals doubt the ability to recognize misinformation themselves and understand the above-mentioned definition. Indeed, the Internet and social media are now an integral part of informational waves that have an impact on all the limiting parameters of disinformation, including who is disinforming who, about what, and for what.

1.2. Importance of Analyzing Disinformation in a Geopolitical Context

In 2007, Estonian government and business websites experienced cybernetic attacks which paralyzed the functioning of many web pages and services. As a response, Tallinn declared that Russia's government was behind the attacks, and ever since, the term "cybernetic weapon" has appeared in official documents and statements released by numerous state officials. The pro-Russia disinformation and propaganda ecosystem often includes news outlets and websites, as well as ordinary users, bloggers, public figures, and opinion leaders. Kremlin-funded network Russia Today is often required to give a platform to Ukrainian interests or to convey aspects of Ukraine positively. Given the failures of the Busse-Orban Commission, the language of neutrality and apoliticism in European media, and the Cold War Shatter Zone created by demagogic domestic and sub-state actors alike, disinformation is an old, new thing in the International System. European online media pathologies, in particular, are many, and they fall outside the gamut of disinformation as defined by the EU. They can be summarized, however, under the three of Mearsheimer's outcomes [4].

In the online world, the lines between news and disinformation often become blurred. Both the Russian government and the Ukrainian government had incentives and opportunities to push false narratives in the wake of the Malaysia Airlines flight MH17 crash in 2014 and during geopolitically charged events. Disinformation is a political tool used by Moscow and Kyiv, and it exists in both Ukrainian- and Russian-language contexts [5]. The disinformation ecosystem of Ukraine must be viewed as interconnected for the three following reasons: first, the level of knowledge of the Ukrainian and Russian language is very high in both countries; second, the two countries' often intertwined histories lead to a situation where disinformation often becomes internalized as information; and finally, disinformation is produced by both sides of the conflict in the Ukrainian and Russian languages and directed at very similar audiences. Russia's role in the disinformation war in Ukraine—and the protection of the information space with anti-Russian legislation—is a common target of Russian disinformation. The Ukrainian government's approach to labelling of Russian disinformation is creating internal information filters in Ukrainian society [6].

2. Methodology

Corpus Construction [1]. The goal is to construct ideologically engaged pro-Russian and anti-Russian corpora and intend difficulty to distinguish between them. Corpora with implicit, oppositional perspectives are primarily intended to be used for studying propaganda, i.e., as resources for analysis of "informational warfare." Methods for corpus construction are algebraic models for the estimation of word distribution similarity and an educated guessing process as a method for quality control. Sources have been selected as a consequence of geopolitical strategy postures, such as supporting positions of Russia in the current conflict zone or Europe-aligned informational policy or geopolitical balance. Through such selection, the dataset has become somewhat partially geo-politically biased, i.e., some sources dislike Russia, while others primarily cover informational issues and feature news about Russian military, political or social interests as well. Combining Qualitative and Quantitative Insights [7]. Combining the qualitative process of media coding with the computational processing of textual data allows us to combine both the distinct benefits of quantitative research (allowing a representative view of textual data to emerge) and qualitative research (providing contextualized, situated interpretations of that data). This is a valuable synergy for geopolitical disinformation studies given the relationship between subtle framing elements of articles and overt news framing narratives. Thus, it makes sense to combine both modes of analysis in this domain. Computational content analysis creates automated procedures that analyze content, while manual content analysis focuses on human experts who are engaged in a systematic procedure for analyzing message content. Existing research combines qualitative and computational approaches in news studies.

Media Ecosystems on Global and Local Levels [8]. Over the last several years, social media and search engines have served as platforms not just for information, but for manipulated information, disinformation and propaganda. Social media's business model, which encourages content to spread further and faster by encouraging "clicks," is often understood to be an exacerbating factor in the information pollution that is present online. The global information ecosystem means that false information and erroneous journalistic coverage in one country can quickly spread to others. That does not mean that on-the-ground data collection and analysis cease to be important: On the contrary. However, it means that supplementing with global data and content analysis becomes increasingly critical.

2.1. Selection of Cross-Cultural Comparison Approach

The comparative method seems to be the handiest way to analyse the layperson's disinformation believability in terms of the role of traditional news media, levels of Facebook use, and conspiratorial beliefs about the conflict in Ukraine. The work is innovative by introducing two important variables in comparative political science: confidence and optimism people hold in the mediation capabilities of classic journalistic storytelling along with disinformation content [9]. There is also a lack of cross-national comparisons in the context of disinformation believability because of the short period from the beginning of the Russian-Ukraine war. Cross-cultural comparisons can be conducted using different approaches, and one of these is the comparative historical approach. The reason for examining historical context stems from the necessity of understanding the effect and the depth of the path and period dependencies among the nations. Despite its benefits, the comparative historical approach was not chosen due to the lack of accessible data in all countries and under all historical circumstances. Consequently, the cross-sectional approach was chosen for this study. This approach is advantageous also in terms of measuring and comparing international differences. Political science literature has also used a longitudinal approach to observing sustainability and change over time across nations. A short period from the beginning of the war was available for both of the method mentioned above, and a multiwave strategy was not possible. These facts narrowed the choice to the cross-sectional approach.

The rapid spread of fake news across different regions has forced media and political scientists to grasp convincedness about the key factors at play – amount, target group, intensity, channel, et cetera [3]. The issue of disinformation has become even more critical by wrangles over the Russian-Ukraine war. The following research in its turn seems to be incomplete without consideration of its findings beyond the borders of Ukraine to provide a comprehensive outcome. This study advances cross-national comparison of disinformation in a geopolitical context with a focus on Ukraine. Aim of the paper is to discover differences named in each theory by providing an example from the case of the Russian-Ukraine conflict [6].

2.2. Data Collection and Analysis Techniques

The main method of disinformation was its natural inclusion in the mass of news without proper verification of facts. The general impression was created that its volume and frequency had already decreased, however, concluding based on primary data should be cautious, since disinformation is a very peculiar phenomenon, even in the case of its operators.

At the next step, a search and analysis of relevant articles, as well as monitoring of information flows (presidential Facebook pages, main news agencies, Twitter), were conducted. Requests for which disinformation could be disseminated were divided into three directions: the internal one - the Republic of Ukraine, the near (close) foreign one - the countries of Western Europe, near, close the European Union, away foreign - distant sector, generally Asia, America (North, Central, South), Oceania, Africa. So, the analysis and monitoring of information were carried out over several years. The sources of disinformation gradually changed from the Russian Federation mainly to local, predominantly Ukrainian ones. Each direction was characterized by its specifics: for Ukraine - the entire mass media field, for the next foreign - in particular, official pages of states and political leaders, news agencies that are spread in Ukraine, and away foreign - societies of countries.

The main idea of the article to analyze the structure of disinformation in the geopolitical context of different countries. There are have recent conflicts with the Russian Federation [5]. Kazakhstan, Moldova, Georgia, Ukraine, Latvia, Lithuania, Estonia, Kyrgyzstan, and Poland were chosen for the analysis [10]. About 80 articles covering the Russian-Ukrainian conflict since 2014 have been reviewed, highlighting the key elements of topics that have been attacked with disinformation. After that, we identified 5 dominant topics: the Ukrainian crisis, the MH17 disaster, the Association Agreement between Ukraine and the EU, the rights of Russian citizens in the Baltic States, and Ukraine as a threat to the linguistic identity of Russians in Ukraine [11].

3. Case Study: Ukraine

One insight from our study that is crucial for policy implications is that the contemporary disinformation campaign on Ukraine, though repackaged, was started by a Russian disinformation campaign in the 1930s aimed at Ukraine's original attempt to gain independence from the Soviet Union, similar to what is happening now in its attempts to achieve independence from Russia now [12].

There are three interlinked threads in our analysis: 1) Ukraine and Ukraine's fraught history with Russia, and how it is remembered; 2) the Soviet disinformation campaign, when Ukraine threatened to secede from the Soviet Union in the early 1930s; 3) anniversaries and other presentations of history. Indeed, Putin and Trump during their first-ever meeting in 2017 both referred to their understanding of Ukrainian-Russian history. In this context, much of the Russian disinformation campaign against Ukraine is viewed through the lens not only of political reasons but also of historical and cultural reasons. These motives, in turn, cannot be disentangled from an analysis of Russian domestic and international politics in the resisting of minority cultures. Understanding eight decades of disinformation, including the Soviet and Russian versions, is indispensable to unmasking what the New York Times called "a week of wholesale mythologizing" that reached from Moscow to Silicon Valley.

The disinformation campaign surrounding the Ukraine Crisis and its annexation by Russia provides a rich context for testing theories and hypotheses from the existing literature on disinformation. We demonstrate how to use spatiotemporal analytics to uncover patterns in the spiral circulation of false and true narratives about the annexation of Crimea. This research can help policymakers understand Russian information operations and strategic communication activities and tailor interventions in response. Russia's disinformation campaign justified the annexation of Crimea by spotlighting Ukraine's involvement with fascists and stereotyped Ukrainians as "nationalistically obsessed with the past" [14]. Subsequently, o lot of articles were written by news organizations, and bloggers, and automatically-generated content that shared on social media. Researchers of Putin's disinformation campaign have largely focused on the Russian diaspora's use of established social media, but we find that it had more success on Facebook. This is due to the demographics of those who came by and engaged with these materials: those sharing Russian disinformation are disproportionately older Americans, many of whom may not use Twitter.

Misinformation, and especially disinformation, is a crucial global and interdisciplinary problem that has gained significant attention from both academic and practitioner communities. Academically, the problem has given rise to several issues of interest to computer science, communications, and information sciences [15]. Previous studies have looked into the spread and impact of true and false information, Sarah Amdor et al. [13] the factors that influence the spread of information, and the effectiveness and intent of fact checks and debunks. Practitioner communities have focused predominantly on how to recognize false information at scale and how to debunk information quickly and effectively. Despite the attention that the problem of miss-and disinformation has garnered, we still know little about the factors that lead to the widespread and sustained belief in false news/narratives.

3.1. Overview of the Geopolitical Context in Ukraine

Due to the increase of hybrid threats and the EU's weak political support for the Association Agreement with Ukraine, such geopolitical reality became evident. The Ukrainian government does not have opportunities to mobilize wide public support for its reform that occurred in 2010-2019. Ukraine started to react to its public trust-shaped crisis when the Kremlin's expected victory in the 2019 Ukrainian presidential election was postponed. The Ukrainian leadership determined NATO membership and resistance to the Russian World's normative or ideational security is national security (Hartmann et al., 2019). Initially, President Volodymyr Zelensky acted with caution towards the pro-Western direction his country had taken. Instead eastern hypercritical foreign and domestic policy was formed regarding Russia. The geopolitical campaign was mainly targeted the European and American digital public opinion with two goals to be achieved: to gain international and domestic political support and reparations and also a wider use of dis- and mis-information in Russian-speaking information spaces to destabilize Russia to make it become a second order actor in the world.

The strategic failure of Russia and the United States stemmed from the inability of the deferred security architecture to adapt to the changes in the global military-political situation, including those related to the changes in the troops numeral dynamics in the Northwest limits of Russia and NATO due to the eastern enlargement NATO and Ukraine [6]. The regions of Donetsk and Lugansk and Kherson are strategic area important for trade with Crimea. The Azov Sea regional depth has significant naval values for merchant and military ships, and we have two gas pipelines and two under-construction connections to Crimea. The Crimea Peninsula's strategic location in the Black Sea is also quite advantageous as a naval base for the Russian Black Sea Fleet. Being strategically important for the world and the name which Russia has been calling it, Crimea has been under the sovereign of the Russian Federation since 18 March 2014 thanks to the 16-March-2014 referendum.

Following the collapse of the Soviet Union and the Zbigniew Brzezinski doctrine of 1997, Ukraine was considered an independent geopolitical player by the United States, which encouraged its development. In Russia, the strategic bipartisan consensus on Russia's support for Ukraine and its independence continued in 1991-2014 [17]. However, during the Obama presidency, Washington began to abandon this course, while Russia showed willingness to use military force in the region. In 2014, this led to the annexation of Crimea by Russia, which, for the geopolitical context of the United States and Russia, became a new phase of confrontation.

3.2. Analysis of Disinformation Campaigns in Ukraine

The aim of this article is to present the similarities and differences in disinformation campaigns carried out using social media during geopolitical conflict in Ukraine, analyzed by means of mixed methods – qualitative, quantitative, both manual and algorithmic. Disinformation techniques (conspiracy theories, fake news, appeals to fear) were discovered through manual analysis of a selected dataset of posts. The content analysis was supplemented by presenting the number of followers and interactions achieved by posts containing disinformation narratives detrimental to national security, so as to assess their potential reach. The real and assumed intentions of the propagators and targets of fake news were reconstructed and compared and the scope of the abovementioned posts was estimated between March 21, 2022, the day of the declaration of the beginning of the special military operation on Donetsk by the Russian president, and April 15, 2022. The study concerns posts on selected Western and Russian social media, both in Russian and in English, Facebook and VKontakte included.

Disinformation, which is presented as information obtained through public sources and intended to mislead, has been inseparably linked with the military conflict between Ukraine and Russia [11]. According to the content analysis of Russian sources in Chinese publications, one of the narratives suggests that the war is waged by and between the ruling elites, and is not fueled by and does not claim people's lives [8]. Research carried out on the contents of posts of conspiracy nature translated from one of the foreign languages revealed that the authors urged to be critical, to effectively verify the sources and to carefully select information channels at the outbreak of geopolitical conflicts [9]. The publications empirically demonstrate differences in the tone and sentiment in the narratives covering the same event by Western, Russian and Chinese state media. The significant number of fake Russian Facebook pages created to distribute disinformation propaganda focused on Ukraine and its NATO aspirations was detected and removed by the Facebook security team.

3.3. Cross-Cultural Comparison of Disinformation Tactics in Ukraine

The research discovered significant interaction between disinformation and debunks in absolute terms as well as in natural units. This indicated certain effectiveness of debunking retweets on traditional Twitter. There are six fundamentally distinct themes equally present in the engagement and activity of debunked disinformation and debunks in terms of real data. There is a logic to this and it is important to answer the fundamental question about the reasons and purposes of spreading disinformation. This can be seen as a stage for some states, particularly developed authoritarian regimes, to test the mass public including international in order to create handy grounds for more dangerous for international stability political moves and military initiatives aimed to seriously revise existing world order.

Ukraine has the most developed system for combating disinformation initiatives, but the general dilemma for it and Russia as well is whether they should be ideologically dominated or fact-checking-based. Other states would prefer a broad range of engagement to debunk disinformation rather than general fact-checking [18]. Disinformation should always be contrasted with real data. If it can obtain wider coverage than disinformation, then the effect of debunking will be greater. Scholars are welcome to operationalize these theories and to test their predictive power in different settings and contexts in various countries and regions of the world.

The origins of disinformation go back centuries and deeply differ according to the geo-cultural heritage of the state that uses it. For instance, Russian disinformation is rooted in the anti-Western propaganda of the Soviet Union and the USSR's antiglobalist slogans [15]. Ukrainian propaganda mostly focuses on the promotion of pro-European and pro-NATO ideas striving to contrast their advantages with diminished Russian projects. The characteristics and areas of usage of disinformation therefore greatly depend on the most perceptible threats to a state and its citizens, so they should differ [14].

4. Conclusion

In the conclusion, two main findings are noted. Firstly, the geopolitical conflict has a powerful impact on the acceptance of disinformation, not only in the case of the ruling party and its electorate but also on the entire Hungarian and Ukrainian population. This is an element that has not yet been substantially researched in the literature on disinformation. Additionally, the two countries compared mirror each other. Sometimes the same scenario, expressed in a different combination of disinforming components related to a given country and its geopolitics, is used to disinform the population. Nonetheless, in both countries, citizens are more affected by the local conflict - Hungarians by the conflict in Ukraine and Ukrainians by the conflict with Russia - than by the conflict between Hungary and Ukraine. Information about local events and activities by neighbouring states is very important, but also very scarce in the countries' media landscape.

The situation is very similar in Hungary, where the ruling conservative party has been in power since 2010. An attack on democratic institutions and freedoms later transformed into the deployment of disinformation in Hungary. According to many dailies and weeklies, Hungary is now an informational autocracy; the ruling party and its government are using all the propaganda and state media tools to serve the party and the government. Pro-government news outlets in Hungary also try to influence the public through disinformation; they lead systematic disinformation campaigns and broadcast pro-Kremlin propaganda [19].

Ukraine is currently one of the most important proving grounds for disinformation within the context of conflict, and our research included this Eastern European country as a case study. During the invasion of Crimea in 2014 and the subsequent armed conflict in the east of the country, a protracted information war began, in which both sides to the conflict waged a disinformation campaign, and all resources to inform the population, including the media, were weaponized.

In this research, we examined the issue of disinformation in the context of geopolitical conflicts, drawing on empirical research from Hungary and Ukraine. We focused on cross-cultural comparisons aimed at the discovery of contexts that increase the spread of false information and result in their acceptance [1].

Key findings from the cross-cultural comparison

A retweet is not necessarily an indication of real belief in or promotion of, the message being amplified. Many user interactions with, or consumption of, social media content are as passive as it is of sites. Items propagated by digital influence campaigns become important topics during a period. The pathways with validation servers are selected for hosting targeted campaign themes. They are also highly retweeted within a primary user community: the United States conservative community. While the power of a message to move through social networks and media sites is seen as valuable, the extent of this advocacy is engagement without diligence. These stories can be considered adversaries to only target audiences and the question of whether engagement is prolonged through shared attributes, ideology or some other cognitive process is open [ref: Additional Materials].

There are no hard and fast rules against inflating followers or friends but these will be taken into account as potential evidence along with others. Follow the primary parties to find that they are attempting to create broad political divisions in the United States. Further go through their direct sharing activity with the accounts to find that they are co-validating their activity [20]. People retweeted the Irish and American primary influence campaign Tweets but were also active in other conversations. The minority of Americans who retweeted were still notable for their amplification of the account's narratives and key messages within the context of speaking to the European elections. However, the decision to stand up against the adversary's activity is one for the Spanish Government's authority.

The posts and interactions between many actually spread content and others have a significant number of interactions. Inside an echo chamber, information can become disguised as representative of external sources, and other users may be more likely to trust the information because it appears to be fact-checked and trusted by their network [4]. Stated that widespread American and similar campaigns embedded themselves in existing social movements to have an impact. Some believe themselves to be white Americans in their digital identities rather their being citizens of another country.

The path forward in developing whole-of-society solutions to adversarial propaganda, disinformation, and misinformation is uncertain. To do so, we will need to think critically about foreign authoritarian states' continued use of underhanded tactics - often with direct harmful consequences for the citizenry within the targeted country. Government, business, civil society, and non-profit decision-makers - individuals and organizations that wield technical, intellectual, financial, or structural power - will need to be at the forefront of this charge, offering resources, protection, and strong lines of defence from abroad and at home to help inoculate our societies from similar foreign deception in the future.

When users engaged with a protective message, they reported a higher level of thoughtfulness, perceived the issue as more newsworthy and believed the source to be more professional than in the absence of a protective message [21]. The article suggests that disinformation-related measures could address the format and the source of disinformation. Some scholars observe that in the CEE region, the lack of effective structures to counter disinformation in national languages contributes significantly to the level of exposure to disinformation, which also reinforces the effectiveness of motivated reasoning leading to belief in and sharing of misinformation. By expanding the spectrum of outlets and means for the dissemination of public diplomacy content, it is knowledgeable that more valid information can be made available to potential external audiences, which would naturally expose the falsehood content of disinformation, and mitigate the effectiveness of misinformation.

Implications for Understanding and Countering Disinformation in Geopolitical Contexts Over the last decade, disinformation, miscalculation, and misinformation have played unique and varied roles in arming conflicts and impeding the peaceful resolution of simmering geopolitical tensions. Russia's strategy of disinformation is aimed primarily at the neighbouring "Jewel in the Crown," Ukraine [1]. Noteworthy is the strategic significance attached to the anti-Ukrainian information warfare: No, Ukraine is not a part of NATO, nor the EU, nor an essential strategic partner of the United States or its allies. Nonetheless, Russian disinformation was used against it as if it posed a strategic hazard powerful enough to undermine the global political order. This hints at the expansionist nature of today's resurgent Russia, and the Kremlin's dogged pursuit of great power status at the doorstep of its neighbors [17].

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Teaching Defence Management to Senior-Level Professional Military Education at the Baltic Defence College

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Abstract

The paper analyses the pedagogical approach to teaching defence management to senior-level Professional Military Education (PME) at the Baltic Defence College (BALTDEFCOL). With its unique position in the region, the College is committed to providing advanced learning experiences, emphasising the importance of forward-thinking and adaptability within the complexities of modern warfare. This study highlights the strengths and limitations of BALTDEFCOL's PME system, with a particular focus on the evolving security environment in the Baltic Sea area. It examines the curriculum design, teaching methods, and implementation strategies employed by BALTDEFCOL to empower senior-level with the knowledge and skills necessary for effective defence management. Additionally, the paper explores potential adaptations for improvements in the future, including innovations in teaching methodologies, collaboration with external stakeholders, and continuous updates to the curriculum. With a steadfast commitment to excellence and innovation, BALTDEFCOL ensures that senior-level leadership are thoroughly prepared to confront the challenges of contemporary warfare and strategic resilience.

KEY WORDS: *BALTDEFCOL, curriculum development, defence management, senior-level PME and NATO.*

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1. Introduction

The Baltic Defence College is a distinguished institution accredited by NATO dedicated to advanced PME [1]. Our unwavering commitment is to provide education at the operational and strategic levels by applying the latest education principles, effective management, and the best use of intellectual and material resources [1]. This is achieved through rigorous applications of contemporary education methodologies and the employment of both intellectual and material assets.

As the vanguard of PME, BALTDEFCOL is dedicated to providing high-level instruction to senior-level and exploring in-depth knowledge and critical insights into defence management. The efforts are directed towards enhancing military preparedness and nurturing the culture of strategic adaptability and resilience.

With an eye on the future, the College is committed to shaping the future of military and security studies. The BALTDEFCOL is oriented toward being forward-thinking and competitive. The goal is to be modern, future-oriented, attractive and competitive, educating military and security-related civilian personnel of the Framework Nations - Estonia, Latvia and Lithuania – as well as allies and partners [1]. The BALTDEFCOL places a particular focus on the Baltic Sea region, with an inclusive embrace of the Nordic area and the broader European context [1].

The security environment of the Baltic Sea is characterised by its dynamic and fraught with challenges and risks. The geopolitical significance of the region and its evolving security environment underline the need for robust defence management processes. These processes must not be only adaptive and responsible but also intrinsically tailored to the region's unique tapestry of uncertainties and unknowns.

In the shadow of ongoing security challenges and the conflict in Ukraine, these emergencies recognise the necessity of equipping the senior level with critical thinking techniques. These techniques are essential for producing strategic-level options for senior leaders to navigate the complexities of warfare developments. In this case, the paper aspires to analyse the realm of PME at BALTDEFCOL, examining the pedagogical approach to defence management. It seeks to convey impactful transformative learning experiences that resonate with current demands and suggest possible future improvements.

At the core of our education philosophy is the interdependency of planning: determining the content and delivery methods most suited for senior-level teaching in defence management. The paper addresses two crucial questions, 'What should be taught?' and 'How should teaching be delivered?' This nexus is crucial, empowering leaders to steer their organisations towards high performance. Through collaborative engagement with diverse academic institutions, the College promotes a creative and critical-thinking culture, embedding its role as a dedicated and continuous learning institution.

2. The Overview: The current landscape of PME

Historical reality shows that the Baltic states have demonstrated a commitment to each other. Amidst shifting security dynamics, their mutual responsibility has forged enduring examples of cooperation. This shared dedication laid the cornerstone for establishing the Baltic Defence College, echoing Benjamin Franklin's wisdom that investing in professional education always pays the highest return [2]. The BALTDEFCOL stands as a testament to this principle, nurturing an educated workforce is the foundation of every community and the future of every economy [2].

2.1. The PME system in the BALTDEFCOL

The BALTDEFCOL, formally established in February 1999, embodies a vital commitment of Framework nations towards regional cooperation. During its inauguration, former Estonia President Lennart Mery articulated three key objectives: building close collaboration amongst Estonia, Latvia, and Lithuania to address collectively security challenges, enabling regional security by strengthening national armed forces and engaging with neighbouring countries to shape the future [3]. Since then, the College has an important mission to train future senior-level leaders with theoretical knowledge and critical-thinking skills to better understand the strategic environment. The curriculum is strategically designed to address the complexities of the Baltic region and the broader Baltic Sea area, with a particular focus on Russia and the roles and interests of NATO and the EU [4].

The PME of framework nations encompasses various courses and programs designed to train from junior officers to senior level. Within the PME system, there are four levels of development. The initial two levels focus on providing basic training and education for junior officers, a Framework Nations' responsibility. The BALTDEFCOL is responsible for delivering the Joint Command and General Staff Course (JCGSC) and Higher Command Studies Course (HCSC), which represent the third and fourth levels of education offered by Estonia, Latvia and Lithuania. This tiered approach to education is visually represented in Table 1 [4], which outlines the progression through the PME.

Table 1.

The tiered approach to education

Framework Nations' PME System			
Development Level 1	**Development Level 2**	**Development Level 3**	**Development Level 4**
Basic	Junior	Advanced	Senior
Tactical	Tactical	Operational	Strategic
Basic and specialist courses	Captain career and intermediate courses	Joint Command and General Staff Course	Higher Command Studies course
National or international military academies	National or international military academies	BALTDEFCOL or international staff/war colleges	BALTDEFCOL or international staff/war colleges
OF 1	OF 1 – OF 2	OF 3 – OF 4 and selected civil servants	OF 4 – OF 5 and selected civil servants

The HCSC is designed to provide advanced education and training for senior-level personnel with a certain civilian status and military rank. It addresses present challenges while preparing for the emerging future. A key component of HCSC is the defence management module, which not only guides senior-level compliance with orders but also reflects on and critically evaluates their performance. This complex approach endows the senior level with a solid strategic vision, essential analytical skills, and decision-making acumen required for senior-level positions.

2.2. The recommended NATO PME

In 2011, NATO introduced an alternative paradigm within PME to bolster the institutional framework for military and civilian personnel. The NATO-recommended officer development phases (See Table 2) [5] encompass three PME levels and do not extend to a fourth level. Notably, the senior-level PME at BALTDEFCOL does not neatly align with NATO's broader framework.

While BALTDEFCOL offers advanced education tailored for senior leaders, the NATO-recommended PME system primarily targets pre-commission, junior officer and intermediate officer levels of education [5]. This apparent discrepancy may reflect a gap in acknowledging the significance and value of senior-level PME within the NATO system. The insufficient recognition of senior-level education within NATO-recommended PME presents a challenge for BALTDEFCOL. However, individual NATO countries maintain a PME system, including a fourth level for senior development. Perhaps the absence of senior-level validation in NATO's recommended system may constrain the acknowledgement of academic credentials and the equivalence of diplomas among the countries sending students to BALTDEFCOL.

Table 2.

Understanding the Dual Nature: Strengths and Limitations

Educational Level	Function	Rank
Pre-Commissioning/Basic Officer	Capable of leading troops at the platoon level	OF1/OF2
Junior Officer	Capable of leading troops at the company level	OF3/Junior Major (OF3)
Intermediate/Senior	Designed to serve on a general command staff for a battalion, bridge, etc.	Senior Major(OF3)/OF4

The BALTDEFCOL PME is characterised by distinctive strengths and notable limitations (see Table 3) in teaching defence management. At the heart of college education lies its multicultural environment, which creates an unparalleled cross-cultural dialogue that extends traditional educational boundaries. The College's regional expertise further enriches this dynamic setting, which offers students critical insights into the complexities of the Baltic Sea region.

Table 3.

The BALTDEFCOL PME characterised by distinctive strengths and notable limitations

Strengths	Limitations
Diverse & multicultural learning environment	Recognition of educational gaps
In-depth regional expertise	Challenges of integrating theory and practice
Practical experience through active learning	Constraints of an unclassified environment
Culture of knowledge exchange within the learning organisation	Resource constraints due to external and internal factors

The module design addresses the dualities of defence management, blending theoretical frameworks with practical applications. Through case studies and syndicate activities (SYNA), students are engaged in real-world scenarios that vividly demonstrate the practical implications of these strengths and limitations. The hands-on approach equips students with the necessary skills and knowledge to assume future strategic roles. As a learning organisation, BALTDEFCOL cultivates a culture of collaboration and knowledge exchange, significantly contributing to professional development and expanding professional networks.

Despite these challenges, the module faces ongoing challenges in achieving the ideal equilibrium between theory and practice. The need for a careful module design is paramount to overcome this challenge. The unclassified status of BALDEFCOL restricts access to classified data essential for defence management. At the national level, budget decisions are made regarding equipment and systems that are almost exclusively unclassified. Additionally, budgetary constraints caused by external and internal factors can lower BALTDEFCOl's ability to bring in subject matter experts (SMEs). This financial limitation is not often apparent to external observers, who may question the College's ability to upload high education standards and attract top-tier experts.

3. Planning: What do we plan to teach, and how do we deliver it?

In preparing senior-level PME for the complexities of defence management, the curriculum is designed to equip students with the knowledge, skills and instruments necessary to investigate, assess and formulate defence management strategies and planning [5]. The module covers a broad spectrum of topics, from defence economics to resources management, offering a blend of theoretical insights and practical applications. As a result, students learn to appraise how financial, material, infrastructure, and personnel decisions influence the implementation of national security policies within resource constraints [5] in an unpredictable world.

3.1. Module Design Process

In the realm of senior-level PME, curriculum design is critical. Each module, including defence management, is a foundation building block tailored to address learning needs and fulfil desired outcomes. The module design process is a testament to the commitment to educational excellence, weaving learning outcomes, student needs, resources, teaching strategies, assessment, and evaluation into a coherent and robust framework.

Learning outcomes: The design begins with an in-depth analysis of the learning outcomes (see Table 4) [5] and the student needs to guide the module's direction. The learning outcomes are aligned with competencies deemed crucial for senior-level defence management, ensuring that each topic is tailored to address the complex challenges within today's unpredictable security environment.

Table 4.

The design of learning outcomes

No.	Learning outcomes
1.	**Formulate** coordinated guidance and implementation concepts for effective defence management.
2.	**Assess** the impact of resource allocation on defence management.
3.	**Consider** the different methods of forming rational, disciplined decisions to allocate resources for efficient and effective capability building in the face of uncertainty.

Integration, structure and adaptability: Module integration and structure are crucial aspects of module design that are aligned with the PME program's overall goals. The module does not exist in isolation but contributes cohesively to future senior-level leaders' holistic development. The curriculum's adaptability reflects the fluid nature of defence management, allowing for regular updates in response to evolving threats, technological advancement, and shifting geopolitical environments. Despite the diversity of framework nations, the training provided is substantial and pertinent for both levels of education (levels three and four). This approach empowers BALTDEFCOL to build upon existing knowledge, fostering advancement rather than overhauling established processes.

Collaboration and pedagogical strategies: Collaboration with (SMEs) is essential in building a module that reflects the latest developments and best practices in defence management. Despite differences between framework nations and their defence organisations, it is vital to gauge both times and expertise, providing examples of 'best practices' that produce envisaged outcomes. Incorporating the knowledge of practitioners, academics, and faculty, the module benefits from varied perspectives and ensures its applicability to contemporary realities. This collaborative approach encourages critical and creative thinking, which aligns with Metz's statement that education suggests broadening beyond the confines of [professional] knowledge and the development of critical thinking and creativity [6].

Learning methods: Adapting case studies and scenario-based learning are highly adaptable teaching styles that involve problem-based learning and promote the development of analytical skills [7]. These methods encourage group discussion and facilitate the development of the higher levels of Bloom's taxonomy of cognitive learning, moving beyond recalling knowledge to analysis, evaluation and application [8,9].

Assessment and evaluation: Assessment standards and evaluative measures are established to gauge the effectiveness of the learning experience, providing valuable feedback for continuous improvement. The module design is an iterative process, constantly refined to maintain relevance and usefulness. Harmonising these elements ensures the module offers a comprehensive and dynamic educational experience that strengthens knowledge acquisition and develops critical thinking and creativity to cope with complexities and uncertainties.

3.2. Teaching methods

In defence management, teaching and practising theoretical concepts are of utmost importance. The faculty body selects a blend of teaching methods tailored to meet the diverse needs of students. This pedagogical approach is not arbitrary; it is a calculated choice influenced by several factors, including:

1. Desired Learning Outcomes: The ultimate goal is to comprehensively understand defence management concepts while using critical thinking and consolidating decision-making abilities.
2. Nature of the topic: The complexity and specificity of defence management topics necessitate a dynamic teaching approach to convey intricate concepts effectively, such as defence economics, defence financial planning, defence acquisition, portfolio management, and human resource management.
3. Assessment methods: Evaluative techniques align with teaching methods to accurately measure students' grasp of the subject matter.
4. Student background: Diverse educational and professional experiences among students require adaptable teaching methods to ensure inclusive and equitable learning. (see Table 5).

Table 5.

Teaching methods and their impact

Teaching Methods	Learning Environment	Application in Defence Management	Learning Outcomes
Interactive Lectures	Classroom & Online Teaching	Introduces Defence management concepts; simulates debates	Enhance critical thinking
Case Study	Group Discussions	Examines real case scenarios from the 3Bs, formulate solutions	Improve decision-making and problem-solving skills

Syndicate Activities	Exercises & Group Work (SYNA)	Facilitates practical decision-making in addressing Security threats	Promote teamwork, leadership, and management skills
Guest Speakers	Seminars & Round tables	SMEs develop strong relations between stakeholders, military services, and BALTDEFCOL.	Expand professional knowledge and increase awareness.

These teaching methods not only broaden the understanding of defence management but also actively engage students through dynamic and interactive learning experiences. The 'learning by doing' approach is particularly effective, as it encourages students to engage in practical exercises, learn from mistakes, draw conclusions, and identify areas for improvement. This approach ensures that students are not passive recipients of information but active participants in their educational journey who are prepared to tackle the challenges of modern defence management.

3.3. The role of technology in PME

The BALTDEFCOL has adeptly integrated technology in PME to address security challenges and technology development better. It has employed Advanced Distributed Learning (ADL) to facilitate education access and promote collaboration between students and instructors. The adaptation of ILIAS, an open-source ADL, has significantly enhanced the education experience by providing tools for learning facilitation and collecting student feedback, thereby fostering a cohesive learning community.

Confronted with the unprecedented disruptions of the COVID-19 pandemic in 2020, BATLDEFCOL swiftly modified its communication and education delivery to achieve objectives set by framework nations. As a result, the HCSC defence management module suddenly shifted to distance learning by introducing Microsoft Teams (MST), as a primary platform for teaching delivery and student communication. Although MST proved effective in maintaining engagement, it also presented challenges in ensuring consistent motivation and delivering high-quality education. The pandemic significantly affected teaching, students and educators across all education levels of PME.

The introduction of MST, despite its benefits, presented challenges for teaching purposes, including the necessity for more frequent clarification of concepts, a potential decrease in flexibility in the learning process, and the complexity of monitoring individual student progress and comprehension in a virtual setting.

Nonetheless, incorporating innovative teaching methodologies and technology in defence management has proven beneficial, especially in empowering senior-level PMEs. Using MST has not only improved access to education resources but also promoted interactive learning experiences in a restricted environment, ultimately contributing to education. By addressing these strengths and limitations, BALDEFCOL can continue to enhance its PME, ensuring it remains relevant and effective in preparing senior-level leaders for the complex strategic environment of the future.

4. Implementation: What do we do in the class, and what can we achieve?

The chapter examines the dynamic relationship between class activities and the tangible outcomes achievable within the context of defence management education. It demonstrates how classroom activities help learners grasp strategic concepts (ends) and translate them into practical actions (ways) to develop effective mechanisms, systems, and infrastructure. Through class discussions and case studies, students are empowered to explore the complexities of defence management. Kolb's experiential learning theory supports this approach, viewing learning as a continuous and holistic process without boundaries [18]. As learners advance, the horizon they once perceived as a limit continually expands, revealing new challenges and opportunities.

4.1. Class activities: What do we do?

Role of lectures in teaching: Lectures serve as foundational tools for knowledge dissemination, with lecturers playing a pivotal role in shaping the education journey. Beyond transferring knowledge, they customise education to meet individual needs and interests. The lecturer itself guides the teaching process. An effective and good lecturer is one who commands the content knowledge, knows the strengths of the student, encourages the students, allows them to express themselves, and knows how to use technology [10].

In senior-level PME, teaching defence management demonstrates a strong relationship between participants and lecturer attitudes is pronounced. In this human interaction, lecturers have a significant influence on teaching. Erdoğdu claims that lecturers' attitudes and behaviours are the second most influential factors affecting students' academic achievement [11]. Despite their importance, the traditional lecture format may sometimes not allow much discussion and other forms of involvement. They may be interested only in delivering their teaching according to the plan, not assessing learning, and time may not allow students to present their input. To mitigate this, the module offers a combined approach. It integrates lectures with group discussions, active interaction, and SYNA activities, fostering dynamic learning environments that promote active participation and enhance learning.

Syndicate activity: A group-based learning approach. In defence management, SYNAs facilitate peer learning among a cohort of six or eight participants. These activities are designed to enrich the learning experience through interaction and increase group dynamics, aiming to develop higher-level problem-solving skills. Effective SYNA implementation involves appointing a team leader who guides the group, facilitates communication, manages conflicts, and ensures timely task completion.

Initially, everyone can raise the following question: What are the benefits of having a team leader? It is an important question that the syndicate has to address. Experience has shown that a syndicate leader with the required competencies and knowledge is crucial for making timely, reasonable decisions. This type of leader steers the group towards a clear understanding of objectives and individual roles, cultivates a cognitive working environment, manages intra-group conflicts, ensures constructive resolution of issues, mentors team members, and facilitates decision-making processes. For an effective leader, open communication and coordination are essential. These attitudes are instrumental in securing the collective triumph of the team.

On the other hand, the absence of syndicate leaders can often result in collective disorientation concerning the task. This void in leadership precipitates a lack of cohesion among participants and ambiguity regarding their respective roles. Such disarray can lead to a poor product that fails to meet the standards required for advisory roles, whether for an 'acting chief of staff' or an 'assessment board' during a group presentation. Experiential precedents within group events have demonstrated inconsistencies in achieving content consensus, detailed examination of particular issues, and clarity on presenting responsibilities.

Another area for improvement is understanding the task and dividing the syndicate into smaller groups may sound like an unnecessary change or breakdown. Initially, segmenting the syndicate into smaller groups ensures a level playing field for all participants. Secondly, the smaller group configuration facilitated a stress-free environment for understanding the task material and the need for constant updates from each participant. Thirdly, using small groups will save time in prolonged and redundant clarifications inefficiencies, thereby allocating more time for group work.

The final consideration within SYNA is the timeline, a tool that identifies the schedule and individual responsibilities. It offers the leader a comprehensive overview, enabling him/her to monitor progress, guide the workflow, facilitate improvements, and maintain effective communication within the chain of command through all development stages.

4.2. Clarifying Desired Achievement: What should we achieve?

Achieving learning outcomes*:* As we delve into the module, we confront the gap between high-level strategic directives and translating them into actionable plans. The module is built to bridge this chasm, empowering senior-level to engage with strategic direction, mastering the art of transforming it into actionable and measurable steps. Key focus areas include resource allocation methodologies, ensuring force readiness, and integration of new capabilities. The quintessential challenge lies in balancing long-term planning with the urgency of immediate needs, which is crucial for effective decision-making in defence management.

The design of the defence management module is to yield concrete and measurable outcomes. These outcomes are not merely academic milestones but the building stones upon which the edifice of strategic defence understanding is built. The class activities are meant to achieve our desired outcomes, and it is imperative to encapsulate them in a format that underscores their significance and applicability. Table 6 outlines these outcomes, each a testament to the comprehensive learning experience that BALTDEFCOL offers. Through these tangible results, we see the delivery of our education, one that marries theory with practice and knowledge with action.

Table 6.

The design of the defence management module

Integrated Learning and Application Outcomes		
No.	Module Learning Outcomes [4]	Corresponding tangible outcomes
1.	**Formulate** coordinated guidance and implementation concepts for effective defence management.	Strategic leadership development
2.	**Assess** the impact of resource allocation on defence management.	Enhanced problem-solving skills
3.	**Consider** the different methods of forming rational, disciplined decisions to allocate resources for efficient and effective capability building in the face of uncertainty.	Promote cohesive teamwork through SYNA

Assignment: The Integration of Case Studies and SYNA Approach. Building upon these foundation insights, the SYNA assignment engages students in employing management methods and tools for real-world defence management scenarios. Students are tasked with utilising techniques such as problem identification, stakeholders and SWOT (Strengths – Weaknesses – Opportunities – Threats) analysis and DOTMLPF-I (Doctrine, Organisation, Training, Material, Leadership, Personnel, Facilities and Interoperability), to formulate recommendations.

Through this assignment, students conduct strategic analysis that integrates theoretical concepts with practical insights acquired throughout the module. They will develop detailed plans that define objectives (*the political end*), articulate resource allocation strategies (*means by which the government allocate resources*), and devise risk mitigation measures (*ways to manage risks*). This exercise is designed to demonstrate studetnts' ability to translate theoretical knowledge into actionable strategies that address complex defence management challenges.

Assessment: Measuring Mastery through a Performance-Based Approach. After developing robust strategies, the module shifts to a critical assessment phase, where the efficacity of learning relies intensely on the teaching process through assessment and constructive feedback. As Wiggins underlines, effective teaching is inseparable from good assessment [12]. The assessment framework is carefully designed to rigorously evaluate both group and individual contributions, with a focus on the clarity of proposals, in-depth analysis, and communication effectiveness.

Assessment criteria are aligned with educational goals and focus on identified strengths, weaknesses and areas for improvement. This performance-based approach ensures the students not only acquire theoretical knowledge but also develop practical skills and critical thinking abilities essential for senior defence management. By linking assessment to real-world applications, the module reinforces the learning process, ensuring that students are fully prepared to navigate the complexities of modern defence management.

In conclusion, teaching defence management to the senior-level PME demands a holistic approach combining theoretical knowledge and practical application. The module equips students with a robust understanding of strategic direction by integrating lectures, syndicate activities, case studies analysis, and a transparent and reliable assessment process. This dynamic learning process ensures our education remains relevant and impactful in preparing future defence management professionals.

5. The Future: Possible adaptations and improvements

In an era characterised by rapid technological developments, geopolitical shifts and non-traditional security threats, the pedagogy of defence management education must embody both agility and forward-thinking. Looking at the current strategic developments, teaching senior-level PME requires a multifaceted understanding of defence management concepts and practices, alongside the flexibility to address the changing spectrum of security challenges. The chapter proposes necessary adaptations and improvements for teaching senior-level PME at the BALTDEFCOL, aiming to equip military and civilian leaders who are engaged with security issues with the essential knowledge and competencies required to adeptly manoeuvre through the complexities of today's contemporary defence environment and future uncertainties.

The 21st-century security landscape is marked by diversity and complexity, necessitating a paradigm shift in how defence management education is approached. To effectively prepare military and civilian leaders to deal with these evolving challenges, the curriculum must go beyond traditional boundaries. It should offer a comprehensive understanding of both foundational defence management concepts and contemporary practices, while also addressing national and international strategic implications. Central to this approach is ensuring that students can articulate and develop required military capabilities by strategically investing in current readiness and future defence systems. This will allow for the optimal use of defence resources, ensuring maximum effectiveness in both present and future contexts.

Recognising the inherently interdisciplinary nature/approach of contemporary security challenges, the module must integrate a broad spectrum of insights from technology, economics, and global affairs. By framing defence management within a wider societal and global context, students will gain a deeper understanding of the interconnectedness between economic stability, technological innovation, and national security. This interdisciplinary approach will not only enhance students' creativity in problem-solving but also cultivate the strategic mindset necessary for effective senior-level leadership in an increasingly interconnected world.

Enhancing strategic decision-making capabilities is paramount in today's dynamic security environment. To achieve this, the module should incorporate dynamic learning tools that simulate real-world scenarios and promote experiential learning. These tools include:

1. Case Studies as Teaching Tools: Employing case studies, particularly those from the three Baltic states, provides senior-level PME with invaluable insights into security challenges and strategic decision-making processes. This approach is supported by Qudrat-Ulah's work on decision-making and learning dynamic tasks, which emphasises the importance of case studies in developing abilities and making decisions [13].
2. Blended learning methodologies: Integrating online resources and virtual reality simulations with traditional classroom activities creates an immersive learning experience. Donovan et al. highlighted the improvements in dynamic decision-making through training and self-reflection, understanding the effectiveness of blended learning methodologies in a complex problem-solving environment [14].
3. Inviting practitioners: Incorporating defence practitioners and SMEs to teach defence management to bridge the gap between theory and practice. Their real-life professional experiences offer invaluable, practical perspectives that textbooks cannot provide. This real-life professional experience aligned with findings in the Wiley Online Libray on learning and dynamic decision-making, which underscore real-life experience's value and importance in enhancing military and civilins' decision-making skills [15].

At the heart of BALDEFCOL's teaching and learning mission is the commitment to excellence and continuous improvement. Investing in the ongoing professional development of faculty members is critical to maintaining and enhancing the quality of the curriculum. Through regular workshops, seminars, and conferences allow faculty members to engage with research projects, emerging trends, and best practices in defence management education [13]. This commitment to lifelong learning culture empowers educators to embrace innovative education methods, enhancing student learning experiences and disseminating new knowledge. This approach requires promoting and fostering collaboration and networking with other academic institutions focused on defence and security issues.

The BALTDEFCOL recognises the inherent value of collaboration and knowledge exchange. The College actively cultivates partnerships with various institutions, think tanks, and research organisations. These collaborative activities facilitate a robust exchange of ideas, best practices, and empirical insights, enriching the education experience and broadening students' perspectives on defence management. For instance, the HCSC 2024 brought together a diverse group of 24 students from 13 countries, demonstrating the dedication to creating an environment that mirrors the cooperative nature required in international security and defence [16]. Moreover, the strategic partnership will offer opportunities for joint project initiatives and knowledge and ideas exchanges, fostering a culture of innovation, creativity and intellectual awareness within the academic communities. The mission of BALTDEFCOL to educate and promote international cooperation is further supported through these collaborative efforts, particularly in curriculum development and updates [1].

To maintain relevance and effectiveness amid evolving security challneges, the curriculum must undergo regular updates. However, these updates should be carefully managed to ensure they do not exceed 20% of the existing content, ensuring a balanced approach between continuity and adaptability. Regular curriculum revisions should be guided by insights from allies, partners, and academic institutions. This approach ensures that our educational standards remain finely attuned to the latest developments in technology, geopolitics and defence strategies. This approach equips learners with the knowledge and skills required to cope with the complexities of the modern security environment. By assembling these elements into a cohesive and responsive curriculum, BALTDEFCOL empowers its education to deliver an education that is both forward-thinking and adaptable [17].

In conclusion, BALTDEFCOL is committed to strengthening its position as a leader in defence management education through relentless innovation, a dedication to excellence, and a spirit of collaboration. By embracing adaptative pedagogical approaches, fostering diverse collaborations, and nurturing a culture of continuous learning, BALTDEFCOL is well-positioned to cultivate the strategic insight and agility needed to confront dynamic security challenges and anticipate future uncertainties. Through these enhancements, BALTDEFCOL ensures that its senior-level PME remains relevant, impactful and at the forefront of defence management education.

6. Conclusions

The BALTDEFCOL stands as a pivotal regional military education institution, particularly in teaching senior-level PME. Through its unwavering commitment to understanding strategic resilience and enhancing military preparedness, BALTDEFCOL has established itself as a beacon of impactful learning experiences that equip leaders with the necessary tools and strategic insights necessary to understand and anticipate the complexities of modern warfare.

Throughout this essay, the distinctive approach of BALDEFCOL to defence management education has been illuminated, showing its strengths in regional expertise, embracing multiculturalism and implementing practical learning methodologies. While acknowledging the challenges of NATO PME framework recognition and possible resource limitations, the institution remains resolute in its pursuit of continuous improvement, embracing innovation, and strengthening robust partnerships to keep pace with the evolving security dynamics of our time.

For the BALTDEFCOL to ensure its enduring commitment to defence management, it must prioritise a series of strategic initiatives. First and foremost, the curriculum must be regularly updated to reflect emerging threats, technological advancements, and shifting strategic priorities. This proactive approach ensures that senior-level PMEs are equipped with the most current and relevant knowledge, enabling them to effectively address the multifaced challenges of contemporary combat scenarios and the broader landscape of modern warfare.

In addition, the continuous professional development of faculty members is essential to maintaining high standards of instruction and relevance. By investing in the continuation growth and expertise of its staff, BALDEFCOL can guarantee that its educational programs remain at the forefront of defence management education, consistently delivering value to its studends and stakeholders.

The effectiveness of defence management education is deeply rooted in a commitment to excellence, adaptability, and progress. As Admiral Stavridis once observed, that victory over adversaries often relies on intellectual superiority - out-thinking opponents rather than merely outfighting them. BALTDEFCOL stands at the forefront of cultivating critical and creative thinking, forecasting, predicting future trends, and enhancing decision-making capabilities. These efforts are crucial in preparing senior-level PMEs to confront and overcome the challenges posed by the warfare of tomorrow.

Ultimately, the role of the BALTDEFCOL in shaping the future of defence management cannot be overstated. As the institution continues to adapt and evolve, its influence extends far beyond the realm of military education, contributing to a broader understanding of security and defence issues. The senior-level PMEs are not only moulded by the wall of theoretical knowledge but also trained to apply this knowledge practically in response to current security developments and trends. This blend of theory on one side and practices on the other, underpinned by a culture of continuous learning and adaptation, positions BALTDEFCOL to sustain its legacy of excellence in defence management education.

By embracing these principles and strategic initiatives, BALTDEFCOL reaffirms its commitment to preparing military and civilian leaders who are not only capable of navigating the complexities of today's security landscape but are also poised to anticipate and shape the security challenges of tomorrow.

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Improvement in the Field of CBRN Prevention, Preparedness and Protection in the Czech Republic

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Abstract

The expert article deals with CBRN threats in the Czech Republic and reflects on the current preparedness for handling adverse CBRN incidents, accidents and attacks. Despite the fact that attention is paid to the areas of prevention, preparedness and protection against CBRN substances and materials and so-called type plans for the Integrated Rescue System are prepared, there are still areas that need to be improved. One of the significant and important management tools is the national strategy and national action plan for the fight against CBRN terrorism. Although many developed countries have such documents ready (for example, Canada already in 2011), the Czech Republic unfortunately does not. The authors of the professional article dwell on this fundamental shortcoming and discuss various safety issues of the given issue. Last but not least, the authors present a possible solution to the given situation using verified foreign models.

KEY WORDS: *CBRN threats; prevention; preparedness; protection; population protection; national CBRN strategy; national CBRN action plan.*

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1. Introduction

Science will continue to develop at high speed, even revolutionary leaps. Improvements in information technology, the benefits of nanotechnology, new innovations in biotechnology, and continued investment in science and technology will provide both opportunities and threats to infiltrate knowledge towards agents with hostile intentions. As a result, the proliferation of WMD will become a much more serious problem. In the areas of defense and protection, information technology will contribute to the acceleration of decision cycles. Space and cyber-space will be interconnected and more widespread through military applications than ever before.

Nanotechnology will enable not only the military, but also various terrorist and extremist groups to use miniaturized, remote-controlled or even robotic systems, while biotechnology will increase the level of personal protection and the accuracy of sensors for targeting biological elements. Ultra-terrorism, sometimes called super-terrorism, i.e. chemical, biological, radiological and nuclear terrorism, represents not only future, but, unfortunately, also contemporary security threats, as demonstrated by the use of super toxic lethal sarin by the Aum Shinrikyo doomsday cult in 1994 and 1995.

Incidents of chemical, biological, radiological, and nuclear (CBRN) situations are on the rise and a clear understanding of the threats, vulnerabilities, and modus operandi of the perpetrators is required for reliable prevention and rapid, effective, and reliable response. CBRN incident management, both prevention and response, is a matter of multiple government institutions and agencies striving for mutual coordination and a clear understanding of rules and jurisdictions. Although international treaties have been concluded prohibiting the use of these weapons, the misuse of chemical, biological, and bacteriological substances by terrorists in any part of the world and at any time cannot be ruled out. Therefore, the response to such events must be quick, effective, and coordinated to avoid casualties and prevent the escalation of such an adverse event.

The Czech government and the responsible Czech authorities consider security problems to be key issues of the State's internal policy. It is obvious that, at present, issues of state security are becoming a priority in the daily activities of the government, constitutional officials, and individual departments of the national economy.

The fear of an escalating conflict has proven to be justified, as stated above, and requires the Czech Republic to take measures to maintain internal security and support international efforts in dealing with all events, be they military and political, hygienic and epidemiological, or other events have a negative effect on life on our planet.

The threat of CBRN misuse is also gaining importance. In 1995, the Japanese religious sect Aum Shinrikyo attacked the Tokyo subway with sarin, causing 12 deaths and nearly 5,000 injuries. [1, 2] Places where large numbers of people gather for various reasons are known to be the target of terrorist attacks causing serious loss of life and health of the population, material damage, and causing fear and panic among the population.

Therefore, it is important that the Czech Republic also pays increased attention to prevention, preparedness and protection against chemical, biological, and radiological terrorism in vulnerable public places (for example, in the Prague Metro). However, they must also seriously deal with all possible catastrophic scenarios of attacks and assaults using CBRN.

2. Responsible body in the Czech Republic

The question of the executive, responsible and control body, which in the Czech Republic is the State Office for Nuclear Safety, is also essential (State Office for Nuclear Safety 2021). It may have escaped the uninformed that a state office that has nuclear safety in its name also includes the following three important expert areas of activity:

- *Non-proliferation of nuclear weapons,*
- *Prohibition of chemical weapons, and*
- *Prohibition of biological (bacteriological) and toxin weapons.*

International and national law enforcement in the country

Nuclear Non-Proliferation

State office for Nuclear Safety (SONS) is the main responsible state body. The main aim in the area of the control of non-proliferation of nuclear weapons is to make the control tasks more effective and thus to reduce further the risks of possible misuse of nuclear items for other than peaceful purposes. The work of the State Office for Nuclear Safety (SONS) in this area is based on the Resolution 1540 of the UN Security Council, which bound UN member states to accept transparent measures for strengthening the control of non-proliferation of nuclear weapons. The goal of these measures is to prevent the illicit trafficking with nuclear materials and other nuclear items suitable for the development and manufacturing of nuclear weapons and so far efficiently reduce the risk of nuclear terrorism.

The verification approaches and measures utilized by the International Atomic Energy Agency (IAEA) to verify that nuclear materials are not diverted from peaceful uses to nuclear weapons or other nuclear explosive devices in accordance with *Treaty on the Non-Proliferation of Nuclear Weapons* (NPT) commitments are commonly referred to as *"safeguards".*

The work of the SONS is targeted on the area of state control over the nuclear items, on fulfilling international obligations of the Czech Republic in accordance with the NPT, the Agreement between the IAEA, Euratom and non-weapon member states in connection with the NPT (Safeguards Agreement) and the Additional Protocol to the Safeguards Agreement. The Additional Protocol issues the inspectors the power to supervise not only nuclear materials and sites where have been previously or is being handled now with the nuclear materials, but the state's nuclear program, for example, the development or manufacture of components for nuclear facilities.

Chemical Weapons Prohibition

Since 2000 The State Office for Nuclear Safety (SONS), as the National Authority of the Czech Republic, has been guaranteeing obligations resulting from the *Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction* (also Chemical Weapons Convention or shortly CWC). The implementation of the chemical weapons prohibition belongs to the priorities of the SÚJB. The target is to contribute to the reduction of the risk of their abuse, including prevention to possible non state party threat.

The SONS carries out the function of state surveillance over the measures related to the prohibition of chemical weapons in accordance with the national Act No. 19/1997 Coll., as amended, on some measures concerning chemical weapons prohibition and the national Decree No. 459/2020 Coll., implementing the Act No. 19/1997 Coll., where chemicals are listed in individual Schedules in accordance with the classification.

The Act No. 19/1997 Coll. has been recently amended by the Act No. 336/2020 Coll. [3] to reflect last changes and development in CWC. As a result of it, the original Decree No. 208/2008 Coll. has been fully replaced by the Decree No. 459/2020 Coll. [4]

This concludes also participation of SONS experts in the activity of international control regimes like Australia Group. Although this may not bring any internationally legal obligations for the Czech Republic, it is understood as an important tool for securing a rigorous fulfillment of the measures related to the prevention of the proliferation of weapons of mass destruction.

All SONS activities in the area of the prohibition of chemical weapons is widely coordinated with the activities of other governmental bodies in this area and respects the principles of the European Union Strategy against the proliferation of chemical weapons, which the Czech Republic accepted. The SONS also closely cooperates with the Organization for the Prohibition of Chemical Weapons.

Biological (Bacteriological) and Toxin Weapons Prohibition

State office for Nuclear Safety (SONS) is the national authority responsible for the fulfilment of the *Biological (Bacteriological) and Toxin Weapons Convention* (BTWC). The Convention is implemented into the Czech legal system by several measures. The main principles of the convention are covered by national Act No. 281/2002 Coll., about biological weapons prohibition (Biological Act). [5]

This Biological Act regulates rights and obligations of natural persons and legal entities as associated with the ban on development, production, stockpiling and use of bacteriological (biological) and toxin weapons; their disposal and with the handling of highly hazardous and hazardous agents and toxins that could be abused to violate the ban on bacteriological (biological) and toxin weapons; and regulates the execution of governmental administration in this area.

There are also other legislative measures and regulations that are closely connected to objective of the Convention (the protection of health of humans, animals, plants and the environment, etc.). The summary of the overall implementation of BWC has been presented as part of the working paper on Meeting of State Parties of the Convention in 2012. All SONS activities in the area of prohibition of biological and toxin weapons are coordinated with activities of other governmental departments and in respect of the European Union Strategy against the CBRN threat. SONS experts also take part in the international control activities such as The Australia Group.

3. CBRN threats in the Czech Republic

Efficient protection of citizens through anticipation, deterrence, preparedness, response and adaptation to crisis situations – in other words, maintaining disaster resilience – faces new challenges. Collaboration between national, European and international stakeholders requires unified processes and management systems as well as technical, procedural, operational and semantic interoperability.

The Czech Republic has certainly not lagged behind in such an important area as CBRN protection. It is possible to be confident of this, be it through the development and introduction of means of radiation, chemical, biological research, means and reagents for the decontamination of equipment, material of all kinds, and persons, individual and collective protection, prophylaxis and the treatment of affected persons of the armed forces and the general population. In 1990 and 1991, the chemical unit of the former Czechoslovak Army was involved in the Gulf War, and its operations within the mission of international forces, equipment, and readiness were positively evaluated at an international forum.

The question of the executive, responsible and control body, which in the Czech Republic is the State Office for Nuclear Safety, is also essential. It may have escaped the uninformed that a state office that has nuclear safety in its name also includes the following three important expert areas of activity: *Non-proliferation of nuclear weapons, Prohibition of chemical weapons, and Prohibition of biological (bacteriological) and toxin weapons.*

In another case, a habilitate work from 2011 focused on the issue of protecting the population from chemical terrorism, where a total of 91 different measures were proposed in specific areas, i.e., preventive measures, punitive measures, rescue and protective measures, liquidation measures and recovery. [6]

The good preparedness of everyone (paramedics, medical personnel, police, special hospitals, special military units, the general population, etc.) for extraordinary events, especially for managing their consequences, including possible terrorist CBRN attacks, requires the following necessary procedures in particular:

- systematic preparation of control units and authorities for the possibility of CBRN terrorism;
- sufficient knowledge of CBRN terrorism acquired by the population (knowledge of the population about possible extraordinary events and emergency situations at the place of their residence or work, including terrorist attacks; clarification of the methods of warning and protection of the population; questions, etc., answered by the administrative authorities at the place their residence);
- basic provision of written instructions related to CBRN terrorism to the general public and their correct response (description of possible emergency events, including terrorist attacks; methods of warning the population; shelters for the population and protection systems; improvised protective equipment and aids, what to pack for an evacuation, evacuation routes, assembly points for the evacuated population, etc.);
- practical training of residents for cases of CBRN attacks; necessary activities and use of various personal protective equipment and aids; production of improvised protective equipment; training in what to pack in the case of an evacuation; training in the evacuation of the population; comprehensive training of acquired skills and habits; training of the population in response to possible extraordinary events and emergency situations);
- theoretical training of rescuers, medical staff and policemen for cases of CBRN attacks and assaults (acquiring the necessary basic knowledge and awareness of CBRN issues);
- practical training of first responders, rescuers, medical staff and police officers on training grounds and in exercises in the case of CBRN terrorism (acquiring the necessary skills and habits for operations in extraordinary events and emergency situations [terrorist attacks]; and
- systematic, regular, and comprehensive verification of knowledge, skills and habits of rescuers through not only written tests, but also practical verification in the field.

The overall preparedness of the population for extraordinary events, emergency situations, and their adverse effects is a very complex, complicated, and long-term issue. In the Czech Republic, a system for preparing all groups of residents for extraordinary events and emergency situations has not yet been created (only partially for primary school pupils and secondary school students). An integral part of such preparation must be regular and systematic preparation of the population for possible CBRN attacks.

Terrorist groups are constantly analyzing, evaluating, and researching all possible ways to cause mass attacks on certain Western targets, especially with the aim of disrupting the Western way of life.

A massive attack would focus on crowded public places such as airports, large supermarkets, sports stadiums, large cultural halls, large-capacity spaces for the population in general, so that the attack not only causes hundreds of casualties and injuries, but also causes other great damage. These are so-called soft targets, which are generally insufficiently protected.

However, terrorists can easily smuggle a large amont of toxic substances or explosives into these public places, which would lead to a mass terrorist event. Terrorists could easily exploit dangerous biological agents or radioactive materials for their aims. Just imagine what could happen at the capital's airport, if an attacker would be armed not only with automatic weapons, but they would simply use a bottle of sarin [alternatively cyclo-sarin, soman, tabun]. How would we deal with such a horrific chemical event that would undoubtedly leave hundreds of people dead?

Many countries have recently begun to prepare for prevention and response, although most are not well prepared for CBRN threats. Typically, the response is based on the capabilities of guards and local first responders. The overall preparedness of society for CBRN attacks and assaults is a complex matter that has been building over many years, and it is essentially a never-ending process of improving CBRN prevention, preparedness & protection.

The current situation in the area of protection against CBRN threats in the Czech Republic is at a fairly good level, but the state of preparedness must be constantly improved.

This was shown when dealing with the protection of the population in connection with the spread of COVID-19. There was a certain spontaneousness, poor organization of measures, starting with the initial insufficient supply of medical equipment, insufficient stocks in the warehouses of supplies (masks, respirators, decontamination agents, solutions and mixtures). This was closely related to unclear management, the announcement of individual measures, when unclear, political decisions were often taken without being sufficiently supported by an expert opinion and without knowing both the short-term and the long-term impacts.

The awareness of the population presented by the leading representatives of the government at daily press conferences became counterproductive over time, gradually provoking mistrust and increasing negative resistance of part of the population, which led to the creation of two differentiated groups of the population with different opinions on solving current protection problems, starting with the use of protective equipment (masks, respirators), limiting public life, limiting the number of people at various events, and especially vaccinations, which led to the organization of protests and the personal attacks on certain people working in health and hygiene.

In this regard, the media also played a negative role, which, although in good faith, gave space to various experts with pedagogical and scientific degrees, but without sufficient education and experience in the assessed problems of medicine, epidemiology, and hygiene. This in itself only contributed to deepening the mistrust of the population and the negative perception of the enforced measures, often leading to them being ignored. In this sense, it is necessary to analyze the way and extent of information transmission and the involvement of professionals and citizens in public discussion. Everyone's interest must be a balanced, expert discussion supported by specific results and statistics, not the daily presentation of politicians in the media. The fact that the Czech Republic still does not have a National Strategy and a National Action Plan for protection against CBRN, which would focus mainly on the protection of the population, the protection of rescuers, and other involved persons, is problematic.

4. Integrated Rescue (Emergency) System in the Czech Republic

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The Integrated Rescue System is determined for co-ordination of rescue and clean-up operations in case, where a situation requires operation of forces and means of several bodies, e.g. firefighters, police, medical rescue service and other bodies, or in case, where the rescue and clean-up operation is necessary to be co-ordinated from the Ministry of Interior of the Czech Republic or by a leader of region's level, or by mayors of municipalities with extended responsibilities.

As the Integrated Rescue System are therefore considered the co-ordinated proceedings of its bodies during preparations for emergencies, and during rescue and clean-up operations.

In case of a chemical, biological, radiological and nuclear (CBRN) threat, the role of the Fire Rescue System has been crucial since 2001 when national Act No. 239/2000 Coll. [7] for the Integrated Rescue System began to apply.

The Integrated Rescue System is not an organization but a coordinated process of its units in planning and preparing for emergencies and carrying out rescue and recovery operations. Basic bodies of the IRS are the Fire Rescue System, Police and Emergency Medical Service, and they operate on a 24/7/365 basis throughout the whole country. If necessary, the main units collaborate with other bodies of the Integrated Rescue System, such as the army, Red Cross, etc. The Act also transferred activities and responsibilities for the Civil Protection from the Ministry of Defense to the Ministry of Interior and then directly to the Fire Rescue System of the Czech Republic. The Fire Rescue System plays a key role in the Integrated Rescue System, because firefighters have the position of officers in charge not only for fires but also for most of other threats including CBRN incidents.

In the beginning, firefighters were mainly focused on industrial and traffic incidents connected with the leakage of hazardous chemicals. However, after several dangerous terrorist attacks across the world, tasks and equipment of the Fire Rescue System of the Czech Republic needed to be updated to cover all CBRN threats.

The national Act No. 239/2000 Coll. on the Integrated Rescue System and on amendment of certain codes, in latter wording, is the basic legal frame.

Basic Integrated Rescue System bodies:

- Fire Rescue Service of the Czech Republic and fire units, based on fire cover,
- Police of the Czech Republic,
- Medical Rescue Service.

Other Integrated Rescue System bodies:

- Specified forces and means of armed bodies,
- Other armed security services,
- Other rescue services,
- Public health protection authorities,
- Emergency, stand-by, specialised and other services,
- Civil Protection establishments,
- NGOs and civil associations, which can be used for rescue and clean-up operations.

As permanent authorities for coordination of Integrated Rescue System bodies are considered the operational and information centers of the Integrated Rescue System, i.e. the operational centers of regional Fire Rescue Services and the Operational and Information Centre of the Directorate General of Fire Rescue Service of the Czech Republic.

The Czech Republic has gradually developed several large and detailed integrated rescue system emergency response plans (type activities) for the most important areas of CBRN, as shown below:

- reaction to the misuse of biological warfare agents and biological agents against the population (General Directorate of the Fire and Rescue Service of the Czech Republic, Emergency Response Plan 2006),
- reaction to dirty bombs or other dangerous radioactive materials (General Directorate of the Fire and Rescue Service of the Czech Republic, Emergency Response Plan 2015),
- reaction to the misuse of chemical warfare agents and toxic industrial chemicals in the Metro in Prague (General Directorate of the Fire and Rescue Service of the Czech Republic, Emergency Response Plan 2013).

The above-mentioned three plans are regularly practiced, for example, it is possible to briefly recall the exercise METRO 2014 (underground, subway, tube), which was a large verification exercise of the entire Integrated Rescue System with a simulated use of the chemical warfare agent, sarin. This thoroughly and consistently verified the correctness, comprehensiveness and reality of the new plan, issued one year before.

We can name the set of measures as a necessary chain: *prevention, preparedness, detection, identification, monitoring of the presence of hazardous substances, protection, rescue, mitigation of consequences, first aid, transport of those affected, hospitalization of those affected, treatment of those affected, disposal of dangerous contaminants, recovery, etc.*

The main task of the IRS rescue units at the scene of a CBRN event is to quickly identify the specific needs that arose in connection with it directly at the specific location where the IRS cones hit. The areas that differ the most from normal procedures are the nature of crisis communication and the preparation of the health care system.

An important difference from standard-type events is the organizational complexity of CBRN incidents, accidents & disasters, precisely because of the heavy burden on the healthcare system. Distinguishing the physical consequences of exposure to CBRN agents and the effects of stress is a particularly difficult task.

5. Missing CBRN Strategy and CBRN Action Plan in the Czech Republic

Despite the fact that the above-mentioned emergency response plans cover the area of CBRN quite comprehensively, we still see certain professional gaps in the area of CBRN protection. That is why it would be very useful and beneficial to create a *National CBRN Strategy* in the Czech Republic and subsequently a *National CBRN Action Plan* to protect the population and professional rescuers from the mentioned threats.

A great advantage is that many developed countries have created such documentation, and it is mostly publicly available (Canada's example). This already created documentation can be very inspiring for the Czech Republic, and it may largely become a basic model to be elaborated in accordance with the conditions in our country.

It may seem that such expert and relatively detailed scenarios can be inspirational and, in this way, also a kind of guide to carrying out a terrorist attack for terrorists and hostile persons. On the other hand, one must see the necessary main and fundamental reason for creating possible terrorist scenarios. To find the best, fastest, and most reliable ways to rescue and protect against CBRN terrorism, we need to ingeniously create such fictional but realistic scenarios of terrorist attacks that will be the basis for countermeasures throughout a complex and interconnected chain of measures.

Here we should chronologically list the measures from prevention, detection, identification, and monitoring of hazardous substances, through the evacuation and sheltering of the population, protection, rescue, mitigation of consequences, first medical care, safe and quick treatment of victims, hospitalization of affected persons and rescuers, to decontamination, restoration, and reconstruction of affected and contaminated areas.

The problem of dealing with extraordinary events and emergency situations is at a very comprehensive level in Canada. In addition, various manuals, aids, guidance documents, recommendations, management plans, and videos are readily available on their website. Why not learn from the experienced, why not use what has already been done and what has worked? It would perhaps be useful to establish fruitful international cooperation in this area.

The most important element of the whole process is the reliable collection of the most accurate information about a CBRN event for the authorities. This will create the necessary conditions for quick and correct decision-making on the need to take various measures. Obtaining the necessary information about the location of the event, the nature of the event, and the results of the first measurements, as well as information about the number of victims and injured and disabled persons, the extent of contamination, and other damages is undoubtedly very important. In addition, the correct and quick evaluation of the event by the control center is of fundamental importance.

Slow, erroneous, and incorrect evaluation of information leads to incorrect and erroneous conclusions and thereby to the incorrect deployment of forces and equipment. This can result in higher casualties, injuries to human health, and higher damages. In such a case, higher costs for dealing with a CBRN event can be expected.

Based on the results of the evaluation, it is then possible to determine the size of the contaminated area where it is necessary to use protective means of individual protection.

The scale of a CBRN event is another very important indicator. Depending on the scale of the CBRN event, the necessity of strengthening forces and equipment from the level of other regions, and from the government (central) level, or whether it is necessary to request international assistance, is subsequently decided on.

For this purpose, it is advisable to immediately request international assistance in the form of immediate contact with the Common Emergency Communication and Information System (CECIS). This involves an exchange of information between the affected area and CECIS, but also the exchange of information and concrete assistance from other countries in dealing with a CBRN event. [7]

Below is the typical and necessary equipment of rescue teams and groups for response and management of CBRN events:

- detection, identification, and monitoring devices for detecting dangerous substances or for determining the presence of radiation or contamination (based on the type of CBRN event);
- personal respiratory protection equipment and personal body protection equipment according to the type of CBRN event (e.g., protective masks, respirators, protective clothing, protective shoes, protective gloves, etc.);
- special sample sets for the safe collection of hazardous substances for subsequent thorough analysis to confirm previously found data on the radiological, chemical, and biological situation;
- decontamination agents, solutions and mixtures for the decontamination of emergency and rescue teams, specifically personnel, equipment, and materials, and the decontamination of contaminated areas;
- safe and reliable equipment for marking and clearly labeling the decontaminated (dangerous) area;
- means of communication and transport; and
- specific additional equipment of the group according to the CBRN event. [7]

Conclusions

There is a clear need to pay great and permanent attention to the issues of defense and protection of the state and its population, and have the necessary documentation prepared for the management of activities in extraordinary conditions at all levels. It is also necessary to prepare not only experts in the components of the integrated rescue system, armed forces, but also crisis managers in the national economy, in state and self-governing bodies, and public institutions.

Understanding the legislative system and the hierarchy of international, European and worldwide regulations is indispensable for a correct orientation in the issue. This is a whole group of national laws and their implementing decrees, as they were presented in this report. Different methodologies and guidelines regulating individual areas are also very important for saving human lives. The relevant Integrated Rescue System emergency response plans (type activities) appear to be pivotal in this field, which are apparently a unique and effective tool for effective protection and reliable liquidation of the consequences of extraordinary events associated with CBRN substances and materials, and clearly and consistently state in detail and interlinked the individual professional activities of the Integrated Rescue System rescue units.

The Czech government and the responsible Czech authorities consider security problems to be key issues of the state's internal policy. It is obvious that, at present, issues of state security are becoming a priority for the daily activities of the government, constitutional officials and individual departments of the national economy. The adverse international security situation, the war in Ukraine and the war in the Gaza Strip, as well as the shocking shooting of a university student at the Faculty of Philosophy in Prague at the end of 2023, are particularly contributing to this. This tragic event claimed 15 lives and injured many innocent people, many of whom remained hospitalized for a long time.

The high-quality and sufficient professional documentation created must be constantly updated, supported by material and technical security, which will represent a long-term burden on the state budget due to the breadth of the problem. The system of education of the population of all age categories, the involvement of educational institutions, the information process to the necessary extent without subjective opinions, which ultimately lead to mistrust and rejection of the measures taken, must also play a role in the CBRN preparedness of the state and its population.

It is worth mentioning that the floods in the Czech Republic, which affected our country in recent years, caused multi-million dollars damages in the Czech Republic and caused the need to take effective preventive measures to guard against repeated events. How financially demanding it is shown by the slow and gradual solution and implementation of the individual proposed measures. Unfortunately, these tragic events did not go without taking a toll on human lives, which is the highest and most painful loss of all.

Therefore, it is very important that the Czech Republic also continues to pay increased attention to protection against chemical, biological, radiological and nuclear terrorism in vulnerable public places (e.g. in the Prague metro). However, they must also seriously consider all possible catastrophic scenarios of attacks and ambushes using CBRN agents and material.

Cruel, brutal, and violent acts of terrorism are planned to affect the public and to create shock and stress in entire nations. Negative experiences resulting from the horrors and memories of dead and disabled victims will leave a lasting impact on all persons affected by the attack, as well as their families and relatives, friends and acquaintances. [5]

State and intelligence services, together with police and state authorities, must focus thoroughly and single-mindedly on detecting any preparation of terrorist attacks in order to prevent such acts of violence worldwide.

Particular attention should be paid to the important issues of CBRN and related rapid and reliable protection of the population as well as rescuers and hospital staff in the Czech Republic and in other countries. CBRN terrorism could cause a very large number of victims. It is obvious that new terrorist threats will not escape the Czech Republic.

If the proposed management system saved a single human life (even though it can protect and save tens, hundreds, if not thousands of lives), it is undoubtedly worth it. The Czech Republic has many important professional publications that could greatly support the creation of a National Strategy for Protection in the field of CBRN and, as a result, a National Action Plan for this area. [8, 9]

It is important to emphasize that the experienced team of selected CBRN experts represents the foundation of a necessary temporary working group that could analyze, evaluate, and discuss the area and propose a comprehensive solution.

This can be implemented both as a public tender of the Ministry of the Interior of the Czech Republic and as a national security project within the framework of a public tender in the field of security at universities or other research and development workplaces and organizations in the Czech Republic.

In the end could be stress that Current Crisis Management and Emergency Planning in the Czech Republic in English you can study at student text. [10]

Acknowledgements

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Educating Cadets Competencies using the Special Relativity Theory

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Abstract

The cadets' competencies in the contemporary geopolitical situation cover a broad spectrum of skills, abilities, knowledge and attitudes. Among other things, it is also knowledge in the field of physics. The standard approach to the teaching of special relativity is about presenting the postulates, then showing the transformation relations between rest and moving frames, following with formulae for the adding of the velocities, dilation of the time and contraction of the length. Here we present another approach to the same topic, which is built on the concept of spacetime, especially on the spacetime diagrams, and with detailed focus on the 'paradoxes', in particular the twin paradox and the ladder paradox. The text is based on author's own experiences with presenting these concepts to the students.

KEY WORDS: *cadets competencies, special theory of relativity, spacetime diagram, twin paradox, ladder paradox*

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1. Introduction

The future world will be volatile, uncertain, complex and ambiguous, but the physical laws are immutable. To estimate how the society will change over time and which knowledge cadets will need to not just survive but also to be successful is very difficult. Therefore, it is important to keep an attention on their competencies, to use the connection of knowledge from various educational areas into broader units with the aim of creating a more comprehensive view of mathematical, natural, social and cultural phenomena.

In the standard physical textbook for engineers which has a chapter on the special relativity [1], [2], there is no notation of spacetime diagrams. Even in the famous textbook on special relativity for theoretical physicists [3], there is just one spacetime diagram with the light cone. But the spacetime diagram approach to the special relativity can be beneficial for the students as the diagrams (and the pictures in general) are easily understandable than the complicated physical formulae.

As a lecture on the special relativity is a part of the syllabus at University of Defence, we present here an alternative way to special relativity to the military students. In general, the teaching of the military students has its own specifics, for the case of University of Defence see [4], [5]. The following text does not have a purpose to replace the standard approach, but more likely to extend it. At least the notion of spacetime diagrams from the first section of this text can be incorporated into teaching, because it naturally expands and supplements the concepts of dilation of time and contraction of the length, which are taught in the standard approach. The second and third section about 'paradoxes' are quite more involved and can be used for the students as the voluntary home assignments.

The following text is based on tutorials which was taught by the author at Masaryk University for six years. The text is enlarged and simplified for the usage at the University of Defence.

2. A first look on spacetime with spacetime diagrams

A spacetime is a collection of the classical three-dimensional space with one-dimension time direction. In this text we will work with just two-dimensional flat spacetime, also known as two-dimensional Minkowski space. A spacetime diagram is a plot with one temporal axis, while the other axis is spatial as usual. For the convenience the temporal axis has label ct, therefore the both axes have the same dimension, as the second axis has label x. The spacetime diagram is always connected with an observer in the rest. While at the purely spatial diagrams, the observer in the rest stays in the one point, which we can choose without the loss of generality as an origin, the spacetime diagram is in some sense 'dynamical'. As one axis is temporal, the observer in the rest can't stay in one point, instead his/her movement through the spacetime diagram is described by an equation

$$x = 0.$$

That means that his/her spatial coordinate is fixed, and his/her trajectory through the spacetime diagram (which is called a worldline) is a vertical straight line, which coincidences with the axis ct.

Let's assume that the observer in the rest (we call her Alice from now) at the spacetime point $(ct, x) = (0{,}0)$ sends a light signal. The light is moving with the speed of light c, thus its worldline has an equation

$$x = \pm ct,$$

where the sign depends on the direction of the light signal, if the Alice sends it to the left or the right (see Figure 1). Let's assume also, that Alice meets another observer, called Bob, at the spacetime point $(ct, x) = (0{,}0)$. But Bob has non-zero velocity with respect to Alice, he has velocity $v_B = \frac{c}{2}$. Therefore his worldline is

$$x = \frac{1}{2}ct.$$

See the Figure 1 for the picture of the situation.

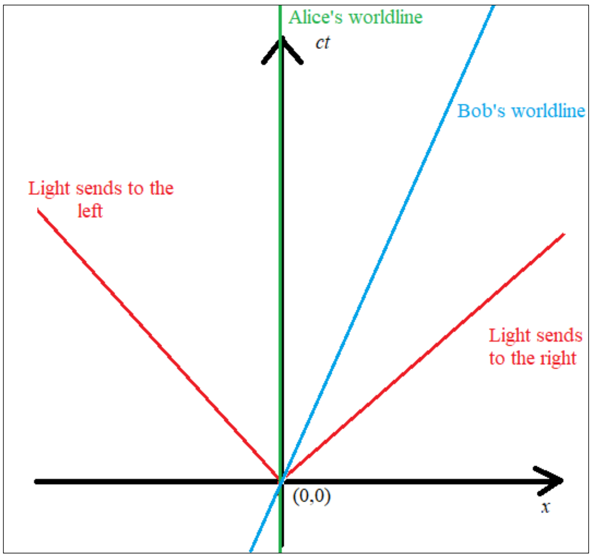

Fig. 1. Alice is in the rest. She sends light signal both ways and also meets Bob at the spacetime point (0,0).

The main idea of the relativity is the following: how does Bob see this situation? Let's denote his temporal axis as ct' and his spatial axis x'. At his frame, he is in the rest, that means his worldline has an equation

$$x' = 0.$$

From his point of view, he meets Alice at the spacetime point $(ct', x') = (0{,}0)$, while Alice has the velocity $v_A = -\frac{c}{2}$ (the magnitudes of velocities are the same, but they have opposite directions), therefore Alice has the worldline

$$x' = -\frac{1}{2}ct',$$

at Bob's frame. And what about the light signal, which Alice sends? One of the postulates of the special relativity is, that the light has the same speed in the all inertial frames. Thus, the equations for the light worldlines are

$$x' = \pm ct'.$$

The situation from the Bob's point of view is depicted on the Figure 2. The transformation from the Alice's frame to the Bob's frame and vice versa is called Lorentz transformation [3]

$$\begin{bmatrix} ct' \\ x' \end{bmatrix} = \begin{bmatrix} \gamma & \frac{v_A}{c}\gamma \\ \frac{v_A}{c}\gamma & \gamma \end{bmatrix} \cdot \begin{bmatrix} ct \\ x \end{bmatrix}, \qquad \begin{bmatrix} ct \\ x \end{bmatrix} = \begin{bmatrix} \gamma & \frac{v_B}{c}\gamma \\ \frac{v_B}{c}\gamma & \gamma \end{bmatrix} \cdot \begin{bmatrix} ct' \\ x' \end{bmatrix}, \tag{1}$$

where γ is so called Lorentz factor, which is defined as

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}},$$

with $\mathrm{v} = -v_A = v_B$. The matrices in the equation (1) are inversed to each other.

One of the key concepts in the special relativity is non-existence of the absolute time. Instead there is a notion of the proper time and the coordinate time. The proper time is different for each observer, as each observer has his/her own clock (or own cell phone). In the example above with Alice and Bob, the proper time of the Alice is denoted t, and proper time of the Bob is denoted t'. The coordinate time is on the other hand always connected to the rest frame. On the Figure 1 the coordinate time is t, which is Alice proper time.

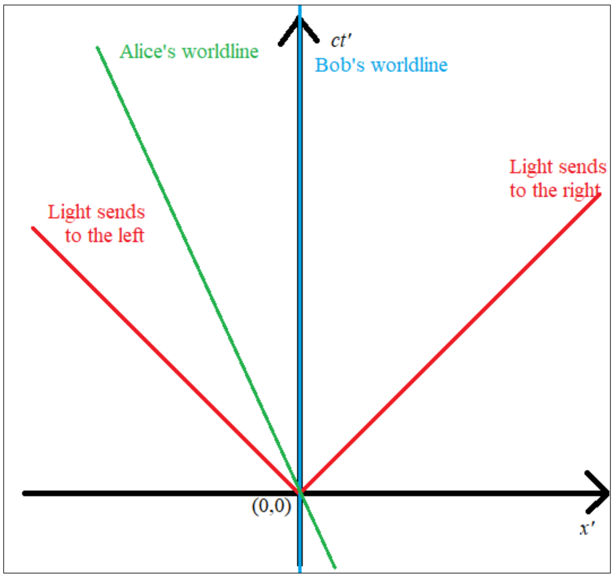

Fig. 2. Bob is in the rest. He meets Alice at the spacetime point (0,0), where she emits two light signals.

On the Figure 2 the coordinate time is t', which is Bob's proper time. The coordinate time serves as universal time for the frame, a time which all observes agree to use, because the communication is easier[3]. The proper times are different in general, as is obvious from the equation (1). If we are interested in the time intervals, i.e. how much time passes in the one frame in comparison to the second frame, we discover the dilation of the time. Let's say that Bob starts a stopwatch in time t_1' and stops it in time t_2' . Therefore, the time on the stopwatch is $\Delta t' = t_2' - t_1'$. But at his rest frame, he doesn't move, he still stays at the position $x' = 0$, thus $\Delta x' = 0$. The question is: how much does time pass in the Alice's frame? The answer is given by the equation (1)

$$\begin{bmatrix} c\Delta t \\ \Delta x \end{bmatrix} = \begin{bmatrix} \gamma & \frac{v}{c}\gamma \\ \frac{v}{c}\gamma & \gamma \end{bmatrix} \cdot \begin{bmatrix} c\Delta t' \\ 0 \end{bmatrix},$$

and by the matrix multiplication we find out that

$$\Delta t = \gamma \Delta t'. \tag{2}$$

This is the famous time dilation. As the γ is always greater or equal to 1 the following holds

$$\Delta t \geq \Delta t'.$$

Or in the words: the Alice always measures the longer time interval in her frame than Bob in his frame. Or in another words: the moving observer get older more slowly with respect to the observe in the rest. These statements have some conceptual loopholes and we get back to them in the next section. The dilation of time is the effect of special relativity on the

[3] The similar real-world situation is with UTC, the time zones times and the local times. There is no special relativity, but as each place has the different time (due to the rotation of the Earth and the Sun), it is easier the agree on one universal time, UTC, or 24 time zones. Otherwise each two locations on different meridians would have different times, and at least public transportation would be almost impossible.

temporal axis, the effect of the special relativity on the spatial axis, called the length contraction, is more involved and can be left to the students as home assignment[4].

On the Figure 1 and Figure 2 we can notice a structure which doesn't change from one frame to another, the light rays. This should not be surprising as light has the same velocity in every frame. Moreover, this structure of the light rays, called light-cone, can be used to discover the causal structure of the spacetime.

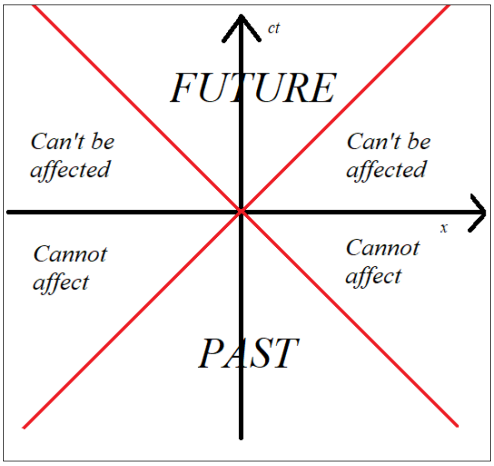

Fig. 3. Light-cone structure of the spacetime.

On Figure 3 there is a spacetime diagram with a fixed observer at the origin of the spacetime, i.e. spacetime point $(ct, x) = (0,0)$. As the speed of light is the maximum speed, the information to the observer in origin could get just from part of the lower half of the diagram, which is between two light rays. This is the 'past', the part of the spacetime which can have an influence on the observer at the origin. The edges of the 'past' are light rays, all other observes which can meet our observer have to be between these light rays, as they speed is smaller than the speed of light. On the other hand, the upper part of the diagram between light rays is the 'future' to the observe at the origin. This part of the diagram can be influenced by the observer in the origin. His/her own worldline, due to being in the rest frame, is the axis ct, but he/she can throw something, or send light signal to affect this part of the spacetime. The last part of the spacetime is on the left and on the right. This part of the space can't be affected by the observer in the origin or cannot have an influence on the observer in the origin. And the reason why is obvious. Because the information has to travel in larger speed that the speed of light. One last note to the light-cone structure, which we have to have in mind, is that the Figure 3 is frozen in one particular time. The spacetime diagram is dynamical, therefore the observer in the origin should move on his/her worldline, i.e. axis ct. As the light-cone is defined in each point of the worldline, it moves with the observer, and each point has another 'past' and 'future'. This brings us to the propagation of the information in the spacetime.

[4] In our example with Alice and Bob, we can formulate the problem as follows. Alice measures the length of Bob's trajectory. In her frame the trajectory is Δx, in Bob's frame the trajectory is $\Delta x'$. The crucial point here is, that the measurement has to be done in the one time, and as Alice is the one, who measures, this means $\Delta t = 0$. Plugging these to equation (1), we can solve the equation for $c\Delta t'$, and plugging this to the second equation we find out the contraction of the length $\Delta x = \Delta x'/\gamma$.

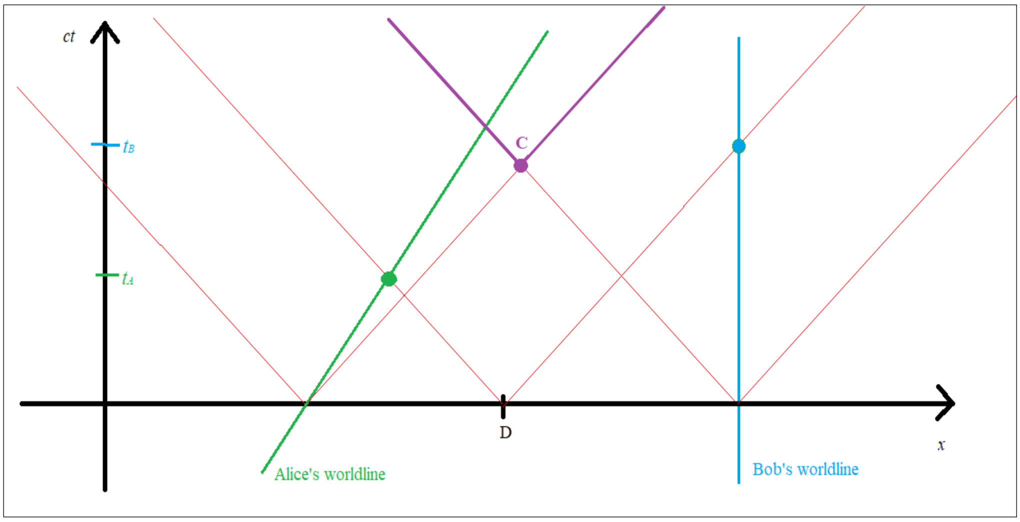

Fig. 4. Propagation of the information in the spacetime diagram.

The information in the spacetime can propagate in various speed, but the maximum speed of propagation is speed of light. As all information could be encoded into binary code, which could be propagate for example by lasers (laser emits a signal is 'one', laser doesn't emit a signal is 'zero'), we will work just with information which propagates with speed of light. On the Figure 4, there are again two observers Alice and Bob. Bob has velocity with respect to the rest frame $v_B = 0$, Alice has velocity $v_A = c/2$. The axes are ct and x, which are different to Alice's rest frame (because she has non-zero velocity) and also to Bob's rest frame (as his worldline doesn't cross the origin of the rest frame). There are also drawn light-cones in the coordinate time $t = 0$. Therefore the first spacetime point which can be affected by both Alice and Bob at time $t = 0$, is the spacetime point C. And the whole part of the spacetime which can be affected by both Alice and Bob is a cone with vertex C. Let's say that in time $t = 0$, something terrible happened (like an explosion of a supernova) in the spacetime point D (the point is in the middle between of Alice and Bob). When they get an information about this event? As we said, the information propagates with speed of light, therefore we draw another light-cone from the spacetime point D. And the intersections between this light-cone and Alice's and Bob's worldline give us the exact moments, when both of them get the information about the explosion. It should not be surprising that $t_A < t_B$, as the Alice moves towards the explosion. But this is one of the crucial ideas in special relativity, that information is not instant, it takes a time to get the information. The concept which could leads to some paradoxical situations as we will see in the ladder paradox.

The last remark in this section is about the second postulate of the special relativity, that the physics in all inertial frames is the same. How we can easily see in the spacetime diagram, that the observe is not in the inertial frame? The answer is very straightforward. The difference between inertial and non-inertial frame is an acceleration. And if an observer has non-zero acceleration, his/her worldline is not a straight line, but rather a curved line, or there is a tip on the line.

3. The Twin Paradox

The statement of the twin paradox is the following: *Consider two twins, first stays on Earth, second travels with the speed, close to the speed of light, to the space. After a time, the second twin turns back home. When they meet each other again on the Earth, the second twin is older, because of the dilation of time. But from the frame of the reference of the second twin, the twin, which stays on Earth, should be older, because the second twin was at his/her frame in the rest and the first twin has non-zero velocity.* And that's the paradox. Except for one thing. There is no paradox, just weakly understood basics of special relativity. If we draw the spacetime diagram for this situation, which is on the Figure 5, we see that the second twin feels the acceleration at the turning point. There is a tip on the worldline of the second twin. Therefore, the second twin is not an inertial observer and thus, the special relativity is not enough to describe this situation. This implies that this can't be a paradox within the theory of special relativity, as it contradicts the one of the postulates of the theory. In fact, if you want to describe this situation, you need general theory of relativity, i.e. theory of non-inertial frames[5].

[5] Also, you need to remove an infinite acceleration at the starting and turning point, which is unphysical. But if you formulate the twin paradox as follows: First twin stays on the Earth, second twin accelerates with acceleration $9.81\ \mathrm{m \cdot s^{-2}}$ for one year, then accelerates with the same acceleration but with opposite direction for two years and finally accelerates with the same acceleration but with the origin direction for last year. After all, the second twin is back on the Earth and the journey takes four years in his/her reference frame. But from the point of the twin on the Earth, the journey takes 4,78 years.

But we can slightly change the settings of the situation to understand more about the spacetime. Let's assume that two twins, we call them Cedric and Dedrick, are totally identical. They have the common medical history and future, i.e. if one of them has a heart attack, the other also has a heart attack. Cedrick stays on the Earth, Dedrick travels to the stars with speed

$$v = \frac{\sqrt{3}}{2}c.$$

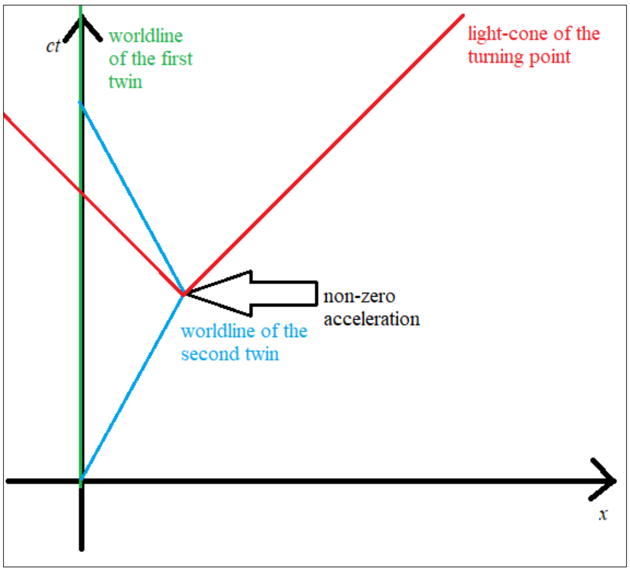

Fig. 5. The twin paradox. The arrow points on the turning point with non-zero acceleration. In the highlighted light cone, there is the part of the spacetime, where the special relativity is non-enough to describe the situation.

Two years after Dedrick's departure, Cedrick has a heart attack. From the dilation of time, equation (2), we can calculate the Dedrick's proper time. Two years are in the Cedrick's frame of reference, i.e. $\Delta t = 2$ years. We know the speed; therefore, we can get the time which has passed in Dedrick's frame of reference, after the calculation we find out that it is $\Delta t' = 1$ year. Thus, he has still one year until he is going to have the heart attack. So, the question is the following, can we send this information to him before the heart attack and possibly save his life? For the answer we use the spacetime diagram. On Figure 6 there is Cedrick's worldline C, Dedrick's worldline D and after two years, the light signal S is emitted from the Cedrick's worldline. The light signal S crosses the Dedrick's worldline in the spacetime point P.

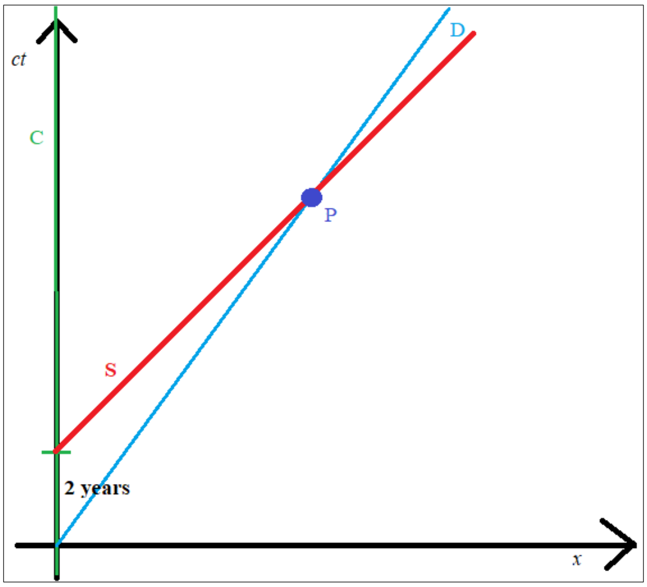

Fig. 6. The spacetime diagram of Cedrick and Dedrick.

This is the moment, when Dedrick gets the information about Cedrick's heart attack. Our task is to find out the spacetime coordinates of this point. And now we will see the power of the spacetime diagrams, because we just need to calculate the intersection of two straight lines. It reduces the abstract physics to the level of high school geometry! Let's calculate. We can think about the worldlines as functions of x. Thus, the Dedrick worldline has an equation

$$\text{D: } ct = \frac{2}{\sqrt{3}}x.$$

The light signal S travels with speed of light and has an equation

$$\text{S: } ct = x + 2.$$

We have two equations with two unknows, therefore we can solve this system of equations. The solution is the spacetime coordinates of the point P in Cedrick's reference frame. The spacetime point P is

$$\text{P} = (ct, x) = (14.93\, c \cdot \text{years}, 12.93\, \text{ly}).$$

The signal crosses the Dedrick's worldline after 12.93 years (14.93 years after the Dedrick's departure) in the distance of 12.93 light years. But keep in mind, that this is calculated in the Cedrick's frame. We have to transform these numbers to the Dedrick's frame. We plug the elapsed time into (2), and we find out, that in the Dedrick's reference frame 7.465 years has passed, therefore, Dedrick's heart attack was 5.465 years ago, and we can't save him. On the other hand, we show that the causality in the special relativity is preserved. The consequence follows the cause, and not vice versa.

One last note on this example. What about numbers that we got? Derick's spaceship is 12.93 light years away from the Earth, but on the spaceship just 7.465 years has passed. That seems that the spaceship flies faster than light? This question can be left as the home assignment for students. The answer is the contraction of the length. The distance 12.93 ly is measured in Cedrick's reference frame. But for Dedrick this distance is moving, because in his frame, he is in the rest, and the rest of the universe is moving. Therefore, he measures the moving length and due to contraction of the length, the length is smaller. We can plug the numbers into formula in the Footnote 2 to see, that in Dedrick's frame, Dedrick travels just 6.465 ly. And it makes sense, he has velocity $\sqrt{3}/2 \cdot c$, he flies for 7.465 years, and if we multiply these two numbers, we get again 6.465 ly. Everything works perfectly.

4. The Ladder Paradox

The ladder paradox shows how our intuition fails in the special relativity problems. It can be formulated as follows: *A person holds a ladder, which is* 2.1 m *long, in front of them. This person has the velocity*

$$v = \frac{\sqrt{3}}{2}c,$$

and runs into a room, which is only 1 m *long. But the person is capable of closing the door when enters the room. Explain why?* On the first sight this is non-sensical situation, you can't fit 2.1 m long ladder into 1 m long room. On the second sight, and with a little knowledge about special relativity, it still not makes sense. The length of the ladder, as the ladder is moving, is contracted. Plugging velocity and length into the formula from Footnote 2 we find out, that in the room's frame of reference, the ladder has just 1.05 m. The ladder is shorter but not enough to fit into room. For the whole answer we need spacetime diagram. We call the person holding the ladder Usain and we work in the reference frame which is connected to the room. The situation is on the Figure 7.

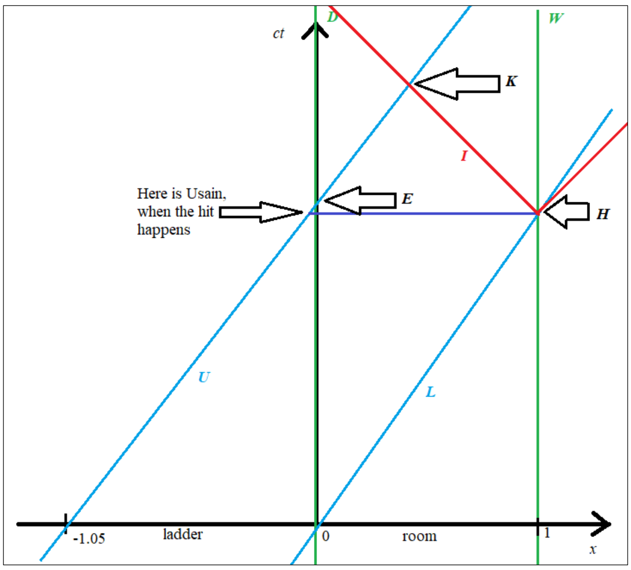

Fig. 7. The spacetime diagram for the ladder paradox.

First look at the axis x, there is the ladder in the moment, when the first part of the ladder enters the room. The ladder is between points -1.05 and 0. Usain is at the point -1.05. On the other part of the diagram, there is the room. At the point 0, there are doors, at the point 1, there is a wall. Because we work in the room's reference frame, the ladder is contracted. These all things are in one moment of time, when $t = 0$. Now we start to draw worldlines. First the easy ones. The room is in its rest frame, it doesn't move, therefore its door has the worldline

$$D: x = 0,$$

and the wall has the worldline

$$W: x = 1.$$

The ladder is moving with Usain's velocity, so the top part of the ladder has the worldline

$$L: ct = \frac{2}{\sqrt{3}}x.$$

The slope of the Usain's worldline is the same, but he is shifted to the point -1.05 on the axis x, therefore, to get his worldline we first write general worldline with the slope $2/\sqrt{3}$

$$U: ct = \frac{2}{\sqrt{3}}x + A,$$

where the A is a constant, which we obtain by plugging the spacetime point $(ct, x) = (0, -1.05)$ into the worldline. Therefore, Usain's worldline is

$$U: ct = \frac{2}{\sqrt{3}}x + \frac{2.1}{\sqrt{3}}.$$

Now we scan the diagram from the bottom to the top to find some interesting events. We scan this diagram with respect to the time flow. On the bottom, there is the past, on the top, there is the future, thus the arrow of time is from bottom to the top. First of the interesting events is when the ladder hits the wall at the end of the room, we denote it with letter H. Where is Usain, when this hit happened? He is still 1.05 m to the left of the top of the ladder, so in front of the doors. But the information about the hit propagates through the spacetime with speed of light. It is not instant. So, we draw a light-cone of the hit and we denote the left light ray as I. We continue with the scanning of the diagram, Usain follows his worldline and at the point E he enters the room. He can do it, as the information about the hit doesn't cross his worldline. He has no idea about the ladder hitting the wall and nothing stops him. He can even run deeper into the room, up to the point K, where the information about the hit crosses his worldline.

But the spacetime diagram is not a proof of Usain being able to close the door. We have to calculate the spacetime coordinates of the point K. This point is the intersection of worldline U and I. We already have the equation of worldline U and for the worldline I, we have to know the coordinates of the point H. The point H is the intersection of the worldlines W and L, both equations can be found above. It is easy to see, that the point H has the spacetime coordinates

$$(ct, x) = \left(\frac{2}{\sqrt{3}}, 1\right).$$

Back to the worldline I. The general form of this left-moving light ray worldline is

$$I: ct = -x + B,$$

where the minus sign in front of x means that it moves with speed of light to the left, and B is a constant whose value we gain by plugging the coordinates of the point H. Again after quick calculation we get

$$I: ct = -x + 1 + \frac{2}{\sqrt{3}}.$$

From the last calculation we obtain the desired coordinates of the point K. We have equations for both worldlines on which the point K lies. These are worldlines U and I. We can subtract these equations from each other to get

$$0 = \frac{2}{\sqrt{3}}x + x + \frac{2.1}{\sqrt{3}} - 1 - \frac{2}{\sqrt{3}}.$$

The solution is

$$x = \frac{\sqrt{3} - 0.1}{2 + \sqrt{3}} \approx 0.437.$$

This means that Usain is almost in the middle of the room when he gets the information about the hit! But wait, is not here the same problem as in the twin paradox? At the point H, when the ladder hits the wall, there is an acceleration. The ladder has to deaccelerate due to the hit. As we don't assume anything about the width of the wall, or material of wall and ladder, we don't know how much it deaccelerates, but it deaccelerates. Therefore, the top part of the ladder is a non-inertial observer and should not be possible to describe its movement with special relativity. And this is true, but just within the light-cone with the vertex H. In this part of the spacetime, there is an acceleration, therefore, the special relativity is not enough to describe the physics here. But the point E and even point K are both out of this light-cone, they are both in the 'can't be affected' part of the light-cone of the point H (compare the Figure 7 with Figure 3). This is the difference between ladder paradox and twin paradox. In the twin paradox, the return of the second twin on the Earth was inside the light-cone of the turning point, in its 'future' part (compare Figure 5 with Figure 3). But one thing has these paradoxes in common. Both are not paradoxes at all within special relativity. And for the full picture of these situation you need to incorporate the general relativity (and in the case of ladder paradox also material properties of the wall and latter).

The last remark about the ladder paradox is also a possible home assignment for the students. They can try to solve the ladder paradox not in the rest frame of the room, but in the Usain's rest frame. The situation in this reference frame is even more absurd. In his rest frame Usain stays at one position, holding the 2.1 m long ladder in front of him. The room is moving with the speed $v = \sqrt{3}/2 \cdot c$ towards him, and the room is just 0.5 m long, as it has to be contracted due its movement. But the result is the same, he is able to close the door. Therefore, from his point of view it looks like you can fit something 2.1 m long into 0.5 m long space! The calculations are similar to the presented ones, it's not hard nor easy, and if a student gets right answer, he/she understands the spacetime in right way.

1. Conclusions

We presented here spacetime diagram approach into special relativity. This approach is established on diagrams with one temporal and one spatial axis. In the realm of special relativity, all worldlines in these diagrams are straight lines, thus the problems in the special relativity are reduced to the level of high school geometry. Any curved line means, that the right physics to describe the situation is the general relativity. Therefore, another advantage of this approach is, that it can be easily generalized and it can be used as the entryway into the studying of the general relativity. Moreover, in the general relativity, there is a notion of another spacetime diagrams, which are called Penrose diagrams, and they are used to investigate the causal structure of the spacetimes.

The advantage of this approach is also its simplicity. For the students it is easier to think in the pictures than in the equations. As everything in the spacetime diagram can be drawn, the student can first draw everything and then think about the equations, which describe the worldlines in the diagram. From the point of view of a lecturer, this approach also easily opens up discussion with students about special relativity and even beyond, which can lead to another interesting topics.

A lecture based on this new approach was performed this year for the first time at University of Defence. It was an extra lecture based on the wish of the students, thus it is not in the syllabus of the subject and no compare tests were written. Also, the evaluation of the anonymous student survey is in the October of this year, therefore there are still no data objective data on this approach yet. All we have is a direct feedback from the students after the lecture, which was very positive.

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Teaching the Subject of Operations Research at Military Universities (Not Only) of NATO Countries

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Abstract

The guarantor of military higher education in the Czech Republic is the University of Defense in Brno. The student must successfully complete a demanding five-year course of study. Individual subjects develop the relevant competences necessary for mastering military service and the requirements placed on future commanding officers. Operations research (OR) belongs to the theoretical subjects. It teaches students logical thinking and helps solve optimization problems.
The authors of the article focused their attention on the subject of OR. The aim was to find out in which military universities (mainly in NATO countries) OR is taught, what is its content and some other characteristics of the teaching of this subject. A questionnaire was created for this purpose. That questionnaire was distributed to selected military schools. A comparison was made based on the information obtained. The examined data are entered into the appropriate tables. Some conclusions are obtained.

KEY WORDS: *operations research; operational analysis; military student; operations research topics, comparison across countries, questionnaire.*

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1. Introduction

In recent decades, there have been significant changes in the economic and political situation in the world. It is crucial that commanding officers are properly educated. The only military college that educates military professionals for the Army of the Czech Republic is the University of Defence based in Brno.

The university training of future officers of the Army of the Czech Republic takes place in accredited study programs in the field of management and resource management applied to the sphere of defence and security. Military study programs combine a broadly oriented theoretical foundation with more narrowly focused study subjects. In our contribution, we will focus on Operations Research (OR), which is taught by the Department of Quantitative Methods at the Faculty of Military Leadership. As part of completing the course, students learn to solve optimization problems, improve their logical thinking and correct judgment.

Operations research is intended for all students of the faculty. The teaching takes place in the second semester of the first year, with a time allocation of 56 hours (28 hours of lectures and 28 hours of exercises). The subject is completed with a credit and an exam. The content of the subject is an introduction to linear programming (production planning problem, mixing problem, distribution problem, graphical method, simplex method, artificial base method, duality), transportation problems, multi-criteria evaluation of variants, multi-criteria linear programming, matrix games. This information is available on the website of our university, see [1]. For more detailed information about the topics and the scope of OR teaching at the University of Defense in the Czech Republic, the reader can be referred to the teaching text [8]. For examples of our work in the area of operations research, see, for example, [9, 10].

The aim of the article is

1) to compare the teaching of OR at military universities, mainly in other European countries and especially in NATO countries;
2) to find out if the OR is taught, and if so, the way how the OR is taught at these universities, i.e. what topics, in which year/semester, the size of the teaching time allocation, number of credits, method of completion of the subject, for which specialization OR teaching is intended, whether the subject is compulsory and whether OR is a part of the final state examination.

2. Data and methods

It is not easy to obtain the necessary information (whether OR is taught at a given school, in which year, subject plan, time allowance for OR teaching, etc.). First of all, we searched on the websites of the selected universities. We started with the university addresses from the document Partner Institutions of the University of Defence in Brno, see [2]. From the selected 26 universities, we found the necessary data for only four of them. At the same time, we approached 26 students who studied at our faculty within the ERASMUS+ program in 2020–2023. We received answers (and other information) only from two Slovak students. We obtained information from Ukraine using our personal contacts. We have already provided information from these six countries (Bulgaria, Czech Republic, Slovakia, Slovenia, Ukraine, USA) in the abstract (mid-February 2024). The websites of these universities are listed in [1, 3, 4, 5, 6, 7].

We created the necessary questionnaire and then sent it to another 84 e-mail addresses and at least 24 countries with a request for completion. Only three of them responded (Austria, Belgium, Romania). We also obtained incomplete data from Georgia (southeast Europe, west Asia) through our personal contacts.

The questionnaire had two parts, a cover letter and a table (excel file) that just had to be filled out. The key part of the cover letter is:

… we need to get information. That is why we ask for your cooperation.

We need to find out at which schools Operational Research (OR) is taught and some other information:

14. In which semester/year?
15. Is it intended for students of which specialization?
16. What is the time allocation for the course/subject? How many lessons/hours?
17. What topics are taught? Ideally, get the Study Plan of the subject.
18. Is OR taught in bachelor's degree, Master's degree, or doctoral study?
19. Is the subject of OR obligatory or optional?
20. Is the subject of OR completed with credit, graded credit or an exam?
21. Is the subject a part of the final state exam?

And there was a large table in the attachment of the email, where the respondents should fill their answers. Here, we devided it into three tables (Tab. 1 – Tab. 3) for better readability.

Table 1.
Operations Research (OR) - information about OR teaching in your country on your university/faculty, part 1.

Country	University	Faculty	Name of subject
Czech Republic	University of Defence	Faculty of military leadership	Operations Research
. . .	. . .	. . .	. . .

Table 2.
Operations Research (OR) - information about OR teaching in your country on your university/faculty, part 2 (Topics of Operations Research).

LP	TP	Duality	MEV	MP	MG	NA	Queue	other topics
Y	Y	Y	Y	Y	Y	N	N	-
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .

Table 3.
Operations Research (OR) - information about OR teaching in your country on your university/faculty, part 3 (Characteristics of Operations Research).

Year	Semester	Hours	End	ECTS	For	Obligatory	Notes:
1.	S	56	exam	4	All	Y	5-years study

Notation used in the tables:

Name of Subject	Operations Research, Operational Research, Operational Analysis, Optimization Methods, ...

Topics of OR

LP	Linear Programing
TP	Transportation Problems
MEV	Multicriteria Evaluation of Variants
MP	Multicriteria Programing
MG	Matrix Games, Theory of Games
NA	Network Analysis, Graph Theory

Queue	Queue Theory, Models of Mass Service
other topics	write other topics of OR if you have
Year	In which year of study is OR teaching
Semester	S = summer, W = winter
Hours	number of teaching hours
End	exam, cr = only credit
ECTS	number of credits
For	All students or Which specialization?
Obligatory	Y/N = Yes or No
Notes:	write what you think is important to say about the topic.

The "Czech Republic" line is a sample.

3. Results

We obtained information from 10 universities in total. There are the names of states, the names of universities where OR is taught and names of the subject in Table 4. The symbol * means that there are more schools (or faculties or branches) in the given state (school) where OR is taught. We always chose one school, one faculty or one field of study for each country. In such cases, the data were mostly similar.

Table 4.

Countries, university names and subject names

Country	**University**	**Name of subject**
Austria	Theresan Military Academy	No OR
Belgium	Royal Military Academy*	Operations Research
Bulgaria	Vasil Levski National Military University*	Operations Research
Czech Rep.	University of Defence	Operations Research
Georgia	Batumi Shota Rustaveli State University	Operations Research
Romania	"Nicolae Balcescu" Land Forces Academy*	Theory of Decision and OR
Slovakia	Armed Forces Academy of General Milan Rastislav Štefánik*	Operations Research
Slovenia	University of Ljubljana	Operations Research
Ukraine*	Kharkiv National University of the Air Force named after Ivan Kozhedub*	Mathematical problems of operations research in electrical engineering
USA	University of Michigan	Operations Research

Table 5 contains the OR topics (LP = Linear Programming, TP = Transportation Problems, Dual = Duality, MEV = Multicriteria Evaluation of Variants, MP = Multicriteria Programming, MG = Matrix Games/Theory of Games, NA = Network Analysis/Graph Theory, Que = Queue Theory, MS = Mathematical Modelling and Simulations), type of study, year, semester, and teaching hours. Symbol Y means yes, i.e. the topic is taught at the school.

Table 5.

Information about the teaching of OR, i.e. topics, year, semester, and hours. Y=yes, i.e. the topic is taught at the school

Country	Topics of Operations Research									Type of study	Year	Semester	Hours
	LP	TP	Dual	MEV	MP	MG	NA	Que	MS				
Austria				Y		Y							
Belgium*									Y	Bc.	3.	S	
Bulgaria*	Y	Y						Y				W or S	30
Czech Rep.	Y	Y	Y	Y	Y	Y				Mgr.	1.	S	56
Georgia						Y					2.	S	60
Romania*	Y	Y			Y	Y				Mgr.	1.	W or S	36
Slovakia*	Y	Y					Y	Y			1.	W	42
Slovenia	Y		Y	Y	Y			Y			2.	S	45
Ukraine*													
USA													

Table 6.

Information about the teaching of OR, other characteristics of the subject

Country	End	ECTS	For	Compulsory	Final state exam	Notes
Austria						
Belgium*	exam	4	All	Y	Y	
Bulgaria*		3				
Czech Rep.	exam	4	All	Y	N	5-year master's degree
Georgia			Computer science			
Romania*	exam	6		Y	Y	4-year master's degree
Slovakia*		4				
Slovenia						
Ukraine*		4				
USA						

Table 6 shows other characteristics of the OR subject, i.e. the way the subject is completed, the number of credits (ECTS), for which specialization OR teaching is intended, whether the subject is compulsory and whether OR is part of the state final exam. The last column serves as a space for entering additional important data. In our table, it was only an indication of the level of study and its length.

4. Conclusions

Obviously, there is little data. For an explanation, see the Limitations paragraph. Data for Ukraine and the USA are almost completely missing, not available on the Internet; we did not find them. We can only base it on the subject name, see Tab. 4. It is likely that many of the mentioned OR research topics are also taught at the respective universities of Ukraine and the USA.

We simply do not have such information. The same is true with the university in Georgia. We have information that at the Theresan Military Academy in Austria, the OR subject is not taught in our sense there, they only have the multicriteria evaluation of variants and wargames topics.

Linear programming is the most fundamental area of Operations Research. From our data, it can be seen that linear programming is also taught at almost all the mentioned universities. The issue of transportation problems is also a classic discipline of Operations Research, and is also almost always taught. The topic of duality is a relatively theoretical matter, the consequences of duality are applied in matrix games, for example. However, duality is only taught in the Czech Republic and Slovenia (according to the data obtained). We see the reason in the theoretical character. Matrix games, for their rich application use, are studied at several universities. Similarly, the issues of multicriteria optimization (Multicriteria Evaluation of Variants, Multicriteria Programming), Matrix Games and Queue Theory are taught at several universities.

In contrast, the topics Network Analysis/Graph Theory and Mathematical Modeling and Simulations appeared only once in Table 2. Perhaps this area of operations research is not taught as often, or perhaps it is taught in another subject or under a different name. For example, at the University of Defense in the Czech Republic, we taught Graph Theory and Network Analysis until 2014, later no longer (due to a reduction in the time allocation for the subject). Or we were just unlucky with the data obtained - again, we can point out the small amount of data.

In general, it can be said that some schools teach some topics, other schools teach other topics of Operations Research. Very often OR is taught in the first year and usually the subject is valued at four credits. Considering the teaching of the OR subject in one semester, the time allowance is similar, mostly from 42 to 56 hours. At universities where we have information, the subject OR is compulsory and ends with an exam.

5. Limitations

The lack of information available from public websites is a big problem. When we do get some information, it is often not complete, it is a different type of information than that of another school.

We tried to obtain additional data by contacting the schools at the e-mail addresses available from the schools' websites and also obtained through the ERASMUS+ coordinators. Unfortunately, the efficiency of the reactions was only very low, approximately 5 %. The authors are aware that it is not possible to draw large conclusions from a small amount of data and that the outputs have low validity.

Also, in this way, we ask representatives of schools, other teachers, to share information about the teaching of the subject Operations research at their university. If you contribute to further research and reach out to us, we will be very happy.

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Military Versus Civilian University Online Education

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Abstract

This paper compares online teaching during the Covid-19 pandemic at a military and civilian university. It is based on three independent questionnaire surveys in which respondents rated the quality, advantages, and disadvantages of online instruction relative to face-to-face instruction and indicated which type of learning they preferred. The data obtained were processed using the descriptive statistics and the cluster analysis. The results show similar perceptions of the pros and cons of online learning at both types of universities. When evaluating online learning, military students showed similarities only to civilian upper-level students and were more accepting of such learning.

KEY WORDS: *military education, online teaching, questionnaire surveys, cluster analysis, descriptive statistics.*

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1. Introduction

With the possibility of internet connectivity and new technologies in computers and their equipment, distance learning is both much discussed and used. During the Covid-19 pandemic, all types of schools including universities had to switch to online education. Some students found it difficult to adapt to this change, while others welcomed the opportunity to learn from home via computer. Some elements of online learning have proven successful and are now being used in hybrid education.

Distance education was already discussed before the pandemic, see for example [11]. Specifically, the works [12], [13] dealt with the analysis of courses taught in a military environment and testing methods applicable in distance and full-time military university courses. Distance learning in the field of advanced military education was addressed in the work [6]. The role of online learning tools and the study of university students' perceptions of online learning during the Covid-19 lockdown were addressed in papers such as [1], [2], [3] and [10]. Similarly, work [9] studied the perceived benefits and challenges of online learning and impact of online classes on student's ability to learn.

Furthermore, studies [8] and [15] compared the evaluation of online and face-to-face teaching by students of economically oriented disciplines. Finally, the research [4] analysed the opportunities and challenges of distance learning based on the experience of education during the Covid-19 pandemic and study [7] compared face-to-face and online military professional instruction during this pandemic.

In this paper we compare three independent questionnaire surveys conducted between 2021 and 2022 at the Faculty of Military Leadership of the University of Defence and the Faculty of Business and Economics of the Mendel University, both in Brno, Czech Republic. The main objective is to assess the contribution of online teaching during the Covid-19 pandemic, to evaluate it subsequently with face-to-face teaching and, above all, to compare the results obtained at the aforementioned military and civilian university.

In the Faculty of Military Leadership, the science subjects Mathematical Methods and the humanities subjects Military History and English Language were chosen for comparison, all taught in the first year of a five-year Master's degree program. The survey was conducted at the end of the second year to allow students to evaluate both types of teaching.

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Only science courses were monitored at the Faculty of Business and Economics, namely three courses of Mathematics in the first year of the Bachelor's degree and the course of Operational Research in the first year of the follow-up Master's degree. The mathematics subjects were assessed by the students at the end of their first year, and Operational Research at the end of their fourth year at the university.

2. Data and Methods

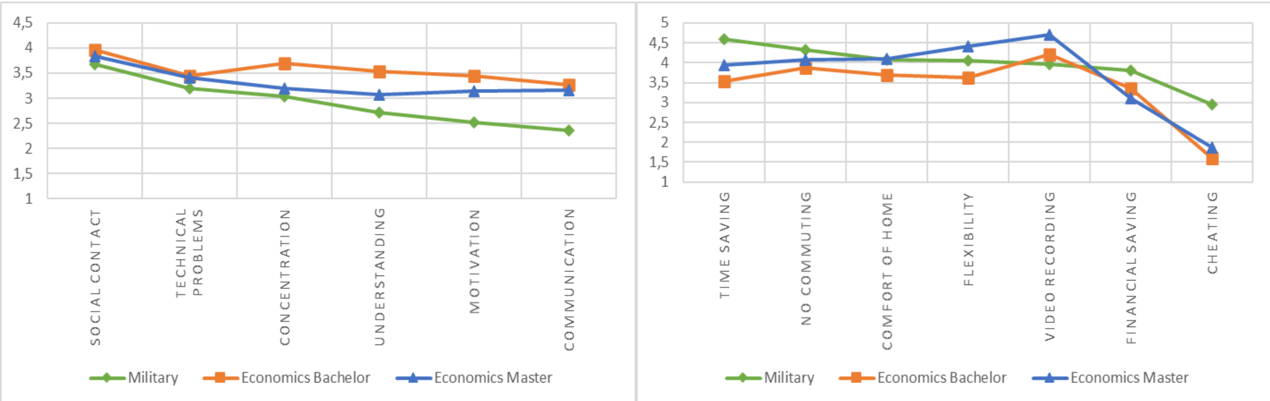
All the questionnaires mentioned above were created in Google Forms for data collection. The number of questions and their content varied from survey to survey. Most questions were closed-ended and used a five-point Likert scale for rating. In all cases, however, respondents rated the quality and satisfaction with online instruction, its advantages and disadvantages and compared it to face-to-face instruction. They were also asked which type of teaching they preferred.

A total of 437 respondents participated in these three surveys, including 100 military and 337 civilian students. The majority of military students were male, whereas the selected civilian field had a more balanced representation of men and women and even in the chosen follow-up civilian Master's degree there was a predominance of women.

Furthermore, data classification was performed using the cluster analysis. This classifies the underlying set of objects, i.e., students, into several relatively homogeneous clusters such that objects within a given cluster are as similar as possible, while objects of different clusters are as dissimilar as possible. The Euclidean distance was used to calculate the distances of the objects. Hierarchical clustering and k-means clustering methods were used to partition objects into clusters, see [5]. A split into two clusters was always used to process the data.

3. Results and discussion

When the disadvantages of online learning were rated on a Likert scale of 1-5 (in Figure 1(a) vertical axis), where 1 indicates no disadvantage, 2 a small disadvantage, 3 a medium disadvantage, 4 a major disadvantage and 5 is a significant disadvantage, all students at both types of universities complained most about the limitation of social contact, which they considered the biggest disadvantage, see in the Figure 1(a). Technical problems were quoted next in order. Civilian bachelor's students reported lower concentration during online learning and poorer understanding of the material discussed in this way and also low motivation in contrast to military and civilian master's students. Military students perceived low motivation and weak communication with teachers as less of a disadvantage than civilian students. This result may be due to the fact that students at the beginning of their university studies are getting used to a new style of learning, where student independent work and self-study predominate.



(a) Disadvantages (b) Benefits

Fig. 1. Average rating of disadvantages and benefits of online learning.

When it comes to rating some of the benefits of online learning, where the numbers 1-5 on the Likert scale mean the following (in Figure 1(b) vertical axis): 1 no advantage, 2 a small advantage, 3 a medium advantage, 4 a major advantage, 5 a significant advantage, the most valued by military students were time saving and not having to commute. The civilian students were most appreciative of the video recordings provided and flexibility, see Figure 1(b). Other benefits included the convenience of home and reduced financial expenses were rated similarly. The possibility of cheating in online exams did not appear to be an advantage to civilian students, it was more appreciated by military students.

If we consider the question of which type of instruction students would prefer, Figure 2 shows the percentage of students in the selected fields. Military students are much more likely to prefer online instruction over face-to-face instruction. On the other hand, civilian students are more evenly split and tend to prefer face-to-face instruction. Similarly, the findings in [14] show that polytechnic students had a slightly higher preference for face-to-face learning.

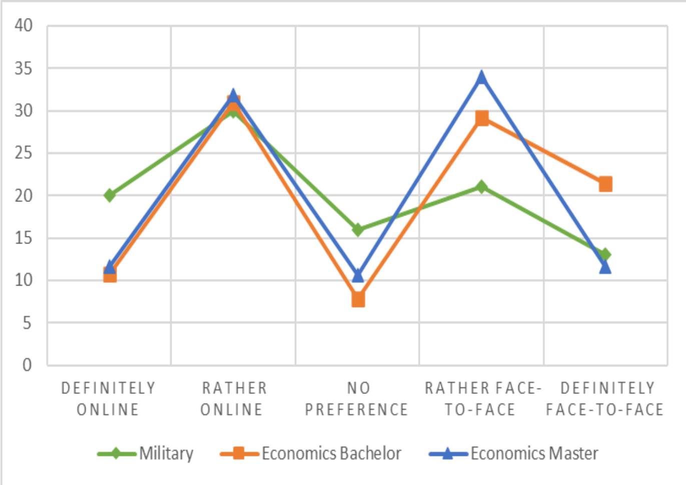


Fig. 2. Preferred type of learning.

From the evaluation of online learning, it is clear that civilian bachelor's students rate online learning worse. Figure 3 shows the percentage of students rating their satisfaction with online learning. Both military and civilian master's students mostly rated the online instruction as rather good, at about 50 percent, while civilian bachelor's students mostly rated it as average and more considered it rather poor.

Fig. 3. Satisfaction with online learning.

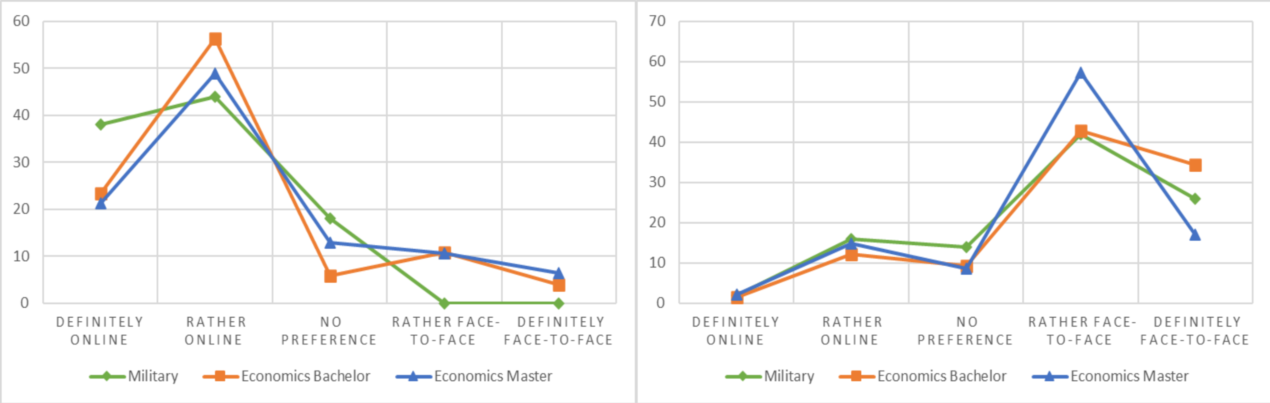
Subsequently, the data were processed using the cluster analysis, where variables for creating clusters were chosen as the selected answers to the questions concerning the advantages and disadvantages of online learning, and the answers to the preferred type of learning. The set was divided into two homogeneous groups in all three surveys. These two clusters were completely identical in terms of number of students in the case of military and civilian master's students. For the civilian bachelor's students, the second cluster was more numerous (57.6%).

The cluster centers are very close when evaluating the advantages of online learning, whereas the cluster centers differ when evaluating the disadvantages, with the cluster 1 centers lying lower than cluster 2 centers. Thus, cluster 2 respondents rate the disadvantages of online learning as more significant. Cluster 1 respondents lean more towards distance learning, while cluster 2 respondents lean towards face-to-face learning.

These two resulting groups could be interpreted as follows, cluster 1 are students who prefer online education, perceive its advantages and are not too bothered by its disadvantages. We will call it the Online Cluster. Cluster 2 represents students who prefer face-to-face learning and feel less the advantages of online learning and are more bothered by its disadvantages. We will refer to this cluster as the Face-to-face Cluster. Both of these clusters are equally numerous, with the exception of a greater representation in the Face-to-face Cluster in the case of civilian bachelor's students.

Let us first look at the percentage of preferences for learning types in each cluster. The Online Cluster, as shown in Figure 4(a), is dominated by students who tend to prefer online learning; there is also a large proportion of military students who definitely prefer this type of learning and that is 38 percent.

In the Face-to-face Cluster, Figure 4(b), there is a preponderance of students who prefer face-to-face instruction, with 34 percent of civilian bachelor's students strongly preferring this type.

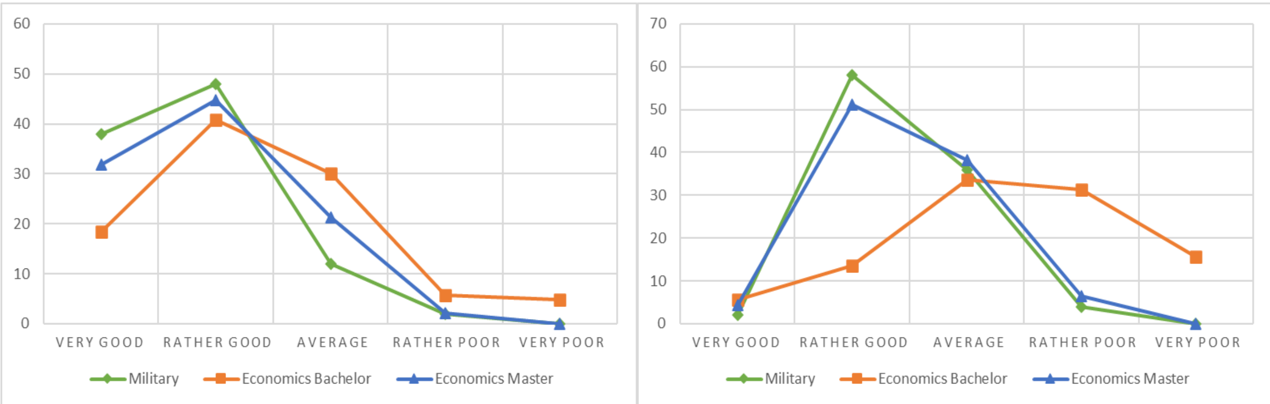


(a) Online Cluster (b) Face-to-face Cluster

Fig. 4. Preference for type of learning in clusters.

Now let us have a look at how online learning was evaluated in each cluster, the data are shown in percentages. The Online Cluster assessed it most as rather good and then very good and student evaluation are similar. The military students rated it the highest, while the civilian bachelor's students rated it the lowest, as can be seen in Figure 5(a).

In the Face-to-face Cluster, for military students and civilian master's students, the predominant rating of online learning is also rather good, and it is over 50 percent, followed by average. However, civilian bachelor's students consider it average to rather poor, and the orange graph shows a shift towards a poor rating. This result is to be expected because the students were surprised by online learning at the beginning of their studies and had not yet formed the necessary habits for studying at university. For this reason, they could rate this type of learning worse.



(a) Online Cluster (b) Face-to-face Cluster

Fig. 5. Satisfaction with online learning in clusters.

4. Conclusions

The observed surveys show that online instruction was accepted by military students as a suitable substitute for face-to-face instruction and was even more preferred by them. Compared to civilian courses, its preference was slightly higher. Satisfaction with online teaching in the military studies was then rated comparably in the civilian follow-up master's course. Although students in the surveys can be divided into two groups of roughly equal size, namely supporters of online learning and supporters of face-to-face learning, both groups show satisfaction with online learning, especially master's students. Therefore, the use of online teaching in higher education can be recommended, also in military studies.

5. Limitations

Online teaching at the military university was compared with only one civilian university, and that of the economics major. The chosen courses were similar in focus but did not cover the full range of courses of the study under review. The aforementioned questionnaire surveys were not identical and differed in some questions.

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Constructive Simulation Tools in the Armed Forces of the Slovak Republic

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Abstract

Currently, simulation technologies are an integral part of training not only in the military sector but also in the civilian sphere. The main aim of this paper is to describe and assess the use of constructive simulators used by the Armed Forces of the Slovak Republic. In this paper, the author analyzes the use of simulation technologies in the training and education of the land and air forces of the Slovak Republic. This paper also analyses the advantages and disadvantages of using constructive simulators for military training. The paper structure respects the general principles of simulation technology and crisis management.

KEY WORDS: *modelling, simulation, virtual simulator, Armed Forces of the Slovak Republic.*

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1. Introduction

Modelling and simulation tools have been used in the military since ancient times. Throughout history, they performed essential cognitive and military functions. Modelling and simulation participated in the overall development of the military, especially in the military art, military tactics, the construction of the army and the training of commanders. Modelling and simulation were used in the period of preparation for wars as well as during the war. In the 1960s, simulation was an increasingly common phenomenon, especially in the armies of more technically advanced countries. Different types of simulators were created, which reduced the financial expenses and time required for training. At the same time, they increased safety and efficiency with the possibility of better analysis and evaluation of the overall activity. The performance of computers could have improved the quality of simulators. Therefore, the development itself was conditioned mainly by the improvement and modernization of computer technology. Over time, more and more modern and realistic simulators began to be developed, which became an integral part of the training of all advanced armies of the world.

The entry of the Slovak Republic into the North Atlantic Treaty Organization brought with it increased requirements for the training of units and the ability to effectively cooperate with the armies of other countries. To achieve these requirements, using simulators and trainers is a rational choice. This initiated the building of simulation centres on the territory of the Slovak Republic. The participation of the Slovak Republic in the Partnership for Peace program enabled the provision of financial, material and personnel assistance in the field of modelling and simulation.

2. Theoretical backgrounds and definitions in modelling and simulation

In the paper introduction, it is necessary to define the basic terms and concepts related to the problem being solved. These are part of the theoretical basis for assessing constructive simulators' use in the Armed Forces of the Slovak Republic. Virtual reality is the simulation of a real or unreal (imagined) environment using a computer and its input and output devices (Uríček, 2019). It is a term to describe a three-dimensional computer-generated environment that a human can explore. A person becomes part of the virtual environment and can manipulate objects or perform a series of actions. We can perceive the virtual reality environment from all directions in space (Quyang, 2014). The basis of virtual reality is the display of spatial models and scenes in real-time with all its regularities and rules. In doing so, basic procedures from the field of computer graphics are used (Ridpath, 1997). Virtual reality is a shift from a simple (two-dimensional) human-machine interaction to a form where this interaction takes place in a three-dimensional environment. These methods are usually enhanced by special peripherals that ensure visual, tactile, sound and positional interaction (Oulehlová, 2017).

Virtual simulator is a set of devices that allow audio and video output. Its aim is to simulate the environment and events as close as possible to reality. The condition is that these devices work together. Primarily these simulators work on the principle of screens and sound speakers or headphones (Mendelová, 2019). Such simulators are often used in the training of various specialists to simulate the conditions, environment, means of action or event as accurately and faithfully as possible. Training simulators can provide virtual training in challenging or hazardous environments (Petz, 2010). Simulation is defines as implementing a model in time. It contains input data that defines the initial conditions or initial state for the simulation. The simulation model produces some form of output data that can be considered as the result of the simulation (Andrassy, 2018b). Simulation is a process where a given problem is solved, or a specific activity is practised on created models. It is a practice performance of various activities according to the type of specific simulation and its purpose (Bučka, 2012).

Simulations since their implementation in the educational and training environment have reflected the need to increase the effectiveness of personnel preparation for events that are very difficult to carry out. The benefits of implementing individual types of simulations and their tools point to the growth of interest and the social need for their use in personnel training. Categorizing simulations is difficult due to the lack of boundaries between categories. The involvement of the human factor defines them. The level of human participation in simulations is very diverse, as is the level of technical equipment. Among the categories of simulations, there is also a category for simulated people working with real equipment (weapons, equipment) missing. A commonly used classification for simulation is:

- Live simulation – persons working on real systems (e.g. a pilot controlling an aircraft);
- Virtual simulation – works on practising motor skills (a pilot piloting an aeroplane in a flight simulator), decision-making skills (deployment of emergency services into action) and communication skills;
- Constructive simulation – involves simulated people working on simulation systems. Living people participate in this type of simulation by entering input data (weather, terrain, situation) but are not included in the outputs (Andrassy, 2018a).

This paper will further analyze specific constructive simulation tools in the Armed Forces of the Slovak Republic. For that reason, it is necessary to mention this type of simulation's main advantages and disadvantages. Constructive simulation is most often used. It is also often referred to as a universal method with vast application possibilities. It is based on computer-based planning and management of staff activities. It shows a virtual synthetic environment based on mathematical methods and the wide use of modern computing and information technology. The basis of simulation is the use of logical and mathematical models. Equations and systems of mathematical equations, inequalities and algorithms express these. Currently, computer technology processes logical and mathematical models in the form of application programs with the corresponding phases of data for their solution. The basic principle consists of simplifying the real system's representation by its simulation model. Experiments are performed based on pre-defined parameters. They ensure the behaviour of the system according to established standards and principles (Rybár, 2000). Among the main advantages of constructive simulation are universality, quantification of phenomena and processes of armed conflict, objective expression of the influence of the terrain and other factors. This kind of simulation applies the influence of subjective factors of armed conflict. The shortcomings of constructive simulation include the difficulty of developing complex models of constructive simulation of combat activity. Constructive simulation is based on a rational basis (suppression of emotional, ethical and volitional aspects of combat activity). This type of simulation can only be used in the field of command and control, while it has high demands on the precision of workers (especially in the preparatory phase).

3. Constructive simulation and its use in the Armed Forces of the Slovak Republic

The main aim of simulation technologies is to provide the armed forces (and other components) through simulations with the most realistic environment for dealing with combat and non-combat situations on the modern battlefield. This contributes to the training of units and the education of leaders. The Armed Forces of the Slovak Republic are no exception. The exercises performed by the following virtual simulators are unique in their preparation and execution phases. A systematic approach was established for the organization of joint exercises using simulation tools, shown in Fig. 1.

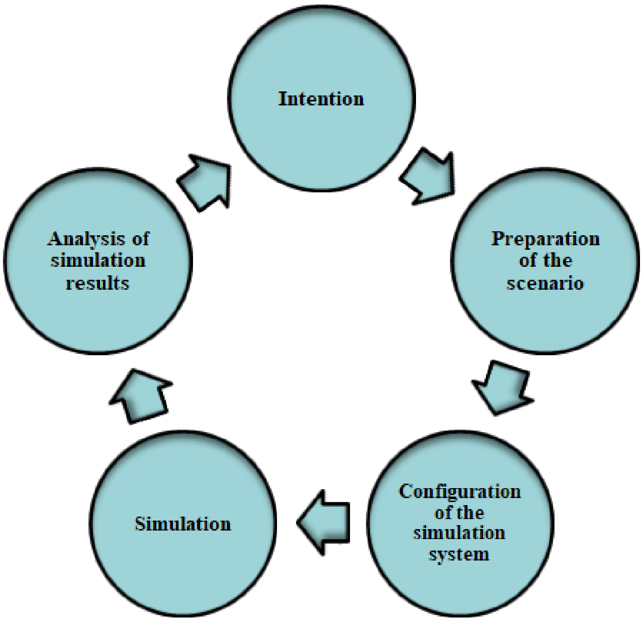

Fig. 1. Scheme of the use of workplaces for the training of the Armed Forces of the Slovak Republic.

3.1. Land virtual simulators

3.1.1. Team Leader Simulator (TLS)

TLS is a virtual simulator designed to support tactical training. Individuals and small groups can be added to the distributed virtual simulation. The primary function of TLS is to generate a virtual synthetic environment as close as possible to actual conditions. TLS creates prerequisites for supporting tactical training of small units, focusing on different types of groups/teams (priority, however, military, rescue, police and fire units). It is used in the Armed Forces of the Slovak Republic to practice crises. TLS complements the existing hardware and software base of the Armed Forces of the Slovak Republic, built on constructive and virtual simulation. It supports the training of commanders of units/groups/teams by simulating the course of resolved crises using virtual synthetic digital terrain. TLS develops coordination and mutual communication, tactical thinking, command and control skills. Emphasis is placed on decision-making (solving tasks of psychological preparation, behaviour in stressful situations, and making decisions under time constraints). It can be used for individual training and to control exercise play within the implemented exercise. Specialized simulator software and hardware provide two workstations in separate cabins (Fig. 2).

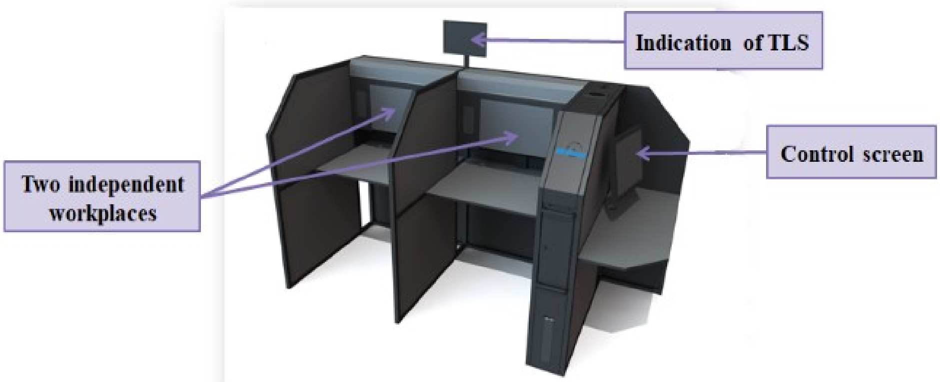

Fig. 2. Division of two independent workplaces of TLS.

Hardware components to ensure the connectivity of the communication interface to the OTB simulation system in 2.5 allow the creation of a complex simulation process. It is connected to a unified environment defined by the DIS protocol. The ASTRA voice communication system simulates a radio connection and allows the simulation of individual radio networks (channels) in conference calls. The view allows an eye-level view of the simulated entity. The trainee obtains information in the same way as in real life, based on observation, cooperation and communication with a cooperating unit, group or team. TLS is a valuable and used system in the Armed Forces of the Slovak Republic. It effectively replaces forms of training for commanders, which would be more demanding in time, material and personnel. TLS provides a wide range of scenario settings. This enables the simulation of various situations and supports the commanders' tactical thinking.

3.1.2. MILES 2000

MILES 2000 is intended for bilateral tactical training. It allows for realistic training with the simulation of shooting and recording of its results without the risk of personal injury or equipment damage by live ammunition. This simulator can be mounted on combat, non-combat, and individuals. It is a tactical simulator and not a shooter. The laser beam does not penetrate obstacles. During the training soldiers of the Armed Forces of the Slovak Republic, it had a negative impact in some situations. It was impossible to hit an opponent who was hidden behind an obstacle. In a real situation, it would be shot through, and the enemy would be eliminated. The principle of operation of the tactical simulator can be seen in Fig. 3.

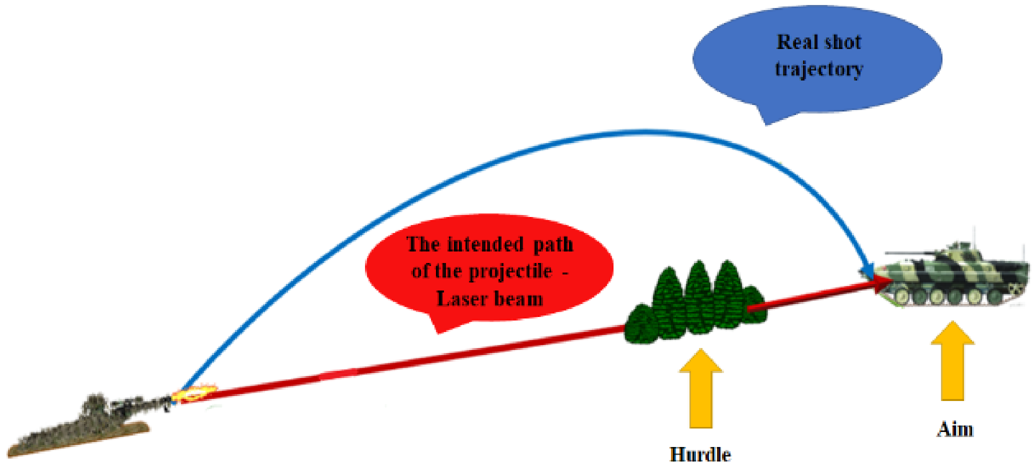

Fig. 3. Working principle of the MILES 2000 tactical simulator.

3.1.3. One SAF Testbed Baseline (OTB)

The OTB simulation system is designed for constructive simulation. Currently, it is used to train commanders and staff at the tactical level of management of the Armed Forces of the Slovak Republic. OTB uses detailed simulations of weapon systems and subordinate units. the software architecture provides a unified methodology and program support for creating and controlling various types of entities on the virtual battlefield. Simulated units can behave autonomously. This means that they can move, shoot, detect, communicate and react without the intervention of any operators. Figure 4 shows the layout of the elements of the OTB simulation tool. The picture shows a detailed simulation of weapon systems and units. It is essential to distinguish between the leadership and management of combat and non-combat operations. The graphical representation enables the simulation of chemical contamination, radioactive radiation, floods and traffic accidents (Hubáček, 2013).

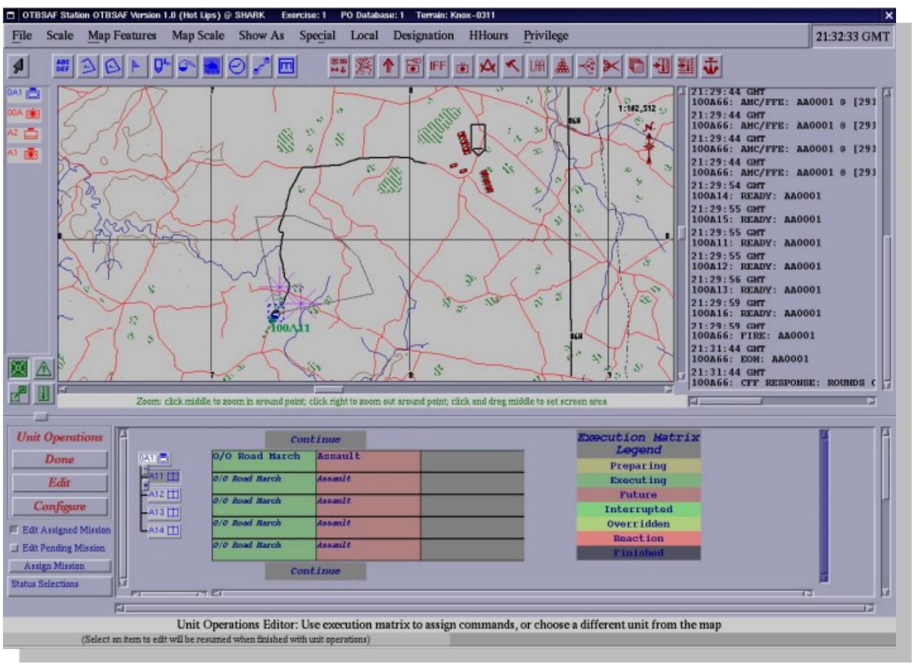

Fig. 4. Layout of OTB simulation tool elements.

As part of the modernization of the Armed Forces of the Slovak Republic, the OTB was expanded to include a module for active camouflage of combat vehicles and the expansion of the tasks of a rocket launcher, mortar and artillery support. In the system, it is possible to conduct research and create minefields or defensive ramparts. Since 2007, the Armed Forces of the Slovak Republic began to cooperate intensively with the Police Force of the Slovak Republic in crisis management. The new aim was to practice activities during non-military situations (for example, demonstrations, rescue operations and eliminating the consequences of natural disasters). Since 2009, the system has also been adapted to the training of EOD units focused on the disposal and handling of explosives.

3.1.4. WASP - Support simulation tool

WASP is also a unique constructive simulation software tool. It allows the simulation of human activity, technology and phenomena associated with human behaviour in a simulated environment. It is designed for computer support of individual and tactical simulation of entities, technologies and phenomena in a synthetic virtual environment. WASP is used to stimulate the situation and develop activities and related accompanying phenomena corresponding to real conditions (Andrassy, 2018b). The technical and program solution ensures ease of use, good configurability and the possibility of expanding the system. The synthetic virtual environment of natural areas for the WASP system is created in the OTFv8 format and allows defining of extensive sets of terrain elements attributes. Subsequently, a generic synthetic virtual environment is used to create and prepare scenarios necessary to ensure the simulation. A specific MDX format is used for 3D visualization of terrain databases. The graphical user interface enables the preparation and creation of scenarios and supports simulation management and display of required outputs (VR Group a.s., 2015).

3.1.5. Virtual shooting range VS – STING

This shooting range is a computerized shooting simulator for training in handgun shooting. It is intended for practising shooting from a place at fixed targets. The trainer works on the optical principle and is entirely safe, as it does not use a laser. The weapons the trainer uses have the exact dimensions, weight, sights and trigger characteristics as real weapons. The virtual shooting range VS – STING uses the evaluation of the course of aiming and the level of the shot. The trainer also includes a set of targets that can be controlled independently. The entire software allows accurate analysis of both aiming and firing. The preparation can be from basic training (handling a weapon, the practice of firing small arms) to the implementation of advanced training (tactical behaviour of trainees in simulated combat conditions).

3.2. Flight virtual simulators

The main educational aim in flight training is the ability to estimate distances correctly. An experienced pilot can judge distances better because of his extensive experience in judging distances. An inexperienced pilot needs to gain this ability and must gain it from flying experience. This aspect of flight training is challenging to train in traditional simulators without depth perception. The screen on which the outside world is projected is placed constantly from the pilot's eyes. Each object projected on the screen appears at the same distance from the pilot (a runway 10 meters from the pilot or a tower 10 kilometres from the pilot). Virtual reality glasses offer stereoscopic screens that present two slightly different images of the same scene. Virtual simulators can accurately and intuitively represent distances in a flight simulation where this aspect is crucial (e.g. during landing practice, where it is essential to correctly assess the height above the runway in a flare, or when a helicopter hovers half a meter above the road). Figure 5 shows the difference in distance perception between the curved screen typically used in traditional flight simulators and virtual reality glasses. Three targets marked with a yellow, green and blue X are shown at the same distance on a curved screen. In virtual reality, they appear to be at the correct distance from the observer. Targets that are further from the observer than the screen appear closer (blue X). Targets closer to the observer than the screen appear further away (green X). Only when the target is at the same distance from the observer as the screen will the distance perception be correct (yellow X).

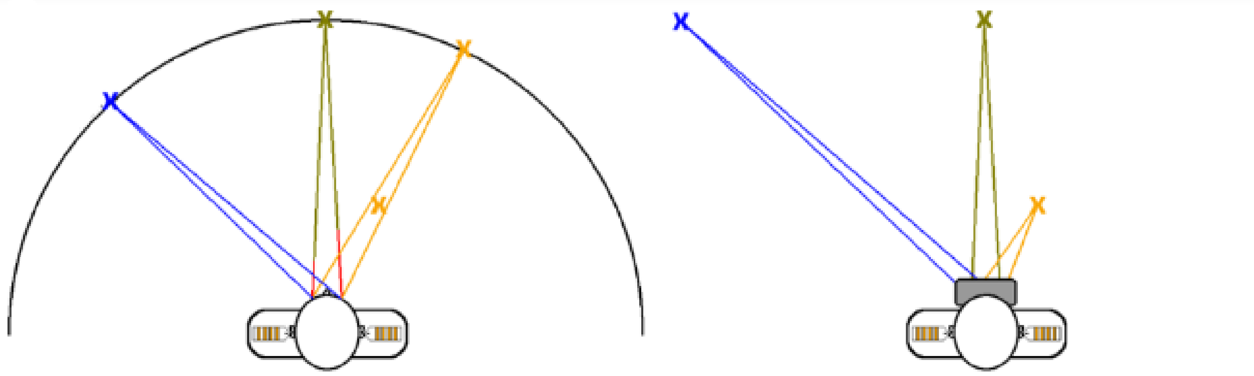

Fig. 5. Working principle of the MILES 2000 tactical simulator.

3.2.1. Flight Visual Information System (LETVIS)

Air traffic management is a complex activity that requires cooperation and mutual communication between workers. This communication aims to ensure the safe and efficient flow of air traffic. Many errors in air traffic control are related to improper coordination between air traffic controllers or insufficient coordination with another station or sector. These errors will likely increase due to the ever-increasing traffic density. The use of simulation in the training of air traffic controllers is the primary and proven method that will find its use in the future as well. In the Armed Forces of the Slovak Republic, the LETVIS is used as a trainer and for air traffic control. A virtual air traffic control simulator was installed at the Armed Forces Academy of General Milan Rastislav Štefánik in 2010. Its construction was divided into several phases to meet the "Real High Fidelity Simulator" requirements. Such a simulator should provide computer simulations that give students a high level of interactivity and realism.

Training on such a simulator is necessary so that the air traffic controller does not acquire bad habits during training. The training carried out through a real certified simulator can provide complex functionality for the training of the Air Force of the Armed Forces of the Slovak Republic. Among them, in addition to the radar air traffic controllers themselves, we also include tower and radar controllers, operators and aircraft pilots. The aim of building this training organization was mainly the creation of a training centre suitable for the training of military air traffic controllers in the service of the Armed Forces of the Slovak Republic. The primary effort was to guarantee the creation of a high-quality and comprehensive workplace where it is possible to conduct training that meets internationally valid standards and regulations. Practical training is the basis for preparing new and existing air traffic controllers, which is why various short-term courses are organized. Among other things, the simulation of unusual and highly stressful situations is also significant for developing and maintaining driver skills (Grega, 2017). According to Baňas (2012), air traffic control is a field in which accuracy and speed of response are required. A big problem in management is optimizing the distribution of visual attention to display devices, communication elements and recording devices.

According to Bálint (2016), LETVIS supports air traffic control operations in the area control centre (ACC – Area Control Centre), in the approach centre (APP – Approach Centre) and the airport control tower (TWR – Air Traffic Control Tower). In addition to the mentioned places, it can also be used in training centres for the air traffic control simulator, for the overview data network, for tracking overview data from several sources, search and rescue operations. The LETVIS system is designed and proven to be modular, flexible and configurable for any size and functionality of the air traffic control system. It integrates solutions for effective airspace control, reliable conflict detection, better interoperability, alerts and warnings, a fusion of overview data from many sources and airspace management. Operational benefits include optimized system life cycle costs and high reliability for business continuity. It is designed to control the airspace efficiently. It simulates radar and flight plan information obtained through its processing and subsequent generation and display.

3.2.2. Mi-17 Simulator FTD/FMS

The FTD provides excellent flexibility in training normal, abnormal and emergency procedures and flight manoeuvres for initial training, refresher training and qualification certification. A realistic loading control system (CLS), combined with vibrating seats, creates a realistic cockpit environment. Steering feel, control forces and displacement characteristics correspond to real helicopters. The Mi-17 Full Mission Simulator (FMS) provides cost-effective, fully secure, initial and repeatable crew training. It is based on an exact replication of the real environment of the helicopter and the mission. FMS systems are designed to cover every aspect of routine, emergency and mission helicopter operations in various scenarios. This includes flying, terrain orientation development and combat mission training. This simulator is based on the HLA motion platform with six degrees of freedom and a hardware copy of the cockpit with realistic copies of all equipment. The FMS has sound effects, an equipment lighting system in the cockpit, instructor operating stations, a media classroom and a spherical display for visualizing the outside world. This simulator can operate in a shared virtual environment between itself and other simulators using the HLA protocol.

The Mi-17 FTD/FMS simulator works on the principle of four main features:

- Networking and interoperability - Network interactions with other simulators or parts of simulators using the HLA 2010 Evolved protocol allow aircrew or formation flight training and the execution of combat missions in formation. The simulator supports integrations with other simulators to conduct interdisciplinary military training with different types of simulators. The simulator supports HLA integrations with air traffic control simulation to teach pilots and controllers (or air traffic control officers) how to work together.
- Cooperation with hardware and hardware simulation - Simulation of onboard systems works based on electrical diagrams. Electrical engineers know how to describe and implement the onboard equipment model with developers. The simulator supports different types of cockpit visualization systems (for example, a spherical screen with a set of glued images from different projectors).
- Operations instructions and operational development - The development of instructor operating stations allows the instructor to monitor the operation of flight and mission tasks, the status of onboard equipment, the environment in 3D and on maps and visualize equipment malfunctions. Recording all distributed activities during the simulation allows the simulation to be replayed from any point. The main aim of modelling airport facilities and environments is to teach pilots how to work with them.

- 3D visualization and terrain - Realistic modelling of areas of real terrain works on automatic zooming using height data, digital vector maps, terrain images and 3D models typical for the given region. 3D visualization of the development of terrain areas simulates these areas precisely as in real conditions (same altitude, terrain types and objects) Artificial intelligence simulates complex patterns such as decision-making, target selection and shooting. Physics and ballistic principles are mainly used in the simulation core of the software.

3.2.3. VRM FMS-M29 (Mig-29 Simulator)

VRM simulator FMS-M29 can be made and applied in two ways. Either as a completely new system or as a complete upgrade of an older Russian KTS-21 simulator or MiG-29 cockpit. Considering the price of the cabin, instrumentation, simulator construction and other aspects, this design is more advantageous for the Armed Forces of the Slovak Republic. Only the cockpit and complete instrumentation are used from the original simulator.

All software and hardware accessories are updated and modernized to date. The display system was also modernized. Six projection systems replaced one screen. The system can project the scene within 180 degrees horizontally and 90 degrees vertically. The simulator has a helmet to aim fire and a real HUD (heads-up display). This system is fixed due to its weight. If it were not fixed, it would not be able to simulate the real acceleration and overload of the Mig-29 fighter. This simulator was created for the needs of the Air Force of the Slovak Republic in 1997 as FSM29, but later in 1999, it was improved and modernized by VRM.

The software generates a 3D image with high resolution and high accuracy of aircraft flight. It contains a navigation system and weapon systems that allow the aiming and firing of cannons, missiles and dropping bombs. When using these weapons, the system also cooperates with the visual and audio parts of the simulator. The map contains two airports, buildings, hills, rivers and landmarks. Of course, it is possible to use 3D objects and change the map. Realistic ortho-maps are available to pilots at Sliač Air Base. Fourteen computers and four powerful speakers ensure the operation of the entire system. At this air base, it is possible to connect the FMS29 simulator with the L-39 Albatros simulator, allowing the simulation of the flight of two aircraft simultaneously. The entire simulation is stored in the so-called black box, which serves to evaluate the simulation. The modernization by VRM aimed to harmonize the simulator with the MiG-29AS version used by the Armed Forces of the Slovak Republic. The cockpit equipment was modernized, and the hardware and software components of the simulator were renewed.

4. Advantages and disadvantages of using constructive simulators for military training in the Armed Forces of the Slovak Republic

Simulation technologies and means are used in the Armed Forces of the Slovak Republic, especially during training in the control of various types of heavy land and air equipment or when practising shooting with small arms or a wide range of weapon systems. This aims to eliminate financial expenses and shorten the time required for training. The main advantages of constructive simulation methods include the following:

- universality results from the mathematical basis - applicability to the description of almost all material-energy processes (Palasiewicz, T., Rolenec, O., Kroupa, L., Manas, P., Coufal, D., 2023) of armed struggle;
- quantification of the phenomena and processes of the armed struggle enables their more accurate analysis and application of optimization in the decision-making activities of command and control bodies;
- objective expression of the influence of the terrain (Jančo, Kompan, 2023) and other environmental factors (Kompan, Hrnčiar, 2024) on the processes of combat activity ;
- CAX-type exercises take place in any geographical region, in different climatic and meteorological conditions, with different opponents and with different (even non-existent) military equipment;
- relatively low economic demands for building training centres for constructive simulation of combat activity and low costs for the maintenance and operation of these facilities - compared to other categories of simulation of armed struggle, constructive simulation in the field of training is the most economically acceptable (low costs for the implementation of exercises in simulation centres and lower difficulty for organizational security of exercises);
- the possibility of high-quality registration of the course of the exercise and its use for a more objective evaluation;
- the possibility of connecting constructive simulation systems with simulation systems of other categories.

Thanks to the simulation of the activities mentioned above, there is no consumption of fuel and wear of equipment, which saves the environment. The possibility of accidents or damage to expensive military equipment is also ruled out. Using simulators is, therefore, an efficient means of training from the financial and time point of view. Simulation devices create an environment where it is possible to practice the operation of heavy equipment and weapon systems in a controlled and safe manner without any risk of injury. By practising various scenarios, the soldiers of the Armed Forces of the Slovak Republic gain the necessary self-confidence and skills that will help them in the future in the absolute control of military equipment and weapon systems. Another positive is that the creation tools of simulators allow the creation of an unlimited number of variants of the environment and training conditions. Soldiers can therefore practice fighting in different climatic and weather conditions, overcoming terrain obstacles, or making decisions and acting in specific situations. Using simulators during training makes it possible to analyze in detail the overall activity of soldiers and evaluate the correctness of their decisions. This benefit can help the soldiers of the Armed Forces of the Slovak Republic to improve gradually. The instructor can accurately and concretely point out the shortcomings and mistakes that the soldiers committed during the simulation while performing the assigned task. Modern simulator software can also collect statistical data.

Using simulation in the military understandably also has its limits and shortcomings. The most significant disadvantages of constructive simulation include the following:

- difficulty in developing complex models of constructive simulation of combat activity, especially DIS (Distributed Interactive Simulation) systems - smaller armies are dependent on the procurement and application of simulation systems from other more advanced armies);
- constructive simulation models are based on a rational basis - emotional, ethical and volitional aspects characteristic of combat activity are strongly suppressed;
- using these methods, they can practice within the so-called CAX-type exercises only the command and control bodies in their decision-making activities, respectively staff work - soldiers cannot practice using these methods and systems. However, their activity is fully simulated by mathematical means;
- the use of simulation systems requires great precision from staff, especially in the preparatory phase of the exercise when filling the database with relevant data on the parameters of weapons, military equipment and the organizational structures of the staff and troops included in the simulation (exercise).

Most military operations are physical activities. These are performed in a specific space containing many variants of the terrain surface, objects, natural obstacles, forests, watercourses, buildings and objects. All these elements in the real world also have their physical, chemical and biological properties. These must be taken into account when creating the most realistic model possible. Creating the most identical virtual three-dimensional space, showing the most significant possible identity with the original, is time-consuming. The subsequent simulation process may need to be more accurate in low model similarity and bring the desired benefits. Powerful and modern computers are needed to calculate and process this vast information flow, especially if it is a real-time simulation. Then the fastest possible response of the computer is needed to ensure the smoothness of the simulation process. If the computing technology's capacities are insufficient, errors and a too-long response of the simulation to a specific action of the subject may occur during significant interaction of the subject with the environment. The financial costs of building a high-quality simulation centre are also directly related to this.

5. Conclusions

The use of simulation technology is one of the fundamental pillars of modern information society's scientific and technical progress. Simulation technologies have a huge benefit in the training of the Armed Forces of the Slovak Republic from several points of view. The training is closer to the real situation and also saves financial resources. Simulation technologies represent a significant trend in the training and education of units and units of the Armed Forces of the Slovak Republic. They enable the preparation and development of individuals and entire groups for more efficient and effective military operations on the territory of the Slovak Republic, but also in cooperation with foreign armies.

By studying this topic, virtual flight simulators are more affordable for the Armed Forces of the Slovak Republic than the training itself. Another advantage of simulators is their safety and the possibility of creating an almost real environment. In this way, the trainee can master the control of the machines and prepare for various critical situations during regular training and combat deployments. An important question is how the Armed Forces of the Slovak Republic will solve the gradual modernization of military equipment. Modernization should occur not only on the equipment but also on individual simulators. In the future, the training requirements in the Armed Forces of the Slovak Republic should reflect the changing training requirements within NATO. Individual training weapon systems are integrated into a unified, centrally controlled evaluation (Sedláček, M., Dohnal, F., Rolenec, O., 2022).

This will subsequently be part of the overall training strategy of the advanced armies of the world. Means of live simulation will become part of combat and support means and equipment of the soldier of the 21st century.

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Educating Soldiers' Competencies Through Battlefield Simulation Systems

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Abstract

The study analyses the development of soldiers' competencies using the Joint Conflict and Tactical Simulation (JCATS). The results of the linear regression analysis identified several key findings regarding the factors influencing competency development with JCATS. Technological knowledge (TEC) emerged as the most crucial component, followed by strategic thinking (STR), both showing significant positive influences. These competencies should be prioritized in training programs and skill development initiatives involving the JCATS simulator. Additionally, the number of training sessions completed (TST) highlighted the importance of practical experience and continuous learning. Although leadership skills (LED) did not reach statistical significance, they may still impact competency development in complex leadership scenarios or over the long term.
This analysis helps to identify where the Armed Forces should focus its resources to maximize the effectiveness of competency development with JCATS, emphasizing technological knowledge and strategic thinking as key areas for effective soldier development.

KEY WORDS: *training of military personnel; soldiers' competencies; JCATS systems; simulated combat scenarios; realistic and immersive training environment*

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1. Introduction

In the modern era, military operations have become increasingly complex and dynamic, necessitating continuous adaptation and improvement in training methodologies [1-7]. To ensure operational success and minimize casualties, it is more important than ever to provide advanced and specialized courses for military personnel. In this context, battlefield simulation systems have emerged as a crucial tool, offering soldiers a virtual platform where they can engage in realistic and intense exercises. Competent and well-prepared command personnel are essential, as they play a decisive role in decision-making, strategy formulation, and battlefield management [8, 9].

The importance of technology in military operations and training has grown with the ever-changing nature of modern conflicts [10-11]. Battlefield simulation systems have become a powerful tool among the technical innovations that have transformed military operations. These technologies offer soldiers a realistic virtual environment to train in a variety of operational scenarios and improve their tactical skills. In recent years, the use of battlefield simulation systems in military training has become very popular [12-16]. These devices reduce the risks associated with live ammunition and real combat scenarios, making them a safe and low-cost alternative to live training exercises. They allow soldiers to rehearse combat scenarios, enhance their skills and improve their decision-making abilities by providing a realistic and immersive training environment [17].

Battlefield simulation tools also make it easier for allied forces and the various branches of the military to conduct joint training and exercises [xx]. Military units can train together in virtual space, thus breaking down distance barriers and improving coordination, interoperability and promoting a better understanding of each other's capabilities and tactics. Battlefield simulation tools are also very helpful for the study and analysis of common strategies and tactics.

Commanders can assess the success of their strategies by simulating a wide range of scenarios and then make necessary adjustments. This process improves military doctrine, identifies problem areas and improves overall operational readiness.

However, it must be recognized that war simulation programs have limitations. The models of the simulation systems and the quality of the data used have a major impact on the accuracy and realism of the simulation programs. It can be difficult to accurately replicate complex real-world environments, and simulation technologies need to be continuously improved to ensure the highest level of fidelity.

Moreover, the effective training programs are essential to ensure that military personnel are equipped with the skills and knowledge needed to navigate this challenging environment. One of the most significant advancements in military training has been the development and implementation of battlefield simulation systems such as the Joint Conflict and Tactical Simulation (JCATS), provide a highly realistic and immersive training environment for military personnel. These systems arrange for soldiers with a virtual platform for realistic and intense exercises, enhancing their readiness for real-world combat scenarios. Also, the competence and preparedness of command personnel are paramount, as they play a decisive role in decision-making, strategy formulation, and battlefield management.

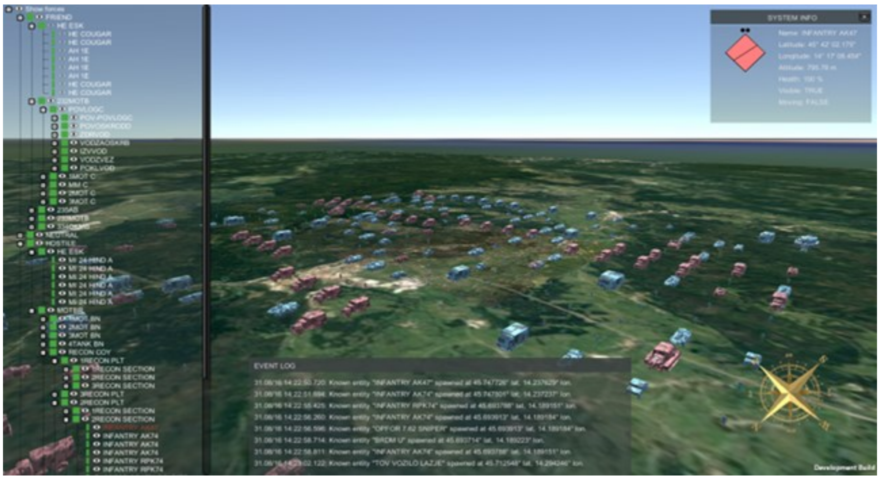

Fig.1. The Joint Conflict and Tactical Simulation (JCATS) system [18].

These advanced systems are designed to replicate real-world conditions as accurately as possible, offering soldiers a comprehensive platform to practice and refine their tactics and strategies. JCATS offer a highly realistic and immersive training environment [19-23]. These systems simulate real-world conditions, allowing soldiers to practice and refine their tactics and strategies in a controlled setting. JCATS, for example, can model diverse combat scenarios, including urban warfare, counter-insurgency operations, and large-scale conventional battles. This versatility ensures that military personnel are prepared for various types of engagements they might encounter.

In the contemporary background of military operations, characterized by complexity and rapid change, the necessity for advanced and specialized training is more pressing than ever. So, the study's primary objectives were to evaluate the impact of the JCATS simulator on soldier training and to provide recommendations for enhancing its effectiveness at the Combat Training Centre of the Lithuanian Armed Forces. By focusing on these areas, the study aimed to improve both the preparedness of soldiers and the productivity of the command staff. The findings and recommendations offer valuable insights into how simulation-based training can be optimized to meet the evolving needs of modern military operations.

2. Method of Investigation

2.1. Study Participants and Data Collection Method

The data collection process started in December 2023 and ended in January 2024. A total of 70 questionnaires were distributed and 61 valid questionnaires were obtained, with a recovery rate of 87.1%. Study participants were men (100%). Based on the information gathered on the respondents' length of service, the experience of the respondents varies from 5 years to 30 years. However, the vast majority, 39% of the respondents who completed the questionnaires, have "up to 5 years" experience. Those with the highest length of service and experience between 26 and 30 years' account for only 3%. The educational backgrounds of the survey respondents were quite diverse. Ten percent of the participants indicated that they have a Master's degree, while 34% of the Lithuanian Armed Forces personnel who participated in the JCATS exercise reported having a Bachelor's degree. This shows that more than a third of the personnel already have higher university education, demonstrating their academic knowledge and their ability to apply it in military activities. Meanwhile, 31% of the staff reported having completed secondary education, which is considered the initial requirement for a military career, indicating that this proportion of the staff meets the minimum level of education.

Prior to the start of the study, the security specialists were contacted and the study was authorized. Soldiers/respondents completed an electronically administered questionnaire, which was designed in accordance with the ethical requirements of the study. Before participating in the study, respondents were briefed on this study. They were given a description of the purpose of the study, an explanation of the importance of the survey and an example of how to answer the questions in the questionnaire correctly. The survey adhered to the principle of voluntary participation, ensuring that all respondents were clearly informed that their involvement in the study was entirely optional. Additionally, the anonymity of the participants was rigorously maintained, with no personal identifiers being recorded, thus safeguarding the confidentiality of the respondents.

2.2. Study Design

One of the primary objectives of this research was to analyze the effectiveness of the JCATS (Joint Conflict and Tactical Simulation) system in developing soldiers' competences. According to scholars [24,25], military competencies are essential for enabling soldiers to perform their tasks efficiently and professionally [26-30]. This study identified several competencies that particularly benefit from improvement through the use of the JCATS simulation system.

The analysis focused on specific competencies grouped into two primary blocks: Block I related to the development of Commander's Individual Competences (CIC) and Block II related to Military Action Planning competences (MAP). Additionally, Block III consisted of statements regarding Continuous Professional Development (CPD) using JCATS.

Commander's Individual Competences (CIC) assessment includes six critical competencies essential for military personnel:

- Teamwork (q1). The ability to work effectively within a team, coordinating actions and communicating efficiently.
- Strategic Thinking (q2). The capacity to develop and implement long-term strategies to achieve mission objectives.
- Situational Awareness (q3). The skill to perceive, comprehend, and project the current and future status of the operational environment.
- Stress Management (q4). The ability to maintain performance and decision-making under high-pressure conditions.
- Technological Knowledge (q5). Proficiency in using advanced military technologies and understanding their applications.
- Critical Thinking (q6). The capability to analyze situations, identify problems, and devise effective solutions.

Likert’s five-point scale was used to measure the statements, when 1 indicated ‘did not improve at all’ and 5 indicated ‘has improved greatly’. The internal consistency of this block was evaluated by Cronbach’s alpha coefficient which was 0.823.

Analyze the effectiveness of the JCATS according to warriors’ Military Action Planning competences (MAP) assessment includes four critical competencies essential for military personnel:

- Tactical planning(q7), which involves the formulation and implementation of detailed plans to achieve specific objectives in a combat scenario. It requires a comprehensive understanding of the battlefield, resource allocation, and enemy capabilities.
- Decision making (q8). Decision making in a military context involves selecting the best course of action among various alternatives under conditions of uncertainty and pressure. Effective decision making is crucial for successful mission outcomes and operational efficiency.
- Personnel management (q9). JCATS supports personnel management by simulating scenarios that require effective coordination and management of troops. Soldiers can practice assigning roles, managing resources, and responding to personnel issues in real-time. The system provides a platform for testing various personnel management strategies and observing their impact on mission success.
- Leadership (q10). Leadership in the military context involves guiding, motivating, and directing troops to achieve mission objectives. Effective leadership is vital for maintaining discipline, morale, and operational success. JCATS enhances leadership skills by placing soldiers in command roles within realistic combat scenarios. The system challenges leaders to make critical decisions, communicate effectively with their teams, and inspire confidence under pressure. By simulating high-stress environments, JCATS helps soldiers develop the resilience and adaptability needed for effective leadership.

To measure these statements Likert’s five-point scale was used, the 1 indicated ‘did not improve at all’ and 5 indicated ‘has improved greatly’. The internal consistency of this block was evaluated by Cronbach’s alpha coefficient which was 0.810.

Continuous Professional Development (CPD) and was focused on few aspects:

- *Ongoing Training*. JCATS supports continuous professional development by offering a platform for ongoing training and skill enhancement. This commitment to lifelong learning is essential for maintaining high standards of competence and readiness. So, this study was focused on training effect estimation to commander’s regular participation in simulations to keep their skills sharp and stay updated on new tactics and technologies.
- *Performance Feedback*. JCATS provides detailed feedback on a commander's performance during simulations. Commanders can use this information to refine their skills, develop targeted training plans,

and track their progress over time. So, to evaluate the feedback is critical for identifying strengths and areas for improvement.

To assess warriors' CPD there were used six statements. The sample statements include 'Rate your overall experience of participating in JCATS exercises', 'Rate the JCATS feedback after the exercise', and others. The responses were recorded on a 10-point scale (1=very bad, 2, 3, 4, 5, 6, 7, 8, 9, 10=very good). The internal consistency of this block was evaluated by Cronbach's alpha coefficient which was 0.913.

2.3. Data Processing

Following the descriptive data analysis, a series of statistical tests were conducted to validate and explore the data. First was conducted the reliability testing, a crucial step in the validation of any survey or questionnaire-based research, was performed to assess the consistency and stability of the measurement instrument. This ensures that the instrument reliably measures the intended constructs. One of the most commonly used methods, Cronbach's alpha, was used for this purpose. This was used to calculate statistical coefficients to assess the internal consistency of each of the three sets of blocks used in the study, ensuring the reliability of the data collected.

Then, Kruskal-Wallis H test was used to identify statistically significant differences based on the frequency of training completion [31]. This non-parametric test was applied because the assumptions of one-way ANOVA were not met, and it helped in determining if there are significant differences between three independent groups.

Also, Exploratory Factor Analysis (EFA) was employed to identify latent factors within the data [32,33]. This technique used for uncovering the underlying structure for each of three blocks set of variables. This helped to reduce of data complexity and to identify clusters of related variables (factors). EFA helps in understanding the dimensions that the JCATS simulator influences.

Finally, a linear regression analysis was conducted to identify the key factors influencing competency development with JCATS [34,35]. This method helped in quantifying the relationship between dependent and independent variables, thus identifying which factors significantly contribute to the development of soldier competencies.

All statistical analyses were performed using SPSS Statistics software version 29.0. This comprehensive approach ensured a robust evaluation of the data, providing reliable insights into the factors affecting competency development through the JCATS simulator.

3. Study Results

3.1. Assessing the Effectiveness of the Use of JCATS by Three Blocks

Following descriptive analysis results on Commander's Individual Competences (CIC) block, can be stated that the greatest improvement was in the area of cooperation and teamwork (q1), with 66.7% of respondents reporting an improvement and 19% reporting a very large improvement, reflecting the JCATS exercise's focus on team tasks. Strategic thinking (q2) showed an improvement with 63% of respondents, and a very significant improvement with 30.4% of respondents, which may be due to the strategic planning requirements of the exercise. Situational awareness (q3) was improved in 48.6% of the respondents' opinion and very much improved in 32.4% of cases. These figures may reflect the effectiveness of the JCATS exercise in training soldiers to quickly assess and react to changing circumstances, which is necessary in real military conditions. Stress management competence (q4) improved in 54.5% of cases after the exercise with the JCATS system, while 29.5% of the respondents indicated that it improved a lot. Despite the positive overall effect, these figures also reveal that some of the soldiers did not experience a significant improvement in their stress management competence. Technological knowledge (q5) improved in 69.4% of respondents, but only 8.3% felt a significant improvement, reflecting the nature of the exercise, which focused more on general system use than on technological understanding. Critical thinking (q6) showed the smallest improvement after the JCATS exercise, with only 11.9% of respondents indicating a significant improvement and 40.5% indicating no improvement (see Table 1). This can indicate that the JCATS exercise may have focused less on scenarios that develop deeper critical thinking skills.

Table 1.
Commander's Individual Competences (CIC) block assessment results

Critical competencies	1 'did not improve at all'	2 'did not improve'	4 'improved'	5 'very improved'
Teamwork (q1)	0,0%	14,3%	66,7%	19,0%
Strategic Thinking (q2)	2,2%	4,3%	63,0%	30,4%
Situational Awareness (q3)	10,8%	8,1%	48,6%	32,4%
Stress Management (q4)	2,3%	13,6%	54,5%	29,5%
Technological Knowledge (q5)	2,8%	19,4%	69,4%	8,3%
Critical Thinking (q6)	11,9%	28,6%	47,6%	11,9%

The warriors' Military Action Planning competences (MAP) block assessments show that the JCATS exercise had a positive effect on the tactical planning (q7) competencies, with 71.8% of respondents indicating an improvement, which may be due to the tactical tasks performed in the exercise, which require in-depth planning. Decision-making (q8) improved for 60.5% of respondents, reflecting the exercise's ability to simulate situations that encourage quick problem solving. Personnel management (q9) improved for 61.1% of respondents, but did not improve for 30.6% of respondents, suggesting that the conditions of the JCATS exercise did not provide sufficient opportunities for all participants to improve their personnel management skills. Improvement in leadership and management skills (q10) was mixed during the JCATS exercise although 55.6% experienced an improvement, it is important to note that 33.3% of respondents indicated no improvement in these competencies (see Table 2). This suggests that despite the many successful cases where this competency has improved, leadership skills development in virtual environments still faces challenges that prevent all individuals from experiencing the desired growth in competencies.

Table 2.
The warriors' Military Action Planning competences (MAP) block assessment results

Critical competencies	1 'did not improve at all'	2 'did not improve'	4 'improved'	5 'very improved'
Tactical planning(q7)	10,3%	10,3%	71,8%	7,7%
Decision making (q8)	7,0%	16,3%	60,5%	16,3%
Personnel management (q9)	5,6%	25,0%	61,1%	8,3%
Leadership (q10)	5,6%	33,3%	55,6%	5,6%

Continuous Professional Development (CPD) and was focused on six statements evaluation (see Table 3). Analysis of the JCATS exercise experience shows that the use of technology in the training context (q11) was favorably received, with 36.1% of respondents giving a score of 7-8, indicating the usual level of satisfaction with this training tool. Realism (q12) is also highly rated, with 26.2% of respondents scoring 9, suggesting that JCATS provides a realistic learning environment. Effectiveness when comparing JCATS with other training methodologies (q13) was rated quite mixed, with 16.4% of respondents scoring 9, which may reflect the advantages of JCATS in the simulation of complex operations and in the integration of hands-on training. However, 21.3% of respondents rated this area as a 6. This may indicate that although JCATS is perceived as a useful training tool, it may not be fully meeting the expectations of some soldiers, or may not always be effective compared to traditional training methodologies. The feedback following the JCATS exercise (q14) received generally positive feedback, with 36.1% of respondents rating it as 7-8, which may indicate a valuable feedback approach that encourages the learning and improvement process during the exercise. The overall experience of participating in the JCATS exercise (q15) received mixed ratings, but 21% of respondents gave it a score of 8. This indicates that a proportion of respondents were very positive about their learning experience with the system, reflecting the ability of the JCATS exercise to provide a meaningful and memorable learning experience. The use of the JCATS system for training purposes (q16) received mostly moderately positive ratings, with 18% of the respondents giving a score of 8, indicating that the system was an effective tool for training.

Table 3.
Continuous Professional Development (CPD) block assessment results

Statements	1 very bad	2	3	4	5	6	7	8	9	10 very good
Rank JCATS as a technological tool (q11)	0,0%	0,0%	0,0%	3,3%	8,2%	21,3%	36,1%	11,5%	8,2%	11,5%
Rank realism of JCATS simulation (q12)	0,0%	0,0%	3,3%	9,8%	8,2%	11,5%	34,4%	26,2%	4,9%	1,6%
Effectiveness of JCATS compared to other training methodologies (q13)	0,0%	0,0%	6,6%	4,9%	11,5%	21,3%	29,5%	9,8%	16,4%	0,0%
Rank feedback provided by JCATS (q14)	1,6%	3,3%	6,6%	1,6%	9,8%	19,7%	26,2%	16,4%	6,6%	8,2%
Rank Overall experience after JCATS exercise (q15)	0,0%	0,0%	1,6%	3,3%	8,2%	19,7%	24,6%	21,3%	14,8%	6,6%
Rank use of JCATS for training purposes (q16)	0,0%	1,6%	1,6%	1,6%	9,8%	13,1%	37,7%	18,0%	6,6%	**9,8%**

To summarise the results of the descriptive statistical analysis, it can be observed that the investigation of the data from blocks CIC and MAP shows that respondents indicated that some competences were more improved after the JCATS exercise. Reviewing the results of the CIC block, it can be seen that more than half (66.7%) respondents felt that their teamwork (q1) had improved, while 19% agreed that they felt a significant improvement. These findings suggest that the JCATS exercise effectively develops team situations, which are essential in military activities, as it promotes collaborative skills. Meanwhile, technological knowledge (q5) is also being developed using JCATS according to the respondents, as even 69.4% of the respondents indicated that their knowledge has improved and 8.3% improved a lot in the case which may indicate that JCATS as a training platform, although it is more focused on teaching practical skills and procedures, is also helping the soldiers to develop their technological competencies.

Moreover, data from block MAP shows that tactical planning skills (q7) improved for 71.8% of respondents, indicating that JCATS exercises provide realistic situations that develop these important military leadership skills. On the other hand, while personnel management (q9) improved in 61.1% of cases, but the 30% of respondents indicated that they did not experience any improvement, which may indicate that virtual exercises do not always provide a sufficiently realistic environment for the development of personal management skills, which often require the direct involvement and interaction of people. These statistics can be explained by the individual learning styles of the participants and the specific way in which each competency is incorporated into the training exercise. JCATS, as a technological tool, can be very effective in developing certain competences, but others require additional support or other training strategies.

In addition, the data analysis in block CPD reflect that the effectiveness of the JCATS exercise is rated favorably, but unevenly in different areas. The use of technology in teaching (q11) received 36.1% of positive ratings, while realism (q12) emerged with 26.2% of the highest scores. An area where JCATS could be improved is in its comparison with other teaching methodologies (q13), as even 21.3% gave it only 6 points. Feedback (q14) and overall experience (q15) are viewed positively, with 36.1% and 21% of respondents giving scores of 7-8 respectively, indicating a strong learning experience. Use for training purposes (q16) is rated moderately positive, with 18% giving a score of 8, but the variety of feedback indicates that there is room for improvement in the use of the system. Therefore, the data in block CPD indicate successful areas of JCATS practice and potential areas for improvement.

3.2. Kruskal-Wallis H Test to Assess Differences in Respondents' Views on Competence Changes

In the analysis of the change in soldiers' competences when the JCATS simulation system is used to develop soldiers' competences, the level of competences achieved by the simulation system user was evaluated in terms of the number of exercises participated. Therefore, in this study, the initial assessment of competences was the soldier's proficiency after the first exercise with JCATS.

These perceived skills were compared with those acquired after more than one exercise, which helped to determine the impact of the simulation system in increasing soldiers' competences. Based on the Kruskal-Wallis H test data provided, an analysis was made of how the respondents rated the improvement in the CIC block competencies (Teamwork, Strategic Thinking, Situational Awareness, Stress Management, Technological Knowledge, Critical Thinking) in relation to the amount of training they had received with the JCATS system (see Table 4).

Table 4.

Kruskal-Wallis H test results for block CIC

Competences	Mean Rank			Kruskal-Wallis H Assim. Sig. (p-value)
	1 training	2-4 training	More than 5 trainings	
Teamwork (q1)	29,76	29,00	40,63	0,222
Strategic Thinking (q2)	27,86	32,70	42,75	0,069
Situational Awareness (q3)	29,54	32,23	35,63	0,604
Stress Management (q4)	29,99	31,27	35,31	0,724
Technological Knowledge (q5)	32,66	28,90	27,06	0,584
Critical Thinking (q6).	27,45	32,73	44,63	0,025

Considering the highest mean rank (MR=40.63; see Table 4), soldiers who have participated in 5 or more exercises agree that the competence Teamwork (q1) is successfully developed in relation to the number of exercises they have had. Only those who have participated in one exercise cannot yet confirm this, as the assessment of the acquired competence Teamwork (q1) after the first exercise is lower (MR=29.76; see Table 4).

Similarly, the other acquired competences 'Strategic thinking' (q2) and 'Situational awareness' (q3) are the highest rated (MR=42.75 and MR=35.63; see Table 4) among respondents who have participated in 5 or more exercises. "Stress management" (q4) also shows the highest average rank (MR=35.31; see Table 4) only in the "More than 5 trainings" group, while "Technological knowledge" (q5) has the lowest average rank (MR=27.06; see Table 4), showing that frequent participation in exercises does not always guarantee a high ranking for this competence.

Finally, Critical Thinking (q6) has the highest mean rank (MR=44.63; see Table 4) among respondents who have participated 5 or more times in the exercises, highlighting the importance and benefits of repeated participation in the exercises for the development of the different competences.

Moreover, the critical thinking, which can be described as an important intellectual skill for a soldier, is essential for a leader, as it requires him not only to understand the available information, but also to evaluate and analyse critical situations and make the right decisions. As soldiers in the army are often faced with complex and unpredictable situations that need to be managed quickly and effectively, they must make quick and correct decisions. Therefore, the statements in block MAP were evaluated in the light of the respondents' experience with the JCATS system after their first exercise and after more than five exercises. The results of the study helped to confirm that more exercises have a greater impact on the critical thinking of soldiers (see Table 5).

Table 5.
Kruskal-Wallis H test results for block MAP

Competences	Mean Rank			Kruskal-Wallis H Assim. Sig. (p-value)
	1 training	2-4 training	More than 5 trainings	
Tactical planning(q7)	27,26	32,23	46,44	0,010
Decision making (q8)	27,20	33,20	44,94	0,021
Personnel management (q9)	29,87	32,03	34,44	0,751
Leadership (q10)	28,75	34,07	35,94	0,389

The competency "Tactical planning" (q7) is best acquired after "More than 5 trainings" in terms of the highest mean rank (MR=46.44; see Table 5), as the mean rank of those respondents who participated in only one exercise is statistically significantly lower (MR=27.26; see Table 5). Meanwhile, when it comes to the success of the competency "Decision-making" (q8), the study reveals that the highest average rank (MR=44.94; see Table 5) is again found among those who have participated in five or more exercises, when compared to the lowest average rank (MR=27.20; see Table 5), which is found among those who have participated in only one exercise. The study also confirms the dependence of the increase in the competency "Personnel management" (q9) on the number of exercises, from MR=29.87 (see Table 5) for those who have participated in one exercise to MR=34.44 (see Table 5) for those who have participated in five or more exercises. However, this increase is not considered statistically significant based on the p-value of the Kruskal-Wallis test (p=0.751; see Table 5). A similar situation is found for the competency 'Leadership' (q10), although the study shows an increase in rank from MR=28.75 (see Table 5) in one exercise to MR=35.94 (see Table 5) in five or more exercises, but this difference is not statistically significant, as shown by the p-value of the Kruskal-Wallis test (p=0.389; see Table 5).

3.3. Linear Regression Modelling Results

To identify the latent factors characterizing the individual commander's skills developed using JCATS, an Exploratory Factor Analysis (EFA) was conducted. The EFA results, supported by Bartlett's test ($p < 0.001$) and a Kaiser-Meyer-Olkin (KMO) measure greater than 0.6, confirmed that the block CIC, consisting of six statements assessing the effectiveness of JCATS in developing commanders' individual skills in the Lithuanian Armed Forces, met the necessary statistical requirements. The analysis revealed that 67.7% of the variance in the extracted factors was explained by two latent factors, which were identified as crucial for the development of a commander's individual abilities: Strategic Thinking (STR) and Technological Knowledge (TEC).

Additionally, an EFA was conducted on the MAP block, comprising four statements, to evaluate the effectiveness of JCATS in developing military action planning competencies within the LMF. The EFA results confirmed that the MAP block meets the necessary statistical requirements. The analysis revealed that 78.9% of the variance in the identified factors is explained by two latent factors, which are crucial for the development of a commander's individual competencies: Tactical Planning (TAP) and Leadership (LED). As well, the EFA and Continuous Professional Development (CPD) block of six statements was administered to assess the competences acquired after the JCATS exercise in the light of the respondents' experience. The study showed that 80.52% of the variance in the extracted factors was explained by two latent factors determining the commander's individual competencies in the development: Exercise Effectiveness (EFF) and Feedback (FDB).

Table 6.
Coefficients of the JCATS competency development efficiency improvement Model

Variables	Unstandardized coefficients		t – value	Sig. p –value	95% Confidence Interval		Importance (IMP)
	β	Standard Err.			Lower	Upper	
Intercept	-0,058	0,285	-2,032	0,047	-1,153	-0,007	
TEC	0,360	0,113	3,190	0,002	0,133	0,586	0,433
STR	0,290	0,121	2,397	0,020	0,047	0,533	0,245
TST	0,064	0,028	2,286	0,026	0,008	0,120	0,223
LED	0,179	0,117	1,529	0,132	-0,056	0,414	0,100

Notes: TEC – Technological Knowledge; STR – Strategic Thinking; TST – how many times the training has been completed; LED – Leadership.

Based on the data provided on the factors influencing the effectiveness of commander's individual competencies EFF (Exercise Effectiveness with JCATS), a linear regression analysis was performed. The aim of the model was to assess how strategic thinking (STR), technological knowledge (TEC), tactical planning (TAP), leadership (LED), and how many times the training has been completed (TST) influence the effectiveness of competency development with JCATS (EFF) and feedback (FDB). The constant in the model is statistically significant (β = -0.058; $p<0.05$, see Table 6). The competency 'Technological knowledge' (TEC) with a coefficient β = 0.360 and a p-value = 0.002 was found to be the strongest positive performance factor with the highest influence (IMP = 0.433, Table 6) on the improvement of the effectiveness of soldier competency development with JCATS (see Table 6).

Additionally, the competency 'Strategic thinking' (STR) with a coefficient of 0.290 and a INF of 0.245; and 'Time spent on exercises' (TST) with a coefficient of β = 0.064 (p = 0.026) were also confirmed as significant factors. However, "Leadership Skills" (LED), despite a positive trend, was not statistically significant (β=0.179; p=0.132), indicating that LED does not have a direct influence on the effectiveness of competence development with JCATS. The model predicts the most important areas to focus on when training soldiers to improve the effectiveness of competency development with JCATS.

A multicriteria regression model is constructed that reveals a linear relationship between the factors influencing the effectiveness of competence development and the improvement of the effectiveness of the use of JCATS. The model can be expressed by the equation:

Effectiveness of competence development with JCATS = -0.058 + 0.360 × TEC + 0.290 × STR + 0.064 × TST+ 0.179 × LED

Technological Knowledge (TEC), with the highest level of significance (IMP = 0.433, Table 6) and a statistically significant p-value (p = 0.002), emerged as the most significant factor for the effective enhancement of soldiers' competencies in JCATS exercises. Strategic Thinking (STR) and how many times the training has been completed (TST) also contribute significantly to the effectiveness, albeit with slightly lower influences (STR: IMP = 0.245; TST: IMP = 0.223, Table 6). Although Leadership (LED) does not reach the threshold of statistical significance in the model, it exhibits a positive trend (IMP = 0.100, Table 6), indicating potential importance for future research and the development of effective strategies for enhancing soldier competencies.

4. Conclusions

The results of this study suggest that more frequent exercises with the JCATS system can contribute to a more effective development of soldiers' competences, especially in the areas of tactical planning and decision-making. The statistically insignificant change in the number of exercises conducted in the development of competences in personnel management and leadership shows that these areas require additional methods or skill development beyond the limits of virtual exercises.

From the linear regression analysis carried out to investigate the factors influencing the effectiveness of competency development with JCATS, a number of key findings emerge. First, technological knowledge (TEC) appears as the most important component of effective soldier competence development with JCATS, while strategic thinking (STR) also shows a significant positive influence. These two competences, given their statistical significance, should be priorities in training programs and skill development initiatives when a JCATS simulator is chosen for soldier development. Next, variable that indicated how many times the training has been completed (TST) showed that practical experience is also important, which highlights the significance of continuous learning and development of practical experience when working with JCATS. Also, despite the fact that leadership skills (LED) appears not statistically significant in this model, it may still have an impact, especially in more complex leadership scenarios or as an aspect of long-term development.

Finally, this analysis helps to identify where the Army should focus its resources to maximize the effectiveness of soldiers' competency development with JCATS, as it shows that technological knowledge and strategic thinking are key competencies that are essential for effective soldier development.

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Possible Approaches to Increasing Fitness in the Military in the Context of the Current Level of Fitness in the Population

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Abstract

Army environment is specific in the variability of stimuli arriving during different time periods throughout the year and their nature. The physical preparation and readiness of the soldier, which is influenced by climatic conditions, equipment and armament as well as limited regeneration time must lead to the ability to use capabilities under difficult conditions and immediately when needed. Currently, there is a trend towards decreased physical activity throughout the day, which also affects professional soldiers. We want to draw attention to both health aspects in the context of body composition and fitness components, namely aerobic and anaerobic capacity and their sustainable development. For these purposes, we present exercise programs based on long term systematic work with load and rest intervals, while the High Intensity Interval Training (HIIT) method is used and workout is based on basic multi-joint exercises that serve not only to increase fitness, but also to prevent injuries.

KEY WORDS: *physical fitness, High Intensity Interval Training – HIIT, anaerobic and aerobic capacity, body composition*

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1. Introduction

The subject of this article is physical fitness and the possibilities of influencing it within the army through various training methods, which can be fundamentally divided into continuous and interval training. When assessing and designing, we draw from the findings of the global scientific community and our own research experience in the field of sports training. We aim to base our work on general relationships and phenomenon that occur in society, which necessarily reflect on various components, including the army environment.

We highlight certain shortcomings in efforts to develop fitness, which we also view as opportunities for improving the motor skills of future professional soldiers, and we explore possible solution proposals. To understand deeper connections, we present the basic principles of general fitness preparation focused on developing fitness.

In the context mentioned, we point out the HIIT method, belonging to the interval training form, as one of the possible means in systematic fitness development. We delve into this method not only with its general characteristics but also highlight the advantages of its application, relevant results published by global authors, and personal experiences with implementing the method in our own research activities. However, for an objective perspective, we also address potential risks associated with the method and other limitations.

In conclusion, we attempt to outline how the physical readiness process for soldiers could proceed in a way that respects not only performance but also health and sustainability.

2. Purpose

Physical readiness and a high level of fitness are key elements for the performance of a soldier's duties. Within the preparation for future service, the importance of this component cannot be overlooked; it needs to be developed and given due attention. Physical training in a military environment is fundamentally divided into nonspecific (general physical preparation) and specific (specialized physical preparation).

This division is somewhat simplifying, as in practice, exercises of varying degrees of specificity are included. While specific physical training focuses on developing motor skills related to specific performance requirements (such as climbing, combat training, swimming, etc.) and is also a decisive condition for technical preparation, the content of nonspecific physical training encompasses a broader spectrum of exercises that form the basis for various types of activities (as mentioned above). The goal of nonspecific physical preparation, which we focus on in this article, is primarily the development of functional and bioenergetic capacities, necessarily accompanied by morphological adaptations. This preparation is characterized by efforts to engage as many muscle groups as possible in multiple planes of movement simultaneously, which relates to the selection of basic multi-joint exercises. The main objective is to establish a stable foundation for specific motor learning and achieve a high level of resilience, which is a fundamental prerequisite for subsequent activities [1,2].

Physical fitness is not only related to physical manifestations but also to abilities in the psychosocial domain (coping with emotions, stress, and cognitive functions). The level of these abilities is largely determined by the results of physical activity because higher physical fitness implies a greater ability to cope with higher demands, especially in the social or emotional areas. The specificity of the army environment is reflected in the diversity of stimuli encountered throughout the year and their nature.

The physical preparation and readiness of the soldier, influenced by climatic conditions, equipment, and armament, as well as limited regeneration time, must lead to the ability to utilize capabilities under challenging conditions and immediately when needed. The aim of physical fitness is to be prepared for potential operational deployment [3].

Given the versatility and diversity of a soldier's work, the development of fitness should be:

• Comprehensive: stimulating the main components of fitness, both aerobic and anaerobic capacity (endurance and strength, terms which we will further develop in the text), affecting body composition parameters (reducing fat tissue, maintaining or increasing muscle tissue), and developing a wide range of motor skills. This should also correspond to the selection of exercises, which should be multi-joint and performed in multiple planes of movement. It is crucial to create a training program from actions that occur in the given activity [4,5].

• Systematic: aimed at gradual load increase and education in the field of physical education for long-term maintenance of health, fitness, and vitality. Periodization over a longer timeframe (weeks-months-years) is important, as well as systematization within a training unit, which can be composed of load and rest intervals.

• Efficient: maximizing lesson time allocation and student potential, as time is perceived as a valuable commodity in today's fast-paced world. This necessitates pressure on its effective use and the search for the most efficient ways for versatile development.

3. Problem

1.1. Social Perspective and Its Refleciton in the Army

In the field of physical education and the level of movement abilities and skills, society is facing a decline in performance, which can be described as an undesirable phenomenon. One of the reasons for the decline in fitness in society may be the increase in physical inactivity combined with a sedentary lifestyle. Authors state that the rate of physical inactivity has increased, especially among young girls and boys aged 15 to 21 [6]. This fact manifests itself in many areas and at various levels, so it is not surprising that we have encountered this negative phenomenon in the military environment as well. Physical preparation in the army should aim at the ability of a professional soldier to apply their fitness when performing duties under pressure. The goal of physical fitness is to be prepared for potential operational deployment. Currently, previously stated decline in daily physical activity is beginning to manifest, affecting professional soldiers as well. Alarmingly, a significant portion of work activities do not directly demand fitness. As a result, there is a decline in performance and an increased incidence of injuries during training of movement abilities and skills. The cause appears to be the absence of comprehensive exercises, which are replaced by one-sided physical activity, and a lack of adherence to principles of organism adaptation to stress over longer periods. One reason for the decline in fitness is the increase in body weight associated with a significant decrease in aerobic fitness and muscle strength, as pointed out in article focusing on the physical fitness of young men entering military service between 1973 – 2015 [7].

Military training primarily consists of long-term physical activities performed at low intensities, which may disrupt optimal muscle strength development with regard to the development of maximal strength and aerobic capacity of the organism [8]. Training programs to increase fitness in professional soldiers should focus on gradual load increase considering various training periods. Some authors lean towards combined endurance and strength training as a recommended training approach to enhance the physical fitness of soldiers [7]. Their studies have shown that military training requires greater variation in training stimuli to induce more effective training adaptations, especially concerning the development of maximal or explosive strength and maximal aerobic capacity. They also highlight the fact that it is essential not only to optimize the training process but also to consider often neglected external negative factors such as lack of sleep, carrying burdens, and equipment. The combination of these stress factors can lead to worsened training adaptation, overtraining, and an increased rate of musculoskeletal injuries.

3.2. Development and Management at the Workplace Level Perspective

To properly grasp the problem and propose solutions, it is essential to consider the specific environment in which the processes occur. As an example, we take the Centre of Physical Education and Sport at the University of Defence, where we work. However, similar issues in preparation, methodology, other procedures, and challenges can also be found at foreign universities and centres of a similar nature. One of the key problems we identify is the inconsistent structure in the content of activities managed by individual assistants and specialized assistants in physical education. This prevents objective assessment of the effectiveness of training methods within scientific research activities and the full utilization of students' conditioning potential. The importance of optimizing the training process can be found on several levels. At the individual level, there is a fundamental effort to maximize physical potential in line with adopted techniques and methods of physical fitness development. At the workplace level, the goal is to create a conducive environment for this development and transform the centre into a globally competitive workplace offering top-notch services in physical education, science, and research. In terms of physical preparation, students attend two training sessions per week with a time allocation of 90 minutes. The content of these units is individually managed in line with credit requirements and falls fully under the competence of assistants and specialized assistants of the Physical Education and Sport Centre. Currently, lessons are often guided intuitively, which can lead to inefficiency and incomparable results. Insufficient systemization is also evident in the training of basic exercise techniques, and there is a lack of detailed instruction necessary for an effective training process and maintaining health and fitness. The following table displays the credit requirements for first-year students for men and women (see Table 1).

Table 1.
Overview of Physical Education Assessment Tests for First-Year Students

Men´s Disciplines	Women´s Disciplines
1000 m Run	1000 m Run
Pull-ups	Pull-ups endurance
10 x 10 m Shuttle Run	10 x 10 m Shuttle Run
SAC (Jumping and Acrobatic Exercise)	SAC (Jump and Acrobatic Exercise)

From the table, it is evident that the development of anaerobic capabilities and strength endurance is crucial for meeting the requirements. Strength and anaerobic capabilities appear as a key component of comprehensive fitness [27]. A soldier should be universally physically prepared, but we are facing a declining trend in fitness levels. In physical education classes, there is a lack of systemization and periodization of fitness preparation. All these aspects need to be considered when seeking an optimal solution.

3.3. The approach to the problem

Given the above, this section will focus on approaches related to the development of fitness prerequisites. Through analysis, synthesis, and deduction methods, potential solutions to the problem and the selection of potentially applicable methods will be outlined.

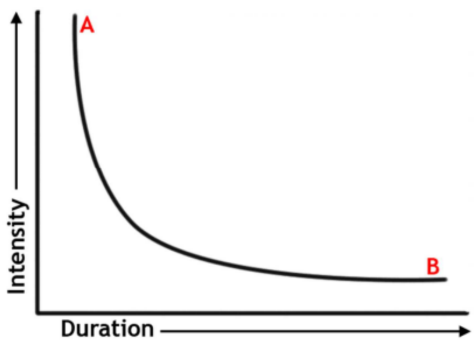


Fig. 1. Curve of Intensity-to-Duration Ratio (https://cerin.files.wordpress.com/2011/08/intensity_duration_curve.gif.).

Conditioning training

Conditioning training is part of the training process primarily aimed at developing bioenergetic, functional, and movement potential in line with the demands of the given performance. Secondarily, it targets the prevention of functional disorders and damage to the organism due to its stress. The desired effect of the training, from the perspective of metabolic, morphological, and physiological changes, is to increase the organism's ability to work more intensively in a shorter time or maintain work intensity over a longer period and resist fatigue (e.g., Fig. 1). The key is the strength of the stimulus, which should reach an optimal level to achieve a positive adaptive effect of "overload," meaning a level between sub and supra-threshold stimulation. Training primarily focuses on developing strength, speed, endurance, and flexibility (motor skills). The development of individual components often complements each other [9].

The fundamental categorization of conditioning training relates to the mode of energetic supply and the development of energetic capacity. Energetic supply occurs either aerobically, utilizing oxygen, or anaerobically, without its utilization, corresponding to the types of conditioning (aerobic and anaerobic) and developmental methods. In the training process, methods are predominantly employed, based on specific requirements, either for the development of aerobic fitness or anaerobic fitness [1]. However, this classification is somewhat oversimplified, and in practice, the characteristics of both methods often synergize or can hinder each other. An example of the interplay between these components could be a soldier prepared for long-distance movement (conditioned by aerobic capacity) but also ready for short-distance runs, combat, carrying heavy loads, throwing, or climbing (conditioned by anaerobic capacity). In conditioning preparation, methods are divided based on the desired outcome into continuous and intermittent loading. The variability in method application is primarily determined by exercise volume and intensity, or the characteristics of loading and rest intervals between specific sets (in interval training, the term "programming" is used). The fundamental difference between methods lies in the mode of energy release, determined by biochemical processes. Essentially, the character of energetic supply is categorized as predominantly aerobic, anaerobic, or mixed [1,9,10].

Aerobic capacity, or aerobic performance, is defined as the maximal oxygen consumption expressed by metabolic indicators of $VO_2Max.kg^{-1}$ and stands as one of the primary indicators of physical fitness. Maximal oxygen consumption is represented by the maximum amount of oxygen delivered to tissues during exertion, which does not increase further despite continued strain. It is primarily determined by the functional capacity of the O_2 transport system and oxidative energetic source levels [11,12].

Anaerobic capacity can be characterized as the organism's ability to sustain high-intensity physical performance even with significant acidosis caused by anaerobic glycolysis energetic supply. The duration of high-intensity muscle activity is approximately up to 60 seconds and typically involves various forms of interval loading. The level of anaerobic capabilities can be measured through anaerobic tests, with the Wingate test being the most commonly used laboratory examination [13].

The development of both energy supply components is exemplified by the HIIT method, which we will detail further in the subsequent text. Primarily, the method focuses on anaerobic fitness development; however, it also enhances aerobic fitness comparably, sometimes even more effectively than methods exclusively aimed at aerobic capacity development. This attribute was confirmed by research from Tabata and numerous other authors in the 1990s, as evidenced by Milanovic's 2015 meta-analysis [1,9,14,15].

The method significantly impacts changes in body composition parameters. At the hormonal level, HIIT stimulates growth hormone, adrenaline, and insulin. At the enzymatic level, it manifests through increased levels of enzymes such as phosphofructokinase, dehydrogenase, and sensitive lipase. By combining these substances with complex exercises, anabolism is supported, with one kilogram of Fat-Free Mass (FFM) representing an energy demand of up to 40 kcal/kg/day compared to approximately 5 kcal/kg/day of Fat Mass (FM). Lastly, HIIT induces substantial energy expenditure, reflecting in the overall energy balance. All these factors influence the change in body composition parameters; however, significant importance is attributed to Excess Post-Oxygen Consumption (EPOC) and the creation of an oxygen deficit, leading to additional calorie consumption and an increase in basal metabolism to levels matching pre-exertional demands [16]. The distinct energy supply processes during aerobic and anaerobic activities are illustrated below (e.g. Fig. 2).

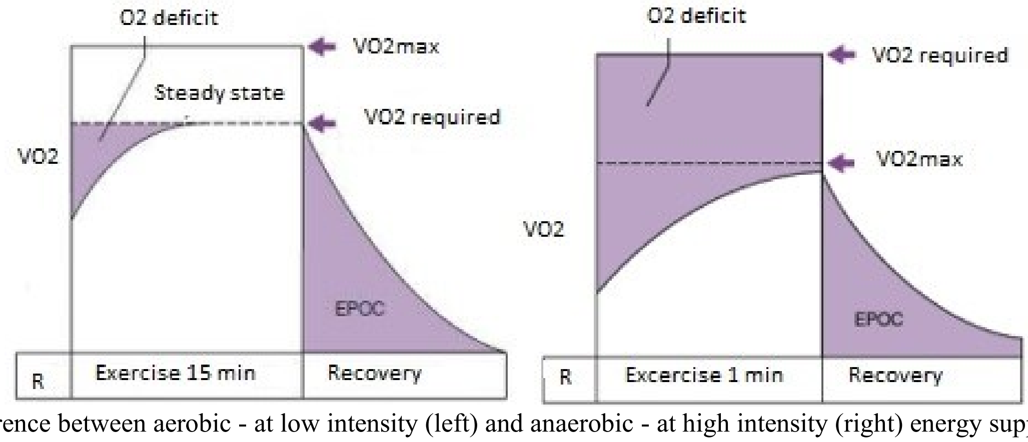


Fig. 2. Difference between aerobic - at low intensity (left) and anaerobic - at high intensity (right) energy supply [1].

HIIT

HIIT is a training method targeted at developing muscular endurance falling into the category of workouts with short to ultra-short intervals [3]. In general terms, HIIT can be defined as a combination of periods where high-intensity exercise alternates with low-intensity exercise or passive rest, known as an inactive phase. The effectiveness of the method is conditioned by the composition of individual variables, known as programming. Authors defined a total of 12 variables, of which intensity of load, duration of load, form of rest, duration of rest, and form of load are considered key [17]. The complete scheme of variables (+ environmental cond., nutrition status, total volume of work) in the HIIT method. (e.g. Fig. 3).

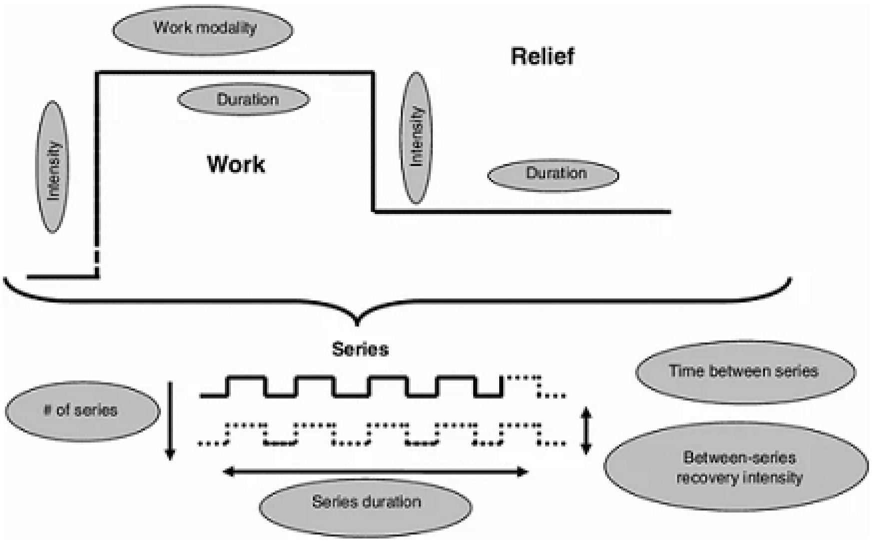


Fig. 3. Scheme of variables HIIT [23].

Based on the above, it is evident that intensity is a key factor for eliciting the desired response. To achieve this, it is essential to select exercises that challenge the entire musculoskeletal system and bodily systems. This need corresponds with the requirements for selecting exercises considering the diversity of a soldier's work and the development of their fitness, as mentioned earlier. From the perspective of developing bioenergetic potential (aerobic and anaerobic capacities – simplistically, strength and endurance), the HIIT method appears to be potentially very effective for a soldier's performance. It is also worth noting that for maintaining health, it is crucial to maintain an optimal ratio of muscle and fat components, on which the method has a proven effect. The most significant effects of HIIT are summarized below in five points:

- Significant stimulation of anaerobic capacity and strength (glycolytic energy cover).
- The method demonstrably increases aerobic capacity [14].
- The method significantly influences body composition parameters (growth of muscle mass and reduction of fat component due to EPOC).
- Additional effects are demonstrated at the hormonal, metabolic, and enzymatic levels; the method also considerably reduces the time individuals spend exercising.
- Efficiency considering time utilization (e.g. Fig. 1).

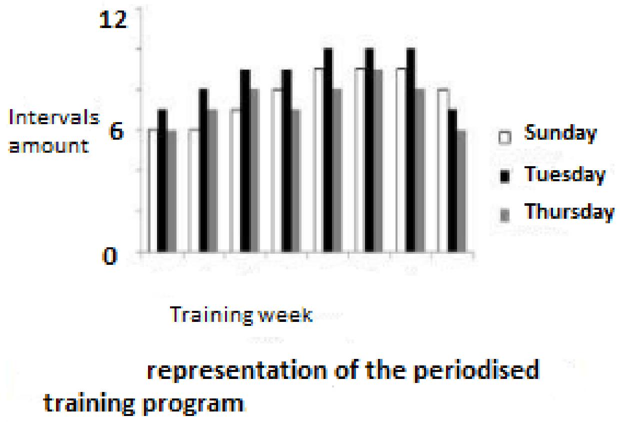
Effects of HIIT in Selected Research

In this section, we present the results of conducted research confirming the hypotheses from the previous section, which we expand upon in some aspects. Attention is paid to the effects, particularly concerning aerobic and anaerobic capacity and body composition. We also provide insights from our own research using the method and highlight various body development systems applied worldwide in connection with HIIT.

HIIT significantly affects the function of the anaerobic energy system (energy cover primarily occurs in anaerobic glycolysis mode), the ability to maintain homeostasis due to increased resistance to hydrogen ions causing a decrease in pH, and the utilization of non-carbohydrate sources (lactate, amino acids, glycerol) in the gluconeogenesis process. All these reactions lead to higher efficiency in ATP production during glycolysis. Through HIIT, strength capabilities are also stimulated, especially muscular endurance and contractile abilities [18].

Consequently, the increase in anaerobic capacity, or performance, is not particularly surprising given the aforementioned, especially with studies confirming this, where an increase of 18 % was observed after completing an eight-week cycle [19] or with an increase of 12.4 % [20] or demonstrating an improvement of 16.5 % [21]. From the perspective of increasing overall bioenergetic capacity, it is undoubtedly worth mentioning studies documenting the intervention's impact on the aerobic capacity component, which may not be entirely evident a priori.

Studies [22,23,24] confirm significant improvements in both aerobic and anaerobic components. Similarly, shifts in AT (anaerobic threshold), VT (ventilation threshold), PPO (peak power output) – peak performance, and the ability for its longer duration, along with overall higher values in the anaerobic area, are noted. Siahkouhian's research [22] measured active (12 respondents) and inactive athletes (12 respondents) and the effect of HIIT training on the aforementioned indexes. Measurements were conducted over eight weeks after 3 sessions each (e.g. Fig. 4). The basis of the study was a 3000m run and its measurement due to the influence before and after training values (e.g. Fig. 5).



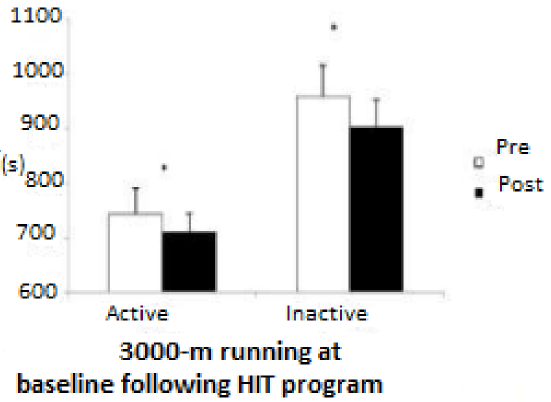


Fig. 4. and Fig. 5. Graphs illustrating training volume (6-10 sets of 30*s* load with a 4*min* passive rest) and a 3000*m* run before and after the study [22,23,24].

As evident from the table below (e.g. Tab. 2), both groups experienced an increase in VO_2max (±7.6 % and ±13.7 %) and a shift in the ventilatory threshold (±4.5 % and ±3.8 %). The first VT1 was automatically generated by the computer upon an increase in O_2 ventilation, irrespective of the equivalent rise in CO_2 ventilation. Conversely, the second VT2 was detected as the point where there was a rapid increase in CO_2 ventilation and an associated observed decrease in partial CO_2 pressure. Participants ran on a treadmill to subjective exhaustion to determine aerobic capacity. For anaerobic capacity and peak power output (PPO – peak power output – e.g., Table 3), the 30*s* Wingate Power test was used on a mechanically braked cycle ergometer at the maximum possible speed. The study saw an increase in both PPO (±8.3 % and ±14.6 %) and MPO (±10.9 % and ±19.0 %) [22,23,24].

Table.2. Table displaying improvements in ventilatory threshold and VO_2Max

Variable	PRE (AG)	POST	PRE (IG)	POST	p
VO_2Max	53.5±4.6	54.4±3.9	41±2.6	46.7±4.9	.005
AVT_1 (%VO_2Max)	63.9±4.2	66.7±3.9	56.3±4.3	58.5±4.3	.005
AVT_2 (%VO_2Max)	78.1±3.5	81.3±3.8	72.3±2.6	75.1±4.3	.005

Values are ± SD
P < 0.05 between the two groups
AC..Active group, IG..Inactive group

Table.3
Table shows an increase in performance both at maximal and average levels, where PPO represents the 5*s* peak power output during the test, and MPO is the average work for the 30*s* segment [22,23,24].

Variable	PRE (AG)	POST	PRE (IG)	POST	p
PPO (w/kg)	11.4±0.9	12.3±0.5	10.4±1.1	11.9±0.8	.005
MPO (w/kg)	7.2±0.8	8±0.6	6.3±0.6	7.4±0.4	.001

Values are ± SD
P < 0.05 between the two groups
P < 0.001 from the corresponding pre-training value

From the tables, it can be inferred that HIIT training leads to an increase in VO_2Max, ventilatory threshold, and consequently, greater maximal performance. One of the most well-known studies associated with HIIT and the development of both anaerobic and aerobic capacities is the six-week Tabata study conducted in the 1990s [15]. The study compared HIIT composed of 8 super-intense 20*s* intervals at 170 % VO_2Max separated by 10*s* passive rest intervals to 60 minutes of continuous exercise at 70 % VO_2Max. Tabata's training protocol demonstrated higher efficiency of HIIT (IT) compared to continuous training (ET) in developing anaerobic performance. After the six-week cycle, there was a 28 % increase (77.9 ml/kg/min) in anaerobic capacity with HIIT compared to continuous training, which did not show improvements in anaerobic capacity (e.g., Fig. 8 – on the left maximum anaerobic capacity on the y-axis versus time on the x-axis). An interesting finding may also be the relatively greater increase in aerobic capacity using HIIT (an increase of 5 ml/kg/min) compared to continuous training (an increase of 4.5 ml/kg/min), as shown in Fig. 6 on the right (VO_2Max displayed on the y-axis versus time on the x-axis).

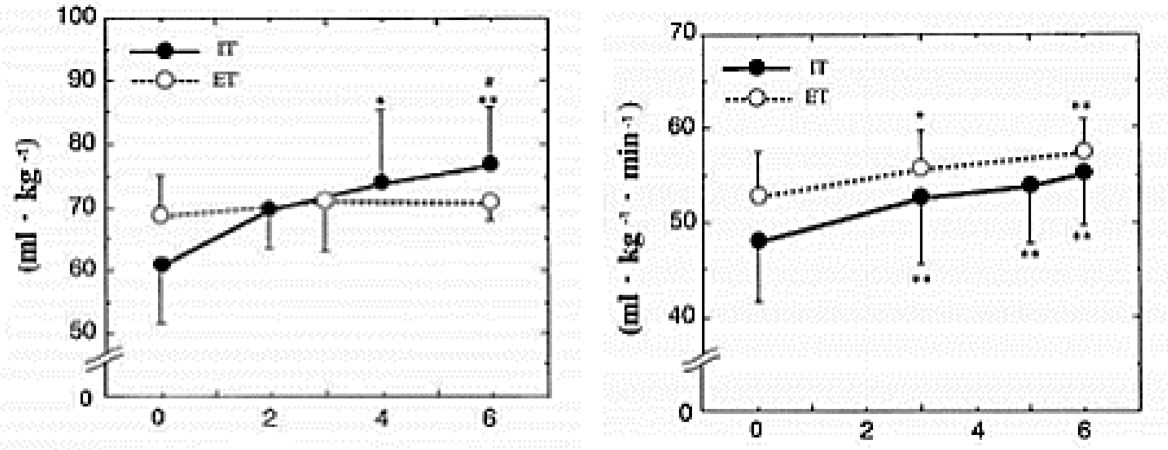


Fig. 6. Comparison of the effectiveness of IT and ET on indicators of aerobic and anaerobic capacity within weekly training load [15].

As a part of the research for the dissertation, we subjected the Tabata system to further examination, by observing the effect on both aerobic and anaerobic capacity parameters and body composition. Considering the issues of programming and the scheme presented in Figure 2, we compared the traditional Tabata, consisting of 20s/10s intervals (2:1 ratio) in eight exercise sets, with a modified version of 20*s*/20*s* intervals (1:1 ratio). Participants (n=46) were divided into two intervention groups and one control group. Within two weekly training sessions, male recreational athletes performed two exercise sets. The selected exercises, chosen for their complexity, were squats with jumps and burpees.

Significant effects on anaerobic capacity performance, as demonstrated by the Wingate test (p=0.0228 for the 2:1 protocol and p=0.0098 for the 1:1 protocol), were observed. Additionally, significant effects on changes in body composition parameters, particularly a reduction in fat mass for the 2:1 protocol (p=0.0001), were confirmed. Interestingly, effects on aerobic capacity, tested using load spirometry for both protocols, were also verified. The monitored parameters included VO_2Max, minute ventilation, and performance converted to kilograms. For the key variable VO_2Max, the value was p=0.015 for the 2:1 protocol and p=0.0819 for the 1:1 protocol. However, the substantive significance expressed by Cohen's d for the 1:1 system indicated a moderate level of effectiveness (d=0.654). The differences (pretest x posttest) for the mentioned values are represented in the figure below (e.g., Fig. 7).

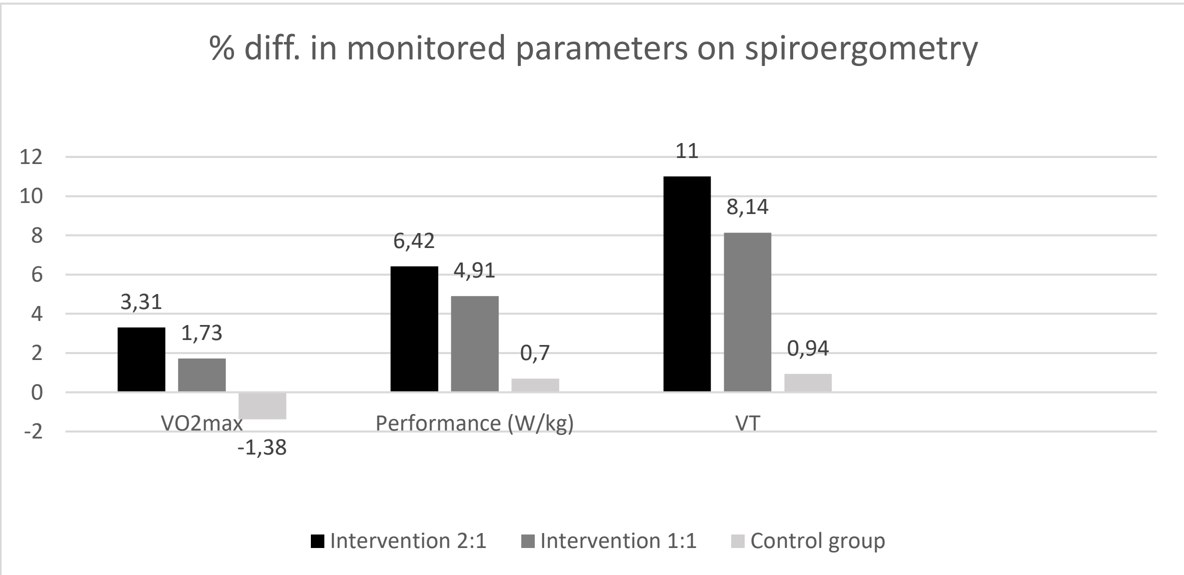


Fig. 7. Percentage differences (pretest/posttest) in the median of the observed parameters on the Spiroergometry [25].

The relationship between HIIT and the development of VO_2Max and other fitness parameters has been explored since the beginning of the millennium [26]. The results, showing the effect, can be seen in the example of twelve studies listed below (e.g. Tab. 4).

Table.4

Analysis of Research on VO_2Max at Various Intensities

Reference	n	Mode	Freq. (d/w)	Weeks	Reps	Intensity (VO_2Max)	W/R duration (min)	Results
Hickson	8 M	R/C	6	10	6	100 %	5/2	↑VO_2Max
Green	10 M	C	1	1	16	90 %	6/54	↑PCr
Keith	7 M	C	2-4	8	2	Th + 30 %	7.5/0.5	↑VO_2Max
Burke	21 F	C	2-4	7	-	85-98 %	0.5-2	↑VO_2Max
Simoneau	10M/14F	C	4-5	15	4-15	60-90 %	0.25-1.5	↑Type1
Rodas	5 M	C	7	2	4-7	All-out	0.25/0.75	↑PCr
Parra	5 M	C	2	6	4-7	All-out	0.5/12	↑PFK
Macdougal	12 M	C	3	7	4-10	All-out	0.5/4	↑PFK
Henritze	23 F	R	5	12	1	Th	NA	↑Th
Nevill	4M/4F	C	3-4	8	2-10	All-out	0.5/10	↑Lac
Tabata	7 M	C	5	6	7-8	170 %	20/10 s	↑VO_2Max
Hamer	7 M	C	3	7	4-10	All-out	0.5/4	↑Th

C..Cycle training, F..Female, Lac.. Lactate, M..Male n..number of probands, R..run training, PCr..Phosphocreatine, PFK..Phosphofructokinase aktivity, Th..Threshold, Type 1.. Muscle fibre type, ↑.. improvement.

The interconnection between both energetic systems (aerobic and anaerobic) and the mutual influence of their respective capacities can be explained through the following principles. When high intensity is used, energetic demands are met anaerobically in the glycolysis process. Glycogen is broken down into pyruvate, which is subsequently metabolized into lactate and hydrogen ions, leading to a decrease in the internal pH. This is the main factor slowing down ATP production — the primary energy source. The term "buffer capacity" is synonymous with anaerobic capacity. The term "buffering" refers to buffers, especially phosphates, hemoglobin, histidine, and carboxylic acids, and it is the readiness of the aerobic system that conditions the ability of the buffering capacity. Maintaining pH stability (striving for homeostasis) also significantly influences the function of the cardiorespiratory system due to the exhalation of CO_2. The ability of the aerobic system for this purpose is stimulated by an increase in maximal cardiac output, increased capillary density, mitochondrial oxidative capacity of skeletal muscle, and ventilation [28,29].

Fitness Programs in Military Environments

In designing an intervention training program and synthesizing the research problem, we were convinced that such programs are not commonly used in military sports environments worldwide. To competently discuss the global uniqueness/specificity of our training program, it was necessary to determine how various countries approach physical fitness development in the context of military conditioning (e.g., Tab. 5). Detailed research revealed information about training programs in European countries (most prevalent), Asia, North and South America, and Australia. These programs focused on measuring different parameters during diverse physical activities, with training periods ranging from 2 to 34 weeks and involving subjects ranging from 17 to 423 participants.

In Greece, the impact of a series of physical tests on army cadet performance was studied. A 12-week intervention training period resulted in improved performance in both specific military physical activities and general movement skills [30]. Cardiovascular performance and maximum strength were evaluated in a control group of 72 tested individuals in the Finnish military environment after an 8-week military training program. The result was an increase in VO_2Max capacity by over 12 % and leg extensor strength by nearly 13 % [31]. Norwegian military cadets (n=107) were examined during a 10-month period of mandatory military service [32]. The objective was to evaluate physical fitness using parameters such as VO_2Max, maximum sit-ups, push-ups, chin-ups, and 3-km running time. Significant improvements were found in sit-ups and push-ups. Other activities did not show significant improvement but also no deterioration. In Brazil, the effect of a 7-month military training program on changes in body composition variables was studied. A sample of 270 Brazilian cadets was divided into two training groups: military physical training routine and specific sport training. The resulting effect was similar for both groups [33]. The Spanish army tested a sample of 21 professional soldiers to determine performance differences after Resisted High Intensity Interval Training (RHIIT) and Endurance High Intensity Interval Training (EHIIT) programs compared to conventional and classic approaches. Significant improvements in cardiovascular parameters were observed after RHIIT and EHIIT interventions [34]. The effect of High Intensity Interval Training was also tested in Israel. Test subjects were divided into two groups – control and intervention. The intervention group underwent high-intensity training, while the control group underwent classic training. The training program lasted 5 weeks. The results showed a significant change in the observed parameters in favor of the intervention group [35]. Changes in the physical performance of Australian army personnel after a 5-week specific physical training program were the subject of a pilot study focused on physical, occupational, and technological assessments. The result showed no significant difference in variables characterizing performance between the control group and the experimental group [36]. A comparative system of results was also used in Iran. The study aimed to determine the effect of Crossfit on cardiovascular parameters and body composition. Soldiers from the Crossfit group showed significant positive reductions in BMI index and heart rate compared to soldiers from the control group [37].

Table.5.

Military Training Programs in Different Countries.

Country	Measured Parametres/Variables	Training Period	Physical Activities	Subjects	Results
Greece	Just performance	12 weeks	Pull-ups, 50m swim, Mile Run, Obstacle Course	423	Improvements
Finland	Cardiovascular (VO2 max), Maximal Strength, BodyMass	8 weeks	Combat training, Marching, Running, Walking, Cycling, Strength Training, Ball games, Shooting	72	Improvements
Norway	VO2 max, TTE (time to exhaustion), Body weight	10 weeks	Running, Strength Training, Ball play	107	Improvements, except pull-ups
Brazil	DXA, spBIVA	34 weeks (5 days/week, 90min/day)	Running, Calisthenics, Resistance, Swimming, Sports training	270	Improvements
Spain	Rate of perceived extertion, heart rate, skin temperature, explosive strength, bodyweight	2 weeks	Resisted high intensity interval training (RHIIT), endurance intensity interval training (EHIIT)	21	Improvements
Australia	Cardiorespiratory fitness, Muscular strength, Occupational capacity	5 weeks	Puhs-ups, Multistage fitness test, squat, strict press, deadlift, floor press, one-leg balance, one-arm plank	17	Depends on group (Control vs. Experimental)
Israel	Maximal oxygen consumption	6 weeks	Running (5-8km 3x times/week), agility and strength training, Army Fitness Test (3km running, pull-ups, squats, dips)	60	Depends on group (Control vs. Experimental)
Iran	BodyMass, heart rate, systolic and distolic blood pressure, VO2 max, maximal power to weight	4 weeks (3 times/week)	Weight-lifting, gymnastics, metabolic conditioning	24	Depends on group (Control vs. CrossFit)
Croatia	Variables in Tests: 20 yard shuttle run, Medicine ball sitting throw, Continuous JumP, 20m dash, Push-ups, Sit-ups, Pull-ups, Squats, Max. bench press, 3200m stuttle run	5 weeks	Continuous running session, calisthenics, exercises in pairs. bench press, 300 yard shuttle run, 3200m stuttle run	124	Improvements in BMPR group, in CERS group except horizontal jump, pull-ups and sit and reach test
USA	Variables in Tests: Push-ups, Sit-ups, 2 mile run, Deadlift, Pull-ups, Flexed arm hang, Standing long	6 months	Self-report aerobic activity, muscle-strenghtening activities	123	Depends on group (Physical activity standards)

Two 5-week training programs formed the basis of research focusing on the physical readiness of Croatian military cadets. They were divided into continuous endurance, relative strength training, and basic military physical readiness training groups. Both groups achieved statistically significant positive changes in various physical activities compared to their pre-training program state [38]. In the USA, a comparison was made between the impact of the standardized older physical test, the Army Physical Fitness Test (APFT), and the new test, the Army Combat Fitness Test (ACFT), on the physical performance of army personnel. They found that APFT is more suitable for increasing muscle strength, whereas aerobic capabilities increase due to ACFT [39].

4. Conclusions

Although the topic of fitness, both in society and in the military environment, is quite complex, and oversimplification could be counterproductive, we will attempt to summarize based on the above information what approaches could be effective in developing the fitness of future soldiers to best meet the specific requirements of the army. Contemporary society is generally struggling with decreasing fitness levels, which is associated with an increase in lifestyle diseases, overweight, and other undesirable aspects. Therefore, it is necessary to find ways to effectively counteract this emerging phenomenon. In the military environment, good physical readiness is not only associated with health aspects but primarily with the defence of the country, and the demands on the physical and mental resilience of soldiers are enormous. One method that comprehensively develops physical fitness and aligns with today's fast-paced trends and demands for efficient methods is the HIIT method. Based on numerous studies which we refer to in this work and based on our own research activities, we know that this method can effectively develop both essential components of fitness: aerobic and anaerobic capacity. Moreover, it is possible to achieve a positive effect on changing body composition parameters, which various authors consider an integral part of fitness. The method has been used with satisfactory results in the armies of Spain and Israel (e.g., Fig. 11). However, due to the complexity of programming, it will undoubtedly be necessary to subject the planned interventions to thorough scrutiny. It should be noted that high intensity is not only associated with physical development but also carries certain risks related to musculoskeletal damage (particularly the occurrence of micro and macro traumas) or the internal environment (mainly involving RO(N)S – reactive oxygen (and nitrogen) species) and local to systemic acute inflammation in connection with cumulative microtraumas. Another question remains at what level will the achieved fitness be maintained after the intervention is completed during the transitional period, or how to maintain the achieved level. All these factors need to be taken into consideration when designing interventions and long-term fitness development planning and subjected to further research. At the same time, we see the lack of clarification of all these causes as certain **limits** of this article. Nevertheless, HIIT can be an effective method for developing motor skills, which, on the one hand, respects the needs of military readiness and, on the other hand, aligns with the demands of society and the trend of the current fast-paced era.

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Challenges of the Formation of the Military Professional at the University of Defence

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Abstract

Higher education for military professionals is provided by the University of Defence, the only military university in the Czech Republic. Like other universities, it has to deal with students who drop out of their studies. Retrospectively collected data on the withdrawals from the study were statistically analyzed using survival analysis methods to assess student dropout rates. With the five-year records, we quantified the effects of two faculties and five classes, which showed that the risk of dropping out is higher for students in technical fields (approximately by 18%). On the other hand, the creation of support groups led to a more gradual dropout rate compared to the previous years without these groups (approximately by 25%). We believe that these results will help the academics and commanders guide students as they become military professionals.

KEY WORDS: *military professional, student, University of Defence, dropout rate, comparison, survival analysis, hazard rate.*

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1. Introduction

The military-economic-political situation in the world in recent years has not been as stable as most people would have imagined. This is reflected in the increase of military conflicts, which affect the lives of more and more people in one way or another. In this situation, the armies of the respective countries play a key role. It is important to have educated people in command positions who serve the democratic principles of their country. In the Czech Republic, the University of Defence is responsible for the education and training of military officers. Three faculties, two institutions and three centers are involved in the bachelor's, master's and doctoral studies in military leadership, technical and medical fields [1].

During the existence of the University of Defence, the study programs have undergone minor and major changes in order to meet the requirements of a modern army and to respond to the military-political situation in the world. As a result, the duration and content of the studies have naturally changed. One of the logical consequences was the transition to a five-year master's program with an emphasis on the formation of the military professional's personality, physical fitness and language skills.

Military students – future commanders – have been enrolled in newly accredited five-year study programs. During their studies, the students have to fulfill not only their academic obligations, but also a demanding military training. For this reason, greater emphasis is placed on physical fitness and mental resilience, as well as language skills and basic theoretical knowledge in selected subjects. Not every student is able to cope with this successfully. In this paper, we will focus on the last mentioned point – the theoretical subjects, which are one of the first challenges students face in their studies. In particular, we compare the dropout rate from the five-year study program at the Faculty of Military Leadership and the Faculty of Military Technology, as well as the dropout rate for each year of study.

The academic performance is the topic which universities are concerned with and not only in the face-to-face education, but also in online education [2]. The dropout and retention is a critical problem in all type of universities and colleges. The spread of higher education has led to a growing demand for graduates, which pose a challenge to universities to guaranteed the very same level of knowledge [3].

In larger groups, there is a possibility of an individual to be hidden in the group and various procedures and processes can be conducted to help students with their study and, as a result, to lowering the dropout rate [4].

Improving the retention of the students, namely the students in the technical fields, is an obvious approach to fulfill the demand of the "civilian" labor market as well as the military subjects [5]. Moreover, with the concept of emerging adulthood [6], the universities have to change their approach to the students and their physical, social and mental needs [7,8]. Several studies have been conducted to describe and model student dropout and retention from a qualitative perspective [9–13].

2. Data and Methods

In this retrospective study, we collected the data in the period from September 2014 to July 2023, which covers the full five year of study for all students enrolled in the new five-year study program. The dataset now includes complete information to assess the dropout rate over the course of the five-year study program.

We examine the dates up to which withdrawing student's studies officially ended. Usually the reasons for dropping out are not known (or in some cases they are confidential); however, some of the reasons can be guessed, such as the discrepancy between the idea of studying and the actual process of studying – in the simple words of one of the students, "more sitting in the classrooms than running in the woods".

We use the same notation as in the first article of the series [14], since this article is a continuation of a long-term study. The students are then divided into five groups with the labels "Class 2014", ..., "Class 2018" standing for the groups of students who started their studies in 2014, ..., 2018, respectively. Newly, we distinguish two groups concerning the affiliation to the Faculty of Military Leadership (FML) and the Faculty of Military Technology (FMT).

The collected data for survival analysis were denoted as follows

(1) the dropout occurred (event),

(2) the student completed the study and graduated (censored)

(3) the student was allowed to repeat the year (censored).

For the survival analysis, we use R program with its libraries (survival, survminer and pch) and apply the Kaplan-Meier estimate of survival functions. Having several survival curves, we utilize the Gehan-Breslow-Wilcoxon test and its modifications – log-rank test and Peto-Peto-Wilcoxon test, which place more weight on later or earlier survival times, respectively. To assess the occurrence of student dropouts during the single years of their study, we apply the piecewise exponential model with constant hazard rate within the given period [15,16]. To quantify an effect given by faculties and classes, we use Cox proportional hazard model [17,18] and calculate conditional survival probabilities [19].

3. Results and Discussion

Given survival data, the first estimate is the Kaplan-Meier nonparametric estimate of the survival function, which is shown in Figure 1. On the left panel of the figure, we can see that the overall survival is slightly better for the Faculty of Military Leadership (in green color). However, the dropout rate during the first year is very similar for students of both faculties and it takes value around 65%. On the right panel of the figure, we can identify a similar pattern of the dropout rate when students are distinguished by the classes. The Class 2018 (in green color) seems to have the best survival rate.

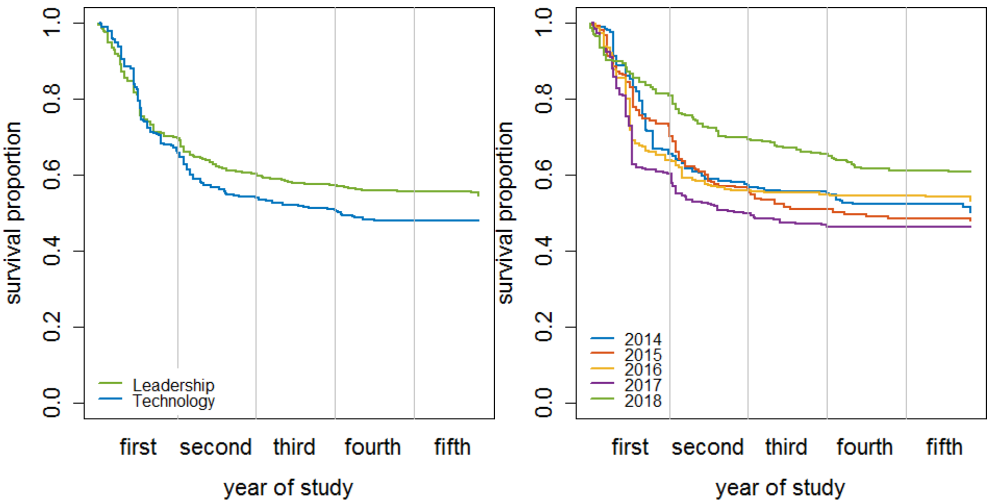

Fig. 1. Kaplan-Meier estimates of the dropout rate stratified by the faculty (left panel) and by the class (right panel)

We supported the visual comparison from Figure 1 by testing for the statistical difference between these curves. Using both the log-rank test (LR) and the Peto-Peto modification of the Wilcoxon test (PPW), we concluded that the survival curves are different. The p-values of the tests (LR: $p = 0.0429$, PPW: $p = 0.1392$) show that the difference between the faculties is very small. On the other hand, the p-values associated with the classes (LR: $p = 0.0005$, PPW: $p = 0.00005$) indicate the statistically significant difference between the classes.

The survival rates of the stratified data are presented in Tables 1 and 2 for the stratification by the faculty and by the class, respectively. The first two semesters exhibit similar behavior in both faculties, which can be related to the students' uncertainty about the right choice of university program [14]. Then, the survival rate is slightly better for the Faculty of Military Leadership.

Table 1.

Survival rates stratified by the faculty in the respective semesters

	F. M. Leadership		F. M. Technology	
semester	survival	confidence interval	survival	confidence interval
1	0.794	(0.767; 0.822)	0.794	(0.761; 0.828)
2	0.695	(0.664; 0.727)	0.656	(0.618; 0.697)
3	0.620	(0.588; 0.654)	0.566	(0.526; 0.608)
4	0.601	(0.569; 0.635)	0.540	(0.500; 0.583)
5	0.578	(0.546; 0.613)	0.519	(0.479; 0.562)
6	0.573	(0.541; 0.608)	0.506	(0.466; 0.549)
7	0.559	(0.526; 0.593)	0.482	(0.442; 0.526)
8	0.556	(0.524; 0.591)	0.480	(0.440; 0.524)
9	0.556	(0.524; 0.591)	0.478	(0.438; 0.522)
10	0.553	(0.520; 0.587)	0.478	(0.438; 0.522)

The survival rate of each class follows a different pattern. We can distinguish few patterns – in the first semester, the Classes 2014, 2015 and 2018 have a higher survival rate than the Classes 2016 and 2017. In the second year of the study, the Classes 2017 and 2018 show different behavior than other classes. At the end of the study, the Class 2018 has the highest survival rate. Their overall survival rate is higher than in other classes, we suspect that this is strongly influenced by the small group tutoring that was introduced that academic year.

Table 2.

Survival rates (with confidence intervals) stratified by the year in the respective semesters

semester	Class 2014	Class 2015	Class 2016	Class 2017	Class 2018
1	0.851 (0.808; 0.896)	0.829 (0.781; 0.881)	0.716 (0.667; 0.769)	0.729 (0.683; 0.779)	0.866 (0.829; 0.905)
2	0.653 (0.597; 0.715)	0.700 (0.642; 0.764)	0.639 (0.586; 0.696)	0.602 (0.551; 0.657)	0.808 (0.765; 0.853)
3	0.588 (0.530; 0.653)	0.584 (0.522; 0.654)	0.573 (0.519; 0.632)	0.523 (0.471; 0.580)	0.723 (0.675; 0.775)
4	0.572 (0.514; 0.637)	0.561 (0.499; 0.631)	0.559 (0.505; 0.619)	0.497 (0.446; 0.555)	0.694 (0.644; 0.747)
5	0.555 (0.497; 0.621)	0.514 (0.452; 0.585)	0.552 (0.498; 0.612)	0.475 (0.423; 0.532)	0.671 (0.620; 0.726)
6	0.555 (0.497; 0.621)	0.509 (0.447; 0.581)	0.549 (0.495; 0.609)	0.462 (0.410; 0.519)	0.654 (0.603; 0.710)
7	0.522 (0.464; 0.589)	0.495 (0.432; 0.567)	0.545 (0.491; 0.605)	0.462 (0.410; 0.519)	0.615 (0.563; 0.672)
8	0.522 (0.464; 0.589)	0.485 (0.423; 0.557)	0.545 (0.491; 0.605)	0.462 (0.410; 0.519)	0.612 (0.559; 0.669)
9	0.522 (0.464; 0.589)	0.485 (0.423; 0.557)	0.541 (0.487; 0.601)	0.462 (0.410; 0.519)	0.612 (0.559; 0.669)
10	0.514 (0.455; 0.580)	0.485 (0.423; 0.557)	0.541 (0.487; 0.601)	0.462 (0.410; 0.519)	0.608 (0.556; 0.666)

Applying the parametric model, the piecewise exponential model, to the data, we can see in Figure 2 that the slope of the survival curve is decreasing, which is true for both faculties and classes. This behavior was more or less expected [14]. However, the model reveals an interesting feature of student survival – the overall dropout rate is decreasing with respect to the classes. This may be due to students getting used to the new program and having older students (from the same program) to help them with any study problems they may encounter.

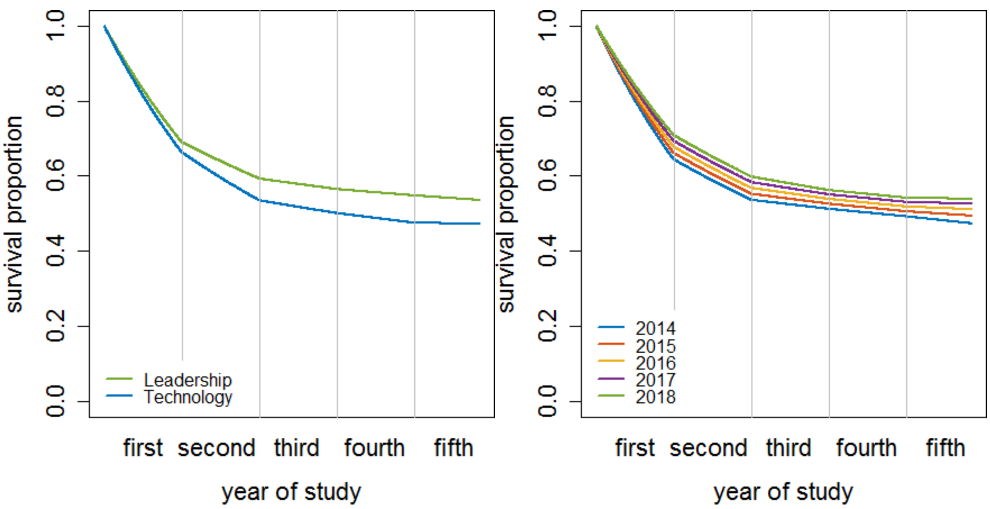

Fig. 2 Piecewise exponential model of the dropout rate stratified by the faculty (left panel) and by the class (right panel)

The hazard rates associated with the piecewise exponential model are summarized in Table 3, which shows another noteworthy feature. The fifth year of study brings a final state examination and defense of the thesis, which is the last and difficult step in the study, and some of the students cannot fulfill the requirements.

Table 3.
Piecewise constant hazard rates (×105) within the years of study for the respective faculties and classes

Faculty	first	second	third	fourth	fifth
Leadership	101.71	46.62	13.12	8.35	7.25
Technology	112.59	58.82	17.95	14.39	1.35
Class	first	second	third	fourth	fifth
2014	120.61	50.09	12.47	10.95	1.26
2015	113.46	49.14	13.46	10.73	7.44
2016	106.74	48.20	14.53	10.50	4.41
2017	100.42	47.29	15.68	10.29	2.61
2018	94.47	46.39	16.93	10.07	1.55

When quantifying an effect that is provided by faculties and classes, we use the Cox proportional model. Although the result of the log-rank test shows that the assumption of constant proportional hazard is not met, we can apply the model (pretest test statistic Q is negative [18]). The resulting model is displayed in Figure 3 along with the corresponding hazard function, which is aggregated by semester to easily see its behavior.

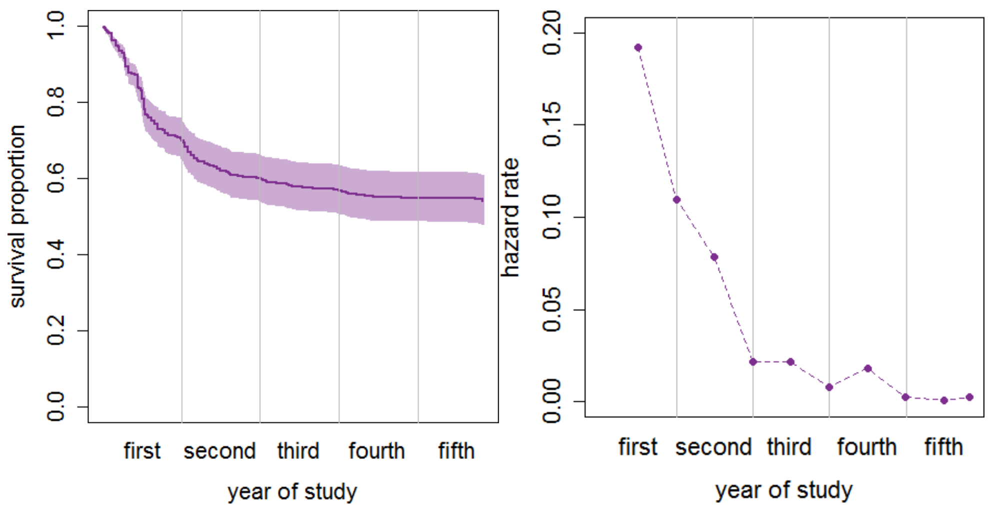

Fig. 3. Cox proportional model with 95% confidence interval (left panel) and the corresponding hazard function aggregated by semester (right panel)

The analysis shows that both factors influence the survival rate (p-value less than 0.0002). The statistically significant difference is found between faculties (p = 0.0365) and between the Class 2018 and Class 2014 (p = 0.0175), which is taken as a reference. The hazard ratio of FMT to FML is 1.18, i.e., a student from FMT is 1.18 times more likely to drop out from the study than a student from FML. It suggests that studying at FMT is more demanding. This is a more general topic, most students in all schools are leaving technical fields [7]. Similarly, the hazard ratio of the Class 2014 to the Class 2018 is 1.35, which means that a student from the Class 2014 had a 1.35 times higher rate of possible dropout than a student from the Class 2018.

Results of the overall survival rates are summarized in Table 4. We can see that the initial one-year survival rate is 0.7. However, when we take into account that the students get accustomed to the university type of study (as opposed to the high school system [20], we see that for the students who have already "survive" the first year the rate of non-dropping out increased to 0.85.

Table 4.

Survival rates from the Cox model compared with conditional survival rates

year of study	survival rate	conditional survival rate
1	0.70	-
2	0.60	0.85
3	0.57	0.95
4	0.55	0.96
5	0.54	0.98

It is obvious that most of the students drop out from the study after the first semester, which is similar to other universities [21]. The first semester is, in a sense, the time when students practically check their choice of the major [22]. The risk of dropping out is still high in the second and third semesters (see Figure 3). There is a small local maximum in the seventh semester (half of the fourth year). We assume that this is caused by the semifinal exam at the end of the third year, with unsuccessful students withdrawing during the seventh semester (the administrative process takes a while).

Overall, we have addressed the issue of dropout rates among military students on the basis of the available data. Although we do not have information on the reasons for their leaving, we could speculate and trace some "critical periods" of increased dropout rates. One could be called "the second choice", students were not accepted to their first choice university and enrolled in their second choice university and did not identify with the specific type of military study. Another reason could be that a student was accepted to his or her "first" university and left after the first year to enroll in the priority school in the following year. Failure to fulfill study obligations due to the difficulty of some subjects also plays a significant role in dropping out.

We cannot influence the first two factors, however, the third one can be improved. The teachers of these subjects should focus more on at-risk students and offer them a helping hand. For example, in the mathematics, the subject "Practice in Mathematics" was included in the study plan in order to eliminate the shortcomings of the students' different secondary school background [23].

4. Conclusions

The paper evaluates and compares the dropout rate of the five-year study program at the Faculty of Military Leadership and the Faculty of Military Technology, as well as the dropout rates of individual classes. We used statistical methods to illustrate this issue with corresponding graphs and tables, including accompanying commentary. As for the reasons for the dropout rate, we only know the official date of withdrawal for each student, but not the factors that led to this decision. Therefore, some of the possible causes of dropout are only conjectures of the authors of the publication.

The outcomes of this study show that the first year is critical for the students of both faculties. Although the reasons for dropping out are not known, we can conjecture that the high dropout rate after the first semester is influenced by the discrepancy between the students' perceptions and the reality of the university studies [14,20]. Unlike other universities, the military university has its own specifics. In addition to academic duties, the future military professional has to complete demanding military training. The factor of psychological resilience also plays a significant role. Therefore, we believe that the high dropout rate after the initial semester is related to the failure of some students to adapt to the military regime.

After the first year, the dropout rate decreases substantially. This may be related to the military adaptation already mastered. Targeting at-risk students seems to be of considerable benefit, as it has positively influenced the number of students leaving the study. This fact can be observed in the Class 2018, which has already been affected by the creation of math support groups, which has led to a more gradual dropout rate in the first three years compared to other classes. From a pedagogical point of view, it is important to pay more attention to the students during this critical period and to motivate them more to study.

In addition, moving the division into professional military specializations from the third to the second year seems to be the right step. This will give students a clearer idea of their future military profession in advance. In our opinion, the logical consequence is increased motivation for successful completion of studies. Subsequently, by successfully completing the five-year university program, the student becomes a full military professional.

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Enhancing Collective Military Training: Integrating the Laser Battlefield System for the Lithuanian Land Forces

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Abstract

This study examines the use of simulation systems in military training of the Lithuanian Armed Forces. It identifies significant gaps between the capabilities of current simulation systems and the needs of effective combat training, and highlights the need for improvements to help soldiers analyse complex situations and adapt to modern battlefield dynamics. The study confirms the need for further research to investigate how Multiple Integrated Laser Engagement System (MILES) can be more effectively integrated into Lithuanian military training programmes and how they can be tailored to specific national needs, including the possible adaptation of the MILES to the Lithuanian Land Forces.

KEY WORDS: *collective military training, soldiers' competencies, laser battlefield system, realistic combat scenarios*

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5. Introduction

Military training through simulation systems has become increasingly pertinent within the contemporary security landscape. The dynamic nature of global political shifts and the emergence of non-conventional threats present significant challenges to national defense strategies [1,2]. These developments underscore the necessity for rapid adaptation to evolving operational environments and the ability to address increasingly complex threat vectors. Continuous learning and the enhancement of skill sets are therefore paramount for military personnel to maintain operational effectiveness [3-7].

Simulation-based training systems offer a sophisticated means of preparing soldiers by replicating a wide array of scenarios that accurately reflect real-world threats and conflict situations [3,8,9]. These systems are particularly critical in the current geopolitical context, where conventional warfare tactics may no longer suffice. The ongoing reconfiguration of the global security architecture—driven by rising interstate tensions, the formation of new alliances, and the proliferation of asymmetric threats such as terrorism, cyber warfare, and hybrid operations—demands that military forces possess the agility to adapt swiftly and operate under novel and unpredictable conditions [10]

In this context, the role of simulation systems in military training is integral to national security imperatives[11,12]. These technologies enable the continuous refinement of soldiers' competencies, ensuring they are equipped to manage a diverse spectrum of conflict scenarios. Additionally, such training enhances cognitive skills, fostering critical thinking, sound decision-making under duress, and cohesive teamwork—attributes that are essential in high-stakes environments.

Moreover, advanced training methodologies facilitated by simulation systems are vital for ensuring that military personnel are adequately prepared to confront emergent challenges [13,14]. Modern combat operations necessitate not only physical endurance but also a high degree of intellectual and technological acumen [15]. Therefore, it is imperative that military training is sustained throughout the duration of a soldier's service, to preserve a state of high readiness and to ensure the military's capacity to effectively counter future threats [16].

The research work that was made in the Lithuania contributed to the exploration of simulation systems in military training through published research results on the Lithuanian Armed Forces. The published scientific article titled "Simulators Usage Assessment for Higher Military Readiness" [13], critically examined the alignment between the needs of combat training and the current capabilities of simulation systems within the Lithuanian military. The researchers identified significant gaps in how these systems meet the expectations for enhancing combat readiness, particularly in enabling soldiers to accurately analyze complex situations and adapt to modern battlefield dynamics [17- 19].

These studies also underscore the potential for improving the utilization of existing simulators to better serve the training objectives of the armed forces.

On an international scale, the topic of military simulation systems has been the focus of extensive research. Notably, Bruzzone and Massei [8], in their seminal work "Simulation-Based Military Training," provided a comprehensive analysis of the evolution from ancient to contemporary simulation systems in military contexts. They emphasized the critical role of these systems in enhancing military preparedness by facilitating the creation of realistic training scenarios that foster the development of essential knowledge and skills. Complementing this perspective, Sadagic and Yates [20], in their article "Large Scale Adoption of Training Simulations: Are We There Yet?" addressed the challenges and opportunities associated with the widespread implementation of simulation technologies in the military sector. Conducted studies demonstrated that simulation systems represent a pivotal component of contemporary military training and defense strategy. These systems not only enhance the efficacy of training protocols but also equip soldiers with the necessary skills to adapt and respond to the rapidly evolving global security environment. Moreover, there was highlighted that the primary barriers to effective adoption are not technological deficiencies but rather organizational and structural challenges, such as insufficient awareness of the capabilities of these technologies and inadequate support from upper management.

Despite the substantial body of research on the application of simulation systems in military training, there remain critical areas that warrant further investigation. Specifically, more research is needed to assess the impact of particular simulation systems on the development of military skills and competencies. In the Lithuanian context, additional studies are essential to explore how these technologies can be more effectively integrated into military training programs and how they can contribute to the overall enhancement of training quality. This research is vital for ensuring that simulation systems not only meet current training needs but also evolve to address emerging challenges in modern warfare. So, this study not only evaluates the strengths and limitations of simulation systems but also explores the potential for their more effective integration into the training programs of the Lithuanian Land Forces to enhance military training outcomes. Additionally, the research specifically examines the adaptation of the Multiple Integrated Laser Engagement System (MILES) to meet the unique needs and challenges faced by the Lithuanian Land Forces. This focus is critical, as while simulation systems are widely employed across global military forces, each nation's military operates under specific conditions and requirements. To ensure optimal effectiveness in military training, these unique national and organizational contexts must be carefully considered and addressed.

6. Method of Investigation

The research methodology employed in this study was designed to provide a comprehensive understanding of the use of the Multiple Integrated Laser Engagement System (MILES) in the Lithuanian Armed Forces through a dual approach involving both qualitative and quantitative analyses (see Fig. 1). The qualitative component of the study involved conducting structured interviews with MILES experts to identify the system's strengths and weaknesses. This approach allowed for an in-depth exploration of expert perspectives, revealing insights into how MILES performs in various aspects of military training, including its effectiveness, limitations, and potential areas for improvement.

Fig. 1. The Multiple Integrated Laser Engagement System (MILES), a training system used by military forces to simulate the realities of combat in a safe and controlled environment.

For the quantitative analysis, data was gathered through a structured questionnaire administered to users of the MILES system. This survey aimed to capture user experiences and opinions on the system’s application in collective military training. It focused on assessing the perceived impact of MILES on training effectiveness and identifying any challenges encountered during its use in exercises.

The integration of qualitative and quantitative methods provided a robust framework for understanding the specific challenges and opportunities associated with MILES within the context of the Lithuanian Armed Forces. The qualitative interviews offered nuanced insights into the expert assessments of the system, while the quantitative data provided a broader perspective on user experiences, ensuring a comprehensive evaluation of MILES in both theoretical and practical terms. This methodological approach facilitated a detailed analysis of MILES's application, contributing to the development of strategies for optimizing its integration into collective training exercises.

6.1. Study Participants and Data Collection Method

The research was conducted through an analysis of responses from Lithuanian Armed Forces (LAF) platoon commanders, deputy platoon commanders, and company commanders, collected via a structured questionnaire survey. This survey was disseminated across various LAF units that utilized the MILES system during 2023, with data collection taking place in December 2023 and January 2024.

The quantitative data collection phase was initiated through collaboration with the Training and Doctrine Board's Collective Training Unit, which provided access to detailed records regarding the deployment of the MILES system throughout 2023. These records offered critical insights into the allocation and operational use of MILES across different Land Forces units, allowing the identification of specific periods and units engaged in military training using this system. Based on this documentation, a targeted selection of Land Forces units was made to ensure that the sample was representative of the broader population. The selected units were then contacted to participate in the study by completing the questionnaires. During this process, each respondent received a thorough briefing on the study's objectives, methodology, and ethical principles, with particular emphasis on the importance of maintaining anonymity and confidentiality. This detailed briefing ensured that all participants were fully informed about the study's purpose and their rights, thus fostering an environment of informed consent and ethical integrity. The rigorous approach to participant engagement not only reinforced the ethical standards of the research but also enhanced the reliability of the collected data by ensuring that respondents were well-informed and comfortable with their participation.

In the qualitative research phase, the Training and Doctrine Board's Collective Training Unit played a crucial role in identifying key specialists with expertise in the MILES system. This collaboration provided direct access to professionals deeply involved in the operation and implementation of MILES. These experts were individually approached to schedule interviews at times convenient for them, ensuring minimal disruption to their professional responsibilities. Before each interview, participants were thoroughly briefed on the study's objectives, research methodology, and ethical considerations. Special attention was given to ensuring the anonymity of the participants, which is fundamental to maintaining the integrity of the research process. The briefing was designed to ensure that all experts were fully aware of the study's nature and scope, thereby enabling them to provide informed consent. This meticulous approach to ethical briefing not only adhered to the highest standards of research ethics but also created a transparent and trusting environment, which is essential for obtaining rich, reliable qualitative data. By ensuring that participants were well-prepared and comfortable, the research process was able to enhance the depth and reliability of the qualitative data collected. The careful consideration of ethical principles and thorough participant briefings are critical in qualitative research, as they directly impact the validity and credibility of the study's findings.

6.2. Research Methodology

Conducting military field training is an essential component of soldier preparation, as it enables the acquisition and maintenance of the combat readiness required for operational effectiveness and the continuous development of critical military skills. However, collective military training presents numerous challenges that can impact its overall effectiveness. This research problem was centred on enhancing the efficiency of collective training within the Lithuanian Land Forces and optimizing the integration of the Multiple Integrated Laser Engagement System (MILES) [21,22]. So, these investigations involved a comprehensive examination of both the theoretical and practical dimensions of simulation systems in military training, with a specific focus on the collective training context of the Lithuanian Armed Forces. The primary objective of this research was to evaluate the efficacy and identify potential issues associated with collective military training when utilizing the MILES, based on feedback gathered from user surveys.

The quantitative component of the research was designed to systematically assess three core aspects, each representing a critical dimension of collective military training. These aspects were organized into the following three analytical blocks:

1. Impact of MILES on the Effectiveness of Military Training [23-25]. This block included nine statements and was focused on determining how the integration of MILES influences the overall effectiveness of military training exercises, with particular attention to its role in enhancing combat readiness and skill development. To measure these nine statements Likert's five-point scale was used, the 1 indicated 'being strongly disagree' and 5 indicated 'being strongly agree'. The internal consistency of this block was evaluated by Cronbach's alpha coefficient which was 0.882.
2. MILES as a Tool for Realistic Simulation and Teamwork Development: This aspect was evaluated by ten statements the extent to which MILES contributes to creating a realistic training environment that fosters the development of teamwork skills among soldiers. The system's ability to simulate real combat scenarios was assessed in terms of its effectiveness in preparing soldiers for collaborative tasks during actual

operations. To measure these ten statements Likert's five-point scale was used, the 1 indicated 'being strongly disagree' and 5 indicated 'being strongly agree'. The internal consistency of this block was evaluated by Cronbach's alpha coefficient which was 0.900.

3. Risk Reduction During Field Exercises with MILES: The final block included two statements examined the role of MILES in mitigating risks during field exercises. This involved analysing whether the use of MILES enhances safety protocols and reduces the likelihood of training-related incidents, thereby contributing to a safer training environment. These two statements were measured by Likert's five-point scale, the 1 indicated 'being strongly disagree' and 5 indicated 'being strongly agree'. The internal consistency of this block was evaluated by Cronbach's alpha coefficient which was 0.809.

Through these analytical blocks, the research aimed to provide a comprehensive quantitative research evaluation of MILES as a training tool, identifying both its strengths and areas for improvement within the context of collective military training.

The qualitative component of this study was conducted through a rigorously structured interview process, wherein experts evaluated specific criteria derived from the theoretical framework concerning the application of MILES in the development of soldiers' skills. The evaluation of MILES within the study centered on two critical dimensions: the development of readiness for real military action and the enhancement of teamwork skills. These dimensions are essential for assessing the effectiveness of MILES as a training tool within the military context, and each was broken down into specific criteria to provide a comprehensive analysis.

I. Developing Readiness for Real Military Action

This aspect of the evaluation focused on how effectively MILES prepares soldiers for the realities of combat, addressing the following criteria:

- *KV1: MILES Provides a Realistic Training Environment*. The realism of training environments is crucial for effective military preparation. MILES was evaluated on its ability to simulate real-world combat conditions, including the replication of battlefield dynamics such as enemy engagement, terrain challenges, and the consequences of tactical decisions. By creating a realistic environment, MILES helps soldiers acclimate to the stress and unpredictability of actual combat, which is essential for maintaining composure and making sound decisions under pressure.

- *KV2: MILES Offers an Immersive Training Experience.* Beyond realism, immersion is key to engaging soldiers fully in the training process. MILES was assessed on its ability to create an immersive experience that captures the attention and focus of participants. This involves sensory engagement, such as the use of realistic sounds, visual stimuli, and immediate feedback, all of which contribute to a training experience that closely mirrors real combat. Immersion in training scenarios helps soldiers develop the mental and emotional resilience needed for real-world operations.

- *KV3: MILES Delivers Actionable Feedback*. Feedback is a vital component of effective training, as it allows soldiers to learn from their actions and improve performance. MILES was evaluated on its capacity to provide immediate, clear, and actionable feedback on soldiers' performance during exercises. This includes information on hits, misses, and tactical errors, which soldiers can use to refine their skills. The system's feedback mechanisms are designed to be informative without disrupting the flow of training, thereby supporting continuous learning and improvement.

- *KV4: MILES Enhances Readiness for Real-World Scenarios*. The ultimate goal of military training is to prepare soldiers for real-world missions. MILES was assessed on how well it translates training experiences into enhanced readiness for actual combat situations. This includes evaluating whether soldiers trained with MILES demonstrate improved tactical awareness, decision-making skills, and overall preparedness for the challenges of real operations. The system's effectiveness in bridging the gap between training and actual deployment is critical for ensuring that soldiers are ready to perform under the pressures of real combat.

- KV5: MILES Reduces the Inherent Risks Associated with Real Field Trainings. Safety is a paramount concern during military training. MILES was evaluated on its ability to reduce the risks inherent in live field exercises, such as accidental injuries or fatalities, by providing a safe yet realistic alternative. The system allows soldiers to engage in combat simulations that mimic real scenarios without the physical dangers of live ammunition. This capability not only preserves safety but also enables more frequent and varied training opportunities, thereby enhancing overall readiness without compromising soldier welfare.

II. Development of Teamwork Skills

The second key dimension focused on how MILES contributes to the development of essential teamwork skills among soldiers. Effective teamwork is critical for military success, and MILES was evaluated on the following criteria:

- *PM1: MILES Facilitates the Development of Tactical Thinking*. Tactical thinking involves the ability to assess situations, anticipate enemy actions, and make strategic decisions. MILES was assessed on its effectiveness in developing these cognitive skills within a team context. By simulating complex combat scenarios, MILES challenges soldiers to think critically and work collaboratively to achieve mission objectives. The system's design encourages soldiers to consider the broader tactical picture and to coordinate their actions with teammates, fostering a deeper understanding of battlefield strategy.

- *PM2: MILES Enables Learning Through the Analysis of Mistakes*. The ability to learn from mistakes is crucial for continuous improvement in military operations. MILES was evaluated on how well it supports this learning process by providing opportunities for soldiers to review and analyze their performance after each exercise. The system's feedback allows soldiers to identify errors, understand their consequences, and adjust their tactics accordingly. This iterative learning process helps soldiers refine their skills and avoid repeating mistakes in future operations.
- *PM3: MILES Enhances Teamwork Capabilities*. Effective teamwork requires not only individual competence but also the ability to operate cohesively as a unit. MILES was evaluated on its role in enhancing these teamwork capabilities by promoting communication, coordination, and mutual support among soldiers. The system's simulations are designed to require collaborative problem-solving and joint decision-making, which are essential for successful team operations in real combat. MILES encourages soldiers to rely on each other’s strengths and to work together towards a common goal.
- *PM4: MILES Equipment is Durable*. The durability of training equipment is crucial for maintaining the continuity and effectiveness of military exercises. MILES was evaluated on the robustness of its components, including their ability to withstand the rigors of repeated use in various environmental conditions. Durable equipment ensures that training can proceed without interruptions due to equipment failure, thereby maximizing the efficiency of the training process.
- *PM5: MILES Equipment is User-Friendly*. User-friendliness is an important consideration for any training system. MILES was assessed on the ease with which soldiers can learn to operate the equipment, including the time required to master its functions and the intuitiveness of its design. A user-friendly system allows soldiers to focus on the training objectives rather than on technical difficulties, thus enhancing the overall effectiveness of the training. MILES's design aims to be accessible to soldiers with varying levels of technical expertise, ensuring that all participants can engage fully in the training process.

The evaluation of MILES across these two dimensions—readiness for real military action and the development of teamwork skills—provides a comprehensive understanding of its effectiveness as a military training tool. By analyzing specific criteria within each dimension, the study highlights both the strengths of MILES in preparing soldiers for real-world combat and the areas where it can be further optimized to enhance training outcomes.

6.3. Study Data Processing

To address the research problem comprehensively and ensure the robustness of the findings, the study employed triangulation. Triangulation involved using multiple methods to validate the results, ensuring that the application of one method corroborated the findings of another. This approach helped harmonize qualitative and quantitative elements of the study, providing a more nuanced and reliable understanding of the research questions.

Expert Opinion Assessment Using Kendall's W. In this study, data were collected from experts through a highly structured survey. Each of the five experts participating in the study was asked to rank and rate a set of criteria in order of importance. This data was then compiled and used for further analysis. First, the level of agreement among the experts was assessed. For this purpose, the Kendall's W coefficient was applied. The statistical software package IBM SPSS 29v was used for the analysis, which offers a reliable means of calculating Kendall's W, allowing researchers to quantify the degree of agreement between experts. The software also provides a significance test to determine whether the observed agreement is statistically significant or whether it may have occurred by chance. The agreement between the experts' opinions was assessed by Kendall's W, which directly affected the reliability of the findings of this study. Thus, using Kendall's W, the level of agreement between the experts' opinions was assessed with statistical precision and the most important criteria were identified.

Quantitative data processing. Following the descriptive data analysis, a sequence of statistical tests were conducted to validate and further explore the data. The first step was reliability testing, a crucial component in the validation of any survey or questionnaire-based research. This testing was performed to assess the consistency and stability of the measurement instrument, ensuring that it reliably measures the intended constructs. Cronbach's alpha, one of the most commonly used methods for assessing internal consistency, was employed for this purpose. This coefficient was calculated for each of the three sets of blocks used in the study, ensuring the reliability of the data collected.

Subsequently, the Kruskal-Wallis H test was applied to identify statistically significant differences based on the frequency of training completion. Additionally, Exploratory Factor Analysis (EFA) was employed to identify latent factors within the data. Finally, a linear regression analysis was conducted to identify the key factors influencing competency development with MILES. All statistical analyses were performed using SPSS Statistics software version 29.0. This comprehensive approach ensured a robust evaluation of the data, providing reliable insights into the factors affecting strategies for enhancing training efficiency with MILES technology.

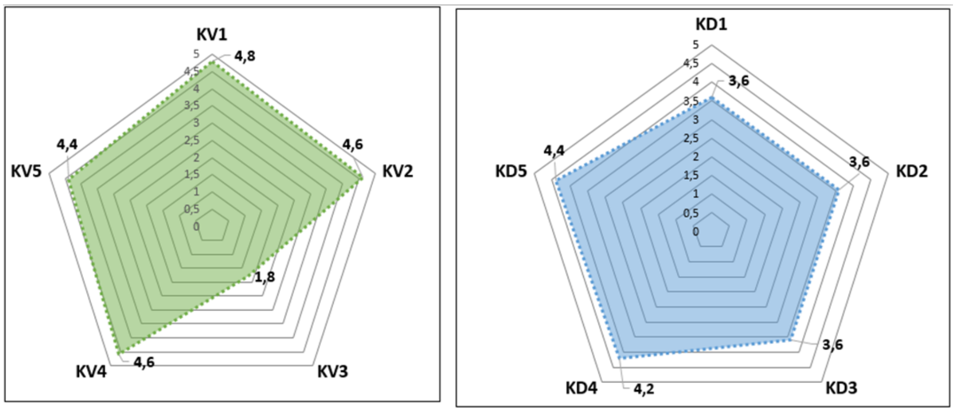
7. Results of the Conducted Research

7.1. Evaluation of MILES effectiveness by Experts

Following analysis design five experts were surveyed to provide their evaluations, aiming to determine the effectiveness of collective military training using the MILES equipment and to explore opportunities for enhancing system integration within the Land Forces of the Lithuanian Army (LFLA). Since the determination of the most important criteria must be based on the Kendall coefficient, the information in collected from experts' survey was used to assess the coincidence of the expert opinions. In order to find out whether the answers of the experts who participated in the study can be relied on, the IBM SPSS 29v package was used and the compatibility of expert opinions was assessed by focusing on two main blocks: (1) Developing readiness for real military action, and (2) Development of teamwork skills.

Thus, in order to assess MILES' influence in developing the readiness of soldiers serving in the Lithuanian Armed Forces for real military actions (block (1)), five criteria were presented: MILES provides a realistic training environment (KV1), MILES provides an immersive training environment (KV2), MILES provides feedback (KV3), MILES increases preparedness for real-world situations (KV4), and MILES reduces the risk of real field training (KV5). The results of Kendall's W coefficient calculations showed that calculated coefficient W=0.616 confirmed a fairly good enough coincidence of the opinions of the experts included in the study, since "Asymp. Sig." has a value of 0.015<0.05, which indicates the need to accept the hypothesis put forward that in this case the coefficient is statically significant.

Therefore, taking into account the assessment of the criteria presented by the experts, a diagram of the significance of "the influence of MILES in developing the readiness of soldiers to carry out real military actions" was compiled. Since each criterion was assigned ranks (specialists evaluated the statements made on scales from 1 – "it does not matter at all" to 5 – " very important"), it is possible to clearly, schematically depict which competencies are successfully developed with the help of MILES (see Fig. 2 a).



(a) (b)

Fig. 2. The experts' opinions in radar chart. (a) Development of readiness for actual military operations: KV1: MILES provides a realistic learning environment; KV2: MILES provides an immersive learning environment; KV3: MILES provides feedback; KV4: MILES increases readiness for real situations; KV5: MILES reduces the risk of real field exercises. (b) Development of teamwork skills: KD1: MILES helps develop tactical thinking; KD2: MILES allows you to learn from mistakes; KD3: MILES improves teamwork; KD4: MILES equipment is durable; KD5: MILES equipment is easy to use.

Based on a graphical analysis of the averages of expert opinions (see Fig. 2 a), it can be said that the experts' least agreed with the statement of KV3 "Feedback is provided with the help of MILES." Analyzing the explanations given by them, it can be seen that this problem arises from the systematization of information, since, as Expert 2 states, "There is a lack of a systematic way to analyze and provide feedback, and therefore its effectiveness is limited."; on the competence possessed by instructors, since Expert 3 states that "Effective feedback is important, but often depends on the competence of individual instructors."; and due to the fact that, due to the technical characteristics, direct feedback is not entirely correct, which is what the Expert 4 "MILES laser propagation speed 300 thousand km. times larger than bullets, this distorts the firing at moving targets, and the penetration of the laser is zero, which leads to no exactly correct direct feedback." It's also because the technical capabilities of the laser beam used by MILES when firing into the distance are limited, as Expert 5 also states, "When shooting into the distance – the laser expands to such a level that with one shot it becomes possible to cover with a laser the whole body of another soldier, which is not accurate." Therefore, this means that using MILES creates a lack of obtaining correct and high-quality feedback, which is very important for a soldier in order to further improve his qualifications and competencies.

In addition, all experts agreed with KV1's statement "MILES provides a realistic teaching environment", since the average of the ranks for this criterion is 4,8 out of 5 (see Fig.2 a). Experts have highly rated the system because it helps to simulate real battles during a 'battle', according to Expert 1 "MILES simulates the real conditions of combat, allowing soldiers to experience situations that are close to reality, but without real danger." and Expert 5 "MILES creates a very large realistic environment during the 'battle' itself.". This means that MILES, in the opinion of experts, is an excellent system for achieving a realistic learning environment.

Thus, to assess the development of teamwork skills, experts were asked to evaluate five statements: MILES helps develop tactical thinking (KD1); MILES allows learning from mistakes (KD2); MILES improves teamwork (KD3); MILES equipment is durable (KD4); MILES equipment is easy to use (KD5). The analysis results are presented in Fig. 2b. The results of Kendall's W calculation (W=0.507) confirmed that the agreement among the experts included in the study is statistically significant, as the "Asymp. Sig." value of 0.038 is less than 0.05. This indicates that the hypothesis put forward is supported, demonstrating that the experts' opinions meet statistical requirements.

The degree of agreement among the experts allowed us to identify that they most strongly agreed with the statement that MILES equipment is easy to use (KD5). Experts noted that "The equipment is designed to be used in various situations, and therefore is universal enough and easy to apply, allowing users to quickly master the basic functions." The criterion related to the durability of the equipment, "MILES equipment is durable" (KD4), also received strong support. According to the experts, equipment that is heavily used requires additional maintenance to keep it operational. The analysis showed that, with slightly lower scores, experts evaluated criteria such as MILES helping to develop tactical thinking (KD1), MILES allowing learning from mistakes (KD2), and MILES improving teamwork (KD3).

7.2. Quantitative Evaluation of MILES effectiveness by System Users

Conducting military field exercises is a necessary and very important part of the training of soldiers, since the exercises allow soldiers to acquire and maintain the necessary combat readiness and develop the available skills. There are many challenges to the collective training of soldiers. The purpose of this research paper was to assess the effectiveness and problems of collective military training using MILES, according to a user survey. This study evaluated three main aspects, which were divided into three essential blocks of collective training of soldiers: (i) The Influence of MILES on the Effectiveness of Military Training; (ii) MILES Creates a Realistic Sense of Exercise to Develop Teamwork Skills; (iii) Risk Mitigation in Field Exercises Through MILES Integration.

7.2.1. The influence of MILES on the effectiveness of military training evaluation

The set of questions that was focused on the influence of MILES on the effectiveness of military training was focused on evaluating nine statements concerning the effectiveness of the Multiple Integrated Laser Engagement System (MILES) in enhancing military training outcomes. The distribution of responses revealed minimal disagreement with the positive impact of MILES, as evidenced by the lack of responses in the "I completely disagree" (1) and "disagree" (2) categories. On the other hand, there was a significant concentration of responses in the "Agree" (4) and "I completely agree" (5) categories, reflecting strong confirmation of MILES's contribution to effective military training. All statements, particularly those ranging from K47 to K56, bring in a high level of agreement, with over 90% of respondents either agreeing or strongly agreeing (see Fig. 3).

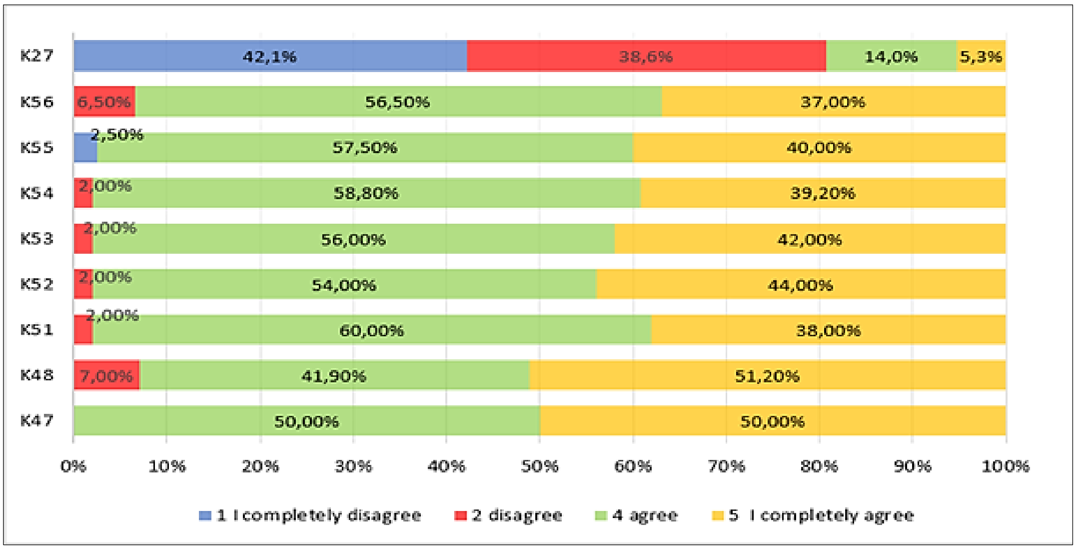


Fig. 3. Respondents' opinions the MILES impact on military training effectiveness.

This consensus underscores the recognition of MILES as a critical tool that substantially enhances the effectiveness of military training, particularly in complex or realistic operational scenarios. The high level of agreement highlights the system's perceived value in preparing soldiers for real-world challenges. However, the evaluation of the statement K27, "*MILES availability is sufficient*," revealed a significant shortfall in the availability of the system to meet training demands.

Specifically, 42.1% of respondents strongly disagreed, and 38.6% disagreed, indicating that the current availability of MILES does not adequately support the needs expressed by the respondents.

The high regard for the effectiveness of collective training facilitated by MILES, coupled with the substantial demand for such exercises, suggests a strong consensus among respondents that MILES is a valuable asset for military training and operational planning. The findings indicate that while MILES is widely recognized for its positive impact on training efficacy, there is a critical need to address the shortfall in its availability to fully capitalize on its benefits (see Fig. 2).

7.2.2. MILES creates a realistic sense of exercise to develop teamwork skills

The second block of criteria in the study received substantial support from the participating soldiers, indicating a broad consensus that the Multiple Integrated Laser Engagement System (MILES) is an effective tool in collective military training (see Fig. 4). The positive reception of these criteria underscores the system's perceived value in enhancing the realism of training exercises and improving soldiers' tactical skills, both of which are crucial for effective military preparedness.

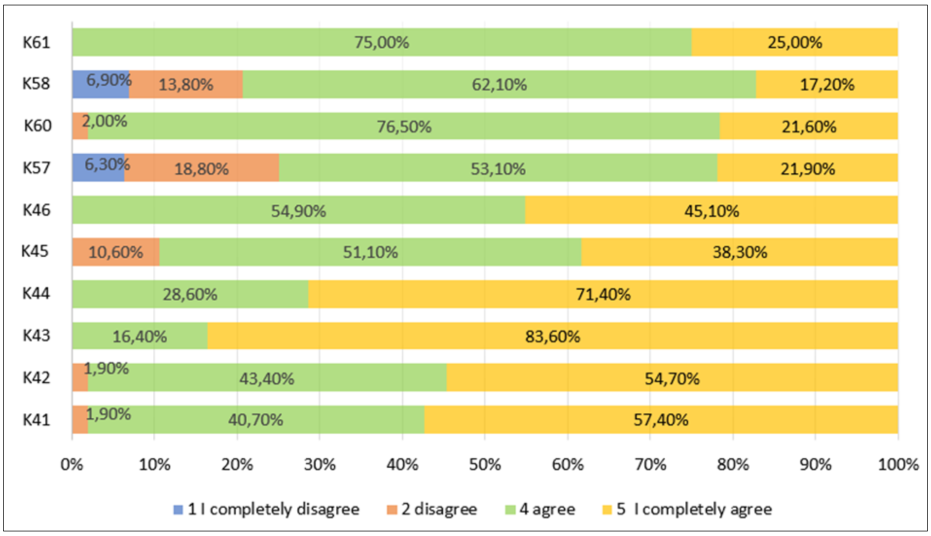


Fig. 4. Respondents' perception of the realistic environment created by MILES in military training.

However, it is important to highlight the findings related to two specific criteria: K58, which assessed the technical reliability of MILES equipment, and K57, which evaluated the durability of MILES under conditions of intensive use. Both criteria received notable disapproval, with over 20% of respondents expressing disagreement. This level of discontent suggests that respondents harbor concerns regarding the technical soundness and durability of MILES equipment, particularly when subjected to rigorous, sustained use. These findings point to a potential disconnect between the overall perceived effectiveness of MILES in military training and concerns about its technical robustness. The respondents' doubts about the reliability and durability of the equipment may indicate underlying issues within the system or a mismatch between the system's performance and user expectations. This divergence warrants closer examination, as it highlights critical areas where the quality and durability of MILES equipment may require significant improvements. In-depth analysis of these responses is essential to identify specific areas for enhancement and to ensure that MILES meets the high standards necessary for intensive military applications. Addressing these concerns will not only improve the system's technical performance but also align it more closely with the needs and expectations of its users, thereby maximizing its effectiveness in military training contexts.

7.2.3. Kruskal-Wallis H Test to Assess Differences in Responces

As a result of the descriptive analysis, differences in opinions were noted, leading to the selection of the Kruskal-Wallis H test to further evaluate respondents' opinions based on their military ranks and the number of times they had participated in exercises with MILES. The study found no statistically significant differences. This was confirmed by the Kruskal-Wallis H test when opinions were analyzed based on the number of exercises attended, with a chi-square value of $\chi^2(2)$ and a p-value greater than 0.05 (the significance level) across all groups of statements: "The influence of MILES on the effectiveness of military training" (8 statements), "Developing teamwork skills with MILES" (10 statements), and "The influence of MILES on risk reduction during training" (2 statements).

Additionally, the Kruskal-Wallis H test examined the differences in respondents' opinions according to their military ranks, and the results showed no statistically significant differences ($\chi^2(4)$, $p > 0.05$) for all twenty statements evaluated. This suggests that, despite the descriptive analysis (see Fig. 3 and Fig. 4) revealing certain challenges in the effectiveness of military training using MILES in the education of soldiers, these challenges do not vary significantly based on military rank or exercise frequency. Therefore, while MILES is an effective tool for enhancing the effectiveness of collective military training, there are also areas that need improvement to achieve the highest possible level of efficiency. In conclusion, MILES positively impacts the effectiveness of military training and creates a realistic exercise environment, but it does not significantly reduce risks during field tactics exercises.

7.2.4. Risk Mitigation in Field Exercises Through MILES Integration

The analysis of the data relating to the respondents' assessments of risk decrease during training exercises using MILES (Multiple Integrated Laser Engagement System) revealed a nuanced distribution of opinions. Criterion K50, which addresses the assertion "MILES reduces the risk of incidents during training," received a notable endorsement from 60.4% of participants. Specifically, 10.4% of respondents fully agreed, while 50% agreed with the statement. This substantial level of agreement indicates a significant perception among respondents that MILES contributes to a decrease in incident risk during training.

On the other hand, the evaluation of Criterion K49, which queries whether "MILES reduces the risks associated with real field exercises," shows a more complex picture. Here, 10.2% of respondents completely disagreed and 28.6% disagreed with the statement. In contrast, 38.8% agreed and 22.4% fully agreed. This distribution suggests a less uniformly positive view of MILES in the context of field exercises.

The difference in responses indicates that while there is general agreement on MILES' effectiveness in reducing training incidents, there is less consensus regarding its efficacy in mitigating risks during field exercises. The variation in opinions may stem from comparisons between exercises conducted with and without MILES. Respondents might have perceived that MILES equipment does not offer significant advantages over traditional training methods, which use similar imitation ammunition but do not involve MILES. This assessment implies that MILES' effectiveness in risk reduction is viewed with some skepticism, and its advantages are not universally recognized.

Overall, the analysis suggests that while MILES is positively regarded in terms of reducing risks during training sessions, its impact on risk reduction in real field exercises is subject to more uncertainty, with some respondents acknowledging benefits and others questioning its relative effectiveness compared to conventional training approaches.

7.2.5. Strategies for Enhancing Training Efficiency with MILES Technology

The conducted Exploratory Factor Analysis let to identify four key latent factors that determine the effectiveness of collective military training using MILES: LA1 – MILES promotes effective teamwork; LA2 – MILES makes responsiveness in difficult situations more efficient; LA3 – MILES easy to use; LA4 – MILES promotes greater involvement of soldiers.

To assess how collective military training can be enhanced through the use of MILES (Multiple Integrated Laser Engagement System), a regression analysis was conducted. A multi-criteria regression model was developed with the dependent variable being the effective utilization of MILES (L1). The independent variables included four key latent factors. Following the requirements for linear regression, three of these variables—namely, "Effective Teamwork" (LA1), "Rapid response in difficult situations" (LA2), and "Reduction of risk during training" (L3)—were found to be statistically significant (see Table 1).

Table 1.
Coefficients of the training efficiency enhancement Model

Variables	Unstandardized coefficients		t – value	Sig. p –value	95% Confidence Interval		Importance (IMP)
	β	Standard Err.			Lower	Upper	
Intercept	3,983	0,061	65,174	0,000	3,861	4,106	
LA1	0,497	0,022	22,221	0,000	0,452	0,542	0,606
LA2	0,372	0,021	17,724	0,000	0,330	0,414	0,386
L3	0,046	0,018	2,550	0,014	0,010	0,082	0,008

Notes: LA1 – MILES promotes effective teamwork; LA2 – MILES makes responsiveness in difficult situations more efficient; L3– MILES decrease of risk during training.

The model's reliability was substantiated by a high determination coefficient ($R^2 = 0.945$) and a robust F-test statistic ($F = 333.078$, $p < 0.000$). This indicates a strong explanatory power of the model. The results demonstrate that to optimize the efficiency of military training using MILES, the statistically significant factors are as follows: Effective Teamwork (LA1) with a standardized coefficient (β) of 0.497 ($p < 0.01$); Rapid Response in Difficult Situations (LA2) with a standardized coefficient (β) of 0.497 ($p < 0.01$); Reduction of Risk During Exercises (L3) with a standardized coefficient (β) of 0.046 ($p < 0.01$). The model further evaluates the impact of these variables on the dependent variable (L1) by analyzing the coefficients of importance (IMP), as detailed in Table 1. The calculated coefficients disclose that "Effective Teamwork (LA1)" has the most significant impact on improving the effectiveness of collective military training with MILES, with an influence coefficient of IMP = 0.606. This analysis highlights the critical factors that contribute to enhancing training outcomes with MILES, emphasizing the importance of effective teamwork, quick decision-making under pressure, and risk reduction during exercises. In the context of military training and the use of the MILES, the developed model demonstrated that three key factors—teamwork (LA1), quick response in difficult situations (LA2), and risk reduction during exercise (LA3)—account for 94.9% of the observed improvement in the effectiveness of collective military training. This high explanatory power suggests that these factors are critically important for enhancing training outcomes:

- Teamwork (LA1): Effective collaboration among soldiers is essential for successful military operations. The model highlights that the ability to work cohesively in a team significantly contributes to the overall effectiveness of training. Teamwork ensures that tasks are completed efficiently, resources are utilized optimally, and strategic goals are achieved. By fostering a strong sense of collaboration and mutual support, soldiers can better coordinate their efforts during actual missions.
- Quick response in difficult situations (LA2): The capacity to make rapid and effective decisions under pressure is another crucial factor identified by the model. Training scenarios that simulate high-stress conditions help soldiers develop the ability to respond swiftly and accurately to emerging challenges. This skill is vital for maintaining operational effectiveness and achieving mission objectives in real-world combat situations.
- Risk reduction during training (LA3): Minimizing risks during training exercises is important for ensuring the safety of soldiers and the success of the training program. By focusing on risk reduction, the MILES helps to create a controlled environment where soldiers can practice their skills without unnecessary danger. This approach not only enhances the learning experience but also prepares soldiers for managing risks in actual combat situations.

The model's findings suggest that repeated use of MILES is beneficial for military training. Regular exercises with MILES allow soldiers to refine their teamwork and rapid response skills, leading to improved decision-making during real military operations. The integration of these elements into training programs ensures that soldiers are better prepared to handle the complexities and demands of their roles. General, the emphasis on teamwork and rapid response, coupled with effective risk management, underscores the importance of these skills in the military context. Mastery of these areas through repeated MILES based training ultimately contributes to the success and security of military operations.

4. Conclusions

The study revealed that the effectiveness of the Multiple Integrated Laser Engagement System (MILES) can be attributed to several critical factors that enhance military training outcomes. Firstly, MILES significantly contributes to the realism of training exercises, which is essential for preparing soldiers for actual combat scenarios. The realistic nature of these simulations allows soldiers to experience and respond to conditions that closely mirror those they may face in real-world operations, thereby improving their overall combat readiness.

Secondly, the system plays a pivotal role in fostering the development of teamwork skills within military units. The collaborative nature of MILES exercises necessitates that soldiers work together cohesively, thereby enhancing the effectiveness of the unit as a whole. Teamwork is a fundamental component of military success, and MILES supports the cultivation of these critical skills.

Thirdly, MILES contributes to the enhancement of soldiers' capabilities, particularly in the areas of tactical thinking and execution within realistic exercise scenarios. The system's ability to simulate complex combat situations allows soldiers to develop and refine their tactical decision-making skills in a controlled environment, which is crucial for their performance in the field.

However, the analysis of survey data also highlighted several areas where improvements are necessary. A significant finding was the inadequacy in the number of available MILES systems, which limits their accessibility and widespread use in training programs. This scarcity of resources could hinder the ability of military units to engage in frequent and comprehensive training exercises, thereby affecting the overall preparedness of soldiers.

Additionally, the study identified several problem areas as reported by system users and experts. One of the key issues is the lack of immediate feedback on the effects of weapon use during simulations, which is essential for soldiers to understand and learn from their actions in real-time. Furthermore, the technical reliability of the equipment was another concern, with users reporting occasional malfunctions or inconsistencies that could disrupt training sessions.

The comprehensive approach of this study has not only highlighted the benefits and challenges associated with the use of MILES but has also contributed to improving the overall quality of collective military training. By addressing these issues, the study offers valuable insights into how to better prepare soldiers for the demands of their roles in various future operational contexts, ensuring they are equipped with the necessary skills and knowledge to succeed.

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Multicriteria Comparison and Evaluation of Vestibular Apparatus Training Methods for Pilots

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Abstract

The phenomenon of spatial disorientation and illusions in flight has been addressed in civil and military aviation for decades. The possibility of training, especially the vestibular apparatus, which is involved in human spatial orientation, is of particular interest in training military pilots. This article aims to analyze and compare, using multicriteria analysis, the different methods for training the resistance of the vestibular apparatus at the University of Defence. In total, five different facilities were compared against nine criteria. The scoring showed comparable results for three of them: Rotation Cage Passive, 360 Swing, and Gyroscope. This analysis has shown that none of the devices cover the entire criteria area. Therefore, further research is required to find suitable combinations of these three devices to achieve the best results. However, the results have already highlighted the importance of preparing pilots prior to flight training and the possibility of preadaptation to a dynamic environment, thus making flight training more efficient.

KEY WORDS: *vestibular apparatus, training, aviation, simulator, military, spatial disorientation*

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1. Introduction

Balance, regulation of position, body movements in space, the perception of gravity, and angular and linear acceleration are significant for every pilot because their processing with possible suppression of false sensations is one of the basic conditions for a successful flight. The vestibular apparatus is involved in the above. This critical apparatus generates sensory perceptions. If not corrected by vision, it may generate perceptions that may not correspond to the real position of the pilot-aircraft system. The reactions of the apparatus, mostly of an unconditionally reflexive nature, may also induce various unusual sensations, unwanted emotions, and illusions, which may be fatal for the pilot. This is because the human body is adapted only for movement on the ground, and its senses cannot properly evaluate the sensations during flight in an aircraft. For this reason, every aircraft is equipped with flight and navigation instruments that indicate its actual position in space, regardless of the dynamic forces acting on it. Their use helps pilots to overcome the imperfections of human perception [1-5].

As part of the preparation of a student of the University of Defence (UoD), specialization military pilot, physical training takes place during the first three semesters before the start of practical flight training. This physical training takes place in the scope of four lessons per week and focuses on:

- Basic physical training (development of physical abilities and movement skills);
- Special physical exercise to increase the body's resistance to the adverse physical factors of flight.

In particular, the specialized training prepares students for initial flight training, which places increased demands on spatial orientation [6]. The flight training takes place in an intensive form of 2 to 3 flights per day in a briefing-flight-debriefing format with progressively more demanding individual flights. This training aims to provide primary flight training and test future pilots' competencies.

For this reason, aerobatic flights are included in the flight training after 30 hours to test spatial orientation skills and organism endurance as prerequisites for the possibility of becoming a fighter pilot [7]. In the context of the current increasing expenditure on armaments and the acquisition of new modern equipment by the Air Force [8], a high emphasis is placed on the training of personnel.

In the international field of military aviation, spatial disorientation training is described in the North Atlantic Treaty Organization Technical Report [1], where the ground-based and in-flight demonstration is described. The standards across different nations are concentrated mainly on demonstrations of vestibular apparatus false reception and the causes and consequences [9]. The devices used for demonstration vary from small to large full-flight simulators. The Polish Air Forces uses specialized training on instruments called Special Aviation Gymnastic Instruments, which consist of looping, aerowheel, and Gyroscope. The influence and effect of that training are described in [10-12] and were concentrated mainly on increasing fitness level and Gz toleration.

This article aims to analyze and compare, using multicriteria analysis, the different methods for training the resistance of the vestibular apparatus at the UoD. Thanks to regular training, students of the military pilot specialization prepare for adverse effects, such as kinetosis caused by irritation of the vestibular apparatus, learning to recognize flight illusions and to react adequately to them. In the special physical training classes, students perform physical exercises with changes in body position, such as various agility exercises, basic gymnastics, and exercises on gymnastic equipment (trampoline, rings, trapeze, etc.). In order to strengthen the resistance of the vestibular apparatus of future pilots of the Czech Air Force to undesirable phenomena of motion sickness and vestibular illusions, the UoD has a training simulator 360Swing, Gyroscope by company Ad-Libitum, Poland, and rotation cage.

2. Method of investigation

At the beginning of the study, the analytical hierarchy process [13] was performed to identify the individual criteria according to which each training method is compared. In total, nine criteria for comparison were identified within the expert team:

- C1 Maximum acceleration values;
- C2 Similarity to flying in an airplane;
- C3 Simultaneous irritation of multiple semicircular canals;
- C4 Variability of training;
- C5 Involvement of cognitive functions;
- C6 Necessity of mastering the technique;
- C7 Current health status;
- C8 Possibility of leisure training;
- C9 Equipment maintenance needs;

C1 criterion examines the highest values of the resultant linear acceleration vectors and the highest values of angular accelerations achieved during measurements on devices using the GoPro HERO 9 camera. The box plot in Figure 1 shows the statistical evaluation of the acceleration pattern.

C2 evaluates the similarity of the magnitude of linear acceleration on the trainer to the aircraft's actual flight. Given the profile of airplane flight, which usually involves simultaneous irritation of multiple semicircular canals, this needs to be considered in the ground preparation in criterion C3.

Criterion C4 represents the possibility of exercise variation, therefore, in how many directions of the body axes (and around them) we can perform movement. During the flight in the aircraft, the pilot must frequently perform other activities besides piloting that require full concentration. In ground training, these activities may be simulated by exercises involving cognitive functions, and this option is assigned a criterion C5. Some forms of training require trainees to have previous experience or mastery of the technique of performing individual exercises (e.g., putting a cage into a rotary motion). The need for prior instruction is reflected in criterion C6. Due to injury and subsequent recovery, the trainee may not always be able to perform a complete workout.

Therefore, criterion C7 affects the ability to exercise even when the exerciser's physical performance is not optimal after injury or illness.

Criterion C8 considers the possibility of performing some exercises outside the special physical training classes or the possibility of exercising a larger group of exercisers simultaneously. For some devices, regular maintenance takes them out of service for a period of time and makes it impossible to train them, as illustrated by criterion C9.

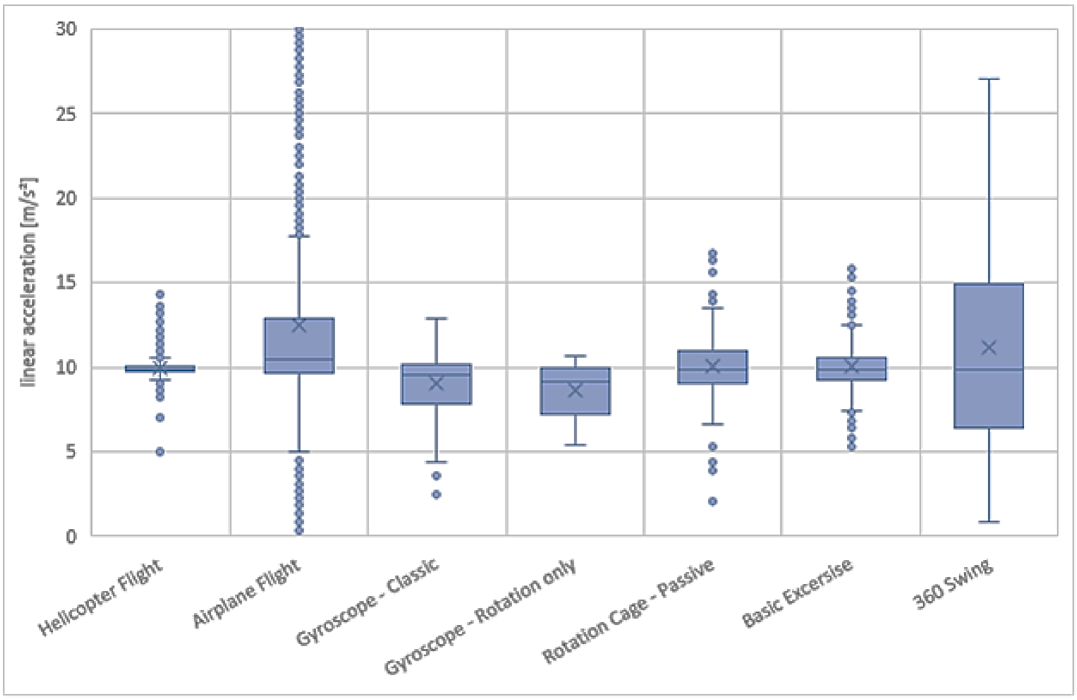

Fig. 1. Measuring of the acceleration vector.

Table 1.

Saaty matrix for criterions

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	G_i	v_i
C_1	1.00	3.00	4.00	5.00	5.00	6.00	7.00	8.00	9.00	4.59	0.31
C_2	0.33	1.00	2.00	5.00	6.00	7.00	7.00	8.00	9.00	3.46	0.24
C_3	0.25	0.50	1.00	5.00	4.00	6.00	7.00	8.00	8.00	2.66	0.18
C_4	0.20	0.20	0.20	1.00	2.00	4.00	4.00	7.00	8.00	1.34	0.09
C_5	0.20	0.17	0.25	0.50	1.00	3.00	5.00	5.00	7.00	1.09	0.07
C_6	0.17	0.14	0.17	0.25	0.33	1.00	2.00	4.00	2.00	0.56	0.04
C_7	0.14	0.14	0.14	0.25	0.20	0.50	1.00	2.00	2.00	0.40	0.03
C_8	0.13	0.13	0.13	0.14	0.20	0.25	0.50	1.00	3.00	0.30	0.02
C_9	0.11	0.11	0.13	0.13	0.14	0.50	0.50	0.33	1.00	0.24	0.02
									SUM	**14.65**	**1**

Weights were then determined for each criterion using the Saaty matrix [14]. The evaluation of the importance of each criterion was carried out by the authors' team and the resulting values, including the geometric mean Gi and the standardized weights vi, are shown in the Table 1.

3. Investigation Results

The result of the comparison is a table of the individual criteria, scored and compared according to the criteria weights. Devices and methods currently available in the UoD environment were included as alternatives:

- A1 Gyroscope;
- A2 Rotation Cage passive;
- A3 Rotation Cage active;
- A4 Basic Gymnastics;
- A5 360 Swing.

The individual scores of these variants without weighting are shown in the spider diagram in Figure 2. The rating of the variants according to the criteria is on a scale of 1 - 5, where a value of 5 is awarded to the best-rated variant according to the criterion, and a value of 1 is awarded to the lowest-rated variant. The training method with the highest numerical rating is considered the closest to the need for increasing resistance of the vestibular apparatus under UoD conditions.

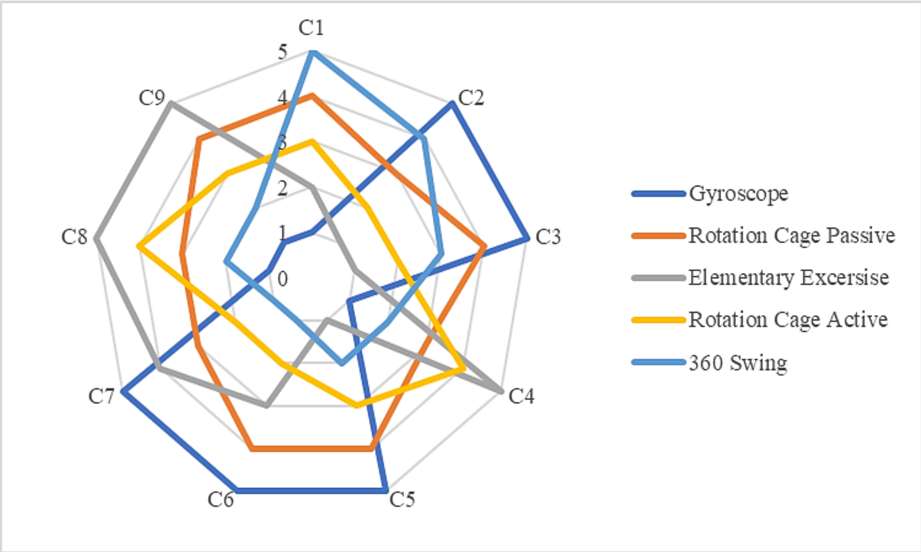

Fig. 2. The spider diagram.

The final calculation and achievement A of the resulting values using equation (1):

$$A_i = \sum v_i \cdot C_i \quad (1).$$

The results where were taking into account both the scores and the weighting of the criterion, is shown in Table 2.

Table 2.

The scores and the weighting of the criterion

Training device	Result
Gyroscope	3.23
Rotation Cage Passive	3.62
Elementary Excersise	1.99
Rotation Cage Active	2.63
360 Swing	3.53

Criteria directly related to vestibular stimulation (maximum acceleration values, similarity to flight environment and multiple semicircular irritation) had the highest weight (more than 0.15). This is due to the targeted focus on pilot training. On the other hand, the criteria allowing leisure training or training during recovery had the least weight. These criteria should be mentioned however they do not have a major impact for comparison. The final evaluation shows that the Rotation Cage Passive exercise scored highest. Maximum acceleration values for the passive exercise on the fixed double circle were the second highest, and the similarity to airplane flight is average. This exercise is also very suitable for the present irritation of semicircular canals. The practitioner alone performs almost no movement, can turn his head in various ways, and thus simultaneously move the endolymph in several ducts. However, stiffening the body during the exercise is essential to avoid injury. The variation in training is rated average because the double-circuit design partially restricts the trainee's movement, and the trainer only allows movement in two directions. However, both the 360 Swing and Gyroscope exercises achieved similar results. During the gyroscope exercise, the acceleration values reached are the smallest compared to other training methods. However, the actual course of these accelerations (especially the resultant linear acceleration vectors) is the most similar to the course of acceleration during an airplane flight. In addition, more semicircular canals are stimulated during the training because the motion of the Gyroscope is relatively random.

During the 360 Swing, the highest acceleration values were measured, and the profile of these accelerations was very similar to the acceleration profile during flight in an airplane. Simultaneous stimulation of multiple semicircular canals is limited due to the active nature of the exercise. However, the practitioner can tilt the head unrestrictedly once the technique is mastered. The training variability is limited because the cage design only allows forward, backward, and sideways rotation.

The involvement of cognitive functions is only passable, as the trainee is primarily focused on spinning the turntable in the initial phase, and it is not possible to observe the taskmaster during the transition over the top. The turntable exercise places the highest demands on prior experience of all the other methods, as the acquisition of the turning technique on this trainer is demanding, and many trainees manage to turn the turntable for the first time only after several hours of special physical training.

4. Conclusions

Despite the above evaluation, none of the alternatives overwhelmingly outweighed the others in absolute numbers and individual criteria. This fact is illustrated in the spider diagram, see Fig. 2, which shows the distribution of the scores in each criterion, not including the weights that would distort the resulting area.

Another potential limitation is the subjective processing of most of the criteria, apart from acceleration measurements and comparison with flight dynamics, so it would be beneficial to introduce other objective criteria in the future, such as heart rate variability measurements. In conclusion, the best training results can be achieved by appropriately combining all the above methods. Finding a suitable combination of methods is also a direction for future research. To have a practical impact, it would be necessary to firmly embed the new training program into the pre-pilot training period. This opportunity presents itself in the form of incorporation into physical training classes in the October-March period, as flight training is usually initiated with the start of the summer season and more favorable weather conditions.

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COVID-19 Restrictions' Effect on Physical Fitness – A Comparative Study of First-Year Students in Pre, During, and Post-Pandemic Eras

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Abstract

This study investigates the influence of COVID-19 restrictions on first-year university students' physical fitness over five years, analyzing data from the University of Defence. The findings reveal a significant decline in first-semester performances in 2020/21, primarily attributed to students who did not undergo physical entrance exams and experienced a partial lockdown along with distant schooling. The class of 2021/22, despite similar conditions, achieved comparatively better results, possibly due to increased control of students during distant schooling at the residence hall. Conversely, the period of 2019/20 saw the most substantial decline in physical performance, suggesting challenges in adapting to abrupt transitions to distant schooling. From these results, it is evident that factors such as physical entrance exams, in-person schooling, and supervision play crucial roles in improving physical performance among university students. These findings underscore the impact of pandemic-related disruptions on physical capabilities, offering insights for education and health policymakers aiming to support student well-being during unprecedented times.

KEY WORDS: *physical fitness, longitudinal study, distant schooling, COVID-19 restrictions, impact assessment, public health dynamics.*

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1. Introduction

Physical fitness plays a critical role in fostering effective and self-reliant behavior among individuals, impacting societal productivity, overall health, and resilience [1]. Despite global efforts to promote active lifestyles and reduce digital media use, the COVID-19 pandemic has introduced unprecedented challenges. Measures such as social distancing, remote work, and lockdowns have exacerbated unhealthy behaviors, leading to a decline in physical fitness [6], [7], [8], [9], [10].

Regular exercise and physical activity (PA) are well-documented for their comprehensive benefits on physical and mental health [11], [12]. Current guidelines recommend that healthy adults engage in at least 150 minutes of moderate to vigorous physical activity (MVPA) weekly to reduce risks associated with all-cause mortality, cardiovascular disease, diabetes, dementia, and mental health disorders [13], [14]. Despite these recommendations, global levels of physical inactivity remain high, with only half of healthy adults meeting the guidelines [15].

Access to recreational areas is pivotal for PA, and restrictions during the pandemic may promote sedentary behavior, contributing to chronic diseases and mental health issues [16], [17]. Large-scale epidemiological studies underscore the mortality benefits of regular PA, while also suggesting indirect benefits in mitigating COVID-19 risks through obesity management and immune enhancement [19], [20], [21].

On March 11, 2020, the Director-General of the World Health Organization declared coronavirus disease (COVID-19) a global pandemic, prompting significant movement restrictions worldwide and within nations, affecting adults' ability to meet recommended levels of physical activity (PA) and exercise. During the early stages of the COVID-19 pandemic, several international surveys revealed substantial declines in self-reported physical activity levels compared to pre-pandemic levels. Furthermore, reductions in physical activity and increases in sedentary behavior were associated with poorer mental health and increased anxiety [22], [23], [24].

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While the exact timeline of the COVID-19 pandemic remains undefined, the most severe countermeasures were implemented during the years 2020 and 2021. Scientific exploration and documentation of physical fitness changes have been conducted; however, many studies have predominantly focused on acute responses to lockdown without follow-up trend inquiries.

This study aims to investigate the impact of COVID-19 on the physical fitness of first-year university students over a five-year period, spanning pre-pandemic, pandemic, and post-pandemic phases. It seeks to understand how acceptance and study conditions before, during, or after COVID-19 restrictions influenced physical fitness trends among students.

2. Methods

The research sample comprised 1,996 male and 253 female soldiers from the Czech Republic Army, all first-year students at the University of Defence. All participants were in good health and possessed sufficient fitness levels to successfully complete the first two semesters' credit disciplines in physical education. Familiar with the tests, participants received training during distance schooling. Ethical approval was obtained from the University of Defence's Ethical Board, and participants were informed of the use of their results for analyses and research by the Centre of Physical Education and Sport.

Data analysis utilized results from the first two semesters of physical education credit disciplines over five consecutive school years (2018-2022). Participants had three attempts for each test during university exam periods, with the best results recorded for the study.

Five physical performance tests were conducted by physical education teachers with a minimum of 6 years of experience. The first-semester disciplines included the 10 x 10 m shuttle run, 1000 m run, and pull-ups for men, and pull-up hold for women:

1. *10 x 10 m Shuttle Run.* Participants perform a dynamic 10 x 10 meters shuttle run, ensuring at least one foot crosses the 10 m line each turn. The number of completed 10-meter segments is recorded by an examiner, with time measured to the tenth of a second.
2. *1000 m Run.* Participants engage in a 1000-meter run on a 300 m athletic track, starting collectively, with individual times recorded.
3. *12-Minute Run.* Starting collectively, participants run for 12 minutes, with remaining time visible. A signal sounds one minute before conclusion, and the distance covered is accurately documented. Personal watches were permitted for self-tracking.
4. *Pull-Ups.* Men perform pull-ups with strict form, starting from a dead-hang position with a straight body. Kipping motions are avoided, and the goal is to lift until the chin surpasses the bar. The number of successful pull-ups is documented.
5. *Pull-Up Hold.* For women, the pull-up hold test begins from the pull-up position, using assistance to reach the starting point. The focus is on maintaining the chin above the bar without contact for as long as possible, with duration measured.

Second-semester tests comprised the 12-minute run and pull-ups for men, and pull-up hold for women.

Data analysis. The following non-parametric methods were used to compare groups: the Kruskal-Wallis test, the Tukey-Kramer-Nemenyi all-pairs test and the Wilcoxon signed rank test (paired), see [25]. Statistical analyses were performed in software R, with the statistical significance level set at $\alpha = 0.05$.

3. Results

Data analysis in this study was categorized into three parts: the first semester, the second semester, and the crossover of the first and second semesters. Each part included two subgroups, one for males and one for females. The data for the first semester disciplines are presented in Tables 1 and 2, Figures 1 and 2. Tables 1 and 2 contain basic descriptive statistics, namely sample size – n, sample mean – Mean, sample standard deviation – St. dev., median (Median), minimum value – Min, maximum value – Max, lower quartile – $Q_{0.25}$, upper quartile – $Q_{0.75}$, skewness – Skewness and kurtosis – Kurtosis for the school years 2018/19 to 2022/23. Graphically, these data are shown in Figure 1 and 2 using boxplots. The school class of 2020/21 distinguished itself with generally the poorest results in all three disciplines – pull-ups, 10 x 10 m shuttle run, and 1000 m run, for both men and women. In the male subgroup, the class of 2018/19 achieved the most favorable results, demonstrating statistically significantly superior performance in pull-ups compared to all other classes, see Table 5 for the p-values of the multiple comparison test. For the purpose of statistical testing, we choose a significance level of 0.05 (a p-value less than 0.05 identifies a statistically significant difference).

Additionally, they showed superior 1000 m run results in all years except 2019/20 and better 10 x 10 m shuttle run results compared to 2020/21, while being statistically equivalent to other classes, see Table 5. For the female subgroup, the class of 2019/20 showcased the best results, with a pull-up hold performance superior to that of 2020/21 and 2021/22. Statistically insignificant differences were observed in the 1000 m run and 10 x 10 m shuttle run compared to other classes.

Table 1 shows the first-semester results over five years for male disciplines. The class of 2018/19 outperformed all other classes in every discipline, while the class of 2020/21 had the lowest scores.

Table 1.

1st semester – males

2018/19	**n**	**Mean**	**St. dev.**	**Median**	**Min**	**Max**	**$Q_{0.25}$**	**$Q_{0.75}$**	**Skewness**	**Kurtosis**
Number of pull-ups	214	11.92	3.57	11	4	23	9	14	0.68	0.03
10x10 m shuttle run	214	25.36	1.19	25.6	18	27	24.8	26.1	–1.93	7.77
1000 m run	214	207.66	11.73	207.5	172	230	200	216	–0.18	–0.29
2019/20										
Number of pull-ups	243	9.6	4.78	9	4	28	6	12	1.01	0.76
10x10 m shuttle run	243	25.58	0.87	25.6	23.1	27	24.99	26.3	–0.23	–0.76
1000 m run	243	210.21	12.18	210	176	230	203	220	–0.28	–0.57
2020/21										
Number of pull-ups	207	9.19	4.56	9	4	25	5.5	11	0.86	0.09
10x10 m shuttle run	207	26.31	0.93	26.4	23.7	30	25.7	27	0.59	2.29
1000 m run	207	216.12	11.52	217	176	230	208	227	–0.62	–0.21
2021/22										
Number of pull-ups	312	9.11	4.3	8.5	4	24	5	12	0.9	0.65
10x10 m shuttle run	312	25.64	0.9	25.7	20.2	27	25	26.32	–0.91	3.13
1000 m run	311	211.86	13.14	213	176	230	203.5	222	–0.54	–0.49
2022/23										
Number of pull-ups	220	10.02	4.92	9	4	22	5	14	0.46	–0.85
10x10 m shuttle run	220	25.65	0.91	25.7	23.3	27	25	26.4	–0.43	–0.67
1000 m run	220	211.55	12.3	212.5	174	230	203	221	–0.43	–0.42

Table 2 shows the first-semester results over five years for female disciplines. Differences between classes are subtler than in males. Generally, better results were achieved by the classes of 2018/19, 2019/20, and 2022/23, while the classes of 2020/21 and 2021/22 performed poorly.

Table 2.

1st semester – females

2018/19	**n**	**Mean**	**St. dev.**	**Median**	**Min**	**Max**	**$Q_{0.25}$**	**$Q_{0.75}$**	**Skewness**	**Kurtosis**
Pull-up hold	43	28.27	11.33	26	15	60	20	33.5	1.16	1.1
10x10 m shuttle run	43	28.26	1.09	28.3	25.7	30	27.65	28.9	–0.33	–0.54
1000 m run	43	248.3	13.89	253	211	267	241.5	258	–0.97	0.17
2019/20										
Pull-up hold	39	30.44	14.03	29	9	64	20.7	38.85	0.62	–0.22
10x10 m shuttle run	39	28.04	1.13	28.1	26	30	26.97	28.84	0.04	–1.04
1000 m run	39	246.05	13.96	247	213	265	236	258.5	–0.22	–0.82
2020/21										
Pull-up hold	59	18.08	9.88	15	8	45	11	23	1.14	0.48
10x10 m shuttle run	59	28.76	0.91	29	26.7	30	28.3	29.3	–0.71	–0.28
1000 m run	59	253.8	10.69	257	225	265	250	262	–1.06	0.17
2021/22										
Pull-up hold	56	18.77	9.33	16.5	8	42	11	25	0.79	–0.28
10x10 m shuttle run	57	28.21	0.94	28.3	25.59	29.9	27.7	29	–0.51	–0.02
1000 m run	57	251.25	13.53	254	203	265	244	263	–1.14	1.26
2022/23										
Pull-up hold	56	26	13.35	23	9	62	16.5	33.25	0.9	0.2
10x10 m shuttle run	56	28.45	0.95	28.5	25.8	30	27.98	29.13	–0.6	–0.13
1000 m run	56	246.61	14.67	249.5	215	264	232.75	260	–0.47	–1.07

The second-semester male results presented in Table 3 show similar performances among the classes, except for 2019/20, which had markedly worse results.

Table 3.

2nd semester – males

2018/19	n	Mean	St. dev.	Median	Min	Max	$Q_{0.25}$	$Q_{0.75}$	Skewness	Kurtosis
12-minute run	200	2818.7	147.95	2800	2600	3400	2700	2900	0.81	0.49
Number of pull-ups	200	11.82	3.5	11	8	24	9	14	0.86	0.21
2019/20										
12-minute run	221	2720.88	193.72	2700	2000	3390	2620	2800	0.53	2.83
Number of pull-ups	221	9.49	3.94	8	5	23	6	11	1.26	1.13
2020/21										
12-minute run	183	2798.96	166.43	2800	2600	3315	2650	2910	0.63	–0.3
Number of pull-ups	183	11.13	4.8	10	6	27	7	13.5	0.86	0.06
2021/22										
12-minute run	268	2836.96	171.65	2840	2600	3300	2700	2950	0.49	–0.48
Number of pull-ups	268	10.92	4.04	11	6	25	7	13.25	0.71	0.01
2022/23										
12-minute run	192	2828.54	176.8	2800	2600	3330	2700	2922.5	0.7	–0.02
Number of pull-ups	192	11.71	4.89	11	6	25	7	15.25	0.54	–0.8

The second-semester results for females in Table 4 show the dominance of the class of 2018/19 in the 12-minute run and the class of 2022/23 in the pull-up hold, while other classes did not markedly distinguish themselves from the others.

Table 4.

2nd semester – females

2018/19	n	Mean	St. dev.	Median	Min	Max	$Q_{0.25}$	$Q_{0.75}$	Skewness	Kurtosis
12-minute run	42	2484.29	172.84	2435	2300	2920	2350	2561.25	0.97	-0.12
Pull-up hold	42	24.65	9.23	23	15	49	17.25	28.75	1.01	0.23
2019/20										
12-minute run	34	2445.91	129.63	2400	2281	2870	2365	2495	1.31	1.65
Pull-up hold	34	27.94	14.81	25	11	78	18.25	31.5	1.56	2.43
2020/21										
12-minute run	60	2414.42	119.61	2365	2300	2800	2307.5	2485	1.03	0.32
Pull-up hold	60	24.58	12.23	19	14	59	15	31.25	1.19	0.35
2021/22										
12-minute run	53	2446.23	145.33	2400	2300	2830	2300	2530	0.85	–0.14
Pull-up hold	53	24.36	10.93	22	12	61	15	30	1.02	0.87
2022/23										
12-minute run	48	2464.9	156.58	2410	2300	2850	2340	2565	0.77	–0.64
Pull-up hold	48	30.65	14.15	28	12	73	20	35.25	1.1	0.7

Table 5 shows statistical analysis of performance differences for each discipline.

Table 5.

Multiple comparisons – Tukey-Kramer-Nemenyi all-pairs test (p-values)

Number of pull-ups					**Pull-up hold**				
Males	*2018/19*	*2019/20*	*2020/21*	*2021/22*	**Females**	*2018/19*	*2019/20*	*2020/21*	*2021/22*
2019/20	<0.001	–	–	–	*2019/20*	0.997	–	–	–
2020/21	<0.001	0.900	–	–	*2020/21*	<0.001	<0.001	–	–
2021/22	<0.001	0.910	1.000	–	*2021/22*	<0.001	<0.001	0.985	–
2022/23	<0.001	0.820	0.320	0.280	*2022/23*	0.699	0.492	0.003	0.019
100 m run					**100 m run**				
Males	*2018/19*	*2019/20*	*2020/21*	*2021/22*	**Females**	*2018/19*	*2019/20*	*2020/21*	*2021/22*
2019/20	0.155	–	–	–	*2019/20*	0.990	–	–	–
2020/21	<0.001	<0.001	–	–	*2020/21*	0.240	0.080	–	–
2021/22	<0.001	0.313	0.003	–	*2021/22*	0.640	0.320	0.950	–
2022/23	0.005	0.706	0.001	0.987	*2022/23*	0.990	1.000	0.060	0.300
Shuttle 10 x 10 m run					**Shuttle 10 x 10 m run**				
Males	*2018/19*	*2019/20*	*2020/21*	*2021/22*	**Females**	*2018/19*	*2019/20*	*2020/21*	*2021/22*
2019/20	0.730	–	–	–	*2019/20*	0.891	–	–	–
2020/21	<0.001	<0.001	–	–	*2020/21*	0.075	0.005	–	–
2021/22	0.190	0.900	<0.001	–	*2021/22*	0.995	0.977	0.012	–
2022/23	0.170	0.840	<0.001	1.000	*2022/23*	0.890	0.336	0.390	0.618

Data for the second-semester disciplines are presented in Tables 3 and 4 and in Figures 1 and 2. The second semester exhibited more diversity than the first semester, with the class of 2019/20 showcasing the lowest results for men in both disciplines. Conversely, for women, the class with the poorest performance was 2020/21. The best results for men in the 12-minute run were observed in the class of 2021/22, and for pull-ups, in the class of 2018/19. Among women, despite the higher scores in the 12-minute run for the classes of 2018/19 and 2022/23, the differences were not statistically significant, indicating equivalent performances across all classes. For pull-up hold, the class of 2022/23 demonstrated the best performances, although statistically significant only when compared to the class of 2020/21, see Table 5.

Table 6.
Wilcoxon test (p-values): comparison of performances in the disciplines pull-ups (males) and pull-up hold (females), 1^{st} and 2^{nd} semester

Males		**Females**	
Year	p-value	Year	p-value
2018/19	0.423	*2018/19*	0.009
2019/20	0.883	*2019/20*	0.006
2020/21	<0.001	*2020/21*	<0.001
2021/22	<0.001	*2021/22*	<0.001
2022/23	<0.001	*2022/23*	<0.001

In the comparison of males in pull-ups between the first and second semesters of the same classes, identical performances were revealed for 2018/19 and 2019/20, while an increase was observed in the second semesters for 2020/21, 2021/22, and 2022/23, see Table 6 and Figure 1. For females, differences between semesters in pull-up hold were statistically significant in all years. Decreased performances were observed in the second semester for 2018/19 and 2019/20, while increased performances were noted in 2020/21, 2021/22, and 2022/23, see Table 6 and Figure 2.

4. Discussion

The primary focus of this study was to investigate how COVID-19-related restrictions influenced the physical fitness of university freshmen during their first year of study. The most severe restrictions occurred in 2020, with a complete lockdown not being an extraordinary measure applied, and 2021, where distant learning was still in use. Our findings of very poor physical performances in the class of 2020/21 during the first semester align with the physical inactivity outcomes reported by Pinho [26]. It is important to note that the low physical fitness of the 2020/21 class might not be solely due to COVID-19 restrictions but also the result of the selection process. This class did not undergo physical entrance exams, and therefore, the fitness baseline itself might be lower than that of classes who did go through the selection process. This fact, in conjunction with the era's difficulties, might be the determining factor, as the class of 2021/22 shared similar characteristics with the exception of a higher level of supervision by their teachers and supervisors during distant schooling at the residence hall, displaying higher physical capabilities.

Entrance exams and no restrictions are characteristics of the 2018/19 class, where the physical fitness level of men was superior to others, and the same goes for the first semester of women in the 2019/2020 class. Silva [27], in their longitudinal study, reported decrements in body composition and cardiovascular fitness after lockdown, and improvements after two months of the reintroduction of in-person classes. Our study supports these findings. Lockdown and distant schooling promoted individual training, often supported by smart apps and other multimedia facilities, which helped mitigate the impact of physical inactivity [28], as evidenced by the improved performances in pull-ups for the 2020/2021 class.

The importance of in-person classes stands out from the overall superior performance of the 2018/19 and 2022/2023 classes, where no distant schooling was applied. The adaptation to the new situation challenged individuals' flexibility, and their reaction was not immediate, resulting in a drop in fitness levels even in normally above-average active individuals during the beginning of new conditions [29], as visible in the second semester of the 2019/20 men's class, where lockdown and individual training during distant schooling were applied.

For the physical education program at the University of Defence, it can be said to display positive results in both normal and distant schooling regimes. Comparing pull-ups and pull-up hold between the first and second semesters showed statistically significant increases in the majority of classes, namely men in 2020/21, 2021/22, 2022/23, and women in 2020/2021, 2021/22, 2023. Stability was observed in men in 2018/19, 2019/20, and decline only in women in 2018/19 and 2019/20, despite the challenging conditions, whereas the general trend of physical fitness among college students is declining [30].

Figure 1 displays boxplots of performances in each individual discipline of the male subgroup in this study. On the left side is a scale representing the number of repetitions in pull-ups, distance covered in meters in the 12-minute run, and time achieved in seconds in the 10x10 m shuttle run, and 1000 m run. Higher values represent better performance in pull-ups and the 12-minute run, while lower values indicate better performance in the 10x10 m shuttle run and the 1000 m run.

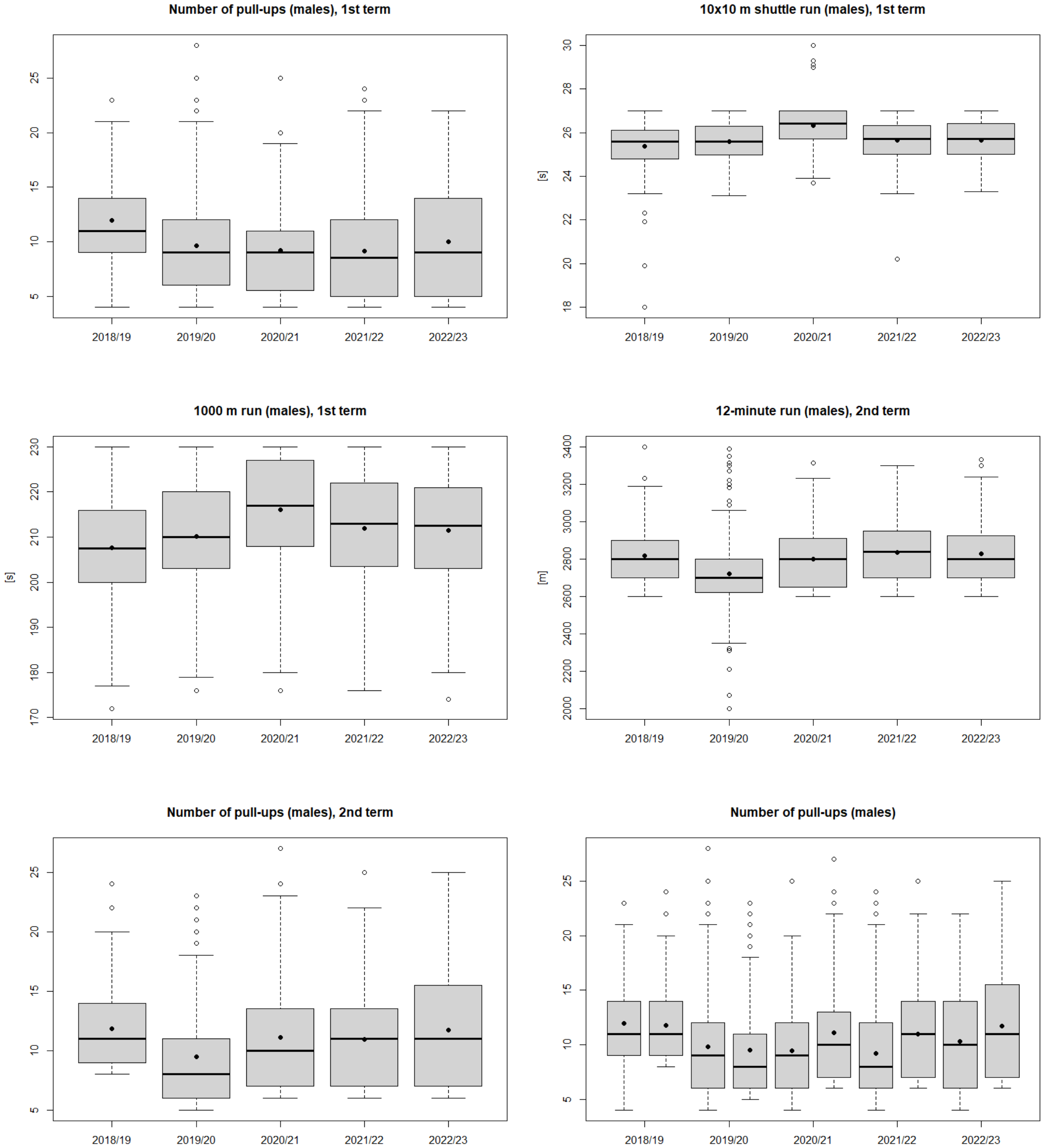

Fig. 1. Boxplots of performances in individual disciplines – males.

Figure 2 displays boxplots of performances in each individual discipline of the female subgroup in this study. On the left side is a scale representing distance covered in meters in the 12-minute run and time achieved in seconds in the 10x10 m shuttle run, pull-up hold, and 1000 m run. Higher values represent better performance in pull-up hold and the 12-minute run, while lower values indicate better performance in the 10x10 m shuttle run and the 1000 m run.

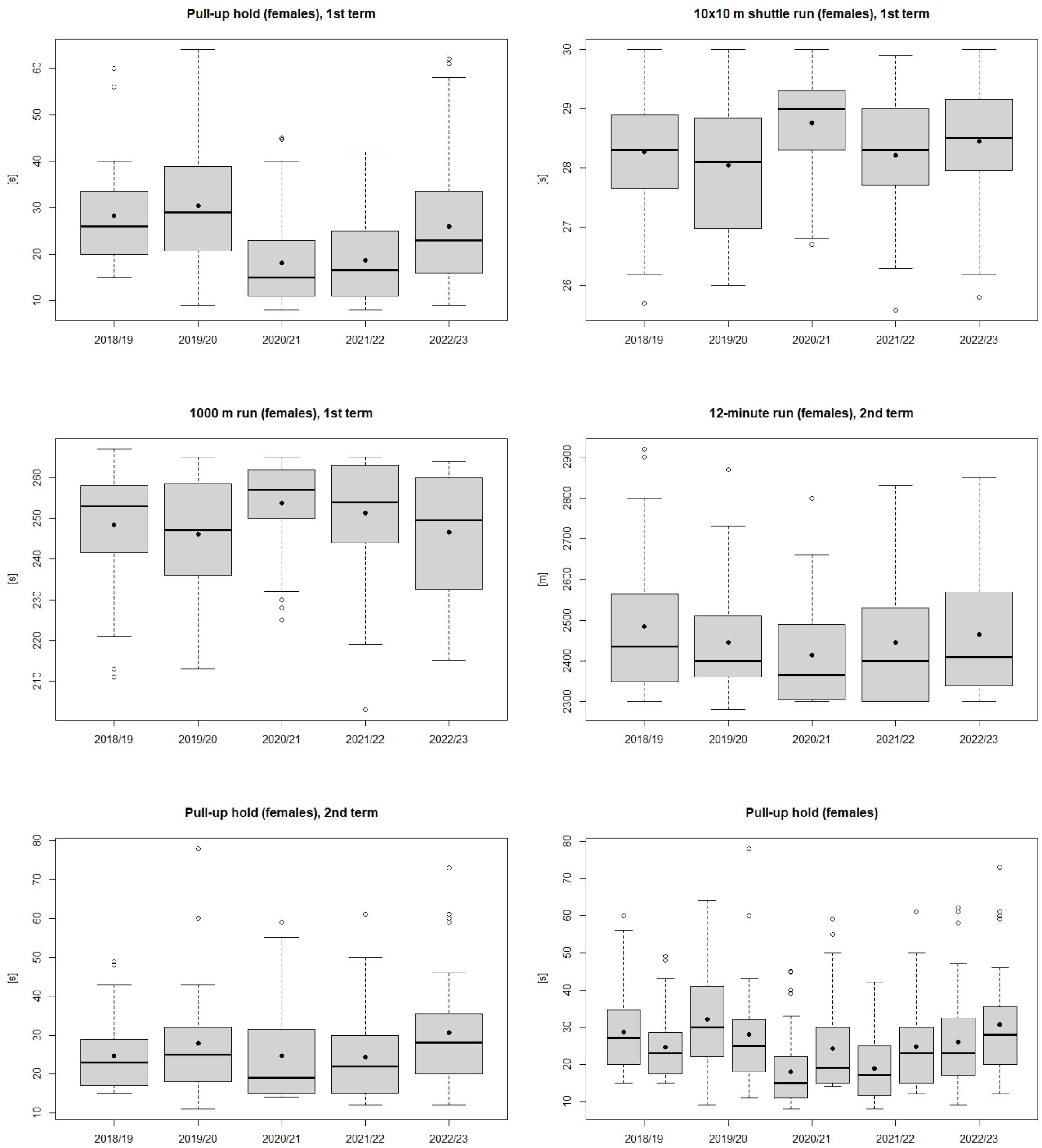

Fig. 2. Boxplots of performances in individual disciplines – females

5. Conclusion

This study analyzes the physical performance of university students in their first year of study before, during, and after COVID-19 pandemic-related restrictions, providing insightful observations on how physical capabilities varied during this period. The notably poor first-semester performances in 2020/21, characterized by students who did not undergo physical entrance exams and experienced a partial lockdown along with a distant-schooling system throughout the semester, suggest a significant impact of COVID-19 restrictions on physical performance. Interestingly, the class of 2021/22, which also did not undergo physical entrance exams but achieved better results, seems to have benefited from higher control of students due to the requirement to be present at the residence hall during distant schooling. The most substantial decline in physical performance in the second semester was observed in the period of 2019/20, suggesting that in-person schooling may be more effective. This highlights the importance of physical entrance exams, present schooling, and supervision as critical factors influencing physical capabilities among university students. The abrupt transition to distant schooling appeared challenging, indicating that students and the system may not have been fully prepared for such a sudden change. The observed decrements in physical performance during lockdown and distant-schooling align with findings from previous research.

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Preferred Leadership Styles: Mid-career Professionals in the Czech Military

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Abstract

Adaptability in leadership styles is widely recognized as a fundamental skill for effective leadership. This article outlines the findings of a comprehensive four-year study on leadership styles within the Czech Armed Forces Senior Officers course. The research, which employed the connective leadership model method, involved 222 participants. The results revealed a consistent trend of nearly equal utilization of all leadership styles across the various groups throughout the years under scrutiny. Notably, the less favored styles encompassed competitive and confiding approaches. Furthermore, the study indicated minimal divergence in the leadership styles employed by male and female soldiers.

KEY WORDS: *connective leadership, mid-career professionals, leadership skills, leadership styles, military leadership*

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1. Introduction

The global and interconnected world poses new challenges and tasks for leaders at all leadership positions and in all spheres of society, including the field of national security and defense. Leadership skills and abilities are required not only from the top management of organizations but also from middle and front-line management [1]. The ability to change leadership styles according to different criteria - the nature of the task, the composition of the work team, etc., with the intention of meeting the set goals in the best and most effective way is considered one of the basic competencies of a good leader [2].

Today, institutions and organizations face increasing demands for leaders who can lead multidisciplinary and transnational teams assembled to accomplish complex tasks and who have the ability to collaborate and connect the different parts of these organizations. These demands require their leaders to be highly flexible in using new ways of working and different leadership styles while adjusting to the particular task, situation, and context [3].

Not even traditional complex hierarchical organizations [4], such as the army and the police, can resist this trend. The implementation of new leadership and management procedures aimed at sharing power and promoting cooperation is desirable in times of rapid technological development and social change. However, it has its limitations due to the nature of security forces consisting predominantly of combat units, where the basic leadership and management style is directive. Even in combat units, it is necessary to have competent personnel who can apply various leadership styles in the everyday operation of organizations. Therefore, mid-career courses were established in the Czech Army to develop and enhance the leadership and communication skills of commanding officers in middle management positions. It is essential for mid-career officers to learn about different leadership styles, identify their own, and recognize the conditions, situations, and contexts under which it is appropriate to use a particular style.

In 2014, the concept of leadership was introduced into the education of Czech military professionals as a separate thematic unit. This was part of the implementation of a competency-based approach to tertiary and career education in the field of military professionals, focusing on soft skills development. The aim of this article is to present the results of a four-year monitoring of leadership styles among participants of the Czech Armed Forces Senior Officers course using the connective leadership method.

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2. Research Method

Description of the method: The Connective Leadership Model (CLM) [3] was developed to address the increasing need for effective leadership in complex organizations. These organizations require leaders who can effectively lead diverse groups that are interdependent and need to collaborate on shared tasks. The model, created by Lipman-Blumen, is based on the premise that the modern world is shaped by "two contradictory forces: interdependence and diversity", which "demand conflicting behavioral responses" [5]. Therefore, traditional leadership styles, especially authoritarian ones, became less effective or ineffective. The CLM and its instruments help to identify the leadership styles employed at a specific leadership position: unlike other leadership instruments, e.g. the Multifactor Leadership Questionnaire [6], the Global Transformational Leadership Scale [7], Leadership Practices Inventory [8], or NEO-PI-R [9], that focus on personal leadership styles and traits in general, CLM and its Achieving Styles Inventory assess the leadership styles used in the context of the task that a leader is to accomplish.

The Connective Leadership Model identifies three main sets of behavioral styles, each of which contains three more specific behavioral strategies that individual leaders use in different contexts. These sets are direct styles (intrinsic, competitive, power), instrumental (personal, social, entrusting), and relational styles (collaborative, contributory, and vicarious). The direct set refers to individuals who prefer to tackle tasks on their own and prioritize mastery (intrinsic), competition (competitive), and power (power style). Those who focus on group tasks (collaborative), helping others (contributory), and mentoring (vicarious) while achieving their goals emphasize the relational set. The instrumental set is typical of individuals who view themselves (personal), their connections (social) and others (entrusting style) as tools to accomplish mutual goals. The connective leadership model of nine leadership styles thus aims to help leaders identify and develop strategies that may be outside their usual approach.

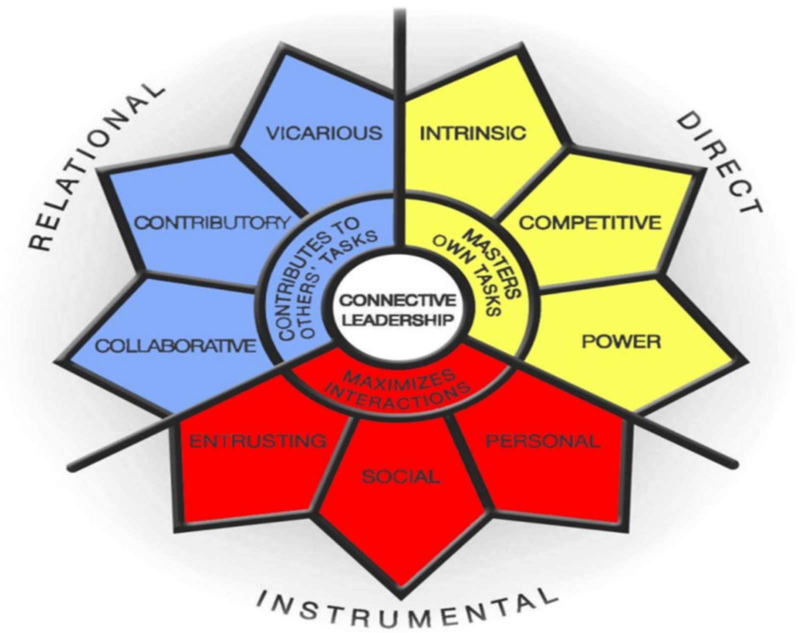

Fig. 1. Connective Leadership Model (Reprinted from reference [10], Copyright Year: 1996, Copyright Owner's Name: Jean Lipman-Blumen, Ph.D.).

The Individual Achieving Styles Inventory (ASI) was utilized to evaluate leadership styles employed in the context of accomplishing work responsibilities. The ASI is a 45-item Likert-type survey designed to identify nine leadership behaviors that individuals typically employ in specific work-related situations. Respondents answer a series of questions to indicate the frequency with which they engage in specified behaviors and receive a score for each of the nine leadership styles, reflecting the frequency of use for each style. While the ASI is available in electronic form in four language variations, a Czech version is not available; therefore, it was administered in English. The administration of the inventory was led by a Connective Leadership Institute Certified Associate.

After completing the inventory, each respondent received a graph, which together with the narrative description, provided their Connective Leadership Profile, identifying the leadership styles that the individual uses most and least frequently. The narrative description outlines the general advantages and drawbacks of each of the most prominent and less prominent styles. Subsequently, individual feedback was provided to each candidate, using coaching questions to guide the respondent to consider possible changes in leadership styles.

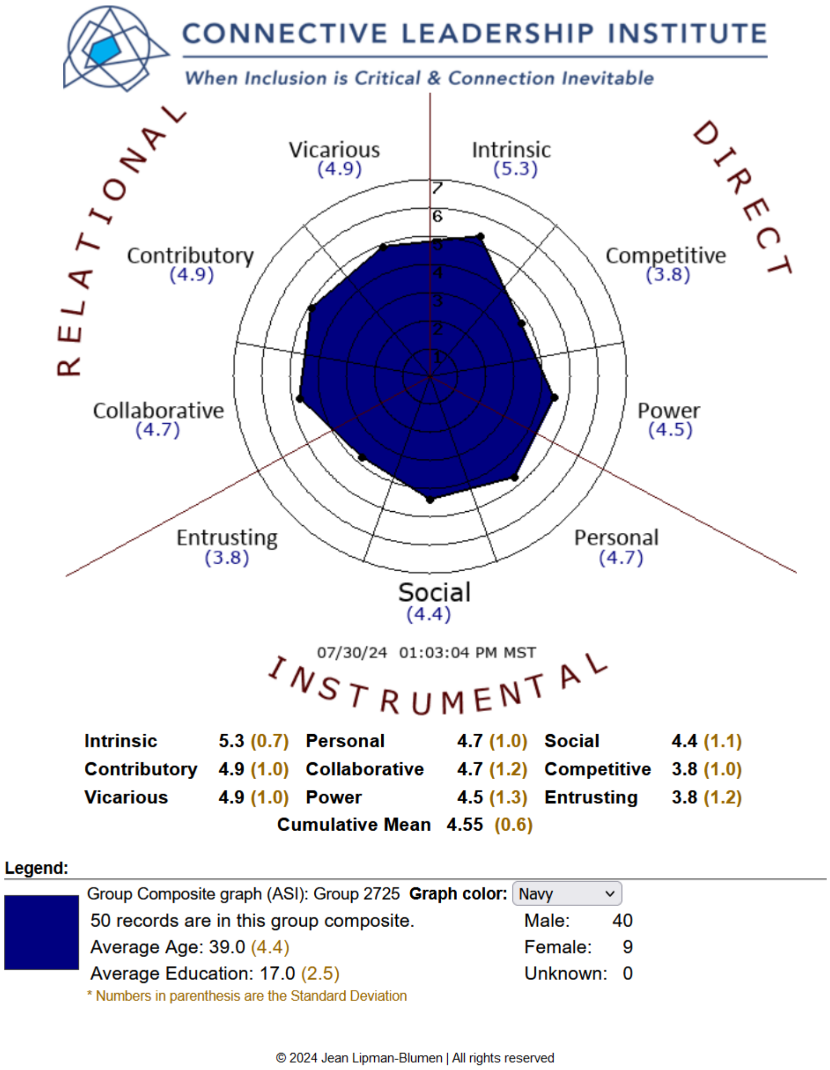

Fig.2 A sub-group results graphs.

Description of the research: The research was conducted between 2018 and 2022 as part of the Organizational Leadership Development in Senior Officer Courses. Respondents' participation was completely voluntary; therefore, the research sample selection was entirely random. Both men and women were represented in the respondent pool. All research participants were university graduates with diverse professional backgrounds, holding middle management positions in various departments and facilities under the Ministry of Defence.

A total of 222 mid-level military professionals participated in the 4-year study. These individuals were in the midst of their military careers and had diverse people management experiences. Among the participants, 181 were men, and 41 were women, reflecting the overall representation of men and women in the military profession.

Table 1.

The project target groups

Y	N	M	F	AA
2018	25	17	8	39
2019	100	86	14	39.5
2020	48	38	10	40
2022	49	40	9	39
SUMMARY	222	181	41	39

Y=years, N=number of participants, M=males, F=females, AA=mean age

All research participants received a thorough explanation of the research method and process. Their individual results were anonymized throughout the test and data processing. Each participant was given a unique code to access their results. Only anonymized data was accessible to the researchers for statistical processing.

The results were processed using Excel. Basic statistical methods were employed, including the calculation of mean and standard deviation. The results are presented as total scores for each style, with 0 indicating no preference and 6 indicating the highest preference.

3. Findings

The findings, as shown in Fig. 2, Fig. 3, and Fig. 4, indicate a consistent pattern of nearly equal use of all leadership styles across all groups over the years studied. Notably, the less preferred styles included the competitive and entrusting styles. These findings reflect the expectation that at the leadership level, middle rank officers are required to restrain competitive tendencies while collaborating with other teams and groups in order to complete their tasks. Additionally, they are expected to handle many tasks independently, which limits their use of a more (en)trusting leadership style. The findings are congruent with the requirements imposed on military leaders, as stated in Twelve Principles of Modern Military Leadership, where one of the most stressed principles is "there is no I in the team" [11].

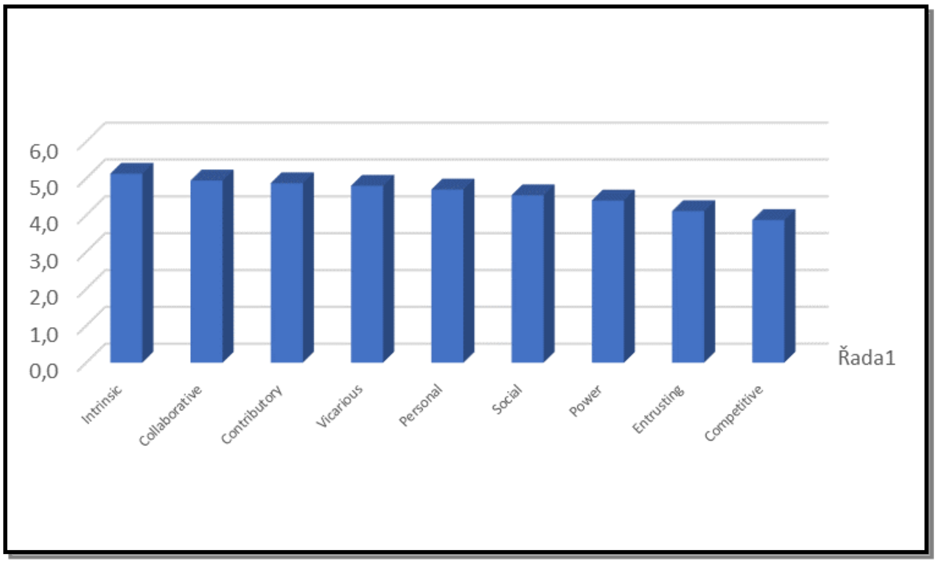

Fig.3 Overall results by preferred styles.

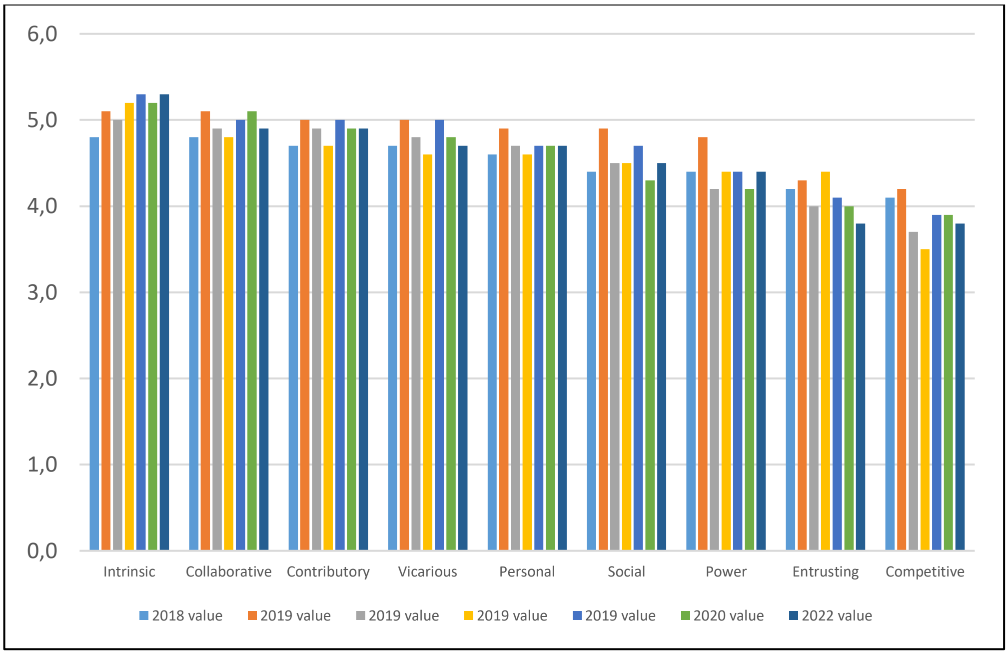

Fig.4 Overall results for the period under review.

As Fig. 5 shows, male and female soldiers do not differ much in the styles they use. The results replicate, with minor variations, the overall results for the whole set. Although the representation of women in the research sample is less than 25%, there is some indication that the environment itself is likely to have a more significant influence on approaches to job tasks in the military environment than the gender-bound personality dispositions of individuals. Again, the findings are in congruence with the findings of the research comparing male and female leadership styles in West Point cadets, where minimal gender differences were found [12].

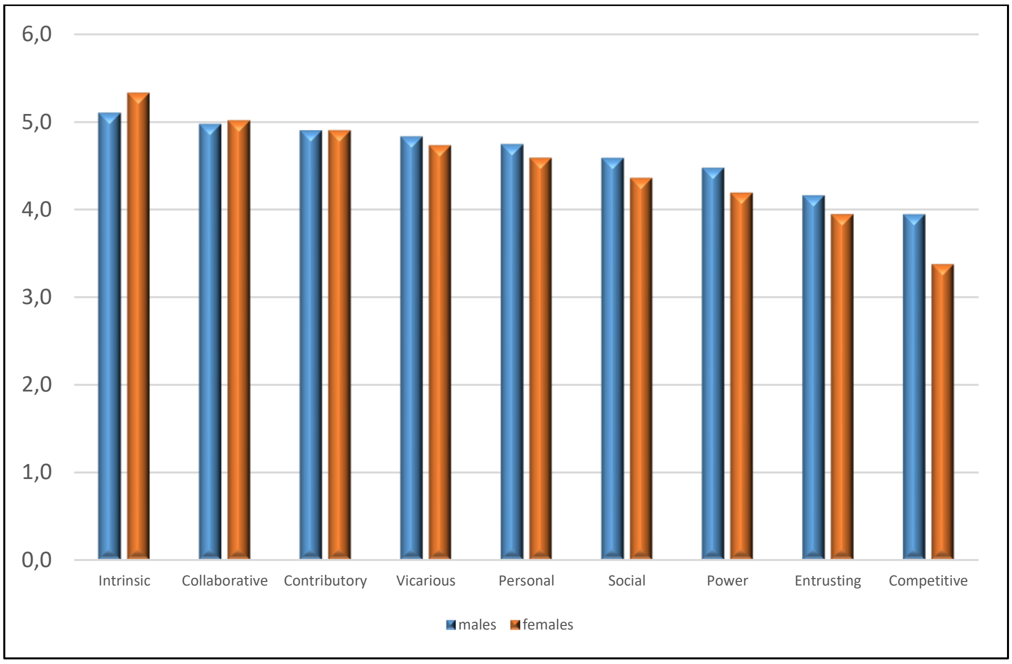

Fig.5. Overall results by gender.

4. Conclusions

Incorporating the internationally proven connective leadership model method into the training of middle management military leaders significantly enhances the training content while helping the participants improve their leadership and communication skills. This approach also allows them to effectively manage challenging situations when leading their teams to accomplish their tasks.

An important finding from long-term work with career education course participants is that mid-career officers recognize the need to improve their leadership skills. They value the feedback provided during the courses and are open to acquiring new knowledge and learning new methods of working with teams. This would enable them to effectively achieve goals even in challenging, non-standard conditions and with team members whose selection they cannot entirely influence.

Acknowledgments

Both authors contributed to the project during all phases – including project preparation, data collection, statistics, and writing the article. One of the authors is a person certified to use the ASI questionnaire.

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Teaching in Software Applications: A Single Robust Built-In Command versus Sequence of More Elementary Commands

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Abstract

We investigate several exercises from the two fundamental disciplines of applied mathematics. We process the exercises in the software applications Maple and MATLAB: the exercises in Maple are from numerical analysis and the exercises in MATLAB are from statistics. For each example, we provide two ways of solution (not two different solutions) and try to explore their advantages and disadvantages for teaching students of university technical fields (undergraduate level). We pit solutions against each other: the first way of solution uses pre-prepared functions (robust built-in commands) for fundamental methods of given disciplines; in the second way of solution we have to "program" these methods by using sequences of fundamental commands. In the process, we theoretically establish parameter of education that needs to be carefully balanced for students' success. However, we are not only thinking about how well the students pass the subject if we use this or that way of solution. We also want to reflect on what we expect and what it is expected that students should learn. Which of the ways will provide them with a more "suitable" type of education for their further development? It seems that with advancing technologies (constantly expanding computing power, the current boom in AI) some of our positions about teaching in software applications need to be re-evaluated – is it really so, or is it just an illusion and the fundamental practices remain valid and they just adapt to new environments? Specifically, for us: Is it still necessary to understand what applications do, or is it enough to remember how to interpret their various outputs? Finally, let us note that we also pay attention to how challenging it is, even for us teachers, to find out what a given robust command actually calculates.

KEY WORDS: *built-in command; Maple; MATLAB; teaching applied mathematics; programming mathematical methods*

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1. Introduction

We teach applied mathematics, especially numerical analysis and statistics. We dare to say that these mathematical disciplines are essential for a large number of university technical fields, the education process for national defence in not an exception, see [1] for an idea of what is included; however, we don't say that technicians are proficient in these disciplines. According to our experience, even long-solved fundamental problems are constantly being solved all over due to the lack of connection between abstract results and procedures used in practice. This may stem from the inappropriate approach of us, the teachers of these disciplines, to teaching.

Numerical analysis and statistics inherently need suitable software for teaching, but, and this is often forgotten, students need to have mastered the basics of the relevant "non-numerical" discipline of mathematics (the fact that students first pass some basic course does not often guarantee this).

Many articles have already been devoted to the teaching of mathematics on computers and their benefits are also often emphasized [2]. However, similarly to how calculators changed our approach to logarithmic tables, new technological means demand readjustment of current teaching methods, see [3]. However, it is natural that there is not one correct approach to teaching but a spectrum of possibilities, see [4,5,6]. And yet we could not find a scientific literature that investigates how necessary it is for students to understand the principle of built-in commands. And this very question will be studied in the following text: Is it necessary for students to have a clear understanding how any given command works?

Considering the focus of teaching at our school we only focus on how to perform some fundamental methods of numerical analysis and statistics in software applications (in the teaching process). Simply put, we are trying to explore the advantages and disadvantages of using pre-prepared functions (robust built-in commands) for fundamental methods of given disciplines over custom "programming" of these methods (just by using sequences of fundamental commands).

Depending on which way of solution we lean towards, it is more or less important, which application we use and also it is more or less important, if we use such application, which then professionals in that given technical field using. A related topic is already addressed in the older article [7], which notes the shift in the role of the computer in teaching mathematics: from an instructional tool (e.g. displaying graphic outputs; see also [8]) to a programming tool. Let us also note that we dealt with the categorization of the way software applications are used in the teaching process in our texts [4] and [5]. Further, let us emphasize that by pre-prepared functions we always mean functions built into an application, not finished user-made functions (scripts). Given this, we will also consider how important it is that we know exactly what the pre-prepared function calculates, i.e., we could program it by hand in any suitable software if needed, but we don't need to know precise implementation to the used application.

2. Methods of Investigation

We focus on pre-prepared functions in the applications Maple (for numerical analysis) and MATLAB (for statistics). We examine what a specific built-in function actually calculates; moreover, we will see how difficult it is, or it is not, to figure it out. Note that in [9] it is examined how Maple calculates the sum of an infinite series and how this can be useful for students. Finally, we will also provide an alternative to the pre-prepared built-in functions: the hand-written code to obtain the same result that the built-in functions provide. In fact, programming the method by hand is often the only practical way to find out what a built-in function actually calculates.

We can look at the matter from another point of view (more global), in which writing scripts goes hand in hand with the use of pre-prepared functions (both built-in and user-made). When solving a more comprehensive problem in practice (for students, for example, when writing a final thesis), it is inevitable that the student will look for solutions (user-made functions, a solution of the problem using built-in functions, etc.) on various web forums. He either find some existing solution or he directly asks. The ability to find and correctly adopt (modify) a solution is absolutely essential today, but be careful, we must not confuse this ability with being educated in the subject. If the student does not orient himself in the subject and only tries one found foreign solution after another, he will easily make a mistake and come to a completely meaningless conclusion, see, e.g., the section “Wrong interpretation of results” from [10]. Unfortunately, due to the described secondary nature, there is no time left for teaching how to find and apply foreign solutions (the student has to learn this ability himself). Materials (textbooks) with prepared code sequences, on the basis of which students create their code, can be a certain starting point for teaching, see [11]. We do not deal with the just-described problem of adopting user-made solutions from the Internet in this text, however, it is an important topic that is now even more relevant than before thanks to the rapidly growing capabilities of AI. Help from AI could even replace to a certain extent the simple search for solutions on the Internet – the question is whether AI is not an even more dangerous source of nonsense than the pure internet searching.

3. Commented Exercises from Numerical Analysis Solved in Maple

Exercise 1. Let us start with a simple exercise from Maple. For the approximate numerical calculation of definite integrals, so-called quadrature formulas are used. Maple has the robust command Quadrature in the package Student[NumericalAnalysis]. The command returns the approximate value of the integral corresponding to the selected formula type and other selected parameters if output is not set. Students should know from the lecture that, for example, in the special case of Newton–Cotes formulas, the interpolation polynomial is integrated, and they should therefore obtain the same result by manually entering the integration of the interpolation polynomial.

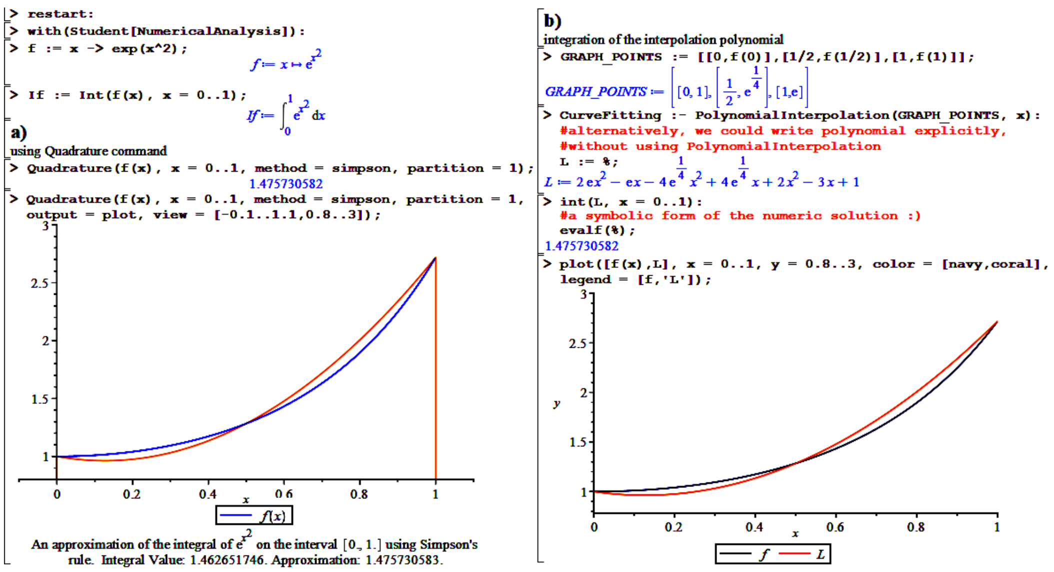


Fig. 1. Solution visualization: a) is more concise and easier for students to implement than the one in b).

The solution in Fig. 1 a) is more concise and easier for students to implement than the one in b). However, there may be a problem with setting the parameter view, more precisely, an explanation of why we set it in presented way (the command Quadrature itself would set the range on the y-axis from the minimum to the maximum value of the function f on the given interval). With the solution in Fig. 1 b), there will be no doubt about the meaning of the value 1.475730582 and what the orange line in the picture is, but even here it will be difficult to tell how the value 1.475730582 relates to the plotted graphs. However, in b), it will be "only" for ignorance of the basics of integral calculus; in a) for ignorance of the numerical integration. Note that if we wanted to numerically estimate the given integral as accurately as possible, we would use the command evalf(If), which uses a very good numerical method.

It should be added, that the code produced in Fig. 1 b) is specific to the quadrature formula used. As a consequence, the code presented in Fig. 1 b) would be diametrically different for other quadrature formulas. In general, we need to know how to determine the nodes and how to calculate the coefficients of the quadrature formula from them. So, it is up for consideration whether we require this level of knowledge from students. Additionally, the more code students write, the more it depends on how proficient they are with the application; common student mistakes in Maple and how to avoid them can be found in [12].

Exercise 2. We find the numerical solution of the equation $f(x) = 0$ on the interval $\langle a, b\rangle$. We assume that there is exactly one root on the specified interval. We use the false position method, to that we construct a sequence $\{x_k\}_{k\in\mathbb{N}\cup\{0\}}$, for which it holds

$$x_0 = a, \quad x_1 = b \quad \text{and} \quad x_{n+1} = \frac{x_m f(x_n) - x_n f(x_m)}{f(x_n) - f(x_m)} \quad \text{for} \quad n \in \mathbb{N},$$

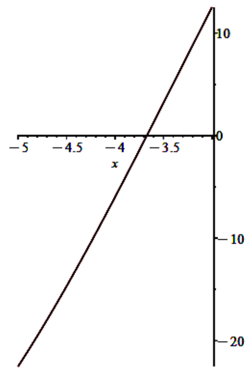
where $m = m(n) \in \{0,1,\dots,n-1\}$ is the biggest number such that $f(x_n)f(x_m) < 0$.

In Maple we use the command Roots with method = falseposition setting. The assignment of the function f and the numbers a and b is given in Fig. 2. We stop the iteration process after five steps, i.e., we have to compute the numbers x_2, x_3, x_4, x_5 and x_6 (five numbers); we do not choose the stopping criterion and the tolerance – it will become clear later why.

```
> restart:
> f := -x^3/2-5*x^2+2*x+50;
  a := -5.0:
  b := -3.0:
  k := 5: #k times the next iteration is calculated
```

$$f := -\frac{1}{2}x^3 - 5x^2 + 2x + 50$$

```
> plot(f, x = -5..-3);
```



a)
using Roots command

```
> with(Student[NumericalAnalysis]):
> Digits := 11:
   #to avoid differences caused by rounding
  Roots(f, x = [a,b], method = falseposition, maxiterations = k,
  output = information);
  Digits := 10:
```

n	a_n	b_n	p_n	$f(p_n)$	relative error
1	−5.0	−3.0	−3.7142857143	−0.787172010	0.19230769231
2	−3.7142857143	−3.0	−3.6719692815	−0.005491647	0.18299970125
3	−3.6719692815	−3.0	−3.6716741937	−0.000034058	0.18293403997
4	−3.6716741937	−3.0	−3.6716723636	-2.11×10^{-7}	0.18293363271
5	−3.6716723636	−3.0	−3.6716723523	$-2. \times 10^{-9}$	0.18293363020

b)
creating procedure

```
> falseposition := proc(function, initial_approx, {iterations := 5})

  local k, f, a, b, p, R, n, i, RLIST, j, xm, tab:

  k := iterations:
  f := unapply(function,x):
  a[1] := initial_approx[1]: #x[0]
  b[1] := initial_approx[2]: #x[1]
  p[1] := (a[1]*f(b[1])-b[1]*f(a[1]))/(f(b[1])-f(a[1])): #x[2]
  R[0] := ['n','a[n]','b[n]','p[n]','f(p[n])','relative_error']:
   #the header of the table (zero row)
  R[1] := [1,a[1],b[1],p[1],f(p[1]),abs(p[1]-b[1])/abs(p[1])]:
   #first row

  for n from 2 to k do
     #finding x[m]:
     RLIST := [seq(p[i], i = 1..n-2),b[1],a[1]]:
     for j from 0 to nops(RLIST)-1 do
        i := j+1:
     until f(RLIST[i])*f(p[n-1]) < 0:
     xm := RLIST[i];
     #construction of the nth row:
     a[n] := min(p[n-1],xm);
     b[n] := max(p[n-1],xm);
      #if b[n] = p[n-1], then ERROR in Roots does not show up
     p[n] := (a[n]*f(b[n])-b[n]*f(a[n]))/(f(b[n])-f(a[n]));
      #x[n+1], n = 2,3,...,k
     R[n] := [n,a[n],b[n],p[n],f(p[n]),abs(p[n]-p[n-1])/abs(p[n])]:
      #ERROR in Roots: b[n] instead of the correct p[n-1]
  end do:

  tab := Matrix([seq(R[i],i=0..k)]):
  return tab:

  end proc:
> Digits := 11:
   #to avoid differences caused by rounding
  falseposition(f, [a,b], iterations = k);
  Digits := 10:
```

n	a_n	b_n	p_n	$f(p_n)$	relative_error
1	−5.0	−3.0	−3.7142857143	−0.787172010	0.19230769231
2	−3.7142857143	−3.0	−3.6719692815	−0.005491647	0.011524179413
3	−3.6719692815	−3.0	−3.6716741937	−0.000034058	0.000080368732200
4	−3.6716741937	−3.0	−3.6716723636	-2.11×10^{-7}	$4.9843771959 \times 10^{-7}$
5	−3.6716723636	−3.0	−3.6716723523	$-2. \times 10^{-9}$	$3.0776166596 \times 10^{-9}$

Fig. 2. Comparison of the two ways of solution using one method of numerical root search

In Fig. 2 notice the blue tables below. Both tables for parts a) and b) have the first five columns exactly the same, so our code gives the same results as Maple's built-in procedure. Only the last column is different, but this is an error of the built-in procedure, not our procedure. We describe the implementation of the false position method into Maple to understand the meaning of the numbers in the tables and to describe why the values in the last columns are different.

Each table contains values a_1, b_1, p_1 ($n = 1$, first row); a_2, b_2, p_2 ($n = 2$, second row); a_3, b_3, p_3 ($n = 3$, third row) and so on. We match the values with our original sequence $\{x_k\}$. It holds

$$a_1 = x_0, \quad b_1 = x_1, \quad p_1 = x_2,$$
$$a_2 = \min\{x_{m(2)}, x_2\}, \quad b_2 = \max\{x_{m(2)}, x_2\}, \quad p_2 = x_3,$$
$$a_3 = \min\{x_{m(3)}, x_3\}, \quad b_3 = \max\{x_{m(3)}, x_3\}, \quad p_3 = x_4 \quad \text{and so on.}$$
Hence $p_n = x_{n+1}$ for $n \in \mathbb{N}$, where p_n is the approximate value of root obtained after n iterates (steps).

Now we describe (define) relative error from the tables. First note that relative error and tolerance together forms one type of stopping criterion for the false position method. Relative error is the number
$$\frac{|x_{n+1} - x_n|}{|x_{n+1}|}$$
for each $n \in \mathbb{N}$. If tolerance is ε, then the iterating process could be stopped by the stopping criterion
$$\frac{|x_{n+1} - x_n|}{|x_{n+1}|} < \varepsilon.$$

The error when calculating the relative errors in Fig. 2 a) is caused by the fact that the command Roots takes the value b_n instead of the value x_n. The value b_n is the maximum of the values x_n and $x_{m(n)}$ and therefore it is not always the required value x_n. Recall that $x_n = p_{n-1}$. Finally, let us note that there is an analogous problem when using absolute error.

Now let us focus on the didactic analysis of both ways of solution presented in Fig. 2. If we start to think about how the students will handle the presented ways of solution, the first impressions will probably be similar for everyone: method b) is difficult to impossible for students. We try to weaken this first impression so that we can even compare the two ways. Let us be aware that for the purposes of this article, method b) is as elaborate as possible and also as transparent as possible (for us), so that it describes the entire iteration process well, especially the calculation of relative error. Additionally, we created a table to match as closely as possible the table returned by the command Roots. It would be enough for students to enter the iteration relation in any way and after the calculation of each value also calculate corresponding relative error. Furthermore, let us note that the formula for the sequence $\{x_k\}$ seems too unapproachable without graphical interpretation of the false position method. Without a graphic idea of the method, all relations seem artificial and technical.

For the way of solution in Fig. 2 a) we very often encounter the fact that students have no idea at all what the meaning of the table is, and in fact they do not even understand the meaning of the individual rows and values in various columns of these rows are. And this despite the fact that we usually want graphic outputs after them (output = plot, output = animation) or even a simple output in the form of a sequence $\{[a_k, b_k]\}$ finalized by the value p_n (only when tolerance is reached). The graphical outputs (that might help especially visual learners in studying) are probably the biggest advantage of using the command Roots over writing own code. It would take us incomparably more work to render an image or even create an animation than just calculating a few elements of the iterative sequence $\{x_k\}$. The advantage of solution b) is that students will necessarily know how individual values are obtained. We dare to say that if students really independently process the calculation of elements of the iterative sequence, they will probably already know their meaning. When creating custom cycles, students must, at least in the end, find out where they need to get to. On the other hand, they do not need to know much about the meaning (graphical, for example) of the used numerical method. It is worth considering whether for students the ability to write their own code that calculate the method is almost as valuable as a thorough understanding of the method. Indeed, if student writes functional code, then he has already mastered most of the technical obstacles and understanding is already within reach.

Exercise 3. In the last demonstration in Maple, we will deal with the numerical solution of ordinary differential equations in the form
$$y' = f(x, y)$$
with the initial condition
$$y(x_0) = y_0.$$
We use the command InitialValueProblem from the package Student[NumericalAnalysis]. Let us note that Maple already has the command dsolve in the base, which can also construct numerical solution, but the command InitialValueProblem is much more suitable for teaching classical methods (Euler's method, Runge-Kutta methods and so on). However, if we wanted to find a high-quality numerical solution to the initial problem $y' = f(x, y)$, $y(x_0) = y_0$, we would use dsolve.

The syntax of the command InitialValueProblem is fairly easy to read with one major exception, which is the choice of method. We specify one particular method as an ordered pair [method, submethod]. If we do not specify submethod, the default one for the given setting of method will be used. Each method has its own default value of submethod. In the official help for the command, we learn which submethods are preset and what we should set if we want to use different method, e.g., for the modified Euler method we have to set method = rungekutta and submethod = meuler. But what we learn in the help to a minimal extent (rather not at all) is what is actually calculated for the selected pair – unfortunately, the name of the method does not always clearly and unambiguously specify the method (the formula). We can immediately ask ourselves whether we really need to know what is being calculated when using the built-in commands, and whether the students need to know this. Whatever the answer is, we think that at the very least teachers should have a good idea of what the command they are teaching actually calculates. Otherwise, it will easily happen that education in numerical methods will be reduced to just learning to alternate different pre-prepared solutions without any inner meaning.

To properly describe and analyze all method settings options (all pairs), i.e., to write which method is used together with the mathematical formula for calculation, would take at least the length of another article. When pairing the setup of pairs (in Maple) with numerical methods supplemented by mathematical formulas, which are e.g. well described in the textbook [13, section 7.2], we cannot avoid the fact that we do not program at least a few steps of the method ourselves. In this text, we analyze only one one-step numerical method. Note that we would sweat a lot more with multi-step methods. If we were to analyze, for example, the method[adamsbashforthmoulton,step$k$], which is a multi-step predictor–corrector method, we would especially have to match the number k with the order of the predictor method and with the number of steps of the predictor method, and further with the order of the corrector method and with the number of steps of the corrector method. Some of the order numbers and number of steps match, but others differ – of course it depends on the definitions, e.g., the meaning of the method order usually differs between the explicit and implicit versions of the method. In addition, with multi-step methods, a one-step method must always be used as a starter (to perform the first steps, when we do not yet have enough values to perform a multi-step method). Fortunately, several mathematical formulas can be found in the official Maple help specifically for this predictor–corrector method, see [14].

In Fig. 3, we only set method = rungekutta. According to the help, it is preset submethod = midpoint. Suppose we do not have a textbook at hand where the midpoint method is described; moreover, even in textbook, the method can be named differently than in Maple. The midpoint method can be easily found on Wikipedia, see [15]. We immediately see mathematical formulas that we can use. However, we do not know if we want the explicit or implicit version: we assume that midpoint in Maple means the more usual explicit version. But beware, below we see "The explicit midpoint method is sometimes also known as the modified Euler method," (in Maple submethod = meuler) a further "Note that the modified Euler method can refer to Heun's method," (in Maple submethod = heun), see [15]. So, are these the same three methods, just specified differently, or are some two different? From the wording of the sentences on Wikipedia, we can conclude that the midpoint method (midpoint setting) and the Heun's method (heun setting) are two different methods, and the only ambiguity is which one is the modified Euler method (meuler setting). How wrong we would be! To make sure our reasoning is correct, let us try using the given formula and see if we get the same result as the one we get using the command InitialValueProblem with the method [rungekutta, midpoint], see Fig. 3.

```
> restart:
> dig := 9:
> with(Student[NumericalAnalysis]):
> DR := diff(y(x),x) = (sin(x)-y(x))/y(x)^2;
```

$$DR := \frac{d}{dx}\,y(x) = \frac{\sin(x) - y(x)}{y(x)^2}$$

```
> x0 := 0:
  y0 := 1:
  b := 3: #endpoint
```

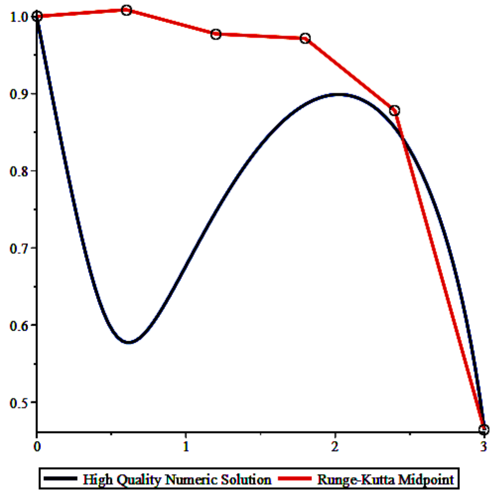
a)

using `InitialValueProblem` command for **Runge–Kutta midpoint method** according to Maple

```
> InitialValueProblem(DR, y(x0) = y0, x = b, method = rungekutta,
  digits = 10):
  y(b) = evalf(%,dig-1);
```

$y(3) = 0.46424060$

```
> InitialValueProblem(DR, y(x0) = y0, x = b, method = rungekutta,
  output = plot, plotoptions = [thickness=3,symbolsize=15]);
```



b)

using the cykle `for` for **Runge-Kutta midpoint method** according to en.wikipedia.org

```
> f := (x,y) -> (sin(x)-y(x))/y(x)^2; #y'=f(x,y)
  h := (b-x0)/5:
```

$$f := (x, y) \rightarrow \frac{\sin(x) - y(x)}{y(x)^2}$$

```
> y[1] := y0 + h*f(x0+h/2,y0+h/2*f(x0,y0)):
  evalf(%,dig);

  for n from 1 to 4 do
    x[n] := x0 + n*h:
    y[n+1] := y[n] + h*f(x[n]+h/2,y[n]+h/2*f(x[n],y[n]));
    print(evalf(%,dig)):
  end do:

  y(b) = evalf(y[n],dig);
  n := 'n':
  x := 'x':
```

0.504718622
0.881875184
0.952991698
0.890038852
0.540197526
$y(3) = 0.540197526$

Fig. 3. Comparison of the two ways of solution using the midpoint method

In Fig 3, by comparison of the blue text with $y(3)$, we can see that the used methods in a) and b) are different. Even the graph in a) clearly says that $y(3)$ is lesser than 0.5 (ignore the different number of decimal places – the numbers from the built-in command are rounded differently for some reason). The graph is definitely one of the biggest advantages of the built-in command. We can create the graph ourselves, but it is inefficient if we mainly want to teach the numerical method.

Let us find out the correct formula for the settting submethod = midpoint. The command *InitialValueProblem* can compare methods. In Fig. 4 we can see that the midpoint method and Heun's method are the same, therefore try to use formula from Heun's method from Wikipedia [16], the result is in Fig. 4, on the right.

c)

comparison of methods and finding the correct method corresponding to the setting `submethod = midpoint`

Attention, we use previously defined variables.

```
> IVP := InitialValueProblem(DR, y(x0) = y0, x = b,
  method = rungekutta, digits = dig-1, output = information,
  comparewith = [[rungekutta,meuler],[rungekutta,heun]]):
  IVP[[1..7],[1,3,5,7]];
```

x	[*R-K Midpt.*]	[*R-K Mod. Euler*]	[*R-K Heun*]
0.	1.	1.	1.
0.60000000	1.0087046	0.50471862	1.0087046
1.2000000	0.97738097	0.88187518	0.97738097
1.8000000	0.97145287	0.95299170	0.97145287
2.4000000	0.87793354	0.89003885	0.87793354
3.	0.46424060	0.54019752	0.46424060

the column *R-K Midpt.* (also *R-K Heun*)

```
> y[1] := y0 + h*(f(x0,y0)+f(x0+h,y0+h*f(x0,y0)))/2:
  evalf(%,dig);

  for n from 1 to 4 do
    x[n] := x0 + n*h:
    y[n+1] := y[n] + h*(f(x[n],y[n])+f(x[n]+h,y[n]+h*f(x[n],y[n])))/2:
    print(evalf(%,dig)):
  end do:
  #according to en.wikipedia.org, this really is Heun's method,
  #but not the midpoint method

  n := 'n':
  x := 'x':
```

1.00870464
0.977380968
0.971452874
0.877933542
0.464240603

Fig. 4. Comparison of the midpoint method, Heun's method and the modified Euler's method

Finally, in Fig. 4, we can see that pairs (methods) [rungekutta, midpoint] and [rungekutta, heun] are the same with formula used in c) and the pair [rungekutta, meuler] is different method with the formula used in b) in Fig 3.

Now we compare the ways of solution. We could already see many advantages and disadvantages from the process of searching for mathematical formulas for methods from Maple. Let us just emphasize that if we were not able to write a simple cycle for to calculate the values, it would be difficult for us to find our way between the methods; the same applies to more complex multi-step methods. This is the clear difference between creating our own solution and strictly using the built-in command InitialValueProblem. For this reason, the second approach might be better for advanced students that are already familiar with Maple and the first approach might serve as an introduction for beginners. In this sense, as teachers, we only have to assess where we are already beyond the scope of what we want to teach, and vice versa, what else we would like to pass on to students. In fact, highlighting potential errors in the software might leave longer lasting impact on students, where they realize not to take everything as granted. Hence, this could lead to enforcement of students' critical thinking processes.

4. Commented Exercises from Statistics Solved in MATLAB

Exercise 4. We will now compare the use of the built-in function and the use of hand-written code using an example from mathematical statistics. Consider the *random samples* $X_1, X_2, \dots, X_k$, where $k \geq 3$, $k \in \mathbb{N}$. Note that each random sample is a *random vector*, i.e., the vector of *random variables* with the same *distribution of probability* (briefly just *distribution*). The assignment of this exercise is to test the null hypothesis

$$H_0\colon \mathrm{med}_1 = \mathrm{med}_2 = \cdots = \mathrm{med}_k,$$

where med_i is the median (50% quantile) for the distribution of X_i for each $i \in \{1,2,\dots,k\}$, against the alternative hypothesis H_1: H_0 does not hold. To test H_0 we use the Kruskal–Wallis test, which is well-known nonparametric test, see [17]. In order to perform this test, we must additionally assume that the random samples are *independent*.

Consider the random samples X_1, X_2, X_3, i.e. $k = 3$, and their realizations

$$\begin{aligned} x_1 &= (55, 54, 58, 61, 52, 60, 53, 65), \\ x_2 &= (52, 50, 51, 51, 49), \\ x_3 &= (47, 53, 49, 50, 46, 48, 50). \end{aligned} \tag{1}$$

Further denote $n_1 = 8$, $n_2 = 5$, $n_3 = 7$, which are dimensions (ranges) of x_1, x_2, x_3, respectively. Note that these values are usually retrieved from a file, but the values in Fig. 5 (a) are entered directly for transparency of this article. Note that the numerical values in (1) were taken from the exercise for Kruskal–Wallis test in [18, page 229].

First, we describe the use of the robust built-in command **`kruskalwallis`** from MATLAB. The input parameter of the command is the matrix in MATLAB of the type 8×3 (having 8 rows and 3 columns) containing the realizations x_1, x_2, x_3 as its columns, missing positions are filled with the symbol **`NaN`** (not a number). As teachers, we recommend that students use a comprehensive output in the form of a table, see Fig 5, variable **`tbl`**. The test can be easily evaluated by using the so-called p-value, which is listed in the last column in the row 'Groups'. It holds $p = 0.0012 < 0.05 = \alpha$, therefore at the significance level α we reject the null hypothesis H_0 in favor of the alternative hypothesis H_1 (this is the formal conclusion of the test). Thus, the testing by using the command **`kruskalwallis`** is quick and effortless. However, we as teachers have to think about whether this is enough for us, or whether we will want more from the students. We usually want to teach things at least in such depth that the students are forced to understand at least roughly "what it is about" and not just repeat teacher's solution. If we decide that we want to teach the internals of the test as well, we must prepare that the robust built-in commands will return different values than the ones we calculate using a sequence of elementary commands according to the formulas from the textbook. The ultimate solution would be to not use the robust command at all and write everything manually. In Fig 5 (b). we present the calculation of p-value, which returns the exactly same number as the command **`kruskalwallis`** from MATLAB. Let us strongly emphasize that getting the same value was difficult. The main problem here and also elsewhere is that the official documentation for the command **`kruskalwallis`**, see [19], usually does not contains explicit formulas for the calculation of the values of the output. Another problem was that the textbook we are using, see [18], does not contain the calculation correction, which in the end was the only one that really caused the difference between our manually obtained value and the value obtained from the command **`kruskalwallis`**.

```
clear
X1=[55 54 58 61 52 60 53 65];
X2=[52 50 51 51 49 NaN NaN NaN];
X3=[47 53 49 50 46 48 50 NaN];
X=[X1',X2',X3'];
[p,tbl,~] = kruskalwallis(X,[],'off');
tbl
```

tbl = 4×6 cell

	1	2	3	4	5	6
1	'Source'	'SS'	'df'	'MS'	'Chi-sq'	'Prob>Chi-sq'
2	'Groups'	466.5857	2	233.2929	13.4117	0.0012
3	'Error'	194.4143	17	11.4361	[]	[]
4	'Total'	661	19	[]	[]	[]

(a)

```
X = [X1',X2',X3'];
R = reshape(tiedrank(X(:)),size(X));
n = sum(~isnan(X));
N = sum(n);
k = size(R,2);
r = sum(R,'omitnan');
q = -3*(N+1)+12/(N*(N+1))*sum((r.^2)./n);
t = groupcounts(rmmissing(X(:)));
c = 1-sum(t.^3-t)/(N^3-N);
p = 1-chi2cdf(q/c,k-1)
```

```
p = 0.0012
```

(b)

Fig. 5. Research calculation description: (a) the values are entered directly for transparency; (b) the calculation of p-value, which returns the exactly same number as the command kruskalwallis from MATLAB.

As the code in Fig. 5 (b) is not transparent enough, we describe the calculation in more detail using mathematical formulas, see [18]. Assuming we already have the 8×3 matrix described above, let us denote it by $\boldsymbol{X}$ (the first, second and third columns are x_1, x_2 and x_3, respectively, not a number otherwise). All $N = n_1 + n_2 + n_3$ values must be sorted, regardless of which sample they belong to. We create the matrix $\boldsymbol{R}$ such that we replace numerical values in $\boldsymbol{X}$ by their order; the order will be described later. The matrix $\boldsymbol{R}$ has the successive columns

$$R_1 = (16, 15, 17, 19, 11.5, 18, 13.5, 20),$$
$$R_2 = (11.5, 7, 9.5, 9.5, 4.5),$$
$$R_3 = (2, 16.5, 4.5, 7, 1, 3, 7).$$

Let us describe the order of the repeating values. The value 50 is repeated three times and these are the seventh, eighth and ninth positions in the simple sorted vector of all numerical values of $\boldsymbol{X}$. However, the order of 50 for the test is 7; it is an arithmetic mean of theirs positions. The realization of the test statistic Q, see [18], is

$$q = \frac{12}{N(N+1)} \sum_{i=1}^{k} \frac{r_i^2}{n_i} - 3(N+1) = 13.331, \tag{2}$$

where r_i is the sum of the values in the vector R_i for $i \in \{1,2,3\}$. The p-value is given by the relation $p = 1 - F(q)$, where F is the distribution function of the Pearson χ^2 distribution with $k-1$ degrees of freedom. By the command **1-chi2cdf(q,k-1)**, where **k=3** and **q** given by the formula (2), we obtain $p = 0.0013$. The result $p = 0.0013$ differs from that in Fig. 5. We must use the correction, which is described, for example, in [19]. Let $\{c_1, c_2, .., c_l\}$ be the set of all numerical values that appear more than once in the matrix $\boldsymbol{X}$. The correction term is

$$c = 1 - \frac{\sum_{i=1}^{l}(t_i^3 - t_i)}{N^3 - N} = 0.994,$$

where t_i is the number of repetitions of c_i for $i \in \{1,2,\dots,l\}$. Clearly, instead of the set $\{c_1, c_2, .., c_l\}$ we can take the set of all values of $\boldsymbol{X}$, since $t^3 - t = 0$ if $t = 1$. For example, if $c_1 = 49$, then $t_1 = 2$, since the value 49 appears once in x_2 and once in x_3. Finally, the p-value is $p = 1 - F(q/c) = 0.0012237$. Note that if all the values in the input realizations are unique, then the correction term c is equal to one 1, and the values

$$p = 1 - F(q) \quad \text{and} \quad p = 1 - F(q/c)$$

are the same.

Finally, let's emphasize that we would never want students to reveal any "secret" formulas for built-in commands. They are not really secret, since MATLAB has accessible source code for each command, but it is indecipherable for an ordinary user (non-programmer). On other hand, if we know the formulas, it is not that hard to construct the matrix $\boldsymbol{X}$ (in MATLAB) or calculate realization q (in MATLAB), see Fig. 6. Each teacher should weigh the pros and cons of both ways of solution; and maybe select some ideal mix of the presented ways. We have to make sure that the student is not left untouched.

5. Conclusions

We solved several exercises in two ways (but using the same method), one way of solving usually relied on one robust built-in command for the used method, and in the other way the method was applied more explicitly by using several elementary commands. Based on these two ways, two corresponding directions of teaching can be distinguished. It could be beneficial to examine how teachers of these and related mathematical disciplines approach these directions. The easiest implementation would probably be using a questionnaire (a survey). The respondents (teachers) would first familiarize themselves with the given exercises in order to have a good understanding of what is involved. Then they would be asked several questions in which it would find out how they teach and which of the partial options (from both ways of solution) seems more appropriate or correct to them. Overall, we suggest using the first approach for broader overview of methods and the second approach for deeper understanding.

Finally, let us point out that the requirements for military students can differ as opposed to civilian students. Furthermore, our results are theoretical in nature and empirical study might be necessary before practical implementation.

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STEM Teaching in Contemporary Education

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Abstract
The education system serves as the primary producer of human capital, responsible for training competent personnel essential for the country's economic progress and rapid technological and economic development. Therefore, the educational standard aims to equip students with knowledge and skills necessary to capitalize on humanity's rapid progress, utilize modern achievements, and become active members of society. Moving beyond passive recipients of knowledge, students should transform into active learners capable of applying acquired knowledge for professional success and societal benefit. The paper explores the objectives of technical and science education, effectively implemented through STEM (Science, Technology, Engineering, and Mathematics), an interdisciplinary practical teaching approach. STEM education empowers children to engage in experiments, make mistakes, and draw conclusions based on personal experiences rather than solely relying on textbook information. This approach fosters active student participation and cultivates competencies such as creative and critical thinking, independent information processing, imagination, and interpretation skills. Moreover, STEM education plays a crucial role in shaping future professions that contribute to national development. While important projects have been implemented within the framework of the Millennium Program of the General Education School of Georgia to train STEM specialists, further efforts are needed. Effective school education and professional personnel training require a conducive school culture, qualified teachers, and abundant educational resources. To address this issue, our research utilized quantitative and qualitative methods, including questionnaire development, literature review, and analysis of international and local projects and training programs. These efforts aim to lay the groundwork for the preparation of STEM specialists. The paper seeks to answer key questions: Who should teach STEM, and how should STEM be taught? By ensuring the education of future generations capable of contributing to the country's economic development, political stability, and security, we aim to foster a prosperous and sustainable society.

KEY WORDS: *STEM education, future professions, interdisciplinary approach, innovative technology, contemporary challenges*

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1. Introduction

The education system functions as the cornerstone of societal development, serving as the principal engine for the cultivation and refinement of human capital. Within this framework, educational institutions play an important role in nurturing individuals with the fundamental knowledge, skills, and competencies to meet the demands of an ever-evolving global landscape. By equipping students with a solid educational foundation, the education system lays the groundwork for their subsequent contributions to various sectors of society, including the workforce, academia, and research and development.

One of the primary responsibilities of the education system is to train competent personnel who are indispensable for driving the nation's economic progress and facilitating rapid technological advancements. These competent individuals serve as the catalysts for innovation, entrepreneurship, and economic growth, thereby propelling the country forward on the path of prosperity and sustainable development.

Through rigorous academic curricula, hands-on learning experiences, and comprehensive skill-building initiatives, educational institutions endeavor to produce a skilled workforce capable of addressing contemporary challenges [11] and seizing emerging opportunities in the global marketplace.

The educational standard aspires to empower students with the requisite knowledge, competencies, and skills essential for navigating and thriving in an era characterized by rapid advancements and transformations across various domains of human endeavor. In recognizing the dynamic nature of contemporary society, educational institutions endeavor to equip learners with the tools and capacities necessary to adapt, innovate, and contribute meaningfully to the collective progress of humanity. Central to this endeavor is the cultivation of a diverse range of knowledge domains, spanning from the sciences and technology to the humanities and arts, thereby fostering a well-rounded and holistic educational experience. By imparting a broad spectrum of knowledge, educational institutions seek to provide students with a comprehensive understanding of the world around them and enable them to engage critically with complex issues and challenges facing society. Moreover, the educational standard emphasizes the acquisition of practical skills and competencies that enable students to harness modern achievements and technologies effectively. From digital literacy and information fluency to critical thinking and problem-solving skills, students are encouraged to develop a versatile skill set that empowers them to leverage the latest tools and resources for personal and collective advancement.

Transitioning from mere recipients of knowledge to active participants in the learning process is paramount in modern education. Rather than passively absorbing information [17] students are encouraged to engage actively with course material, apply critical thinking skills, and seek connections between concepts and real-world contexts [19]. This shift in educational philosophy acknowledges that learning is not merely about memorizing facts but rather about understanding concepts deeply and being able to apply them in diverse situations. Active learning strategies, such as collaborative projects, problem-based learning, and experiential learning activities, are instrumental in fostering student engagement and promoting deeper understanding [12]. Through hands-on experiences and interactive tasks, students have the opportunity to explore concepts in depth, experiment with different approaches, and gain practical skills that are applicable beyond the classroom.

Furthermore, the educational standard aims to instill in students a sense of civic responsibility nurturing their capacity to become active and engaged members of society. By fostering values such as collaboration, empathy, and social awareness, the educational system aims to prepare students to contribute positively to their communities and address societal challenges. In essence, the educational standard is designed to prepare students not only for academic and professional success but also for active participation in civic life. By equipping learners with the knowledge, skills, and values necessary to navigate an increasingly complex and interconnected world, the educational standard lays the foundation for a more inclusive, equitable, and prosperous society.

2. Basic Principles of STEM Education

One of the basic principles of STEM education is the transformation of students into active learners capable of applying acquired knowledge for professional success and societal benefit, accordingly requiring a shift towards active, constructive learning pedagogies, professional skills development initiatives, and opportunities for civic engagement. By embracing these principles, educators can cultivate a generation of empowered and socially conscious individuals who are equipped to make a positive impact on the world. The paper delves into the fundamental goals of technical and science education and examines how these objectives are realized through the implementation of STEM (Science, Technology, Engineering, and Mathematics) education representing a holistic and interdisciplinary approach to teaching and learning that integrates concepts and principles from multiple disciplines to solve real-world problems [10].

At its core, the primary objective of technical and science education is to equip students with the knowledge, skills, and competencies necessary to succeed in an increasingly complex and technology-driven world. This includes cultivating a deep understanding of scientific principles, technological advancements, engineering design processes, and mathematical reasoning [13]. By developing proficiency in these areas, students are better prepared to navigate the challenges and opportunities of the modern workforce and contribute to innovation and progress in various fields [25]. STEM education serves as a conduit for achieving these objectives by providing students with engaging and hands-on learning experiences that bridge the gap between theory and practice. Through project-based activities, experiential learning opportunities, and collaborative problem-solving tasks, students are able to apply their knowledge and skills in authentic contexts and gain a deeper appreciation for the interconnectedness of STEM disciplines [3]. Moreover, STEM education emphasizes the development of critical thinking [4], creativity communication, and collaboration skills [29], which are essential for success in the 21st-century workforce. By encouraging inquiry-based learning and fostering a growth mindset, STEM education empowers students to think critically, explore innovative solutions to complex problems, and work effectively in teams.

The paper aims to shed light on the transformative potential of STEM education in achieving the objectives of technical and science education. By examining the principles, practices, and outcomes of STEM education, we can gain insights into how to prepare students for success in an increasingly interconnected and technology-driven world.

21.1. STEM education promoting lifelong competences

STEM education empowers children by providing with opportunities to engage in hands-on experiments, allowing them to explore scientific concepts firsthand and develop a deeper understanding of the world around them [14]. Through experimentation, students have the freedom to explore, test hypotheses, and make discoveries, fostering curiosity and a sense of wonder about the natural world. Furthermore, STEM education encourages students to embrace failure as an essential part of the learning process. By allowing children to make mistakes and learn from them, STEM education cultivates resilience, perseverance, and problem-solving skills [27]. When students encounter challenges or setbacks during experiments, they are encouraged to analyze their mistakes, revise their approach, and try again, reinforcing the idea that failure is not a deterrent but rather an opportunity for growth and learning.

Moreover, STEM education emphasizes the importance of drawing conclusions based on personal experiences and empirical evidence rather than relying solely on textbook information. Through STEM education, children learn to approach problems with curiosity, creativity, and an open mind, preparing them to tackle the complex challenges of the 21st century. By fostering a culture of experimentation, resilience, and critical thinking, STEM education equips students with the skills and mindset necessary to thrive in an ever-changing world. This approach to STEM education fosters active student participation by encouraging students to take an active role in their own learning process [25]. Instead of passively receiving information from teachers, students are actively engaged in hands-on activities, experiments, and projects that require them to think critically, solve problems, and collaborate with their peers [12]. Through active participation in STEM activities, students develop a range of competencies that are essential for success in the 21st century. One of the key competencies cultivated by STEM education is creative thinking. By engaging in open-ended tasks and projects, students are encouraged to think outside the box, explore alternative solutions, and come up with innovative ideas. Creative thinking skills enable students to approach problems from multiple perspectives, leading to more innovative and effective solutions.

In addition to creative thinking, STEM education also cultivates critical thinking skills [21]. Students learn to analyze information, evaluate evidence, and make reasoned judgments based on evidence. Critical thinking skills enable students to question assumptions, challenge existing ideas, and develop well-reasoned arguments. By honing their critical thinking skills, students become more discerning consumers of information and empowered to become independent thinkers and lifelong learners, better equipped to navigate the complexities of the modern world.

STEM education also promotes independent information processing skills. Through research projects and inquiry-based learning activities, students learn how to gather, evaluate, and synthesize information from multiple sources [16]. They develop the ability to think critically about the reliability and validity of information, discerning between fact and opinion, and making informed decisions based on evidence.

Furthermore, STEM education encourages the development of imagination and interpretation skills. Students are encouraged to explore their creativity, think imaginatively, and envision new possibilities [23]. They learn to interpret data, analyze patterns, and make connections between different concepts and disciplines. Imagination and interpretation skills enable students to see the world in new ways, fostering a sense of curiosity and wonder about the world around them.

STEM education promotes practicability, nurturing a mindset focused on real-world application rather than abstract theory. By emphasizing hands-on learning experiences and project-based activities, STEM education encourages learners to become creators and innovators, actively engaging in the design and development of solutions to complex problems [9]. This approach fosters a culture of experimentation and exploration, empowering individuals to apply their knowledge and skills in practical ways to address societal challenges and drive positive change. Ultimately, STEM education cultivates a generation of progressive doers who are equipped to make meaningful contributions to society through their ingenuity, creativity, and problem-solving abilities.

Thus, STEM education grows future professionals who are equipped with the interdisciplinary skills and knowledge needed to thrive in a rapidly evolving world [28]. By integrating science, technology, engineering, and mathematics disciplines, STEM education prepares individuals to tackle complex challenges and seize opportunities in diverse fields such as healthcare, engineering, computer science, environmental science, renewable energy, and environmental sustainability. Through collaborative projects and real-world applications, STEM learners develop critical thinking, communication, and teamwork skills essential for success in the global workforce. Moreover, STEM education fosters a spirit of innovation and entrepreneurship, empowering individuals to drive economic growth, fuel technological advancement, and shape the future of industries and societies worldwide.

21.2. STEM promoting future professions

In today's rapidly evolving technological landscape, the demand for skilled STEM professionals is increasing across industries. STEM education ensures that students are well-prepared to meet this demand and excel in the careers of the future. For example, advancements in fields like artificial intelligence, robotics, and biotechnology require a workforce with strong STEM backgrounds to drive innovation and address complex challenges. STEM education fosters a culture of innovation and entrepreneurship, empowering students to develop new technologies, products, and solutions that address societal needs and drive economic growth. By encouraging students to think creatively, take risks, and pursue their ideas, STEM education nurtures the next generation of innovators and leaders who will shape the future of their industries and communities. Overall, STEM education is essential for building a skilled workforce, driving innovation, and fostering economic development in the 21st century [1]. By preparing students for careers in high-demand fields and empowering them to become innovators and problem solvers, STEM education lays the foundation for a prosperous and sustainable future.

3. Methodology

To address the challenges and complexities surrounding STEM education and the preparation of STEM specialists, our research employed a comprehensive methodology that combined quantitative and qualitative approaches. Quantitative methods were utilized to gather numerical data and statistical insights, providing a quantitative understanding of various aspects related to STEM education. These methods included the development and administration of questionnaires to gather data from stakeholders such as students, teachers, and policymakers.

Within a study, 20 public and private school principals, 80 teachers, and 200 pupils and BSU students were interviewed. In addition to quantitative methods, qualitative approaches were employed to gain deeper insights into the subjective experiences, perceptions, and motivations of individuals involved in STEM education. This involved conducting literature reviews to explore existing research, theoretical frameworks, and best practices in STEM education. The literature review process involved synthesizing findings from a diverse range of sources, including academic journals, books, reports, and policy documents, to inform our understanding of the current landscape of STEM education and identify gaps or areas for further exploration. Furthermore, qualitative analysis techniques were applied to analyze data collected from international and local projects and training programs in the field of STEM education. By examining program evaluations, and qualitative research findings, we sought to identify promising practices, innovative approaches, and challenges encountered in the implementation of STEM initiatives.

The qualitative analysis helped to contextualize our findings within the broader educational landscape and provided valuable insights into effective strategies for preparing STEM specialists. Overall, our research efforts aim to lay the groundwork for the preparation of STEM specialists by employing a rigorous and multidimensional research methodology. By integrating quantitative and qualitative methods, conducting thorough literature reviews, and analyzing real-world examples, we sought to generate actionable recommendations and evidence-based insights to inform policy, practice, and future research in the field of STEM education.

The paper seeks to answer key questions: Who should teach STEM, and how should STEM be taught? In addressing these questions, our paper delves into the multifaceted nature of STEM education and the diverse roles of educators in facilitating effective learning experiences for students. One key consideration is the qualification and expertise of teachers in the STEM disciplines. We explore the qualifications, training, and professional development opportunities necessary for the effective implementation of STEM teaching. This includes discussing the importance of content knowledge, pedagogical skills, and technological proficiency in preparing teachers to deliver high-quality STEM instruction.

4. Research Findings

The research conducted with school principals provided the following insights. Regarding the first question on What is STEM education? The directors provided the following responses: “STEM refers to the integrated teaching of science, technology, engineering, and mathematics”; “STEM is the core of integrated learning”;” The integrated teaching of various subjects encompasses the following fields: natural science, technology, engineering, and mathematics”; “STEM education involves developing research skills and promoting project-based learning in students from an early age”.

Who should teach STEM? According to the interviewed principals, 40% believe that STEM should be taught by mathematics teachers, 20% by physics teachers, and the remaining 40% considers it should be taught by other educators.

Does your school conduct STEM teaching? The majority of respondents, 18 principles, stated that STEM is not taught at school at all. Others admired that it is taught through project-based learning or partially, while integrating it into the teaching of various subjects.

Should technology, engineering, and programming be taught in contemporary schools? If so, how? The responses were as follows: "As desired”; "Yes, an appropriate space and a specialist should be allocated to ensure the inclusion of students interested in this direction in research projects”.

What are some ways generating interest in STEM education and engaging students in STEM subjects? The principals provided the following responses: employing professional teachers, encouraging students through the implementation of projects tailored to their interests in science, technology, or related fields, and ensuring schools are equipped with appropriate infrastructure.

To the question - what is needed for Georgia to provide transition from a consumer of technology to a producer? We received the following responses from the directors: "The authorities should invest more money in education”; "Promoting interest in STEM education and student engagement in STEM subjects”; "It is necessary at the state level to begin opening appropriate enterprises and employment opportunities for the population, which will increase interest in this field”.

When asked which is the most effective methodology for teaching STEM subjects in the modern educational space, the respondents named: Interesting activities, Project-based learning, Inquiry-based learning, Differentiated teaching, Experiments for STEM literacy development, Inquiry-based learning, among others.

In response to the question about the attitude of teachers/students towards STEM education, the principals noted: “Neutral”; “Positive”; “Teachers' attitudes toward STEM education may vary based on many factors, including culture, socioeconomic status, education, personal interests, and perceived desire for resources and knowledge. Consequently, students may also show less interest in this direction”.

The directors' answer to the question: How do socioeconomic factors affect access to quality STEM education? "Socioeconomic factors have a 100% impact", "They directly affect", "Official-economic factors can significantly affect access to quality STEM education in several ways, primarily through financial resources, school funding inequality, and parents' involvement and education. If the school is provided with all the necessary resources, the quality will be high, but unfortunately, there is no proper infrastructure in the schools."

What challenges do educators face when implementing project-based learning in STEM subjects?" Teachers find it difficult to work with technologists"; "Technological resources and their correct use"; "It is important that teachers used various modern methods, project-based teaching, etc."; "Teachers do not have the necessary resources and space to implement projects, and it is necessary to integrate different subjects"; "They don't have the appropriate environment, laboratory or infrastructure."

The survey conducted with teachers provided the following responses to the question - What is STEM education? What does STEM mean? Some teachers mentioned: "STEM stands for Science, Technology, Engineering, and Mathematics"; "STEM is about joint teaching and integration of different subjects"; "It is a teaching method that combines subjects such as physics and mathematics"; "STEM focuses on learning science, technology, engineering, and mathematics so that students can relate what they have learned to everyday life and future plans. This enables them to see the practical significance and be able to apply these concepts".

To the question - Who should teach STEM? 60% of the surveyed teachers named the physics teacher, 20% named the math teacher, and 20% mentioned - others.

To the question - Is STEM taught in your school? 80% of the respondents answered "no", 5% stated that it is taught in the form of projects, and 15% mentioned that it is integrated into daily learning and used in the teaching process, as well as in the format of informal education within various activities.

To the question - What is needed in order for students to be interested in STEM education? Some of the respondents consider: technologies and innovative approaches, raising awareness, interest in demonstration lessons in laboratories, increasing the level of awareness in school communities.

What challenges do educators face in implementing project-based learning in STEM subjects? We received the following answers: one challenge is the competence to use technologies, as students may have difficulty understanding the essence of the project and working on it. Additionally, educators often face the challenge of insufficient resources.

Should STEM be taught in modern schools? Almost 98% of respondents confirmed the need to teach STEM.

How can STEM be integrated into education to improve learning outcomes? The teachers suggested the following option: by embedding it into projects, technology can be taught from elementary school. This approach will undoubtedly create a strong foundation for the future in all the mentioned areas, despite the challenges faced in its implementation. 10% of respondents stated that they do not know.

What is needed for Georgia to promote transition from being a consumer to a producer of technology? According to the interviewed teachers, it requires having adequate technology resources and teaching the meaning and essence of production from the primary level. Additionally, training teachers and providing relevant services from the primary level, along with appropriate technological and internet support for schools, are essential.

The results of a survey conducted among pupils and students. When asked, "What is STEM education?" 40% of the respondents answered, "I don't know." 15% mentioned "engineering and mathematics," another 15% described it as "a chance to deepen their knowledge of science and technology," and 30% stated that "STEM education is an innovative teaching method that considers the integrated teaching of science subjects, which in turn is focused on practical teaching."

The comments of some students regarding the mentioned question:"STEM is a set of academic disciplines whose teaching has a special role in the development of a child's technical skills"; "STEM provides a paradigm shift in early childhood education and seeks to sustain children's curiosity and genius into adulthood"; "STEM education is a branch of pedagogy that is adapted to the younger generation and helps to increase motivation in children. It is focused on practical teaching, which contributes to the development of the student; "STEM education involves combining 4 scientific subjects with modern approaches and all the subjects that a child needs";"STEM education includes creativity, development in many aspects. A chance to deepen the knowledge of science and technology"; "It is a teaching method in which subjects are taught sequentially and not in isolation. It focuses on bridging the learning gap by placing children at the center of the experience, turning them into active learners and not passive listeners"; "STEM education is an innovative method of teaching that considers the integrated teaching of science subjects, which in turn is focused on practical learning"; "STEM offers a paradigm shift in early childhood education, aiming to sustain children's curiosity and ingenuity into adulthood."

To the question - What subjects does STEM include? 30% of the surveyed respondents state that they do not know; 15% mentioned Science, technology, engineering, and mathematics (STEM); 15% cited mathematics, physics, chemistry, engineering; 10% referred to biology, physics, chemistry; 15% mentioned information technologies, engineering, natural sciences, and mathematics; 5% specified mathematics, physics, chemistry; 10% indicated "STEM means technology, engineering, mathematics, and science (including social sciences: psychology, economics, sociology).

Does your school teach STEM? 35% of respondents stated – No; 25% mentioned "science subjects are taught separately, not integrated "; 20% responded yes, STEM is taught at my school. I think this is a new teaching method that should be in every school because it is very necessary in the 21st century; 20% indicated it is taught through projects conducted in different subjects.

Should technology, engineering, and programming be taught in a modern school? How should it be taught? We received the following responses: "Yes, it should be taught." This should be done using modern technologies and systems"; "These subjects must be taught by a competent teacher who knows the subject well"; "There should be a dedicated class for STEM because it involves practical teaching"; "Yes, studying technological subjects is necessary because our modern world demands it"; "The 21st century is the era of technology, where subjects like engineering, programming, and technology should be taught from an early age"; "Definitely, it should be taught by qualified teachers, and students should understand the purpose and significance of their studies"; "Complex subjects should not be taught at school. School is a place to establish an elementary foundation"; "I believe that STEM should become an integral part of the school curriculum; it equips students with fundamental knowledge in the fields of science"; "Yes, it should be taught at least at a basic level"; "Yes, solely studying theories cannot motivate students as much as practical activities. Through practical application, students can understand and engage with the subject matter more profoundly"; "It should be taught practically, tailored to the students' interests, with the aim of fostering their development and discovering new possibilities within them"; "Of course, it should be taught. These professions are the professions of the future, so it is essential to master them from a young age"; "Yes, not with theoretical material but with practical work, because it's boring to learn only theory. It will be more interesting to learn STEM by doing."

As the research showed, most of the interviewees do not have information about STEM education as it is conducted just in 2 private schools in Batumi. Some of the respondents believe that STEM includes engineering, mathematics, programming, technology, and physics. Others believe that it involves integrating chemistry, biology, and mathematics. Students reveal the knoledeg of STEM teaching foundations.

The analysis of the qualitative and quantitative research results showed us that STEM should become an integral part of the school curriculum, providing students with fundamental knowledge and preparing them for practical life in the future.

5. Recommendations for Educational Environment Promoting STEM Education

Research findings highlights the need to train teachers with appropriate STEM competence.While significant strides have been made through initiatives like the Millennium Program of the General Education School of Georgia to train STEM specialists [15], there remains a pressing need for further efforts to fully realize the potential of STEM education. Despite the progress achieved, challenges persist in ensuring equitable access to quality STEM education, fostering a supportive learning environment, and addressing gaps in teacher preparation and professional development.

To facilitate the effective teaching of STEM education, the article outlines activities and initiatives aimed at enhancing the effectiveness of STEM education programs:

1. Curriculum Development: Regular review and updating of STEM curricula to align with evolving industry needs and technological advancements.
2. Teacher Training and Support: Providing comprehensive training programs and ongoing support for STEM educators to ensure they have the necessary skills and resources to deliver high-quality instruction.
3. Student Engagement: Implementing innovative teaching methods and extracurricular activities to engage students and foster their interest in STEM fields from an early age.
4. Community Engagement: Collaborating with local communities, businesses, and organizations to create hands-on learning experiences and real-world applications of STEM concepts.
5. Technology Integration: Leveraging technology tools and resources to enhance teaching and learning experiences, including virtual labs, and interactive simulations.

By prioritizing these activities and initiatives, stakeholders can build a strong foundation for STEM education and prepare the next generation of innovators and problem solvers.

STEM students need to develop proficiency in a wide range of subjects to succeed in their academic pursuits and future careers. Some of the key subjects include:

1. Science: Understanding fundamental scientific principles, conducting experiments, and analyzing data across disciplines such as biology, chemistry, physics, and environmental science.
2. Technology: Mastering technological tools and platforms, coding languages, and software applications to solve problems, design solutions, and innovate in fields like computer science, engineering, and information technology.
3. Engineering: Applying mathematical and scientific principles to design, build, and test structures, machines, systems, and processes in areas such as civil engineering, mechanical engineering, electrical engineering, and aerospace engineering.
4. Mathematics: Developing strong mathematical reasoning, problem-solving, and analytical skills to tackle complex problems and models in fields like algebra, calculus, geometry, statistics, and data analysis.

To support STEM education in secondary and higher schools, a variety of programs and initiatives should be introduced, including:

1. Project-Based Learning (PBL): Implementing hands-on, inquiry-based projects that allow students to explore real-world problems, collaborate with peers, and apply STEM concepts in authentic contexts.
2. STEM Clubs and Competitions: Establishing extracurricular clubs and participating in competitions like robotics challenges, science fairs, and coding competitions to foster student interest and engagement in STEM fields.
3. Career Exploration Programs: Providing opportunities for students to interact with STEM professionals, visit workplaces, and participate in internships or job shadowing experiences to gain insight into potential career paths and industry expectations.
4. Maker Spaces and Innovation Labs: Creating dedicated spaces equipped with tools, materials, and technology for students to design, prototype, and test their ideas, fostering creativity, experimentation, and entrepreneurship.
5. Professional Development for Teachers: Providing ongoing training, workshops, and resources for educators to stay updated on the latest pedagogical approaches, technology tools, and content knowledge in STEM disciplines.

By implementing these programs and initiatives, educational institutions can create a dynamic learning environment that inspires curiosity, cultivates critical thinking, and prepares students for success in STEM fields and beyond. By building upon the foundation established by existing STEM initiatives and committing to ongoing collaboration and investment, educational experts can work together to address the challenges and opportunities associated with STEM education.

5.1. STEM teachers equipped with diverse range of competences

Central to the success of any educational endeavor are qualified and competent teachers who possess the knowledge, skills, and pedagogical expertise necessary to facilitate student learning effectively. STEM teachers play a vital role in preparing students for success in today's rapidly evolving world. To effectively teach STEM subjects and inspire students' interest in these fields, STEM teachers require a unique set of skills and competencies. Some key skills and competencies for STEM teachers include:

1. Content Knowledge: STEM teachers must have a strong foundation in the subject areas they teach, including deep knowledge of scientific principles, mathematical concepts, engineering principles, and technological applications. They should stay updated on advancements in their respective fields to provide students with accurate and relevant information.
2. Interdisciplinary Thinking: STEM education emphasizes the integration of concepts from multiple disciplines. STEM teachers should have the ability to make connections across different subject areas and demonstrate how concepts in science, technology, engineering, and mathematics are interconnected.
3. Problem-Solving Skills: STEM teachers should be skilled in problem-solving techniques and be able to guide students through the process of identifying, analyzing, and solving real-world problems using scientific inquiry and mathematical reasoning. They should encourage students to think critically and creatively to develop innovative solutions.
4. Hands-On and Inquiry-Based Learning: STEM education often involves hands-on, experiential learning experiences that allow students to explore STEM concepts through inquiry and experimentation. STEM teachers should design engaging and interactive lessons that encourage active participation and foster a spirit of curiosity and exploration.
5. Technology Integration: Technology plays a significant role in STEM education. STEM teachers should be proficient in using various digital tools, software applications, and multimedia resources to enhance instruction, conduct simulations and virtual experiments, and facilitate collaborative learning experiences.
6. Innovative Thinking: STEM teachers should cultivate a culture of innovation in the classroom by encouraging students to think creatively, explore new ideas, and approach problems from multiple perspectives. They should provide opportunities for students to brainstorm, experiment, and take risks in their learning process. By fostering an atmosphere of innovation, STEM teachers empower students to develop the confidence and resilience needed to tackle complex challenges and propose novel solutions.
7. Communication Skills: Effective communication is essential for STEM teachers to explain complex concepts, facilitate discussions, and provide feedback to students. They should be able to communicate clearly and effectively both verbally and in writing, adapting their communication style to meet the needs of diverse learners.
8. Critical Thinking and Analytical Skills: STEM teachers should foster students' critical thinking skills by challenging them to analyze data, evaluate evidence, and draw logical conclusions. They should encourage students to ask questions, explore multiple perspectives, and think critically about scientific phenomena and mathematical problems.
9. Collaboration and Teamwork: STEM education often involves collaborative projects and teamwork. STEM teachers should facilitate opportunities for students to work together in groups, communicate effectively, and collaborate on complex tasks and projects that require interdisciplinary approaches.
10. Continuous Learning and Professional Development: STEM fields are constantly evolving, and STEM teachers should engage in ongoing professional development to stay updated on current trends, research findings, and best practices in STEM education. They should be open to learning new instructional strategies, technologies, and pedagogical approaches to enhance their teaching effectiveness.

Overall, effective STEM teachers possess a diverse range of skills and competencies that enable them to engage, inspire, and empower students to become critical thinkers, problem solvers, and innovators in STEM disciplines. By nurturing students' interest and proficiency in STEM subjects, STEM teachers play a crucial role in preparing the next generation of scientists, engineers, technologists, and mathematicians to address global challenges and drive positive change in the world.

5.2. Educational resources creating enriching environment

The availability of abundant educational resources is essential for creating engaging and enriching learning environments. These resources may include textbooks, laboratory equipment, digital learning tools, multimedia resources, and access to educational technology. In addition to the mentioned resources, effective STEM teaching also requires access to a variety of supplementary materials and support systems that facilitate hands-on learning, collaboration, and real-world application of concepts. Here are some other resources that are crucial for effective STEM teaching:

STEM Kits and Materials: Teachers need access to specialized STEM kits and materials that allow students to engage in hands-on experimentation and exploration. These kits may include robotics kits, engineering design materials, 3D printers, circuitry components, and renewable energy kits. Having access to such materials enables students to apply theoretical concepts in practical, tangible ways, fostering deeper understanding and retention of STEM principles.

STEM Curriculum Resources: Well-designed STEM curriculum resources provide teachers with a structured framework for delivering engaging and rigorous instruction across STEM disciplines. These resources may include lesson plans, project ideas, assessment tools, and alignment to academic standards. A comprehensive STEM curriculum ensures that teachers have a roadmap for covering essential content while also fostering inquiry-based learning and critical thinking skills.

By ensuring access to a diverse range of educational resources educators can create dynamic and impactful STEM learning environments that inspire curiosity and creativity in students.

5.3. STEM education foundation of future professions

Education plays significant role in shaping the socio-economic landscape of nations by equipping individuals with the knowledge, skills, and competencies needed to thrive in a rapidly changing world. A well-educated workforce is essential for driving innovation, fostering entrepreneurship, and fueling economic growth [5]. By investing in STEM education, we empower individuals to harness the power of science, technology, engineering, and mathematics to address complex challenges and seize opportunities for advancement. STEM education plays an important role in preparing innovative individuals for a wide range of professions across various sectors [2], [8], [22]. Professions that are directly linked to STEM education:

Software Developer: STEM education provides the foundation for mastering programming languages, software development methodologies, and computational thinking skills required for designing, developing, and maintaining software applications, systems, and platforms.

Engineer (Civil, Mechanical, Electrical, Aerospace, etc.): STEM education equips individuals with the knowledge of mathematics, physics, and engineering principles necessary for designing, building, and testing infrastructure, machinery, electrical systems, aircraft, spacecraft, and more.

Biomedical Scientist or Researcher: STEM education offers the scientific background needed to conduct research, analyze data, and develop solutions in fields such as biology, biochemistry, pharmacology, and biomedical engineering to address medical challenges, develop new treatments, and improve healthcare outcomes.

Data Scientist/Analyst: STEM education provides the analytical and statistical skills required to interpret and analyze large datasets, derive insights, and make data-driven decisions across various industries, including finance, healthcare, marketing, and technology.

Physicist or Astronomer: STEM education lays the groundwork for understanding the fundamental principles of physics and astronomy, enabling individuals to explore the nature of the universe, conduct research, and contribute to advancements in fields such as astrophysics, cosmology, and particle physics.

Chemical Engineer or Chemist: STEM education fosters an understanding of chemistry, chemical engineering principles, and laboratory techniques essential for developing new materials, pharmaceuticals, chemicals, and processes to address environmental, industrial, and societal challenges.

Environmental Scientist or Engineer: STEM education provides the knowledge and skills necessary to study the environment, assess environmental impacts, and develop sustainable solutions to mitigate pollution, conserve natural resources, and address climate change.

Mathematician or Statistician: STEM education cultivates proficiency in mathematical reasoning, problem-solving, and statistical analysis, enabling individuals to pursue careers in academia, research, finance, insurance, and data science.

Robotics Engineer or Technician: STEM education offers the technical expertise needed to design, build, program, and operate robotic systems used in manufacturing, healthcare, agriculture, exploration, and other industries.

STEM Educator or Curriculum Developer: STEM education prepares individuals to teach and inspire the next generation of scientists, engineers, and innovators by developing engaging curriculum, hands-on activities, and inquiry-based learning experiences that foster curiosity, critical thinking, and problem-solving skills.

These professions represent just a fraction of the diverse career opportunities available to individuals with a background in STEM education. From technology and healthcare to energy and sustainability, STEM disciplines play a crucial role in driving innovation, economic development, and global progress.

5.4. STEM education – investment in future stability

Education serves as a catalyst for stability and social cohesion by promoting civic engagement. It plays a crucial role in promoting peace and security within a country and among the nations [6]. By investing in education, we invest in the future stability and security of our societies, paving the way for a more harmonious and peaceful world. As the national security depends on the strength of the nation's economy. The vibrancy of that economy depends on the advancements in science and engineering. Similarly, the ability of the nation's military to prevail during the conflicts in different missions depends heavily on continued advances in the technology base. A workforce with robust STEM capabilities is critical to sustaining a nation's technological advancement and innovation, which are essential for maintaining a competitive edge in the global landscape [20]. STEM education can significantly contribute to the safety and security of a nation [18]in several ways:

Technological Innovation: STEM fields drive technological innovation, leading to the development of advanced security systems, surveillance technologies, and defense mechanisms. Innovations in areas such as cybersecurity, biometrics, and data analytics enhance the ability of security agencies to detect and prevent threats to national security.

Critical Infrastructure Protection: STEM professionals, including engineers and computer scientists, play a vital role in designing and safeguarding critical infrastructure such as transportation networks, energy grids, and communication systems. By implementing robust security measures and utilizing advanced technologies, they help protect these essential assets from cyber-attacks, natural disasters, and other risks.

Defense and Military Technology: STEM expertise is essential for the development and deployment of defense and military technologies [7] including weapons systems, aircraft, and unmanned aerial vehicles (UAVs). Research and innovation in defense-related STEM fields enhance national defense capabilities and strengthen deterrence against potential threats.

Emergency Preparedness and Response: STEM education equips individuals with the knowledge and skills needed to respond effectively to emergencies and natural disasters. Professionals in fields such as engineering, environmental science, and emergency management develop contingency plans, design resilient infrastructure, and coordinate disaster response efforts to mitigate the impact of emergencies on public safety and security.

Cybersecurity and Information Assurance: In an increasingly digital world, cybersecurity is paramount for protecting sensitive information, critical infrastructure, and national interests. STEM professionals specialized in cybersecurity develop advanced encryption methods, intrusion detection systems, and threat intelligence solutions to safeguard digital assets and prevent cyber-attacks from hostile actors.

Health Security and Biodefense: STEM expertise is essential for addressing public health threats and bioterrorism risks. Scientists and researchers in fields such as microbiology, epidemiology, and bioinformatics work to identify and mitigate infectious diseases, develop vaccines and medical countermeasures, and strengthen healthcare systems to respond to biological threats effectively.

Thus, by nurturing STEM talent and investing in STEM education and research, nations can enhance their capabilities to address emerging security challenges, protect their citizens, and promote stability and resilience in an increasingly complex and interconnected world.

6. Conclusion

Overall, the education system serves as a catalyst for societal progress and development, playing a crucial role in shaping the future trajectory of nations. Through its multifaceted endeavors, the education system nurtures human capital, fosters innovation and creativity, and fosters a culture of lifelong learning and continuous improvement, thereby laying the foundation for a prosperous and sustainable future. The paper provides insights and guidance on the effective teaching of STEM subjects by addressing the complex interplay of educator qualifications, instructional approaches, and learning environments. By prioritizing education and investing in STEM teaching methodologies, we can empower individuals to become active agents of change and contribute to the prosperity, stability, and sustainability of society. By equipping future generations with the knowledge, skills, and values needed to address global challenges and seize opportunities, we can build a brighter future for all.

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Challenges to Senior Professional Military Education. Observations from the Baltic Defence College

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Abstract

The paper discusses the main observations of the Higher Command Studies Course as a senior professional military education program at the Baltic Defence College, relating them to ongoing debates. It draws upon data from publicly available sources. The Higher Command Studies Course faces challenges similar to most of its Western counterparts. However, the unique ownership structure of the BALTDEFCOL, the curriculum of the course, and its faculty provide flexibility and responsiveness. These findings may be used to inform the debates on senior professional military education.

KEY WORDS: *Professional military education; PME; senior level; Baltic Defence College; BALTDEFCOL, Higher Command Studies Course*

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1. Introduction

The 2018 National Defense Strategy instigated a contentious debate regarding professional military education within the United States, critically evaluating how well it could achieve its stated goals. In this recent discussion on professional military education, a spectrum of perspectives, opinions, and recommendations has been offered, all aimed at enhancing the quality of graduates' preparation for subsequent assignments, refining the scope and methods of educating officers at successive levels of development, and assessing student performance. Numerous stakeholders have engaged in discussions concerning the structure and effectiveness of military educational institutions. Many evaluations and suggestions have been put forth within these discussions, focusing on intricate aspects such as curriculum content, teaching methodologies, assessment techniques, and more. While much attention has been devoted to scrutinising the structure and efficacy of US military educational institutions, there exists a notable dearth of contemporary research on European equivalents, often relying on outdated sources. This study seeks to address this gap by critically examining the current landscape of senior professional military education and sharing relevant observations from experiences at the Baltic Defence College.

The ongoing debate pertains specifically to senior professional military education, which aims to equip senior officers and their civilian counterparts with the skills necessary for strategic-level responsibilities. Politicians and government officials cooperating with the military have acknowledged the complexity of challenges inherent at this level. In the United States, congressional representatives have noted a gap in professional military education, observing that while it effectively prepares officers for joint operations, it falls short in fostering cooperation at the strategic level with politicians who often lack historical context and cultural insight. While recent institutional efforts have been made to enhance the synergy between senior professional military education and lower-tier levels of education within individual branches of armed forces, tangible outcomes are likely to materialise only in the foreseeable future. The renewed emphasis on NATO's fundamental mission of collective defence and deterrence underscores the heightened significance of adequately preparing officers at all levels of professional military education. This imperative pertains to the quantity and quality of graduates at every tier of professional military education. Given the diminishing expertise in high-intensity warfare within Allied militaries over recent decades, a clear requirement exists to realign professional military education to address the evolving security environment more effectively. This necessity extends beyond the United States and encompasses all Allied nations in Europe.

This research employs a critical analysis of official documents, academic research, and ongoing debate surrounding senior professional military education. It seeks to bridge insights from this discourse with solutions implemented at the Baltic Defence College.

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A key focus was comparing observations and recommendations from the Western educational community, particularly the U.S. military educational community, with those specific to the Baltic Defence College. The retrospective scope of this study is confined to the past decade, although earlier data was utilised to contextualise assessments related to the researched period. The research draws upon data extracted from publicly available documents, academic research, and inputs shared within communities of practice.

2. Institutional Perspectives on Professional Military Education in the United States

A critical assessment of the state of the U.S. PME in the National Defence Strategy 2018 took place just a few years after the U.S. Congress issued a report on the long-term transformation of the education system for the needs of joint forces. The Congressional report "Another Crossroads? Professional Military Education Two Decades After the Goldwater-Nichols Act and the Skelton Panel" assessed that the "PME system was still basically sound." Nevertheless, some aspects of professional military education were identified as requiring improvement. The report pointed to two main areas: systemic and institutional issues. The first referred to the conceptual framework of education, the competencies and skills of graduates at various levels of education, and its role in shaping the professional development of officers. The report revealed, among other things, a lack of a complete correlation between obtaining a specific education and being assigned a respective military position. Cultivating strategists was considered unsatisfactory, and it was concluded that PME does not play a fundamental role in shaping strategists. The report noted progress regarding the qualitative content and delivery of the PME and improvements to rigour. The Subcommittee found that PME curricula adapt at differing but generally appropriate levels to new demands while retaining suitable emphases on the enduring subjects of history and strategy. The need for senior leaders to maintain ownership of PME was underlined (Committee on Armed Services, 2010). To sum up, it must be noted that the above report provided a balanced view of the PME's measurable achievements and identified potential areas for improvement.

The conclusions of the congressional report remain in stark contrast with claims included in the 2018 National Defense Strategy. Its summary states that PME has "stagnated" and "focused more on exercising mandatory credit at the expense of lethality and ingenuity." In the light of previous assessments of the Congress, the conclusions included in the national defence strategy seem excessively critical and characterised by the beliefs of the then Secretary of Defense. Although this first sentence resonated widely in military circles, the strategy also discussed other problems related to PME. It emphasised "intellectual leadership and military professionalism in the art and science of warfighting" (U.S. Department of Defense, 2018). One may speculate that the personal experience and preferences of the Secretary of Defense Gen. (ret.) James Mattis led to an emphasis in the strategy on the value of deepening knowledge of history. However, it put history on equal footing by embracing new technology and techniques to better prepare officers to counter competitors. Independence of action in warfighting concepts was praised as a prerequisite to lessen the impact of degraded/lost communications in combat. Finally, the 2018 National Defense Strategy highlighted the role of PME as a strategic asset to build trust and interoperability across the Joint Forces and with allied and partner forces. PME was viewed along with talent management, which was supposed to develop leaders competent in national-level decision-making. The strategy acknowledged that it would require broad revision of existing policies for talent management among the Armed Services. It listed, among other things, fellowships, civilian education, and assignments that increase understanding of interagency decision-making processes, as well as alliances and coalitions as possible ways to manage talent. The concerns voiced in the National Defense Strategy 2018 were reflected by the Joint Chiefs of Staff in their document "Developing Today's Joint Officers for Tomorrow's Ways of War. The Joint Chiefs of Staff Vision and Guidance for Professional Military Education & Talent Management," which was published in May 2020 (Joint Chiefs of Staff, Vision, 2020).

2. The ongoing debate on the senior professional military education

Problems of professional military education have been discussed in recent decades by a relatively small group of researchers, usually directly associated with PME institutions. References to education are also present in publications and speeches of practitioners in the field of security and defence, including politicians, government officials and active or retired officers. In most cases, the debate revolved around the U.S. professional military education system and was mainly attended by U.S. specialists. A limited group of people with expressive views published subsequent articles in specialised military or academic periodicals, and the discussion revolved around traditional topics related to PME – the role of professional military education, model curricula, and delivery of educational programs. It required some effort to follow this debate as it was niche and low profile (Cieślak, 2018). The situation changed in 2018 when a critical assessment of U.S. military education in the newly published U.S. National Security Strategy reinvigorated a heated discussion on professional military education. The debate was important because it engaged a broad group associated with military education. What's more, the presented views, opinions, and assessments proposed detailed systemic and institutional solutions that were used in officer education or should, in the authors' opinion, be applied in professional military education. In addition to apparent emotions and views reflecting specific observations from a single PME institution, the debate has also offered more balanced views and broad general observations accumulated by interlocutors during their decades-long commitment to education (Andres, 2018). Two main narratives may be observed within the ongoing discussion on PME inspired by the critical assessments of its state in the National Defense Strategy 2018. The prevailing belief among a relatively wide group of specialists has been that, despite certain deficiencies and limitations, PME fulfilled its role in the professional preparation of officers and required some, but not fundamental, changes (Ellinger E. & Posard M. N., 2023). A smaller group of authors have formulated more radical judgments. They believe that PME is not adapted to the needs of the armed forces and requires fundamental changes or even a revolution to become relevant again (Allen, 2019, Schultz, 2018).

There is a far-reaching consensus regarding the scope of teaching at respective levels of military education. Professional military education is generally delineated into precommissioning, primary, intermediate, and senior levels, as well as General Officers'/Flag Officers' education. Those consecutive levels are supposed to serve the development of officers along their professional developmental paths. Despite some minor national peculiarities, the first two levels focus on tactical proficiency; intermediate education covers operational aspects of warfare. At the same time, senior PME is meant to study strategic-level issues. General Officers'/Flag Officers' education usually covers short-term courses. Publicly available guidelines and policies on professional military education and educational programs contain requirements regarding teaching areas and often also teaching content (Joint Chiefs of Staff, Policy…, 2020). Other than some extreme views, one can see the desire to maintain the existing general framework for officer education at their respective levels. The subject of discussion is the proportions of educational content and the balance between history and the future. In the case of senior PME, the main effort is to prepare senior officers and their civilian counterparts to serve at the strategic levels, being ready to work within the national security and defence establishment (interagency environment) and in the international environment (allied and coalition partners). Therefore, most experts agree that curricula for senior PME should include a comprehensive study of the security environment, security and defence policy, and strategy. While developing junior officers contains a relatively significant portion of tactical and technical training, it shifts to more universal and academic skills later. Although some believe that senior officers should be preparing mainly for their first assignment after the respective senior PME programme, most experts favour universal education and the development of critical thinking skills. Some call even for a critical thinking spirit (Antrobus, S. & West, H., 2022). They believe senior PME should reinforce officers' and their civilian counterparts' critical thinking, research, and communication skills rather than exercising staff procedures. As senior PME is built on foundations laid by junior and intermediate education, there is a consensus that it should not repeat its curricula.

The ongoing debate on professional military education has seen lengthy disputes about its focus and scope. For senior PME, strategy is the primary and uncontested topic of study. This is not the case for the history of war and innovations competing for primacy. Some experts argue for more history in the PME curricula, while others point out that the professional military education system and curricula are already dominated by military history too heavily. Those overwhelmed by military history propose more focus on instilling creativity and devoting more time to economics, organisational and social psychology, computer science, geography, and other fields that can aid in preparing officers for the complex operational and strategic environment in which they will find themselves. Noticeably, while there are numerous suggestions on what to add to educational programs, it is less frequent to see meaningful suggestions on what to remove or limit in senior PME curricula. Even among practitioners, there is no complete agreement on the immediate utility of senior professional military education. Some of them support the orientation of curricula toward developing specific skills, which may be utilised immediately after graduation (Tornhill, 2018). This approach is focused on serving the first assignment after graduating from a senior PME program. A former U.S. Army War College commandant, Robert H. Scales, postulated in 2017 an exceptionally rigorous two-year program of case studies, regional staff rides, and on-force operational-level war games (Scales, 2017). He wanted to eliminate extraneous distractions dictated by the regular college curriculum. Their interlocutors, who stress the importance of broad education, warn that a short-sighted focus on skills immediately needed after graduation might harm critical and strategic thinking and other functional competencies later in the career. Such observation might be valid as, for most officers, the senior PME programme they attend might be the last formal education in their military career that can stretch for a decade or two afterward.

Active learning is the mantra in the ongoing discussion on professional military education. The need for case study-based education is advocated. However, there are differences in opinions on whether those case studies should be rooted in military history or future-oriented and tied to current security and defence developments. Many interlocutors call for exposing students to different forms of experiential learning. Some are very specific with the type of wargaming they propose, while others point to the need to use multiple forms of experiential learning. Those who propose board game wargaming across all schools (Lacy, 2019) are criticised by others who claim that one size fits all might be more harmful than helpful (Lee C. & Lewis B.). There is a clear understanding that wargaming has a place but is no panacea for military professional education, and various immersive programs might serve to achieve multiple learning objectives. The debate also stresses the importance of a holistic approach to the curricula of senior professional education programs and not viewing them as checklists for required activities.

Debating senior PME is often tied to capitalising on its graduates. There is an expectation that the graduates will be assigned planning assignments at strategic levels, and their primary responsibilities will include developing strategies and strategic operations plans. Senior PME is viewed as a way of creating future strategic leaders. Selection of candidates is elitist by design, and senior courses are available to a small percentage of the best officers and their civilian counterparts. Usually, candidates for senior PME represent approximately ten per cent of the cohort and are constituted of a group with professional and intellectual predispositions for promotion to higher positions at strategic levels. Advocates for increasing the elitism of senior PME point not only at requirements for candidate selection but also to academic rigour during studies and potential attrition of students. Although significant in some countries, the number of students in senior PME is proportional to the size of their armed forces and officer corps. Many researchers would like to see the attrition levels in senior PME programs comparable to the undergraduate programs at top civilian universities. They tend not to see a highly competitive selection process that serves the same purpose. Despite the apparent elitism of senior PME, it is not a guarantee of influential, growing future strategic leaders and thinkers. Although education plays a vital role in that process, it must be considered as one of the enablers of achieving the desired outcome.

There are strong opinions on who should teach the senior PME programmes. Many authors stress that the faculty that is expert in teaching curriculum should be developed and cultivated. This proposal is often contrasted with a stark conclusion that the faculty of many PME institutions is inadequate, ossified, has little academic recognition, and is not diverse enough. There is a desire for a greater diversity of thought in the PME faculty. Some observe that civilian faculty should not consist predominantly of military historians and some political scientists, but it should embrace more teachers of economy, organisational and social psychology, computer science or geography to prepare the graduates better for operating in complex strategic environments. For PME programs involving many students, there is a concern about using "underqualified military instructors to deliver a standardised curriculum design, simple evaluation metrics and other tools of the education industry" (Lowther & Mitchell, 2020).

The ongoing debate on professional military education touches upon numerous other topics. The literature review of the best practice principles for professional military education compiled by Goode in 2019 points to critical thinking, endemic openness, the need for diversity, curriculum design, assessment design and administration. Additionally, Goode reviews best practices of institutional self-assessment, establishing alumni networks, building online communities of practice, as well as seeking regular feedback from students. The discussion on the best practices for professional military education also touches upon incorporating more variety in assessment tasks, using a portfolio approach to demonstrate students' progression through the program and distance learning modules before the face-to-face course, and reflecting on the academic rigour of programs, which everyone passes (Goode, 2019). While these are valuable topics, the limited scope of the paper precludes them from being covered in more detail.

3. Observations from the Baltic Defence College

The philosophy of senior Professional Military Education offered at the Baltic Defence College is rooted in the College's origins. The school was established in 1999 by three Framework Nations, Estonia, Latvia, and Lithuania, to prepare their newly established militaries to adopt Western standards and be ready to operate alongside NATO and Allies. Initial training and education delivered by BALTDEFCOL focused on the tactical level. However, it became soon apparent that a strategic-level professional military education program was needed to meet the Framework Nations' requirements. Initially, such education was provided during the Colonels Course. However, it was for military officers only and focused on preparing them for assignments within national defence ministries and military headquarters. Opening the course to civil servants from ministries of defence and foreign affairs and extending the scope of the course beyond national requirements paved the way to establishing the Higher Command Studies Course. The HCSC was inaugurated in 2004 to educate senior military officers and government officials on the challenges of adapting national, Allied, and European defence institutions (Corum, 2012). The course was meant to prepare its students to participate in the full spectrum of twenty-first-century operations. The underpinning philosophy of the course was to prepare the Baltic States' armed forces to make effective contributions to international efforts to face the strategic security challenges. The HCSC was to ensure that the defence leadership of the Baltic States would comprehend the requirements for the transformation of their defence establishments and be ready to lead significant defence development programs. At the same time, the course graduates were prepared to serve in NATO headquarters and the European Union institutions as the Baltic States had joined both organisations. Such an approach attracted international interest in the course, and the number of states sending their students to HCSC started growing immediately after its establishment (Corum & Johanson, 2019). The course is half a year-long, although there were some efforts in the past to extend it to one year, similar to most of the Western war college programs (Corum, 2012). By June 2024, the BALTDEFCOL delivered twenty iterations of the course. Overall, three hundred thirty-nine students from thirty-four countries have graduated from the Higher Command Studies Course (BALTDEFCOL, 2024). The path of evolution the Higher Command Studies Course has undergone is now followed by Ukrainian senior PME programs (Salkutsan S. & Stolberg A., 2022).

While the wording of the aim of the Higher Command Studies Course has changed over time, the essence remains the same. The course aims to prepare senior military officers and civilian government officials from the Framework Nations, as well as their Allies and Partners, for executive responsibilities at strategic levels both nationally and within the international community. In contrast to national war colleges or their equivalents, the HCSC tries to serve a more significant number of states and their militaries. First, the Baltic States' major senior professional education program fosters multilateral security and defence cooperation between Estonia, Latvia, and Lithuania. At the same time, it aims to introduce the Baltic States' security and defence concerns to Allies and Partners by contributing to developing regional expertise by their respective senior officers and civil servants. In practical terms, HCSC prepares senior military officers and civilian governmental officials of at least ten nations annually for strategic-level assignments. It applies to Allies contributing to NATO's enhanced forward presence in the Baltic States and other states with regional security interests. HCSC continues to support Georgia, Moldova, and Ukraine, helping them develop strategic-level leaders (Šiuparis, 2024).

The competencies and skills honed through the Higher Command Studies Course do not differ from those developed by other Western senior professional military programmes. The programme aims to develop critical and strategic thinking, effective communication skills, and leadership traits needed for service within interagency and multinational environments. The learning objectives of the HCSC envision developing graduates who can assess critical drivers and trends in the evolving security environment and appraise their implications for the security and defence of the Euro-Atlantic community, the Baltic

Sea Region, and the Baltic States. The course graduates are supposed to be prepared to contribute to developing and implementing defence policies, strategies, plans, and management decisions to achieve national and Allied strategic objectives. Leadership competencies constitute an essential part of the course learning objectives. The HCSC curriculum is designed to help develop "creative, proactive, and agile leaders prepared for executive responsibilities at the strategic level in interagency, national, and international environments, demonstrating the traits essential to the profession of arms". Graduates of the HCSC are also expected to be able to formulate and communicate solutions to complex security, defence, strategic leadership, and high command problems using critical thinking and practical communication skills (HCSC 2024 Course Plan, 2023).

The HCSC curriculum has been designed as a modular one. It comprises seven discrete and sequential core modules. The course starts with a preparatory module focused on academic foundations. The first two modules of the course deal with the security environment and Russia, serving as an introduction and providing a broader context to further parts of the curriculum. A module on strategic leadership follows them. The second part of the curriculum introduces students to defence policy and strategy development, defence management and strategic operations planning. The final module of the course discusses strengthening deterrence and defence. It culminates the curriculum and allows students to utilise knowledge and skills accumulated throughout the course. HCSC students can choose from fourteen spring semester electives covering various security, defence and management topics (HCSC 2025 Course Plan, 2024). While all elective programmes are open to all BALTDEFCOL students, "the Strategic Decision Making in NATO" elective has been created to prepare HCSC graduates for their prospective assignments at NATO HQ. The core modules are open to external participation from the military organisations of the Framework Nations and Allies. In recent years, the module on Russia attracted the involvement of the Joint Warfare Centre officers and some allied senior officers. An individual research project complements the core modules. It focuses on preparing a research report on a timely security and defence-related topic deemed necessary for the Framework Nations or students' sending nations. The HCSC curriculum includes two study trips: the International Study Trip outside the Baltic States and the Baltic Defence Study Trip, which visits Estonia, Latvia, and Lithuania's capitals. The International Study Trip combine the annual visits to NATO HQ, the European Union Military staff, and the Belgian Defence Staff with a visit to one of the Allied and Partner states. The planning cycle envisages three categories of states: a major ally, an ally in the Wider Baltic Sea Region, and a partner. These broad categories of states are visited rotationally to build comprehensive awareness of the security environment among the HCSC students' cohort and faculty (BALTDEFCOL Development Plan, 2024). The core modules are delivered in residence. However, depending on the circumstances, a part of the curriculum may be offered through distance and blended learning using MS Teams and other advanced distributed learning platforms. Such learning proved its value during the COVID-19 pandemic, but it serves to reach valuable speakers who cannot come to Tartu and teach in person. MS Teams allows the College Faculty to follow some of the HCSC lectures. It is also used by the course students who are absent from the class to follow the lectures and participate in seminar discussions and group activities.

The course adheres to the standard methodology adopted by other senior PME courses. While lectures introduce new themes, seminar discussions and group activities allow for in-depth treatment of specific topics. The course strives to remain future-oriented, while contemporary history often serves as a reference to the discussion on developments in security and defence. The educational philosophy emphasises adult, student-centric learning that demands active learning. Each week consists of twenty-seven contact hours of educational activities and seventeen hours of students' preparations. Additional individual study days are included in the curriculum to ensure sufficient time for students' independent research. Summative and continuous assessment is used for the core modules. Students must write a policy paper or similar written assignment for every module. Module group activity ends with a group presentation of a solution to a problem given to a syndicate of students. Usually, the class is divided into three syndicates for group activities, and each syndicate's members and leaders rotate among the course modules. This allows every student of HCSC to lead an international syndicate and be exposed to different national perspectives during every group activity. Each group activity is supported by senior subject matter experts whose core expertise is tied to the respective module. Subject Matter Experts supporting HCSC in recent years included, among others, former ministers and vice ministers of defence, high-level military intelligence specialists and defence policy and management experts. The module coordinator and the course senior mentor continuously assess students' contributions to achieving module learning outcomes. It is based on observation of the quality of the student's interventions, their team leadership and specific contributions to group learning.

While national regulations vary, senior professional military education programs (also named Level 4 courses), which are in most cases the war colleges and their equivalents, accept senior military officers with ranks of Lieutenant Colonels and Colonels along with their civilian counterparts from ministries of defence, ministries of foreign affairs, and security and defence-related institutions. For national war colleges, this is defined by respective personnel management policies. In the case of international senior PME institutions such as the BALTDEFCOL, there is broad agreement among the Framework Nations about admission criteria to the Higher Command Studies Course. Estonia, Latvia, and Lithuania agreed on the number of slots for each country and declared a percentage of military and civilian students. In most cases, admission to the course requires completion of the Level 3 course (command and staff college or its equivalent), notable service experience, strong potential for promotion, and adequate English skills. These requirements are communicated to Allied and Partner nations in the invitations to nominate students for the HCSC. Out of approximately twenty-five students annually, less than half is for the Framework Nations, while the rest is offered to Partner Nations and Allies. The gender balance and civil-military mix vary over the years. Still, it is more or less maintained to ensure the diversity of the students' body and potential for peer learning. HCSC remains highly international, representing more than twelve nations in each course (Johanson, 2024).

As the graduates of the HCSC come from so many nations, the BALTDEFCOL has no absolute control over how their military or civil servant careers are shaped. The Framework Nations assign HCSC graduates top military positions, and their civilian counterparts are promoted to higher level responsibilities within the civil servants' communities both nationally and within NATO and the European Union. Depending on national personnel policies, the Allies and Partners consider HCSC a prerequisite to be promoted to Colonels or Brigadier Generals. Some nations decide to send students to get better insight into regional security and defence. For those nations, graduating from the HCSC does not translate into promotion. It helps the graduates be assigned within the region as defence attaches or at military headquarters involved in NATO's enhanced Forward Presence. Some nations, for example, Slovenia, demand HCSC graduates to complement their education at the national Level 4 course. For partner countries, sending candidates who previously graduated from the BALTDECOL Joint Command and General Staff Course is frequent. Depending on the nation, graduates may immediately and directly capitalise on their participation in the Higher Command Studies Course or benefit from it in later stages of their careers.

One of the central topics in the ongoing debate on senior professional education is faculty. Close cooperation with civilian institutions was always viewed as a prerequisite for quality military education at the college (Corum, 2012). Therefore, the decisions taken in the early years of the HCSC resulted in external speakers teaching a significant portion of the curriculum. However, the college has an academic faculty that provides for the continuity of its educational approach and teaches part of the course curricula to degrees varying for respective courses. For the Higher Command Studies Course, college faculty acts as module coordinators and research project advisers, and, in most cases, they teach introductory topics to the modules and issues tied to their research focus and lead seminar discussions and group activities. The HCSC tries to balance academics, think tanks and practitioners' perspectives. Such an approach exposes students to a broader spectrum of opinions and narratives. Leading researchers offer in-depth knowledge about the theoretical framework of studies for respective topics. They also honestly review academic and political discourse on specific security and defence problems. The course benefits significantly from support from institutional speakers. Top-level military and governmental or institutional officials bring up-to-date insights and real-life challenges. Former top military and politicians add long-term insights that transcend the official narratives. A 360-degree approach translates into a geographical and institutional balance of the speakers. The Baltic States' perspectives are confronted with Western, Nordic and Southern ones. NATO and national insights are complemented by those of the European Union and multilateral security and defence cooperation formats. Busy schedules of top-level speakers make their availability challenging and require considerable early planning and coordination efforts. Nevertheless, the efforts pay off well when considering the final results.

As a relatively small course, the HCSC benefits significantly from students' feedback. The formal feedback system supports quality control efforts and includes weekly, module and course feedback. The solutions adopted at the BALTDEFCOL do not differ significantly from those used by other senior PME courses. However, because of a small number of students and college cohesion, around ninety per cent of the HCSC students regularly provided weekly and module feedback. At the end of the course, each student provides formal feedback. The feedback system is supported by the course director's counselling sessions that help address students' concerns and facilitate their performance review. In addition, the class prepares for the end of the course after an action review, presenting their findings to the College's leadership and faculty. Many students offer not only their assessments but also provide actionable solutions. This helps validate specific portions of the curriculum, assess guest speakers, and improve the organisation of the modules and the course. The BALTDEFCOL reaches out to the HCSC graduates and their superiors regularly, asking about the relevance and usefulness of their educational experience. The results of this questionnaire are used for the educational requirements seminars held every three years with the Framework Nations to discuss long-term changes to the HCSC curriculum.

4. Conclusions

The paper attempts to bridge insights from the ongoing debate on senior professional military education with solutions implemented at the Baltic Defence College's Higher Command Studies Course. It compares observations and recommendations from the Western educational community, particularly the U.S. military educational community, with those specific to the Baltic Defence College. The ongoing debate surrounding senior professional military education touches upon several crucial aspects. There is a far-reaching consensus on the scope of senior professional education, and its primary focus is on strategy. Less agreement has been reached on the role of military history versus innovation. Opinions differ on the purpose of senior PME, with contrasting views advocating mere preparation for the following staff assignments at the strategic level versus broad education that might be useful for future assignments. Senior PME programs are expected to involve active learning with a spectrum of experiential learning forms. The curriculum is expected to be delivered by a diverse faculty offering insights from the fields that are useful for the preparation of the graduates to operate in complex strategic environments. The graduates of senior professional military education programs are expected to be promoted to key command and staff positions at the strategic levels within national defence establishments and international organisations.

The Baltic Defence College has conducted its Higher Command Studies Course for twenty years. As it was modelled after Western war colleges, its primary aim and educational philosophy do not differ much from those of its counterparts in NATO member states. Owned by three Framework Nations, Estonia, Latvia, and Lithuania, the College and the course are unique in terms of ownership and management. The Higher Command Studies Course serves a much broader community of several allied and partner nations, preparing senior military officers and civil servants for assignments at strategic levels

nationally and within international organisations. Its curriculum is rather oriented toward the long term as it does not focus entirely on preparing graduates for their immediate assignments. It is future-oriented, with studies centred on recent and ongoing developments in the security environment. The course puts a premium on active learning and relies on external speakers for a substantial part of its educational activities. Blending expertise of high-level professionals in security and defence with the educational approaches of the college faculty proves productive and keeps the curriculum relevant to the evolving security environment. The course remains responsive to the needs of the Framework Nations and relies heavily on the feedback system that assures quality control and guides improvements to the curriculum and delivery. While the College does not have absolute control of the HCSC graduates' careers, recent years have shown a clear trend of assigning them important positions at strategic levels both nationally and within the international community.
The topic of senior professional military education warrants heightened consideration, especially in the European PME community. While senior education is predominantly a national responsibility, it is also facilitated by international educational institutions such as the Baltic Defence College. Observations from the Higher Command Studies Course reflect unique institutional lessons learned that are not necessarily fully applicable to other senior professional military education programs in Allied or Partner nations. Nevertheless, sharing insights on challenges and best practices associated with preparing senior officers and their civilian counterparts for executive roles at strategic levels directly enhances the relevance and responsiveness of professional military education to evolving security dynamics.

Disclaimer

The author explicitly states that the views expressed in the paper are strictly their own and do not reflect the official positions of BALTDEFCOL or the Framework Nations.

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The Importance of Physical Performance: Case study of University of Defence Cadets

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Abstract
The aim of the research was to analyze the physical performance of University of Defence (UD) students, explain the correlation structure of observed variables using exploratory factor analysis, and identify and name individual latent factors. A total of 89 male students from UD (age: 21.1 ± 1.26 years; body height: 180.3 ± 6.69 cm; body weight: 80.6 ± 9.32 kg) were tested as part of mandatory physical tests. For the examined group of UD students, basic statistical characteristics were calculated for individual variables (n = 18), and a seven-factor correlation structure of observed variables was identified through exploratory factor analysis (EFA).

KEY WORDS: *body composition, body size, exploratory factor analysis, military students, motor test battery, physical performance factors*

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1. Introduction

Physical fitness represents the cornerstone of military readiness. Armies worldwide are interested in ensuring that their soldiers are in the best possible physical condition. Physical fitness tests play a crucial role in evaluating and ensuring soldiers' readiness for demanding tasks. Military service performance is generally both mentally and physically demanding. Currently, various studies analyze the trend of declining physical fitness in the general population and specific groups, including soldiers. In some countries, there is a noticeable decline in endurance capabilities among military recruits at the beginning of their service, accompanied by an increase in body weight. Research by [2] (2007–2017) revealed some mild deterioration in certain physical fitness parameters among Czech Republic army recruits, although the findings cannot be generalized as some components showed slight improvement. Lower physical fitness levels in soldiers decrease the likelihood of successfully completing basic training and increase the risk of musculoskeletal injuries related to training. This also correlates with a higher probability of premature discharge from military service. Conversely, a high level of endurance, primarily general endurance, can positively impact the handling of physical demands during basic training and may be associated with successful completion thereof. When assessing military readiness, the main factors of performance are considered to be the level of strength and endurance capabilities. Long-term research has confirmed a positive trend in increasing performance among Czech soldiers in endurance and strength disciplines. Conversely, a study [9] examining the level of physical fitness among Czech army soldiers in 2015–2018 using standardized physical tests showed no significant changes in performance during those years. However, it is assumed that the general trend of deteriorating health and declining physical fitness due to lack of physical activity and poor dietary habits leads to an increase in body weight, percentage of body fat, and body mass index (BMI). A study [10] using the SFAS (Special Forces Assessment and Selection) test battery found that anthropometric data and body composition are predictors of soldiers' physical performance in the US Army. A narrow correlation between body composition and physical fitness in the US Army was also found in research [11]. Recent studies suggest that combined strength and endurance training is the most optimal training method for improving overall physical performance of soldiers. Soldiers involved in combat situations also require an appropriate level of anaerobic capacity to perform high-intensity tasks in rapidly changing life-threatening situations.

Significant differences in the initial physical performance of recruits have led military units to develop safer and more efficient training programs. Physical fitness of soldiers is often tested using tests designed for testing the general population, such as the 12-minute run and push-ups. Basic physical fitness tests for the majority of the population are conducted in light sports clothing, although most operational military tasks are performed in combat gear and body armor, increasing the weight carried and negatively affecting soldiers' overall performance. Lower body fat percentage (BF) and more fat-free mass (FFM) positively influence a soldier's performance in these tasks. In addition to general physical tests, specific military fitness tests assessing soldiers' performance in specific tasks and combat readiness have been developed. Soldiers perform tasks with combat loads including personal weapons, combat gear, etc. These high-intensity tasks typically include sprinting, lunges, climbing, rapid changes in movement direction, jumps, crawling, lifting and carrying loads, or casualty evacuation. Armies of various countries assess the physical readiness of military applicants and monitor the current level of physical fitness of all soldiers throughout the year using physical tests (test batteries) based on each army's internal regulations. Physical fitness training should focus primarily on developing endurance, strength, mobility, and flexibility considering the tasks soldiers must perform during service. There is no unified approach worldwide to the content of physical tests. NATO countries have their own test batteries, usually verifying strength (push-ups, sit-ups, pull-ups, and plank) and endurance (running various distances, especially 2–3 km) capabilities. Conversely, speed and coordination abilities are not typically tested. This also applies to swimming (except for the US Coast Guard). Some countries use specific tests such as load lifting and carrying (UK) or obstacle courses (Romania). Regular physical fitness assessments are conducted 1–2 times a year, often using similar test batteries as those used for army entry. The history of test battery development for the US Army was examined in their article [22]. They concluded that the relationship between the content of the APFT (Army Physical Fitness Test) and the requirements of current shared soldier tasks needs to be verified. [23] suggested that body fat percentage may be an important variable in determining or improving cardiovascular and muscular endurance, but not performance in the APFT. The APFT primarily focused on strength and endurance while neglecting key soldier activities such as dragging, lifting and carrying loads, or speed abilities. Therefore, the APFT was replaced by the ACFT (Army Combat Fitness Test), which focuses on combat readiness and better prepares soldiers for combat situations. [24] investigated the correlation of ACFT with body composition and body composition of army personnel. According to [26], another type of US Army test battery is the OPAT (Occupational Physical Assessment Test), which assesses recruits' physical abilities by measuring muscle strength, muscular endurance, cardiorespiratory endurance, explosive strength, and speed (standing long jump, seated medicine ball throw, deadlift, and interval aerobic run). Different variants of OPAT were also examined by [27]. The validity and reliability of other test batteries consisting of strength and endurance tests were examined by [28]–[29]. The combination of strength and endurance training is often used in athletics, the military, and for improving performance in the civilian population. As mentioned, physical training of soldiers in the Czech Republic and elsewhere focuses mainly on developing strength and endurance capabilities. In the Czech Republic, after successfully joining the army, military students can enroll in the University of Defense. As part of their studies, all soldiers must pass mandatory physical tests every semester, failure of which may lead to termination of their studies. Training and testing of military students at the University of Defense primarily focus on developing strength, speed, speed-coordination, and endurance capabilities. The aim of the research was to analyze the results of physical tests of UD students and to explain the correlation structure of the observed variables through exploratory factor analysis, identify, and name individual latent factors.

2. Methods

Participants

A total of 89 male students from UD (age: 21.1 ± 1.26 years; body height: 180.3 ± 6.69 cm; body weight: 80.6 ± 9.32 kg) were tested as part of mandatory physical tests. Ethical approval was obtained from the Human Subjects Ethics Committee of the University of Defence.

Procedures

The measurements and tests were focused on two areas (Table 1): body size and composition (6 tests), motor performance (12 tests). All tests were conducted by physical education professionals at the University of Defence, each possessing a minimum of five years of teaching experience. Participants were explicitly instructed to exert their best effort during each testing session. Testing of students took place at UD sports facilities and occurred over the course of one week.

Table 1.
Overview of anthropometric measurements and motor tests (n = 18)

Variables		Jednotka
Body size and composition		
1.	Body height (BH)	m
2.	Body mass (BM)	kg
3.	Waist hip ratio (WHR)	index
4.	Body fat (BF)	%
5.	Muscle mass (MM)	%
6.	Fat free mass (FFM)	kg
Motor performance		

7.	Handgrip strength right hand (SR)	kg
8.	Handgrip strength left hand (SL)	kg
9.	Forced expiratory volume in 1 second (FEV1)	litres
10.	Forced vital capacity (FVC)	litres
11.	Physical Working Capacity 170/kg (PWC170)	watts
12.	Sit-ups test 2 minutes (SU)	number
13.	Push-ups (PU)	number
14.	Triple jump (TJ)	meters
15.	Throwing a hand grenade (THG)	meters
16.	Running 5 km (Run5)	minutes
17.	Swimming 100 m (S100)	minutes
18.	Swimming 300 m (S300)	minutes

Body size and composition

Body size and composition measurements were conducted in the morning at the beginning of the first day of testing and included measurements of body height, body mass, and body mass index (BMI). Body mass index was calculated as body mass (kg) divided by body height squared (m^2). The measurements were conducted by trained personnel from Physical Training and Sports Centre in Brno. Test subjects arrived fasting and wearing light clothing after waking up. Body weight was measured without shoes using a calibrated electronic scale (InBody270, Soul, South Korea). To measure the amount of body fat and muscle (in %) relative to total body weight, the waist-to-hip ratio (WHR - an obesity indicator), and fat-free mass (FFM in kg = total body weight in kg - fat in kg), we used the InBody270 body composition analyzer.

Dynamometry

Maximal hand grip strength was measured with a hydraulic hand dynamometer Saehan DHD-1 (Saehan, South Korea). Dominant and non-dominant hand grip strength was assessed in a standing position, elbow extended, and the arm positioned with the dynamometer parallel to the subject's side. Participants were asked to perform a maximal voluntary contraction, squeezing the dynamometer as hard as possible for three seconds. The maximum force (in kilograms) achieved among two trials for each side was recorded.

Spirometry and cardiovascular endurance

We used a handheld spirometer to assess the most commonly measured parameters of lung function. These included the Forced Expiratory Volume (FEV, in liters), which is the total volume of air exhaled forcefully from the lungs after a deep inhalation. Additionally, the Forced Expiratory Volume in one second (FEV1, in liters) was measured, which is the volume of air exhaled forcefully within 1 second.

To determine and evaluate the adaptation of the cardiovascular system to endurance stress, the PWC170 test (Physical Working Capacity) was employed. A stationary bicycle ergometer of Cateye EC 1600 type controlled by computer software was used. This test, performed on a bicycle ergometer, does not require maximal effort, making it a submaximal intensity test. The result of the test is the power output (W) that the tested individual can achieve at a heart rate of 170 beats/min. Performance data were converted to kilograms of body weight (W/kg) for interpersonal comparison. The individual's heart rate determines the load size corresponding to their current physical fitness level. Upon mounting the ergometer, the tested individual familiarized themselves with the displayed data on the screen, adjusted the seat and handlebar height, and attempted pedalling at the prescribed pace (65 revolutions/min). After starting the test, the load on the ergometer is automatically adjusted by computer software to achieve the target heart rate of 170 beats/min. The basis is a 3-stage load, which is modelled by the computer based on the tested individual's heart rate values.

Sit-ups

Muscular endurance of the abdominal muscles was assessed via the sit-up test, where the recruits completed as many repetitions as possible in 120 s. The participants laid on their backs with their knees flexed to 90°, heels flat on the ground, and hands cupped behind their ears. The feet were held to the ground by a partner during the test. On the start command, recruits raised their shoulders from the ground while keeping their fingers were interlocked behind the head and touched their elbows to their knees. The recruit then descended back down until their joined hands touching the ground and completed as many repetitions as possible.

Push-ups

Upper body strength endurance was assessed using the maximal push-up test, where participants performed as many repetitions as possible. Participants started in the standard "up" position, with the body stretched and straight, with the arms positioned shoulder width apart with the fingers pointing forward. They lowered themselves until their chest touched the ground, and then stretched into elbows and returned to the starting position. The recruits performed as many push-ups as possible using this technique.

Triple jump

Explosive strength of the lower limbs was measured using a standing triple jump. The participant performed three consecutive jumps from a standing position with feet hip-width apart, utilizing a simultaneous swinging motion of the upper limbs. The total length of the jump (in meters) from the takeoff line to the nearest heel touch point was evaluated.

Throwing a hand grenade

The explosive strength of the upper limbs was tested by throwing a 350g dummy grenade. Participants threw it in any manner (three attempts, measured in meters) into a designated sector.

Swimming 100, 300m

Participants swam using any stroke, and they could switch strokes during the test. The achieved time was evaluated (with accuracy to one second).

3. Statistical analyses

Descriptive statistical methods (mean, standard deviation; minimum value, maximum value; coefficient of variation; Pearson correlation coefficient) were used for statistical data analysis. The correlation structure of observed variables and identification of individual factors were examined using exploratory factor analysis (maximum likelihood method, varimax rotation). The effect size of the correlation coefficient r was evaluated as follows (Cohen, 1988): $r = 0.1$ (small); $r = 0.3$ (medium); $r = 0.5$ (large). The level of significance was chosen to be $p = 0.05$.

4. Results

An overview of basic statistical characteristics (somatic and motor) of all participants is provided below (see Table 2). Participants ($n = 89$) were aged 20.0–26.0 years (age: 21.1 ± 1.26; body height: 180.3 ± 6.66; body weight: 80.6 ± 9.26). The coefficient of variation (CV) values for somatic indicators ranged between 3.7–18.2 %, with the least variability observed in body height and the greatest in body fat percentage.

Table 2.
Basic statistical characteristics – body size and composition ($n = 89$)

Variables	Age	BH	BM	WHR	BF	MM	FFM
M	21.1	180.3	80.6	0.8	20.9	73.3	63.6
SD	1.26	6.66	9.26	0.03	3.80	3.79	6.40
Min	20.0	164.6	61.1	0.70	11.4	64.1	50.8
Max	26.0	196.0	102.4	0.90	30.2	82.6	82.7
CV	6.0	3.7	11.5	3.8	18.2	5.2	10.1

Notes. BH = body height (cm); BM = body mass (kg); WHR = waist hip ratio (index); BF = body fat (%); MM = muscle mass (%); FFM = fat free mass (kg); M = mean; SD = standard deviation; Min = minimum value; Max = maximum value; CV = coefficient of variation (%)

In Table 3, basic statistical parameters of the results of motor tests for the entire sample are provided. The coefficient of variation (CV) values for motor indicators ranged between 6.1–22.0 %, with the least variability observed in the triple jump and the greatest in push-ups.

Table 3.
Basic statistical parameters – motor performance ($n = 89$)

Variables	HSR	HSL	FEV1	FVC	PWC	SU	PU	TJ	THG	RUN5	S100	S300
M	51.2	48.5	4.3	5.2	3.1	79.0	41.0	7.67	44.0	22:35	1:50	6:42
SD	7.62	7.53	0.65	0.71	0.43	9.20	9.04	0.47	6.49	1.61	0.24	0.65
Min	31.1	29.0	2.2	3.3	2.2	65	26	6.3	27	18:24	1:09	4:47
Max	68.4	65.1	6.2	7.0	4.3	105	70	8.6	70	26:23	2:15	8:30
CV	14.9	15.5	15.1	13.7	13.9	11.6	22.0	6.1	14.8	7.2	16.0	10.1

Notes: HSR = hand grip strength right hand (kg); HSL = hand grip strength left hand (kg); FEV1 = forced expiratory volume in 1 second (litres); FVC = forced vital capacity (litres); PWC = physical working capacity (170/kg; watts); SU = sit-ups test 2 minutes (number); PU = push-ups (number); TJ = triple jump (meters); THG = throwing a hand grenade (meters); Run5 = running 5 km (minutes); S100 = swimming 100 m (minutes); S300 = swimming 300 m (minutes)

For the examined group of UD students (n = 89), basic statistical characteristics were calculated for individual variables (n = 18), and a seven-factor correlation structure of observed variables was identified through exploratory factor analysis (EFA). The values of the correlation coefficient *r* between individual variables and factors F1–F7 are provided below (see Table 4).

Table 4.
Structure matrix coefficienfts for observed variables (n = 18)

Variables	F1	F2	F3	F4	F5	F6	F7
BH	*(-0.195)*		0.591		0.479		
BM	0.423		0.806	0.329			
WHR	0.933						
BF	**0.973**						
MM	-0.971						
FFM			**0.898**	0.363			
HSR				0.818			
HSL				**0.903**			
FEV1					**0.837**		
FVC					0.772		
PWC		0.480					
SU		0.430					
PU		**0.782**					
TJ							0.433
THG							**0.630**
RUN5		-0.437					-0.356
S100						**0.975**	
S300						0.756	

Notes: For α = 0,05 is r_{krit} = 0,206. Factor loadings <0.3 (ES small) are suppressed. Variables with the highest loadings for each factor are in bold.

The individual latent factors can be designated as follows: F1 = "body size and composition" (highest loadings found in body fat, .973), F2 = "strength endurance" (highest loadings found in push-ups, .782), F3 = "body size" (highest loadings found in fat-free mass, .898), F4 = "*muscle strength*" (highest loadings found in HGS left, .903), F5 = "*vital lung capacity*" (highest loadings found in forced expiratory volume, .837), F6 = "*swimming skill*" (highest loadings found in swimming 100 m, .975), F7 = "explosive strength" (highest loadings found in throw a hand grenade, .630). Based on the results of EFA, the reduction of the number of measurements and tests to a total of seven can be considered, using variables with the highest loadings.

5. Discussion

The results of the analysis of physical performance among Defence University students based on anthropometric and motor characteristics can be compared with several other studies [1], [2], [6], [8], [10], [17], [23], [28] allow for partial comparisons with our results in the area of anthropometric and motor characteristics. The results from a study examining the developmental trends of American recruits (soldiers) between 1975 and 2013 indicated that in the last year tested (2013), the value of BM (mean = 80.0 kg) was the same as in our study. The values of FFM (mean = 69.4 kg) were slightly higher (+5.8 kg), while BF (mean = 17.5 %) was lower (-3.4 %). The study showed minimal temporal changes over the years in terms of body height, while body weight, body fat, and lean body mass increased over the years. Test results for muscle endurance (push-ups, sit-ups) demonstrated negligible changes over time [1]. Another study of American soldiers (n = 795) examined anthropometric data, body composition, and their impact on physical performance (selection for SFAS = Special Forces Assessment and Selection). Selected soldiers had higher BH (179.0 ± 6.60 cm), BM (85.8 ± 8.80 kg), LBM (lean body mass), values of which did not differ much from FFM (67.2 ± 7.30 kg) and BF (17.3 ± 3.4%) compared to unsuccessful candidates. Similar average values compared to ours were achieved for BH, LBM, with higher values for BM (+5.2 kg) and LBM (FFM, +3.6 kg), and lower for BF (-3.6 %). It was found that lower height predicted better performance in push-ups and pull-ups, while taller stature predicted better performance in running and marching with a load [10]. According to another study, soldiers with BF ≤ 18 % achieved significantly better results in seven out of ten physical fitness tests (Group 1; n = 44; age: 26.6 ± 6.10 years; BH: 176.8 ± 8.64 cm; BM: 76.4 ± 9.54 kg; BF: 13.3 ± 3.70 %; FFM: 66.8 ± 8.20 kg; SU: 73.6 ± 16.20). Lower values compared to ours were achieved for BH (-3.5 cm), BM (-4.2 kg), SU/2 min. (-5.4). Soldiers with similar FFM but less body fat had better aerobic and anaerobic capacity and greater muscle strength [17]. Similar BH and BM values but significantly lower BF (-7.2 %) compared to ours were achieved in a study of American military cadets (n = 11; age: 21.8 ± 3.80 years; BH: 179.1 ± 8.13 cm; BM: 78.6 ± 10.31 kg; BF: 13.7 ± 2.8%). A significant negative correlation between SU and BF was also demonstrated [23]. Lower BH (-5.3 cm), SU/2 min. (10), and similar BM and BF values compared to ours were achieved in another study of American soldiers, where test battery results significantly correlated with LBM (n = 41; age: 22.0 ± 3.00 years; BH: 175.0 ± 8.00 cm; BM: 81.4 ± 12.90 kg; BF: 22.0 ± 5.70 %; SU = 69.0 ± 11.00) [28]. Similar values for push-ups (38.5 ± 12.70) compared to our study were recorded after the first week of training for recruits in the Australian army (n = 184) [6]. Long-term monitoring of the physical fitness of Czech army personnel (men; n = 268; age: 29.3 ± 4.70 years) showed average values for push-ups (32.1 ± 0.73), which is less than in our study (-8.9) and for swimming 300m (5:41 ± 0:05 min), which is less (1:01 min.), but in this case indicates better performance. According to the authors, there was an overall improvement in strength and endurance disciplines over the period studied (2012–2019) [8]. Comparison with the PWC170 test is possible only through a study examining Czech recruits between 2000 and 2017, where slightly lower values (mean = 2.83 W/kg) were recorded compared to ours [2].

6. Conclusions

The analysis of physical performance of University of Defence students using exploratory factor analysis demonstrated a seven-factor structure of observed variables. The individual latent factors can be identified as "body size and composition, strength endurance, body size, muscle strength, vital capacity, swimming skill, explosive strength." The reduction of the original eighteen measurements and tests to a total of seven can be considered.

Limitations

Although there are methods for determining the optimal number of factors when using EFA, the interpretation of factors may depend on the researcher's subjective assessment and knowledge. Selecting inappropriate methods for analysis (e.g., incorrect type of factor analysis) can lead to incorrect results. If too many factors are selected, it may lead to excessive model complexity and difficulties in interpretation.

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Differences in Second Language Learning Motivation

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Abstract

The aim of the paper is to provide a detailed view on motivation for learning second languages in the Czech Armed Forces. As an important prerequisite of interoperability, foreign language proficiency represents an integral part of competences necessary for the personnel serving in modern western militaries. Therefore, language education belongs to significant components of professional military education. As in any other human activity, motivation represents one of the key factors influencing resulting effectiveness. Complexity and diversity of motivation with focus on language learning motivation rather than language classroom motivation have been considered alongside with striving for higher effectiveness of the second language learning process. Motivational factors include respondents' goals, attitudes and efforts. Awareness of the fact which motivational factor is the driving force behind students' willingness to study second language and their success will definitely contribute not only to the production of tailor-made courses, but also to the qualitatively improved overall approach towards the second language learning process within the Czech Armed Forces.

KEY WORDS: *motivation, motivational factors, intrinsic and extrinsic motivation, second language learning, survey, descriptive statistics, Czech Armed Forces.*

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1. Motivation and Language Learning

One of the key elements of learning process effectiveness is the motivation of learners, understanding the sources of learners´ motivation and potential differences in motivation of different groups of learners.

Motivation is a concept, which is not only extremely important, but also immensely complex. Therefore, the term *motivational factor* has a quite broad connotation within our research (cf. Holcner, Dvořák, Vápeník, 2023). Complexity, as well as diversity and context, are notions related to the subject matter and make research into the area of motivation, in our case motivation for second language learning in the Czech Armed Forces, quite challenging. Moreover, individual differences and subconsciousness may also be added on the list of motivational variables. Drillings and O´Neil (1994) note that "individual differences vary along two dimensions: a) the trait of the individual, and b) the state of the individual, that is, affective reactions that vary in intensity, fluctuate over time, and result from specific environmental conditions and level of the trait that an individual possesses." Regarding subconsciousness, Locke and Latham (1994) describe subconscious minds as "all the person´s knowledge, values, motives, beliefs, memories, etc., which are not, at any given time, in conscious awareness."

Dornyei (2001) states that "motivation explains why people decide to do something, how hard they are going to pursue it and how long they are willing to sustain the activity." Motivation is perceived as a conative factor. According to Ellis (2015), besides the conative factor there are also other factors that are at stake and closely interrelated, i.e. cognitive factors, such as language aptitude and intelligence, and affective factors, such as language anxiety. Although we are aware of the fact there are numerous theories on motivation (cf. Brown, 2007; Pandya, 2004), as well as numerous motivational factors to be considered, the queries in the questionnaires, as well as our hypotheses focus on *intrinsic and extrinsic motivation*. This significantly important concept is defined by Deci (1975), in case of intrinsic motivation as activities “for which there is no apparent reward except the activity itself” and internally rewarding consequences are aimed at “feelings of competence and self-determination” and in case of extrinsic motivation as activities “fueled by the anticipation of a reward from outside,” such as money, prizes, grades, positive feedback, and also avoidance of punishment. Ryan and Deci (2000) quote outcomes of various researches into intrinsic and extrinsic motivation and point out that “tangible rewards, threats, deadlines, directives, and competition pressure diminish intrinsic motivation because people experience them as controllers of their behavior.” Intrinsic motivation is, on the other hand, “enhanced by the opportunity for choice and self-direction.” Thomas K.W. (2009) mentions four intrinsic rewards, which can be briefly summarized as meaningfulness, choice, competence, and progress.

The Motivation to Stay in Service in the Armed Forces in Selected Groups of Military Staff (Dolejšová, 2023) and Motivation of Military Professionals for Language Learning (Konečná, 2021) are theses having been recently defended in our area of interest. The fact they have been written in the Czech language is a limiting factor for an international audience.

2. Research Methods

The research presented in this paper was designed to examine validity of the following hypotheses:

1. The Czech Armed Forces personnel, serving in a largely directive-managed organization with strictly defined language and career requirements, are motivated to learn second language dominantly based on extrinsic rather than intrinsic factors.
2. There are no significant differences in relative importance of different motivation factors among male and female learners (Czech Armed Forces personnel).
3. For younger learners (Czech Armed Forces personnel), internal motivational factors are more prevalent than for older ones.

Data needed to test the hypotheses above, i.e. overview of different factors of motivation for second language learning among the Czech Armed Forces personnel, were collected via a questionnaire survey among 454 participants of 2022/2023 language courses at the Czech University of Defence (UoD) Language Centre. These learners represent different categories of primarily military but also civilian personnel of the Czech Armed Forces and the Ministry of Defence (MoD) of the Czech Republic. Data on motivational factors were gathered within the survey enabling to rank relative significance of individual language learning motivational factors as well as to examine language learners´ perception of these factors as either intrinsic or extrinsic. Survey has been designed to enable data classification based on different groups of learners (e.g. by gender, military rank and age).

The survey was administered to professional military and civilian MoD personnel who participated in the survey upon their enrolment in a language course. This course could span anywhere from 7 to 20 weeks, with a commitment of 30 instructional hours per week. The response rate was notably high, as the respondents were required to complete the survey during a mandatory class session. The survey was designed to be completed anonymously, but respondents were given the option to voluntarily disclose their identities.

The survey comprised 17 items. The initial twelve items required the respondents to indicate whether these statements served as motivational factors for their pursuit of foreign language learning. They were given a choice of five options, which followed 5-point Likert scale, ranging from a very high significance to a negligible significance of motivational factor. Additionally, they were asked to specify whether they perceived the motivating factor as intrinsic motivation, extrinsic motivation, or a combination of both. This part of the survey is the primary focus of our research. The twelve statements can be categorized into two thematic groups. The first group contains statements pertaining to the actual execution of the respondent´s professional duties, while the second group centres on the motivation to learn a foreign language for personal use in the respondent’s private life, see the list of statements below. Some statements deviate from directly addressing the motivation to learn a foreign language and instead measure the respondent’s attitude towards foreign language learning. The survey concludes with the aforementioned classifications, which serve as the basis for evaluating the collected data.

The list of statements:

1) Language requirement for the job position;
2) Supervisor’s language stipulation;
3) Advancement in career;
4) Prolongation of military service;
5) Working positions at a foreign military workplace;
6) Deployment to military operations abroad;
7) The opportunity to learn something new;
8) Increased job prospects on the labour market;
9) Interacting with foreigners;

10) The ability to follow foreign media;

11) Use of a foreign language in work-related tasks;

12) The necessity to comprehend professional texts in a foreign language.

Data gathered were analysed using basic statistical methods, especially descriptive statistics, the test of equal proportions and Kendall correlation coefficient (Devore, 2012). Statistical analysis of the data was performed using the software R 4.3.1.

This research covers motivation of second foreign learners just within one academic year at the University of Defence Language Centre. Subsequent repeated surveys aimed to confirm results gained and/or identify trends in perception of second language learning seems to be useful for forming impartial and more comprehensive picture of the issue examined. Analogously, comparison with results of similar research in other countries represents a great potential added value for future research.

3. Survey Results Summary and Discussion

First, unlike expected, results show that motivational factors perceived intrinsic prevail over extrinsic ones (indicated by respondents to be app. three times more important).

There are more motivational factors having effect at the same time and influencing students´ decision making process and their behaviour. Some of these factors may tend to be contradictory and it is quite natural that one or more motivational factors prevail over the others. It is important to take into consideration the fact that there is not a clear-cut dividing line between the motivational factors, which contribute solely either to intrinsic or extrinsic motivation. Ryan and Deci (2000) state: "Students can perform extrinsically motivated actions with resentment, resistance, and disinterest or, alternatively, with an attitude of willingness that reflects an inner acceptance of the value or utility of a task." We believe this statement is valid and applicable in case of both language classroom motivation and language learning motivation.

Table 1.
Survey results by gender of respondent

Males (n=306)	Mean	Median	Rank	Motivation		
				Extrinsic	Intrinsic	Both
Q1	2.52	2	6	27.0%	32.6%	40.5%
Q2	2.55	3	7	35.5%	30.6%	33.9%
Q3	2.42	2	3	14.5%	49.5%	36.0%
Q4	2.51	2	5	23.9%	42.9%	33.2%
Q5	3.10	3	10	19.1%	46.4%	34.5%
Q6	3.07	3	9	20.3%	46.4%	33.2%
Q7	1.91	2	1	5.3%	70.1%	24.7%
Q8	2.46	2	4	7.3%	69.9%	22.8%
Q9	2.37	2	2	8.0%	64.8%	27.2%
Q10	2.91	3	8	8.6%	71.1%	20.3%
Q11	3.31	3	11	17.9%	41.9%	40.2%
Q12	3.42	4	12	18.1%	48.8%	33.1%

Females (n=59)	Mean	Median	Rank	Motivation		
				Extrinsic	Intrinsic	Both
Q1	2.00	2	2	25.4%	13.6%	61.0%
Q2	2.19	2	6	40.7%	15.3%	44.1%
Q3	2.10	2	3.5	13.6%	49.2%	37.3%
Q4	2.10	2	3.5	20.3%	33.9%	45.8%
Q5	3.29	4	9	25.0%	48.2%	26.8%
Q6	3.42	4	10	25.9%	40.7%	33.3%
Q7	1.69	2	1	1.7%	78.0%	20.3%
Q8	2.24	2	7	1.7%	74.1%	24.1%
Q9	2.10	2	5	0.0%	70.7%	29.3%
Q10	2.78	3	8	3.4%	75.9%	20.7%
Q11	3.46	4	11	15.5%	43.1%	41.4%
Q12	3.59	4	12	21.1%	50.9%	28.1%

Second, the hypothesis of no significant differences in perception of relative importance of different motivational factors between men and women has not been rejected. Such an outcome may be explained by standardized language requirements for soldiers regardless of gender. Second language learning motivation might also be influenced by the shift in general motivation of soldiers to serve in the Czech Armed Forces with rather external motives of rewards, which are equally appealing for both genders. Differences might more likely be discovered in the groups of soldiers of different age and educational background.

Table 1 shows that the ranking of the questions according to the arithmetic mean does not differ much for men and women, the Kendall correlation coefficient has a value of 0.718 (p-value 0.00124). Therefore, it can be concluded that the ranking of the questions according to the importance rating of the motivational factor is similar for men and women.

Table 2.
Test of equal proportions by gender of respondent (p-values)

	Extrinsic	Intrinsic	Both
Q1	0.932	0.006	0.006
Q2	0.545	0.025	0.178
Q3	1.000	1.000	0.965
Q4	0.670	0.257	0.090
Q5	0.409	0.920	0.335
Q6	0.458	0.532	1.000
Q7	0.395	0.284	0.585
Q8	0.196	0.620	0.965
Q9	0.052	0.474	0.871
Q10	0.279	0.562	1.000
Q11	0.798	0.976	0.983
Q12	0.729	0.890	0.554

In terms of assessing the perception of the motivational factor, it can be stated that, with exceptions (questions Q1 and Q2), there are no significant differences between men and women, see Table 2.

Finally, the assumption that intrinsic motivation would play a more important role for younger learners compared to older learners was not confirmed. There is nothing bad about such an outcome. This outcome may have the same explanation as the one mentioned in the first paragraph of this chapter. We remember senior soldiers, quite old, who participated in language courses for joy, and not because they were afraid they would fail the final test, not meeting their language requirements. On the other hand, junior soldiers, usually younger learners, might see certain language requirements in the distance as a task imposed externally, as a goal they have to achieve, with no joy on their way towards it (Čechová, I., Neubauer, J., Sedlačík, M., 2019**)**. The fact, which should be taken into consideration, is that extrinsic motivation may spark intrinsic one in the next stage of military career.

Table 3.
Test of equal proportions by age of respondent (p-values)

	Extrinsic	Intrinsic	Both
Q1	0.437	0.300	0.878
Q2	0.254	0.050	0.559
Q3	0.177	0.520	0.836
Q4	0.927	1.000	0.885
Q5	0.936	0.358	0.428
Q6	0.333	0.892	0.270
Q7	0.843	0.168	0.215
Q8	0.291	0.410	0.878
Q9	0.672	1.000	0.826
Q10	0.973	0.465	0.507
Q11	0.212	0.233	0.023
Q12	0.588	0.843	0.438

Table 3 summarizes the results now sorted by age of respondents (under 40, over 40). The results in Table 3 show that the ranking of the questions according to the calculated average significance is partially different for the two age categories, the value of the Kendall correlation coefficient is 0.636 (p-value 0.00318).

Results of the submitted analysis enabled us to confirm validity of two out of three initially formulated hypotheses.

4. Conclusions

In spite of the fact that the armed forces represent an organization characterized by a directive style of management, incl. strict language requirements policy obligations to fulfil them, survey results show that intrinsic factors play a more significant role in foreign language learners´ motivation than extrinsic. It is also worth considering the fact that respondents might want to be seen in a better light. Therefore, they might answer what they think is more correct rather than what their real attitudes and opinions are. Furthermore, respondents can perceive their attendance in a mandatory language as an opportunity to learn something they always wanted to learn, yet could not bring themselves to in the past. The mental state of some other respondents might result in them taking the ordered mandatory course and the related language exam as their internal challenge. All these aspects complicate the distinction between intrinsic and extrinsic motivation.

Confirmation of the expected lack of significant differences in perception of second language learning motivational factors between men and women probably reflects the fact that in the Czech Armed Forces conditions for military service, career system and therefore also language requirements and learning opportunities are set and implemented as equal for both genders. Although women are more responsible learners in language courses than men (confirmed by semi-structured interviews with lecturers), survey results show that motivation is the same across genders.

Not having the expectation confirmed that the motivation of younger learners is different from that of older learners can be perceived as a certain surprise. With reference to the historical and political development in Czechoslovakia and then in the Czech Republic, the older generation did not live from a young age in an environment so intensely influenced by Anglo-Saxon culture as it is nowadays (mainly thanks to modern technology). It might be argued that the older generations understand that English language skills are now an important skill that offers many advantages. It can be also partially explained by the fact that learners understand the added value of second language competences not just with regards to their current and prospective career requirements in the military but also in the context of their future second career if they retire from the military or in their private life. In addition, this result can be also connected with the fact that generally higher ranks, i.e. older military personnel serve at positions with higher language requirements.

Results of the research indicate that there is an opportunity for the human resource policy-makers to enhance language learning effectiveness by adjusting the language education system in the Czech Armed Forces. Such an adjustment should lead to a more informal and voluntary education model, which would utilize the intrinsic will of the learners to "learn something new" on one hand, on the other hand would establish conditions, such as time frame, instructors, consultation, learning materials etc. Similar perception of motivation across different groups of learners would make for efficient implementation of similar or equal treatment with regards to different personnel categories.

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Cyber Security and Business Continuity Management: Ensuring Resilience in a Digital World

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Abstract

This article examines the critical importance of implementing Business Continuity Management (BCM), particularly in the field of cybersecurity, to address unexpected disruptions to organizational operations. With a focus on cyber threats and technological disruptions, the study emphasizes the need for close integration between cybersecurity and BCM to minimize risks and effectively mitigate impacts. Drawing from the legal frameworks of the European Union and the Slovak Republic, the article highlights the imperative of integrating BCM into the processes of providing essential services by organizations. Through impact analysis methodology, the article evaluates key processes within a representative entity in the energy sector, identifies critical areas, and resource requirements to maintain continuity. The findings underscore the necessity of proactive planning and response strategies to ensure the stability and competitiveness of the organization in an environment with evolving cyber threats. The study concludes with insights into future research directions, emphasizing the evaluation of supporting processes and their impact on the overall workflow stability within BCM.

KEY WORDS: *cyber security, business continuity management, impact analysis, requirements.*

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1. Introduction

Unexpected disruptions to an organization's operations, including cyber security incidents, technological failures, and process errors, underscore the need for implementing Business Continuity Management (BCM) with a focus on cyber security and the use of information technology. Cyber threats have become an integral part of the business environment, making it essential for organizations to take measures to minimize risk and mitigate the impacts of these incidents.

Business continuity in the context of cyber security involves planned procedures and actions designed not only to ensure the continuity of providing products or services after a cyber incident but also to minimize damages and restore normal operations. Within business continuity management, it is necessary to consider specific threats and vulnerabilities associated with information technologies and ensure that recovery and resilience measures take the cyber context into account.

The implementation of BCM in the realm of cyber security includes the development of plans, testing their effectiveness, and continuously updating them based on new threats and technological developments. Close integration between cyber security and BCM is critical to ensuring that organizations can respond rapidly and effectively to cyber events and minimize their impacts on their business operations.

New dimensions in the realm of compliance with security standards, reliability, and business continuity in cybersecurity are linked to measures of the European Union concerning cybersecurity through the NIS I [1] and NIS II [2] directives. Within the Slovak Republic, the NIS directive has been transposed into the Act No. 69/2018 on cybersecurity [3]. This law and its implementing regulations require the integration of business continuity into processes related to providing essential services in the cyber domain. Organizations subject to this law must demonstrate that they have developed a business continuity strategy, conducted impact analysis, and defined business continuity plans.

Within business continuity management, it is imperative to consider specific threats and vulnerabilities associated with information technologies and ensure that recovery and restoration measures take into account the cyber context. Implementing BCM in the realm of cybersecurity involves developing plans, testing their effectiveness, and continuously updating them based on new threats and technological developments. Close integration between cybersecurity and BCM is critical to ensure that organizations can quickly and effectively respond to cyber events and minimize their impact on business operations.

As Kosutic [4] states, the basic elements of business continuity refer to the primary components used to build a company's resilience, including risk assessment, business impact analysis, continuity strategy, and business continuity planning (including incident response and disaster recovery). In the context of business continuity, it is essential to mention the ISO 22301:2019 standard "Security and resilience – Business continuity management systems – Requirements" [5]. The ISO 22301 standard specifies requirements and rules to ensure business continuity and assists companies in rapid recovery in the event of unforeseen events. Its aim is to prepare companies and protect them in case of extraordinary unforeseen events such as natural disasters, power outages, fires, workforce shortages due to pandemics, terrorist attacks, mass IT outages, malfunction of key production or technological equipment, and other threats.

42. An essential prerequisite for effective continuity planning is to have predefined scenarios of various events that could potentially have a negative impact on the organization's regular activities. Typical categories of BCM scenarios include sudden [6]:
   - Unavailability of personnel,
   - Inoperability of workplaces or buildings,
   - Inoperability of technologies,
   - Unavailability of media.

43. Based on the requirements of the ISO 22301:2019 standard "Security and resilience - Business continuity management systems - Requirements" (BCM), it can be argued that the organization's management should formally decide which incident scenarios, considering the organization's limited resources, are subject to business continuity management. In the context of information and cybersecurity, the scenarios mentioned above are most commonly defined in practice. In general, an organization prepares for the interruption of its activities. By planning and enhancing the employee culture regarding accepted security incidents, the organization creates conditions to increase its success in addressing a real incident. Based on continuity plans, the organization establishes conditions to manage a real incident or failure of processes, services, or technologies, in order to return to productive activity in the fastest and most effective way possible, thereby minimizing potential negative impacts. Business Continuity Plans are generally defined for these three areas [4]:
   - Continuity of disrupted priority activities at a predefined level
   - Recovery of disrupted priority activities to the normal level of service, process, technology
   - Mitigation of the impacts of a security incident.

To achieve the organization's capability to create and validate business continuity plans, it is essential to define a business continuity strategy [7]. Within the BCM strategy, approval of recovery time objectives and assessment of third-party capability to ensure supply chain continuity are included. Establishing and selecting an appropriate BCM strategy are based on the results of risk analysis and Business Impact Analysis (BIA) [8]. BIA represents a crucial building block for the BCM process. Through BIA, it is possible to more accurately identify and quantify potential impacts and losses in the event of operations disruption. The goal is to delineate primarily those processes that are critical to the organization, often referred to as critical processes. Business Impact Analysis (BIA) involves assessing the economic, reputational, and regulatory impacts and estimating the costs of process recovery in case of downtime, at various time intervals from the onset of the outage. Assessing dependencies of individual processes on critical resources provides a basis for creating critical process recovery plans. V Within BIA, it is possible to determine attributes that are crucial for determining the criticality of processes, such as [5]:

- Recovery Time Objective (RTO) - the time within which an acceptable level of activities is restored after an outage, or the maximum time it would take to restore the functional state of applications in the event of a sudden service loss. For each process, a predefined recovery time goal, known as RTO, is established, with this time determined based on the criticality of the process.
- Recovery Point Objective (RPO) - the maximum acceptable data loss measured at the time of the recovery point. In other words, it is the data loss that would be acceptable for customers and the organization to recover operations and also considers the acceptability factor of data loss. In relation to process recovery, the activation of the recovery process is required.
- Maximum Tolerable Downtime (MTD) - the maximum outage time representing the time limit for restoring fully functional status. After this time elapses, it is likely that the organization will incur losses.

Disaster recovery significantly differs from business continuity planning (BCP) as it focuses on specific responses to incidents and is often more technologically oriented. While BCP deals with organizational processes, disaster recovery concerns the operation of information technologies and is closely dependent on the specific technological environment [9].

The requirement for continuity is typically found in various legal regulations, such as banking laws, GDPR, and cyber security legislation. According to a general definition, business continuity is referred to as the organization's ability to plan and respond to events and incidents in order to maintain its operations at an acceptable level. This definition often aligns with the ISO 22301:2019 standard [5]. Business continuity is of paramount importance, especially in the realm of critical infrastructures and industrial systems. In relation to the Law No. 69/2018 on Cyber Security of the Slovak Republic and the Regulation of NBU No. 362/2018, we can discuss security measures in this area, which organizations were required to implement within 12 months from the date of inclusion in the list of essential services (law). Within this article, we will focus on implementing impact analysis into a selected organization.

Impact analysis is the first step in the process of managing process continuity [6]. Its output is to identify critical processes for the organization's core activities and the assets that support these processes. Based on the outputs of impact analysis, the organization decides which process continuity strategy to adopt, as it is important for it to have resources - material, financial, and human - available and in what quantity to be able to recover from an incident resulting in the interruption of its core activities. The process following impact analysis is then the creation of continuity plans and recovery plans.

2. Method of Investigation

The chosen company for the research is a representative entity governed by the Cybersecurity Act, operating within the energy sector. Classified as a Small and Medium-sized Enterprise (SME) based on its employee count, the company specializes in the production, sale, and distribution of heat for both households and businesses. Details such as the company's name, location, and other identifying information are intentionally withheld to maintain confidentiality. The disclosed information is partial, constituting a subset of available data, and is presented with the aim of safeguarding sensitive company details.

The impact analysis was conducted through a combination of methods selected to achieve the defined objectives.

Interviews were a crucial method for gaining subjective insights and information from relevant participants. In the context of impact analysis, they were utilized in initial meetings to understand expectations, goals, and the analysis process. This method served to identify potential areas of interest and contributed to forming a comprehensive picture of the situation based on direct experiences and opinions of stakeholders.

Moderated workshops with owners of relevant processes were strategically employed to gain a deeper understanding of their activities. In the impact analysis, these workshops were used to identify potential risks and impacts. This method facilitated direct involvement of key stakeholders and created a space for the collective identification of potential issues, ensuring a comprehensive view of the analyzed issue from the perspective of internal processes.

Analysis of internal documents was used in crafting the scope of processes and activities for a detailed examination of internal documents. These documents included information about processes, information systems, and their dependencies. Analyzing this input data allowed a better understanding of the context and factors influencing the organization, providing an informational foundation for subsequent impact analysis.

By employing **risk analysis**, the impacts of potential unavailability of processes on the organization's main processes and activities were identified.

The process of conducting impact analysis was structured into several main phases:

1. Introduction Meeting to Impact Analysis: A series of introductory meetings were organized to familiarize stakeholders with the goals and procedures of impact analysis. These meetings also served to set expectations and gain support from involved parties.
2. Proposal of the Scope of Processes and Activities: This phase involved proposing the scope of processes and activities to undergo impact analysis. The proposal was developed based on information obtained about the organization's structure and main processes.
3. Moderated Workshops with Owners of Relevant Processes and Activities: These workshops aimed to gather input data necessary for conducting impact analysis and garner support and cooperation from relevant stakeholders.
4. Impact Analysis: The actual impact analysis was conducted based on collected input data. In this phase, potential risks and their possible impacts on defined processes and activities of the organization were identified.

3. Investigation Results

Impact analysis is based on processes within the organization, during which the following were investigated:

• Data and information used in individual processes.
• Requirements for data and information availability.
• Supporting assets processing data (hardware, software, human resources, suppliers, and others).
• Contexts and dependencies between individual processes.
• Quantitative resource requirements in processes.

Impact analysis was conducted based on information obtained from the provided internal documentation of the analyzed organization. This analysis was performed for the information systems supporting the organization's core processes, as listed in the table below. The provided information is partial and not comprehensively presented due to the extensive amount of information.

Table 1.
Main Processes

Business Process	IS Activity within the business process / IS	Type of IS process
Production Process	his system provides planning and control of production processes, management of material storage, tracking of their consumption, as well as management of raw material orders / MRP-Material Requirements Planning	Main Process
Supply Chain Process	The Supplier Management System ensures tracking and management of material and information flow within the supplier network, including order management, deliveries, and supplier relationships / SCM - Supply Chain Management	Main Process
Production Planning Process	The Inventory Planning System ensures optimization of production resources and capacities based on demand and resources. It includes the creation of production plans, production resource planning, production order management, and plan performance tracking / IPS - Inventory Planning System	Main Process
Distribution and Logistics	Sales and Distribution Management System (SaDS) is a system that manages customer orders, product distribution, shipment tracking, and customer relationship management.	Main Process

The impacts of potential unavailability of processes, information systems, and associated data were assessed on a scale from 0 to 5. These criteria are listed in Table 2.

Table 2.
Description of Impacts

Value	Description of Impact	Financial Loss	Operational Impacts	Legislative Impacts	Reputational Impacts
1	Negligible Impact, Losses	10	Internal, One Person	Disciplinary	Internal dissatisfaction within the department
2	Small Impact, Loss	100	Internally, multiple people	Change in internal legislation	Internal dissatisfaction across multiple departments
3	Significant Impact, Loss	1000	Internally, department	Initiation of corrective action (low penalty)	Internal dissatisfaction throughout the organization, unfavorable publicity
4	Significant Impact, Loss	10 000	Part of the company	Initiation of corrective action (high penalty)	National negative publicity
5	Catastrophic Impact, Loss	More than 100,000	Impact on the entire company	Initiation of corrective action at EU level leading to a high penalty	International negative publicity

Based on interviews, potential impacts for individual processes, as well as RPO and RTO values, were determined. In addition, process owners and possible external dependencies were identified. Prioritization of recovery was established for the main processes. We provide an example for main processes only. Due to sensitive company data, the numbers presented are adjusted.

Table 3.
Operational impacts during outage

Business Process/ IS	<12 hours	<1 day	<3 days	<7 days	<4 days	Impact	Critical Processes	Recovery Priority	RTO/ hours	RPO/ hours days
Business Process	Negligible Impact, Loss	Minor Impact, Loss	Significant Impact, Loss	Significant Impact, Loss	Significant Impact, Loss	13,10	Yes	1	< 3days	2 day
Production Process	Negligible Impact, Loss	Minor impact, loss	Significant impact, loss	Significant impact, loss	Significant impact, loss	13,10	Yes	2	<3 days	2 days
Supply Chain Process	Negligible impact, loss	Minor Impact, Loss	Minor Impact, Loss	Minor Impact, Loss	Significant impact, loss	11,30	Yes	4	<7 days	2 days
Production Planning Process	Negligible impact, loss	Minor Impact, Loss	Significant impact, loss	Significant impact, loss	Significant impact, loss	12,80	Yes	3	< 3days	2 days

Based on the impact analysis, it is necessary to decide on a continuity management strategy and develop specific plans/procedures in the event of a disaster that would require the recovery of all processes or some parts of the processes and their supporting IS. When creating plans, it is crucial to consider, above all:

- The need for alternative space
- Ensuring internet connectivity
- The need for devices - end stations, printers, network elements
- Contractual arrangements for cooperation with critical suppliers
- Minimum office equipment (desks, chairs) • The possibility of remote work

As part of the further development of the impact analysis, an evaluation of supporting processes related to the main processes will also take place. In the event of a disruption to these supporting processes, there would be a disruption to the main processes as well.

4. Conclusions

In the context of current cyber threats and technological disruptions, it is evident that the implementation of Business Continuity Management (BCM) is essential for maintaining the stability and competitiveness of organizations. The continually evolving digital landscape brings forth numerous challenges that can significantly jeopardize the operations and integrity of business systems and processes. This article undertakes an impact analysis as the initial step in the BCM process, aiming to identify critical processes and resources necessary for sustaining business continuity. It is crucial to emphasize that effective protection against cyber threats requires not only technological measures but also well-thought-out risk management and continuity strategies. The close interconnection between the realms of cybersecurity and BCM is pivotal for an efficient response to incidents and the minimization of their negative impact. This connection becomes even more critical in the context of the legal framework for cybersecurity, imposing heightened responsibilities and requirements on organizations for safeguarding sensitive data and critical infrastructure.

The presented article illustrates an impact analysis focusing on the evaluation of the organization's key processes in terms of their criticality and the time required for their recovery. This process enables organizations to gain crucial insights into which areas of their operations are most vulnerable in the event of a disruption and what resources will be needed to restore normal operations. These insights are then fundamental for developing continuity plans and facilitating a prompt response in crisis situations.

The further research will focus on evaluating supporting processes within the framework of the ongoing development of impact analysis. The main objective is to assess the relationship between these supporting processes and the core processes, identifying their impact on the overall workflow. In the event of an interruption in these supporting processes, it is anticipated that the main processes would be disrupted and halted. This research aims to contribute to understanding the significance and stability of supporting processes within the broader context of impact analysis.

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Development of Secure Routing Algorithms in Computer Networks

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Abstract

The paper delves into the contemporary information security challenges within computer networks. It scrutinizes the existing methods of message packet routing, identifying several drawbacks associated with them. When examining issues concerning information security, it's crucial to consider the unique characteristics of this aspect of security. Security forms an integral part of information technologies, a field evolving at an unprecedented pace. The paper addresses the challenges associated with developing secure routing algorithms within Wide Area Network (WAN) environments. The paper presents and elucidates on novel secure routing algorithms characterized by a qualitatively innovative approach to resolving security concerns. Thanks to a novel suite of essential features in each variant of the proposed method, which includes specifying information about the communication network's structure, initial data regarding network nodes and users, and calculating integrated security metrics, secure routes between network nodes are meticulously selected from all available communication pathways among users. This ensures that network users are furnished with a secure route.
The paper pertains to the realm of information communication and can serve as a valuable resource for planning or developing new network connections in networks like corporate intranets and extranets.

KEY WORDS: *computer networks, routing algorithms, information security.*

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1. Introduction

Information security stands as a paramount facet of integrated security, regardless of the level at which it's considered - be it national, industrial, corporate, or personal [1, 2].

What holds significance here are not merely individual solutions such as laws, training courses, or software and hardware products, which undergo periodic updates. Rather, it's the mechanisms for generating novel solutions that enable us to keep pace with the rapid advancements in technology. Information security has not only become exceedingly crucial but has also emerged as a highly trendy and lucrative field of endeavor. It's quite natural that the interests of numerous departments, companies, and individuals clash in this domain, leading to a struggle for spheres of influence, and sometimes even for survival. Connecting an organization to a global network like the Internet notably enhances the organization's efficiency and unlocks a plethora of new opportunities for growth and development. Simultaneously, the organization must prioritize establishing a robust system for protecting its informational resources, catering to those who wish to utilize, modify, or enhance them. Irrespective of the particulars, the organization's security system when operating in global networks should be oriented towards safeguarding its information resources [2].

In such circumstances, it becomes imperative to explore new approaches to guaranteeing information security. One of these areas involves managing the routes of information exchange between users within a communication network [6, 11-13].

The TCP/IP stack is not entirely secure and leaves room for various types of attacks. To execute such attacks, an attacker needs access to one of the systems connected to the Internet. This access can be obtained, for instance, by hacking into a system or by utilizing a computer connected to the Internet [3]. Attacks on TCP/IP generally fall into two categories: passive and active. In passive attacks, the attacker's actions at the TCP level are limited to monitoring available data or communication sessions. Eavesdropping, for example, entails intercepting network traffic and analyzing it. Due to the lack of encryption in TCP/IP traffic, an attacker equipped with appropriate tools can intercept sessions of TCP/IP packets and extract usernames

and passwords. It's important to note that this type of attack is difficult to detect because it doesn't alter the network flow. Attackers frequently employ passive scanning to determine the TCP ports on which domains respond to network requests. A typical scanning program will reveal connections to different ports and report port numbers to the attacker [4].

The current methods of routing message packets exhibit several drawbacks, such as insufficient adaptation to changes in the network structure, low communication security, and various other limitations. Selecting a transmission route involves establishing the sequence of transit network nodes through which messages should be forwarded to the intended recipient. This selection process typically occurs within the network nodes of the provider operators. The presence of nodes with low security levels creates conditions for network intrusions, consequently diminishing communication security [7, 8].

The approaches outlined in the paper and the algorithm presented are geared towards enhancing communication security by effectively managing information exchange routes between network users.

The model presented in the paper closely aligns with the technical essence of "The method of choosing a route to be used for equal commutation in the network" employed in routers. The method involves presetting initial data that includes the quality criteria of the routes. Information regarding the structure of the communication network, including the addresses of network nodes and the existence of connections between them, is stored within the router. A set of possible communication routes is established. Upon receiving a message intended for a target network address, a route is selected based on predetermined route quality criteria, and messages are transmitted along the chosen route.

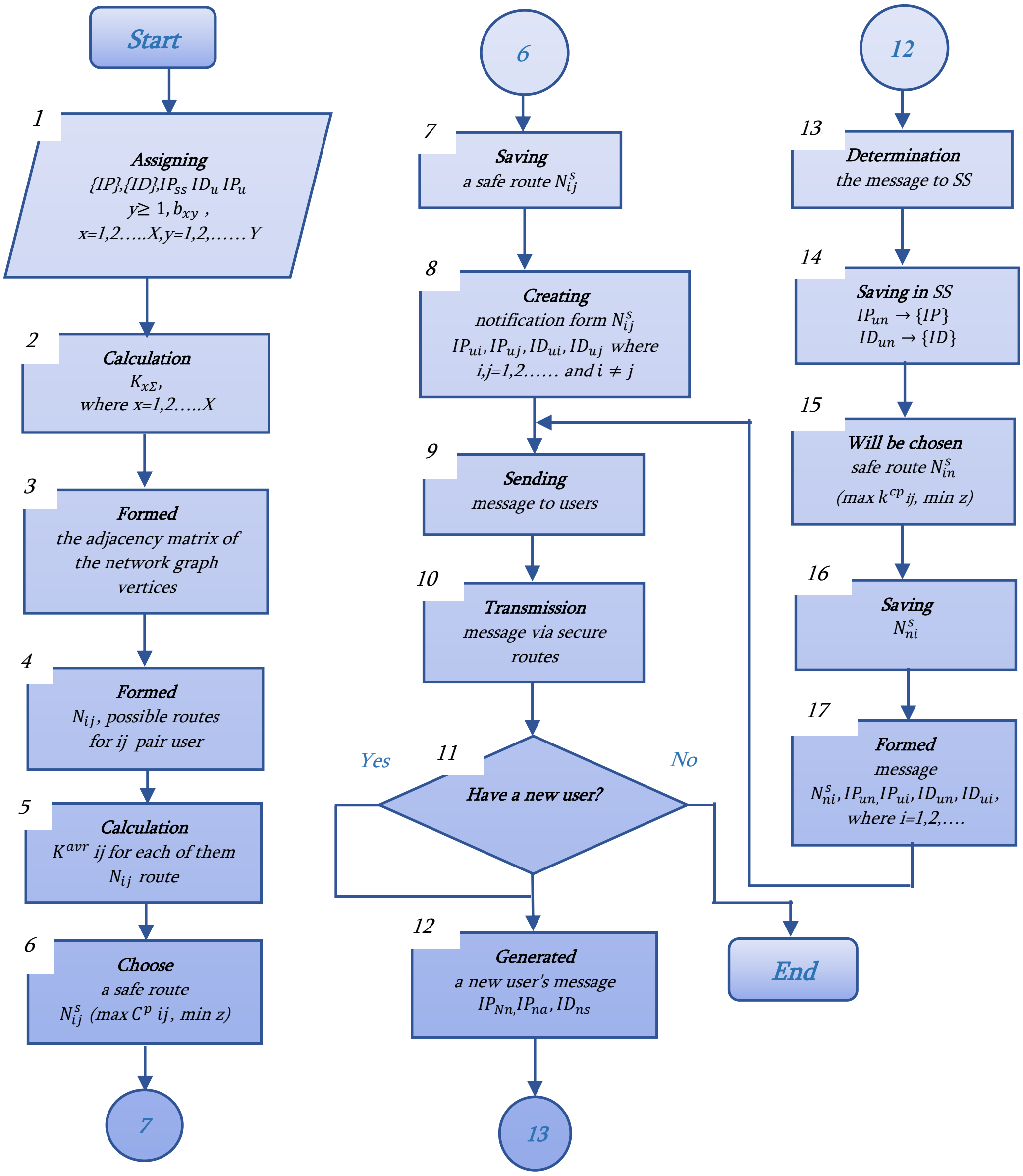

Fig. 1. The block diagram of the first version of the secure routing algorithm for message packets

Nevertheless, a drawback of this method is the relatively low security of communication when utilizing the selected route for information exchange among users in the communication network [10]. A secure routing algorithm for message packets is introduced, comprising two versions for selecting a secure route within a communication network.

The first version (Fig.1.) pertains to a communication network where each node possesses $X \geq 2$ connections. Initial data is pre-assigned to the network nodes, and information regarding the network structure is recorded, including the IP_{Nn} addresses of the network nodes and their connectivity. A set of N potential communication routes is generated, from which a secure route is selected for transmitting messages.

N_{ij} represents the graph tree of the communication network, illustrating the routes between users i and j, and is calculated by the formula:

$$N_{ij} = B_0 * B_0^T,$$

Where $B_o = M * K$ is the matrix of neighboring vertices of the graph representing the communication network, with $M = M_p - 1, K$ - representing the number of rows and columns of the matrix respectively. M_p - denotes the number of adjacent rows of the original matrix, equal to the total number of communication network nodes; B_0^T represents the transposed matrix of B_o.

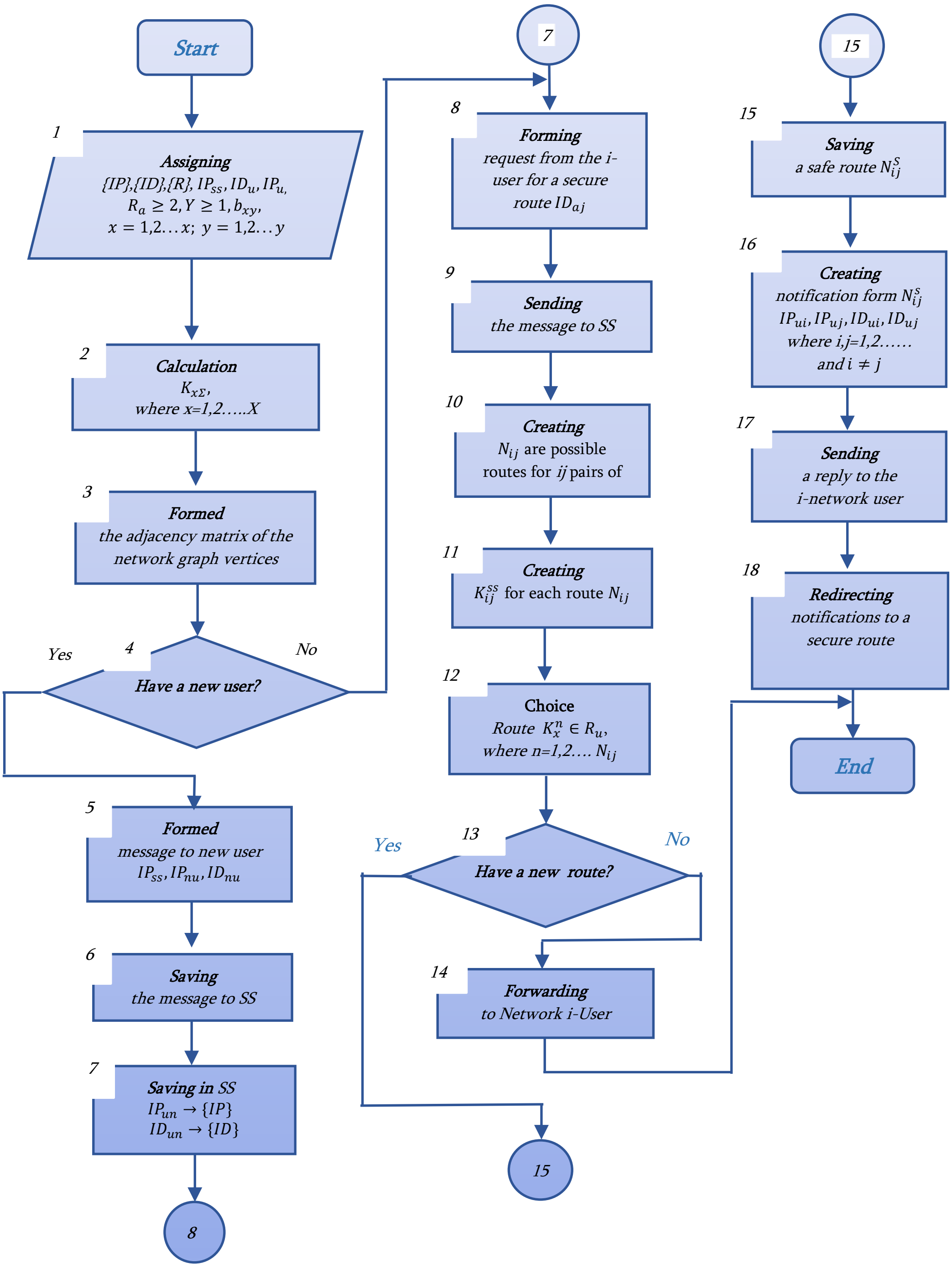

Fig. 2. The block diagram of the second version of the secure routing algorithm for message packets

The second version of the algorithm addresses a communication network where each node possesses $X \geq 2$ connections. Initial data are pre-assigned to the network nodes, and information regarding the structure of the communication network is recorded, including the IP_{Nn} addresses of the network nodes and their connectivity possibilities. A set of N potential communication routes is established, from which a secure route is selected to transmit messages.

In contrast to the previous algorithm, the predefined initial data now includes, in addition to the structural and identification arrays of the network, the security indicator of the permitted route, the IP_{Nn} address of the security server, the corresponding ranks of the information to be transmitted in the network R_{inf}, and the complex security indicators $k_{x\Sigma}$ of the network nodes. The number of routes N_{ij} in the communication network graph between network users i and j is calculated by the formula:

$$N_{ij} = |B_o \times B_o^T|$$

Where $B_o = M * K$ - is the matrix of neighboring vertices of the graph representing the communication network, with $M = M_p - 1, K$ - representing the number of rows and columns of the matrix respectively. M_p -denotes the number of adjacent rows of the original matrix and is equal to the total number of communication network nodes; B_0^T -represents the transposed matrix of B_o.

2. Principle of Operation of Secure Routing Algorithms

To facilitate the exchange of information between users within a communication network, a secure communication route must be chosen from the set of available routes connecting the network's users. Routing a message entail identifying the sequence of nodes within the transit network through which the message should traverse. Determining the route poses a challenging task, particularly when numerous potential routes exist between a pair of users. Route determination involves selecting one or more routes from the set of possible options based on specific criteria. In existing methods of route selection, typical criteria include nominal bandwidth, congestion of communication channels, delays introduced by channels, number of intermediate network transit nodes, reliability of channels, and network transit nodes. However, in many cases, a contradiction arises between the need to ensure communication security and these existing methods. The proposed method (versions) seeks to address this issue. Accordingly, the first version of the presented method is implemented as follows.

In general, Fig. 3 depicts a communication network comprising: 1. X network nodes, 2. Security server, 3. Network users, 4. Combined physical communication lines. The number of nodes X in the network is greater than or equal to two. All these elements are identified using identifiers common in the TCP/IP protocol stack, such as network IP addresses. The set of addresses connecting users and network nodes to the communication network does not overlap. The transmission of messages between network users occurs through network nodes, with the most secure connection being selected from all possible communication routes. Connections between network elements are characterized by only two values: the presence of a connection and its absence. Other parameters of the communication lines are considered constant and are not taken into account, as the most probable and easily implemented method of unauthorized monitoring of information exchange in the communication network is through connection to its nodes.

Fig. 1 illustrates a block diagram outlining the sequence of actions performed in the first option of selecting a secure route in the communication network of the developed method, where the following notations are introduced:

- {IP} - structural array;
- {ID} - identification array;
- IP_{ss} - the network address of the security server;
- ID_u - User ID;
- IP_u - user's network address;
- Y - the number of security parameters of network nodes to be considered;
- b_{xy} -Value of security parameter y of network node x, where x = *1.2, ..., X, y = 1.2, ..., Y;*
- $k_{x\Sigma}$ - complex security indicator of each x network node;
- N_{ij} - the number of communication network graph trees corresponding to the set of possible communication routes between i and j network users, where $i = 1.2,..., j = 1,2,...,$ *and* $i \neq j$;
- K_{ij}^{avr} - the average security indicator of the communication route between network i and j users;
- N_{ij}^S **-** secure communication route between users of network i and j;
- Z_n- n number of graph tree vertices, where $n = 1,2,..., N_{ij}$, corresponding to the number of network nodes;
- **SS** - security server.
- In the second version, Fig. 2. the following additional notations have been introduced:
- {R} - an array of compatibility between R_u ranks of users and complex indicators of security of network nodes $k_{x\Sigma}$;

- R_u - Ranks of network users.

At the initial stage, initial data are set on the security server, including structural {IP} and identity {ID} arrays, security server address IP_{ss}, identifiers ID_u and IP_u addresses of users connected to the communication network, as well as security parameters for each network node X, where $x = 1, 2,..., X, Y \geq 2$ and their value b_{xy}, where $y = 1,2,...,Y,$ which are given in Table 1.

Table 1.
Initial data identifiers security parameters for each network node X

x \ y	1	2	…	Y
1	b_{11}	b_{12}		b_{13}
2	b_{21}	b_{22}		b_{23}
…				
X	b_{x1}	b_{x2}		b_{xy}

Structural array *{IP}* – stores data about the addresses of the IP_{SS} security server, IP_{Nn} nodes and IP_u network users, as well as information about the presence of a connection between them (Table 2), which is characterized by only two values, "1" - the presence of a connection and "0" - its absence.

Table 2.
Characterization the presence of connection

	IP_{SS}	IP_{n1}	IP_{n2}	IP_{n3}	IP_{n4}	IP_{n5}	IP_{ni}	IP_{nj}	IP_{nn}
IP_{SS}		1	0	0	0	0	0	0	0
IP_{n1}	1		1	1	1	0	0	0	0
IP_{n2}	0	1		0	1	1	1	0	0
IP_{n3}	0	1	0		1	1	0	1	0
IP_{n4}	0	1	1	1		1	0	0	1
IP_{n5}	0	0	1	1	1		0	0	0
IP_{ni}	0	0	1		0	0		0	0
IP_{nj}	0	0	0	1	0	0	0		0
IP_{nn}	0	0	0	0	1	0	0	0	

Identification array *{ID}* - the array stores data about ID_{SS} security server identifiers, ID_u of communication network users and corresponding IP_u addresses of network users and IP_{SS} security server addresses (Table 3).

Table 3.
Identification array *{ID}*

Network Host Address	Network Host Identifier
IP_{SS}	ID_{SS}
IP_{ui}	ID_{ui}
IP_{uj}	ID_{uj}
. . .	. . .
IP_{un}	ID_{un}

Security parameters of network nodes are established based on recognized standards from ISO/IEC JTC 1/SC 27. The values of security parameter y = 1 for b_{x1} nodes of the network are defined according to the specifications provided by the manufacturers of the network node devices, which can be obtained from physical addresses. For instance, let's consider a node N_{n1}, with a hypothetical physical address like 00:01:e3:3F:D4:E1. The first three values of this address may indicate the manufacturer, corresponding to a value of the security parameter b_{11} = 0.3. Similarly, the security parameter values b_{x1} for network nodes *Nn2-Nn5* are determined as $y = 1$, along with the security parameter values b_{xy} for all $Y \geq 2$.

For each node X of the network, based on its security b_{xy} parameters, the values of the complex security index $k_{x\Sigma}$ are calculated. The calculated indicators are presented in Table 4.

The complex security index $k_{x\Sigma}$ for each node x of the network is calculated either by summing $k_{x\Sigma} = \sum_{y=1}^{y} b_{xy}$ or by multiplying $k_{x\Sigma} = \prod_{y=1}^{y} b_{xy}$ or by the arithmetic mean of the node b_{xy} security parameters $k_{x\Sigma} = (\sum_{y=1}^{y} b_{xy})/y$.

Table 4.

The calculated indicators

Network Node	k_{Σ}
1	$k_{1\Sigma}$
2	$k_{2\Sigma}$
x	$k_{x\Sigma}$
X	$K_{X\Sigma}$

The method of calculating the complex security index $k_{x\Sigma}$ fundamentally does not impact the outcome of selecting a secure route. The computed values of the security complex index $k_{x\Sigma}$ for each node x in the examined variant of the communication network, considering the values of the corresponding security parameters b_{xy}, are provided in Tab.5.

Table 5.

Values of b_{xy} nodes

Network nodes $x = 5$	Host security settings $Y = 3$				x-node security complex index $k_{x\Sigma}$		
	$y = 1$	$y = 2$	$y = 3$		$\sum b_{xy}$	$\prod b_{xy}$	$(\sum b_{xy})/Y$
$x = 1$	0,3	0,13	0,4		0,83	0,0156	0,276666667
$x = 2$	0,3	0,16	0,4		0,86	0,0192	0,286666667
$x = 3$	0,2	0,1	0,34		0,64	0,0068	0,213333333
$x = 4$	0,5	0,2	0,25		0,95	0,025	0,316666667
$x = 5$	0,05	0,08	0,01		0,14	0,00004	0,046666667

Next, a matrix of neighboring vertices of the network graph is created. In this matrix, IP_{SS} addresses of network nodes and IP_a addresses of network users are organized into a structured array, along with details about the connections between nodes and network users. Methods for generating the matrix of neighboring vertices of a graph are well-documented [9]. The matrix representing the neighboring vertices of the communication network graph will take the following structure as is presented in Table 6.

Table 6.

The neighboring vertices of the communication network graph structure

b=

	Nn_1	Nn_2	Nn_3	Nn_4	Nn_5
Nn_1	0	1	1	1	0
Nn_2	1	0	0	1	1
Nn_3	1	0	0	0	1
Nn_4	1	1	0	0	1
Nn_5	0	1	1	1	0

Afterward, network ID_a, ID_{SS} identifiers, along with IP_a and IP_{SS} addresses of network users and security Server, are collected in the identification array.

Each n- tree of a communication graph, where $n = 1,2,...,$ N_{ij} consists of z_n vertices corresponding to the number of nodes in the network. The total number of trees N_{ij} in the communication network graph between network users i and j can be determined by different methods. In the presented method, the total number of communication graph trees N_{ij} is formed by using the neighboring vertices of the matrix.

By deleting any row of the matrix B, we get the initial B_0 and the matrix B_0^T transposed with it:

$$B_0 = \begin{pmatrix} 1 & 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 0 & 1 \\ 1 & 1 & 0 & 0 & 1 \\ 0 & 1 & 1 & 1 & 0 \end{pmatrix}; \; B_0^T = \begin{pmatrix} 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 \\ 1 & 1 & 1 & 0 \end{pmatrix}$$

The calculation of the number of trees N_{ij} between users *i* and j of the communication network graph is performed by multiplying the obtained matrices B_0 and B_0^T, and then finding its determinant.

$$N_{ij} = |B_0 \times B_0^T| = \begin{pmatrix} 3 & 2 & 2 & 1 \\ 2 & 2 & 2 & 0 \\ 2 & 2 & 3 & 1 \\ 1 & 0 & 1 & 3 \end{pmatrix} = 5$$

Establishing communication routes between users based on the graph tree of the communication network entails identifying all potential communication paths while excluding blocked routes that are unsuitable for message transmission.

Reasoning and objectively selecting a potentially safe communication route from the set of N_{ij}=*5* between network users *i* and j involves calculating the average security indicator k_{ij}^{avr}**.** It is obtained as network nodes by calculating the complex security indicator, i.e. the arithmetic mean k_{Σ}^{n}, and includes connection *n-th* communication routes $k_{ij}^{avr} = (\sum k_{\Sigma}^{x})/z_n$.

As a result of calculating the complex security index of the network nodes in various methods, the communication routes formed between network users *i* and *j* with the average security index k_{ij}^{SS} are calculated. The results are presented in Table 7.

Table 7.

Values of the complex security indicator of network nodes

Route N_{ij} = 5	Number of nodes on *n*-route	Z_n number of nodes on the *n*-th route	Average safety indicator of the *n*-th route		
n = 1	123	3	0,78	0,0139	0,26
n = 2	1234	4	0,82	0,0167	0,27
n = 3	12345	5	0,68	0,0133	0,23
n = 4	235	3	0,55	0,0087	0,18
n = 5	2345	4	0,65	0,0128	0,22

A secure route between users *i* and *j* of network N_{ij}^{s} is selected based on the highest value of its average security index k_{ijn}^{SS} . If several routes with equal average safety values are found, the shortest route is selected from the identified routes. This means selecting the route with the smallest number of Z_n nodes in it. Afterward, the selected route is memorized. From the results presented in the table, it can be seen that for all calculation methods, the second *n = 2* routes have the highest values of the average security index k_{ij}^{avr}, which are shaded accordingly. It can be concluded that the calculation method of $k_{x\Sigma}$ does not directly affect the result of choosing a secure route. This way, a set of all possible route options between all users of the network is formed.

The result is generated via messages that include memorized routes N_{ij}^{S} between *i* and all *j* users, ID_{aj} identifiers, and IP_{aj} addresses of all j users. Afterward, generated messages are sent to all *i*-users in the network. Thus, each user of the network is informed about secure routes that can be established between all other users of the network.

To transmit messages between users, the message ID_a is selected based on the recipient's IP_a address and the secure N_{ij}^{S} route to the user, after which the message is delivered to the recipient. Well-known routing protocols such as RIP, OSPF, NLSP, BGP serve to transmit user information (source-specified routing) using routing methods and facilitate information exchange from the source to the receiver along a designated route. Thus, users have the option to send messages directly via a designated secure route. When a new user connects to the communication network, a message is generated for them, containing the IP_{n4} address of the N_{n4} network node, the recipient's ID_{an} identifier, and the recipient's IP_{an} address. The generated message is sent to the security server, where it is stored in structural and identification arrays, updating the information in the communication network's security server. Following a similar process as described earlier, secure communication routes are selected and stored between the new user and all *j* users of the network.

At the next stage, a message is formed containing information about the network structure and its users. These messages, which include stored information about secure communication routes, are generated from each existing user *j* of the network to the new user and sent accordingly. Consequently, the new user is informed of secure routes to all other users in the network, while the remaining users are notified of available secure routes to the new user within the network.

In the initial version of the method, secure routes are selected based on the communication network's structure, initial data about network nodes and users, and the calculation of complex security indicators for network nodes. By managing information exchange routes, the aim is to enhance the security of communication between users within the network.

The second variant of the method introduces a new concept of ranks for network users. In this version, the selection of a secure route between network users occurs only upon the user's request and based on predetermined user ranks. If a secure communication route is unavailable, the user is notified accordingly.

Figure 2 illustrates the block diagram depicting the sequence of actions for the second version of the method, which involves the selection of a secure route in the communication network.

At the initial stage, similar to the first variant of the method, the initial data is specified on the security server.

In the initial data, unlike the first variant of the method, the security index k^{perm} of the permissible route is not specified. In addition, compared to the second variant of the method, the correspondence matrix of R_a rank *{R}* of the users and the complex security indicators $k_{x\sum}$ of the network nodes are introduced. The array *{R}* contains the corresponding values of the ranks of network nodes $R_a \geq 2$ users and complex security indicators $k_{x\sum}$. For example, the user rank $R_a = 1$ corresponds to the $k_{x\sum}$ values of complex security indicators of network nodes from 0 to 0.2. After setting the initial data, similarly as in the third variant of the method, for each network node *x*, the complex security index $k_{x\sum}$ is calculated from the values of its security parameters b_{xy}. The calculated indicators are given in the table.

In the initial data, unlike the first variant of the method, the security index k^{perm} of the permissible route is not specified. Additionally, compared to the second variant of the method, the correspondence matrix of R_a rank *{R}* of the users and the complex security indicators $k_{x\sum}$ of the network nodes are introduced. The array *{R}* contains the corresponding values of the ranks of network nodes $R_a \geq 2$ users and complex security indicators $k_{x\sum}$. For example, the user rank $R_a = 1$ corresponds to the $k_{x\sum}$ values of complex security indicators of network nodes from 0 to 0.2. After setting the initial data, similarly as in the third variant of the method, for each network node *x*, the complex security index $k_{x\sum}$ is calculated from the values of its security parameters b_{xy}. The calculated indicators are given in the table.

Subsequently, similar to the first variant, the adjacency matrix of the vertices of the network graph is created. In the event of connecting a new user to the communication network, similar to the third variant of the method, a message is generated containing the *NS4* IP_{ns4} address of the network node to which they are connected, as well as the ID_{an} and IP_{an} addresses of their identifiers. The generated message is sent to the security server, where it is stored in structural and identification arrays. This process updates the information about the structure of the communication network and network users. Then, a message containing the user-recipient identifier ID_a is formed. Similarly, to the third variant of the presented method, its address IP_a and secure route N_{ij}^{s} are selected. Afterward, the message is transmitted to the receiving user using the chosen route.

In addition, as proposed in the second variant of the method, the set of possible communication routes between network users *i* and *j* is created in the form of trees of the communication network graph N_{ij}. Unlike the first variant of the method, the secure communication route N_{ij}^{s} between the *i*- and *j*-users of the network is selected if the complex security indicators $k_{nx\sum}$ of the nodes included in it correspond to the equal or higher rank R_{ai} of the *i* user of the network. For example, for network user *i* $R_{ai} = 1$, the complex indicators of security of $k_{nx\Sigma}$ nodes satisfy the selected secure communication route N_{ij}^{s} and are in the range of values from 0 to 0.2 (Table 8).

Table 8.

The network is selected if the complex security indicators of the nodes are included in it

Rank of Network users $R_a \geq 2$	$k_{x\Sigma}$
1	0…0,2
2	0,2…0,4
3	0,4...0,6
4	0,6...0,8
5	0,8...1

In this way, a secure communication route between users *i* and *j* is selected at the request of user *i* of the network and according to the predetermined ranking of the users of the network. In addition, as in the first variant of the method, secure route N_{ij}^{s} including backup route is protected, message generation N_{ij}^{s} and j user's address IP_{aj} and the generated message is sent to network *i* user.

If there is no secure route between network users *i* and *j*, meaning there is no route among the possible communication routes where the security indicators of the nodes included in it match the rank of the user, a response is generated and sent to network user i indicating the absence of a secure route to network user *j*.

Contrary to the first variant of the method, the secure communication route N_{ij}^{s} between the *i*- and *j*-users of the network is chosen if the complex security indicators $k_{nx\sum}$ of the nodes included in it align with the equal or higher rank of information transmitted in the network $R_{inf\ i}$. For instance, if the information to be transmitted to the network user *i* has a rank of $R_{inf\ i} = 1$, then the security complex indicator $k_{nx\sum}$ in the chosen secure communication route N_{ij}^{s} falls within the range of values from "0 to 0.2".

The complex security indicators $k_{nx\Sigma}$ of the nodes involved in the established communication routes serve as the foundation for an objective evaluation of the selected secure communication paths between network users. They enable us to take into account the essential conditions required for choosing a secure route in communication.

Therefore, the second algorithm of the method also achieves the intended technical outcome - enhancing the security of communication among network users.

Figure 3 illustrates an example of selecting a secure route to a security server in a communication network between users *i* and *j*.

The complex security indicators $k_{nx\Sigma}$ of network communication nodes and their security parameters b_{xy} are calculated, and the values are presented in Table 3.

From the example provided, it's evident that utilizing the second version of the secure route enables the exclusion of transit nodes with a low level of security within the network. This helps mitigate the risk of unauthorized access to messages transmitted by users in the network. In this example, as illustrated in the calculation table, N_{S5} demonstrates high values of the network security index $k_{5x\Sigma}$ and user security parameters b_{5y}, which are highlighted accordingly (Figure. 3).

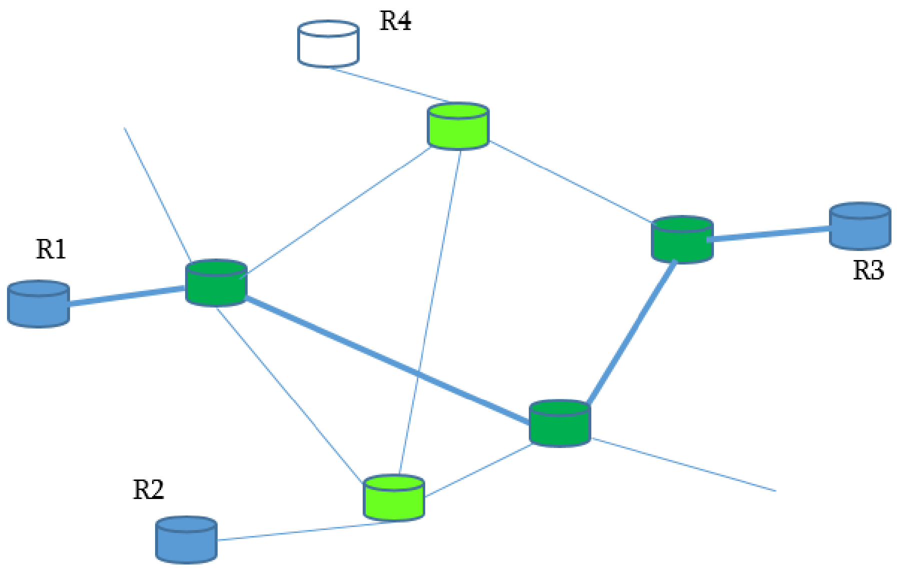

Fig. 3. An example of selecting a secure route to a security server in a communication network

Table 9.

The indicators of complex security $k_{nx\Sigma}$ for communication nodes

Network node	Security settings of network nodes b_{xy}			Security indicator of Network node
	y=1	*y=2*	*y=3*	$k_{x\Sigma}$
Nn = 1	0,3	0,13	0,4	*0,83*
Nn = 2	0,3	0,16	0,4	0,86
Nn = 3	0,2	0,1	0,34	0,64
Nn = 4	0,5	0,2	0,25	0,95
Nn = 5	0,5	0,08	0,01	0,14

Thus, the chosen secure communication pathway, delineated by bold lines, between users *i* and *j* traverses through the transit nodes of the network, characterized by the highest security rating. This minimizes the likelihood of unauthorized interference in the exchange of information between network users.

Conclusion

From the examples provided, it is evident that utilizing the proposed method for selecting a secure route enables the exclusion of low-security transit nodes within the network, which significantly reduces the risk of unauthorized interference with transmitted messages.

Based on the findings presented in the paper, it can be concluded that both options of secure route selection in the proposed method led to enhanced communication security by effectively controlling information exchange routes among users in the communication network.

The algorithm represents a novel approach to addressing security concerns and aims to mitigate the drawbacks associated with existing methods of routing message packets in computer networks.

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Effects of Physical and Psychological Stress on Cognitive Performance in Czech Army Students

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Abstract

We present preliminary findings and partial analyses concerning the cognitive abilities and coping mechanisms of military students engaged in simulated combat scenarios. The Short Neuropsychological Battery (KNB) was used to measure cognitive abilities, the Coping Strategies Questionnaire (SVF-78) was used to assess stress coping strategies. Our initial data suggest that cognitive performance varies among individual students, although certain patterns emerge. Significant statistical variances were detected between pre-test and post-test assessments across cognitive domains, including attention, language, visuo-spatial aptitude, and executive functions.

KEY WORDS: *coping strategies, cognition, physical activity, command staff, field training*

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1. Introduction

Stress is an essential part of every individual's life, yet we know that excessive stress has a negative impact on both mental and physical health [1]. From the broadest perspective, we define stress as the body's nonspecific response to any demand [2], in a narrower sense, stress arises in situations with high demands and high risk [3]. Military service inherently involves high demands and high daily risks; therefore, the stress burden is understandably high for military personnel. Research findings support the claim that stress burden is higher among soldiers compared to the general population [4]. Aside from common stressors, significant stress is also brought by issues directly related to military topics [5], and we can observe a negative impact on mental health associated with distress stemming from military duties [6].

Similarly, members of the Czech Army (ACR) are exposed to demanding conditions in performing their duties – whether it's psychological, physical, or environmental stress. Any type of (excessive) burden causes distress. Acute and chronic stress affect an individual's performance at various levels [3]. We also know that high or chronic stress levels have negative impacts not only on a person's health, where physical and mental health is a fundamental requirement for any profession. This raises the question of how to protect the health (and consequently, performance) within our military. While there are external protective factors or methods to reduce the impact of adverse working conditions (e.g., the positive effect of caffeine on cognitive functions during sleep deprivation) [7], it's also important to understand the internal (or individual) protective factors of individuals – their coping strategies.

Systematic reviews demonstrate a significant influence of environmental stress on cognition in soldiers [8], with dehydration, inadequate nutrition, and excessive physiological response to cognitive tasks being among the most significant environmental factors [9]. This makes environmental stress highly relevant to our conditions. However, in our circumstances, we have not yet defined the areas affected by psychological, physical, or environmental stress. In the development of students (but also in general, for the protection of the mental and physical health of Czech Army personnel), it's necessary to understand which domains and skills are influenced by stress and how to minimize the negative effects. It is important to emphasize the significance of prevention and cognition development among students at the University of Defence, as they are military personnel preparing for command positions.

Foreign sources highlight the necessity of having a military-specific psychodiagnostic battery to assess the cognitive abilities of its members [10]. In our context, however, we do not have comprehensive tools and methods for systematically evaluating cognitive performance in relation to stress burden or a specific battery used for these purposes within the Czech Army.

Standard psychodiagnostic methods are commonly used for assessing cognitive performance within the Czech Army, but they are not tailored to the specific requirements for the education and development of future military leaders. Therefore, we started with complete cognition profile to realize what is the important part to adjust psychodiagnostics tools for military purposes in the future.

2. Objectives and Methodology

Main objective for both, this article and educational project, is to map coping strategies and cognitive performance of third-year students at the University of Defense, both in a resting state and after the stress induced by a combat simulation game during field training.

Circumstances of the field training: Within the framework of compulsory education, third-year students at the University of Defense participate in an intensive 48-hour training. During this training, students work in groups to complete tasks prepared in the context of simulated combat conditions. These tasks include, for example, casualty evacuation, shooting, S.E.R.E (Survival, Evasion, Resistance, and Escape), wading, map reading, all while carrying full field gear. Throughout the tasks, students are exposed to physically and mentally demanding conditions (sleep deprivation, physical exertion, stress during task solving, etc.). The aim of the training is not only practical training in military-technical skills but also the rehearsal and development of communication skills and leadership practice. In addition to skills training, psychological testing is conducted, providing students with individual feedback. The schedule of the training and the psychological testing was as follows in Table 1.

Table 1.
Timetable of the training and psychodiagnostics

<table>
<tr><th></th><th>Midnight to 2 a.m.</th><th>2-4 a.m.</th><th>4-6 a.m.</th><th>6-8 a.m.</th><th>8-10 a.m.</th><th>10-11:59 a.m.</th><th>12-2 p.m.</th><th>2-4 p.m.</th><th>4-6 p.m.</th><th>6-8 p.m.</th><th>8-10 p.m.</th><th>10 p.m. - midnight</th></tr>
<tr><td>DAY 1</td><td colspan="3"></td><td>Start of the training</td><td colspan="3">Pretest KNB (version A); SVF-78</td><td>Teambuilding activities</td><td colspan="4">Field training</td></tr>
<tr><td>DAY 2</td><td colspan="9">Field training</td><td colspan="2">Posttest KNB (version B)</td><td>Rest/sleep</td></tr>
<tr><td>DAY 3</td><td colspan="3">Rest/Sleep</td><td colspan="2">The end of the training + debriefing</td><td colspan="7"></td></tr>
</table>

Psychodiagnostic methods: The project employed psychodiagnostic methods targeting two areas: cognitive performance and stress coping strategies. Both methods used are validated on the Czech population, including normative sample for evaluation. To measure cognitive performance, the Short Neuropsychological Battery (KNB) was used, consisting of 17 subtests covering a complete cognitive profile (memory – both the short-term memory and long-term memory; attention; executive function; speech function; and visuospatial abilities). The test is administered individually and takes 35-45 minutes. The KNB Version A is used for the initial testing (pretest), and KNB Version B for the subsequent testing (post-test). KNB-A and KNB-B are parallel versions used to monitor changes in cognition over a short period. With standardized and comparable results, a comparison can be made between baseline (resting) cognitive performance and cognitive performance under stress. The second method used is the stress coping strategies questionnaire (SFV-78). The SFV-78 questionnaire consists of 78 items, and administration is simple in terms of time and organization, taking approximately 20 minutes to complete and capable of group administration.

Target group in the project: In total, during the field training we tested 114 students of the University of Defence who study the third year at Faculty of Military Leadership. After data cleaning, data from 110 students were analysed using statistical methods in the SPSS statistical software.

3. Results

Cognitive performance: Our results data suggest that cognitive performance varies among individual students, although certain patterns emerge. Significant statistical (in pair sample t-test) variances were detected between pre-test and post-test assessments across nearly all cognitive domains, including attention, language, visuospatial abilities, and executive functions. In our sample, the short-term memory did not change after stress (mean = -0.302, SD = 0.627, resp. mean = -0.309; SD = 0.733). Whereas a significant reduction in long-term memory was observed after stress from field training, which demonstrated the highest change among all measured cognitive abilities (t = 8.88, df = 109, p < 0.001), with a substantial decrease (mean = -0.205; SD = 0.48; resp. mean = -0.945; SD = 0.887). Similarly, a statistically significant reduction in speech function was observed after the stress exposure (t = 4.48; df = 109; p < 0.001). Both executive functioning and visuo-spatial function remained without statistically significant changes in both measurements. However, a mild improvement in executive function was noted after filed training (mean = -0.554; SD = 0.588; resp. mean = -0.413, SD = 0.646); t = -2.04, df= 108, p=0.44), while no changes were observed in visuo-spatial function in pretest and posttest (mean = -0.589, SD = 0.71, resp. mean = -0.594, SD = 0.71; t = 0.064, df = 107, p = 0.949). A statistically significant improvement post-stress was only observed in the attention (mean = -0.378, SD = -0.124, mean = -0.124; SD = 0.78, t = -4.73, df = 108, p < 0.001).

Table 2.

Cognition difference in pre-test and post-test

Cognitive Domain	N	Pretest		Posttest		Mean* Difference (pre&post test)	Pair sample t-test		
		Mean*	SD	Mean*	SD		t	df	P
Short-term Memory	109	-0.302	0.627	-0.309	0.733	-0.007	0.96	108	0.924
Long-term Memory	110	-0.205	0.48	-0.945	0.887	-0.74	8.88	109	<0.001
Executive functioning	109	-0.554	0.588	-0.413	0.646	0.14	-2.04	108	0.44
Visuo-Spatial Function	108	-0.589	0.72	-0.594	0.71	0.005	0.064	107	0.949
Attention	109	-0.378	0.754	-0.124	0.78	0.254	-4.73	108	<0.001
Speech Function	110	-0.229	0.539	-0.551	0.661	-0.322	4.48	109	<0.001
Total Score	106	-0.372	0.332	-0.492	0.398	-0.12	3.59	105	<0.001

N=number of cases; SD=standard deviation; t = Student's t-test; df= degree of freedom; p=significance; * means are in z-scores.

As evident in Table 2, there is a statistically significant difference in total score of the cognitive performance (t = 3.59; df = 105; p < 0.001), with the average score in the pretest (mean = -0.372; SD = 0.332) being higher than the posttest score after stress (mean = -0.492; SD = 0.398).

Association between pretest and posttest: Within the dataset, a correlation analysis was conducted to examine relationships among various cognitive domains in both the pretest and posttest phases (see Table 3).

Table 3.

Correlation between pretest and posttest cognition performance

Correlated domains	R	Correlated domains	r
STM pretest & LTM prestest	0.353**	Visuo-spatial pre & post	0.414**
STM post & LTM post	0.53**	Executive Function pre & post	0.325**
STM pre & STM post	0.334**	Attention pre & post	0.733**
LTM pre & LTM post	0.297*	Speech pre & post	0.226*
Total score pre & post	0.569**		

STM=short-term memory; LTM = long-term memory; r= Pearson correlation coefficient; *p < 0.005; **p < 0.001

All identified correlations were positive. Total Score of cognition demonstrated a correlation coefficient of r = 0.569 (p < 0.001) between the pretest and posttest. The highest correlation was observed in the attention domain (r = 0.733, p < 0.001), followed by visuo-spatial function (r = 0.414, p < 0.001), short-term memory (r = 0.334, p < 0.001), executive function (r = 0.325, p < 0.001), long-term memory (r = 0.297, p < 0.005), and speech (r = 0.226, p < 0.005). Given the theoretical and practical interdependence of short-term and long-term memory, correlation relationships were explored across both types of memory at all timepoints (both pre- and posttest). In the pretest, the correlation between short-term and long-term memory was r = 0.353, whereas in the posttest, the correlation between short-term and long-term memory was higher (r = 0.530).

Stress coping strategies: Overall, adaptive coping strategies prevail among students over maladaptive mechanisms (see Table 4). The most frequently used coping strategies are positive strategies from the POS 3 group (mean = 16.1; SD = 3.4), which include Positive self-instruction (mean = 16.8; SD = 4), Reaction control (mean = 16.6; SD = 3.9), and Situation control (mean = 16.6; SD = 3.9). In the research sample, respondents achieve higher scores in adaptive coping strategies from the POS 2 group (mean = 12.1; SD = 3.4; Diversion and Substitute satisfaction) than in strategies from the POS 1 group (mean = 11.6; SD = 2.9; Underestimation and Denial of guilt). Among the negative strategies, Perseverance (mean = 11.6; SD = 5.1) predominates, while for Resignation (mean = 6; SD = 3.1) the research sample shows the lowest scores. Neutral coping mechanisms (not classified as adaptive or maladaptive, rather following preference) are more represented in the sample than negative ones: Need for social support (mean = 12. SD = 5.2); Avoidance (mean = 14.6; SD = 4.2).

Table 4.
Coping Strategies in Students

Group	Coping Strategy	Mean	SD	Group Mean	SD
POS 1	Underestimation	13.1	4.3	11.6	2.9
	Denial of guilt	10.2	3.3		
POS 2	Diversion	13.1	3.7	12.1	3.4
	Substitute satisfaction	11.2	5		
POS 3	Situational control	14.9	5	16.1	3.4
	Reaction control	16.6	3.9		
	Positive self-instruction	16.8	4		
NEUTRAL	Need for social support	12	5.2		
	Avoidance	14.6	4.2		
NEG	Escape tendency	8.4	3.7	8.8	3.2
	Perseverance	11.6	5.1		
	Resignation	6	3.1		
	Self-blame	9.4	4.2		

4. Discussion

Interest in the effects of stress on performance is especially relevant in military settings, where training personnel to handle stress and minimizing performance deficits under challenging conditions are crucial. Although extensive information on this topic exists in current literature, generalizing findings is difficult due to the complexity of combat operations [11]. Addressing these problems involves two main strategies: 1) isolating and experimentally measuring individual factors, which may reduce the ecological validity, and 2) simulating complex combat conditions, which complicates the understanding of specific influences due to the increased number of uncontrollable variables. This project aims to compare cognition in controlled versus combat-simulated conditions and to use these results to improve training methods. Instead of focusing on identifying individual variables that affect performance, our aim is to place our findings within the context of broader research.

However, aligning our results with other academic studies is challenging because the literature does not always offer consistent findings. The effects of physical exercise on mental functioning vary widely – ranging from significantly positive to no effect or even negative effects on cognitive performance [12]. These variations could be explained by differences in environmental conditions, methodologies, specifics of military training across different countries, and individual differences among participants. For instance, factors like resilience and aerobic fitness have been shown to significantly buffer the impacts of stress on cognitive performance [13]. Thus, we view our results as specific to our conditions and preliminarily relevant to existing findings.

A significant stressor reported by trainees was the heavy weight they had to carry. Carrying heavy loads, especially during long marches, can impair cognitive functions [14]. Influences of the carried load and terrain are also documented, affecting attention, memory, and executive functioning [15]. The carried load also increases error rates in auditory tasks and slows responses in visual tasks [16]. Heavy loads also exacerbate the physical strain, which correlates with cognitive decline—particularly in critical operational areas like memory and recognition [17]. Observations from simulated combat training show changes in memory, attention, and reasoning associated with these conditions Increased attention is interpreted in the context of a systematic review that shows current physical activity has a positive impact on attention – and this considering the fact that increased attention was not fully consistent in individual differences. This supports the notion that attention increases mainly in individuals who are long-term physically active [18], and that the performance of soldiers in military tasks depends on overall physical activity and nervous system stability [19].

Regarding coping strategies, students predominantly use positive strategies, such as Positive Self Instruction, Reaction Control, and Situation Control, which are beneficial in military contexts. It's essential not only to promote these adaptive strategies but also to identify and support students who rely on less effective strategies, providing them with tools to manage stress better. These strategies play key roles in performing military duties effectively.

In general, our findings are supported by the literature, but further research that includes more detailed and controlled studies is necessary. Future research should aim for more precise measurements of physical and psychological variables and strive to minimize the influencing external factors to better understand the connections between physical exertion, cognitive outcomes, and psychological resilience.

5. Conclusion

A predominance of adaptive coping strategies was found among the students at the University of Defence. Changes in cognitive performance in response to stress exposure were observed. The overall cognitive performance score showed a significant difference between the pre-test and post-test, with a general decline in cognitive performance following stress. While short-term memory and visuo-spatial function remained mostly unaffected in both resting and post-training states, the most pronounced differences were found in long-term memory showing significantly lower scores after the training session.

Moreover, a reduction in cognitive performance was evident in speech function, demonstrating a statistically significant difference. Also, in executive functioning the change can be seen, even though the progress after the training is not statistically significant. Interestingly, attention showed a significant improvement following exposure to stress. A more significant association between short-term and long-term memory was noted in the post-test than in pre-test.

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Other Central Administrative Authorities in the Crisis Management System

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Abstract

Other central administrative authorities are part of the crisis management authorities with national competence in the Czech Republic and are subjects of the state security system. Their activities are focused on specialized sections of the state administration, and they have a certain degree of independence, which is why in some cases they are not associated with tasks and activities in the field of crisis management. Other central administrative authorities must also fulfil the requirements of normative legal acts and be able to respond to differentiated risks. Against this background, the article examines the extent to which the requirements of the Crisis Management Act are being fulfilled. Using an analysis of interviews and written inquiries with their representatives, a comparison and evaluation of their involvement in crisis management is made. The results show that the requirements of the Crisis Management Act are fulfilled in each of the other central administrative authorities. However, their level of details is differentiated depending on the scope of their activities.

KEY WORDS: *crisis management; other central administrative authorities; exercises; crisis management units; crisis preparedness; crisis plan; crisis management authorities*.

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1. Introduction

The Act on Crisis Management [1] defines categories of crisis management authorities (the government, ministries and other central administrative authorities, the Czech National Bank, regional authorities, and other authorities with competence in the territory of the region, authorities of municipalities with extended competence and municipal authorities). All these authorities are part of the state security system and play a key role in the performance of national public administration and their interdependence and cooperation is crucial. There are established 17 other central administrative authorities with the national competence in the Czech Republic. In the public administration system, they have the same status as the ministries. This category of other central administrative authorities is the least mapped and published group of crisis management authorities, although they must fulfill the requirements of normative legal acts [1], [2] and be ready and able to respond to differentiated risks.

Based on the above, the article examines the scope of fulfilling activities related to ensuring preparedness and dealing with non-military crisis situations according to the requirements of the Crisis Management Act [1]. The aim of this article is to fill in a gap in information about other central administrative authorities in national crisis management contexts and it provides a division of other central administrative authorities according to their competences in relation to crisis management into two categories. The first part of the article defines the basic aspects of the embedding of other central administrative authorities within the public administration and the crisis management system of the Czech Republic. The main practical part of the article is concerned with the results of the survey itself and deals with the extent to which requirements of the Act on Crisis Management [1] are met for each of the other central administrative authorities.

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2. Methodology and Limitations

Due to the issue under research, qualitative research was carried out based on semi-structured interviews or written questionnaires. The semi-structured interview was chosen to allow more flexibility in the conversation. For the semi-structured interviews, priority has been given to officials responsible for crisis management in the relevant other central administrative authority. Due to the low interest of the representatives of other central administrative authorities to answer during the interview, written questionnaires were also used, either on the official emails of the authority or in accordance with Act No. 106/1999 Coll., on free access to information [3]. The reason for the chosen data collection was the fact that information on the researched issue is not freely available on the official websites of other central administrative authorities. Based on the data collection, a comparison was made focusing on the fulfilment of the tasks established by the Act on Crisis Management [1], involvement in exercises of crisis management bodies and crisis management. Out of a total of 17 other central administrative authorities, 2 agencies were not included in the survey, namely the Digital and Information Agency, due to its recent establishment at the beginning of 2023, and the Industrial Property Office, which did not provide any information.

3. The anchoring of other central administrative authorities in the public administration

Other central administrative authorities act as executors of the national state administration with a given sub-jurisdiction. Their list is set out in the Competence Act [4] and the structure and difference between ministries and other central administrative authorities is illustrated in Figure 1.

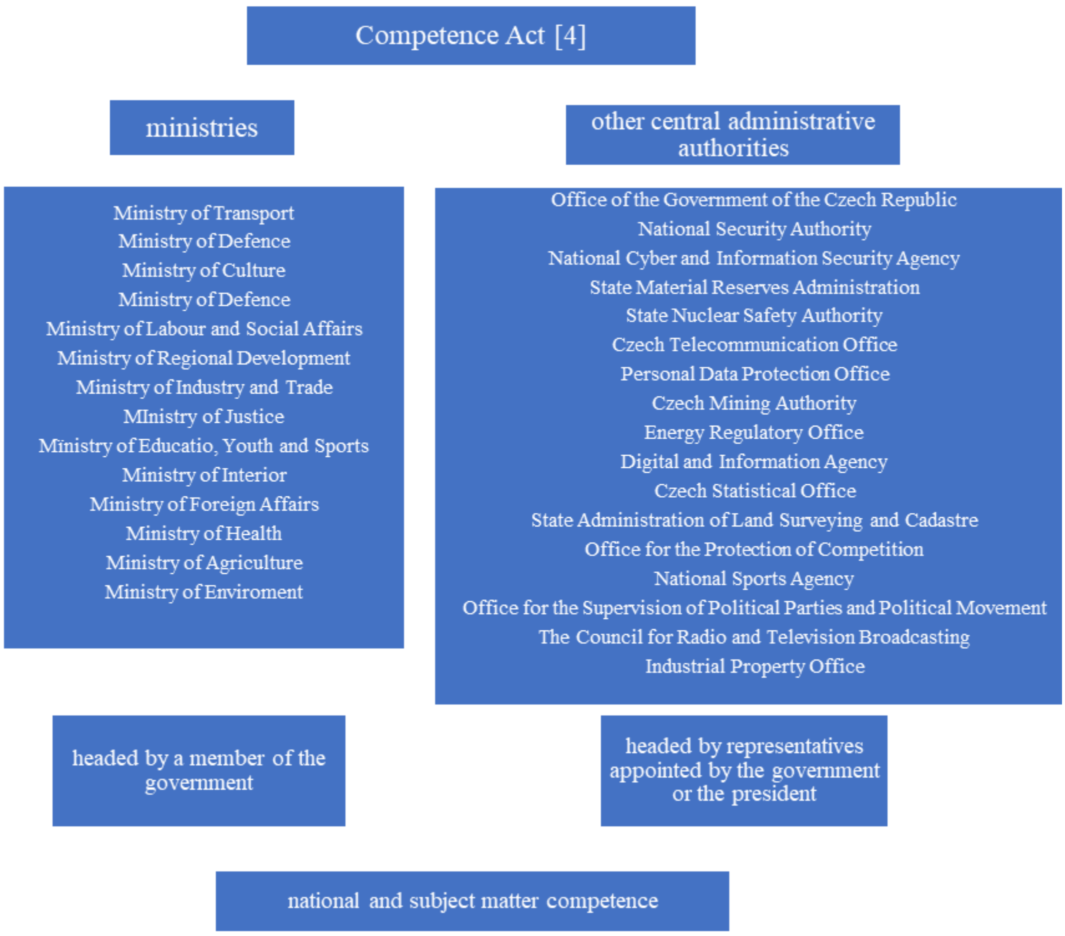

Fig.1. List of the ministries and other central administrative authorities and their differences [4]

The scope of activities of other central administrative authorities, which are a fixed organizational unit of the state besides the ministries, is defined by their substantive competence and is aimed at specialized sections of state administration [5]. Oulehlová describes [6] that their specific competence gives them a degree of independence that is not present in some other central administrative authorities when carrying out certain activities. Those activities falling within their competence are determined by only by law and do not accept any other instructions from any other authority; they are referred to as 'regulators' within their competence. Other central administrative authorities also have their national security obligations enshrined in normative legal acts. The article focuses on the application of the Crisis Management Act [1].

4. Survey results

In the first part of the survey, based on the comparison, other central administrative authorities in relation to crisis management or ensuring state security can be divided into two categories. This classification also indicates that the first category is more proactive in crisis preparedness activities, as it is related to their scope of activities. The first category of other central administrative authorities has a direct link to crisis management or security in one or more of its relevant competences defined by the founding normative legal act (e.g. State Material Reserves Administration, National Cyber and Information Security Agency, State Nuclear Safety Authority). The second category is without such a direct link (e.g. National Sports Agency, Office for the Protection of Competition, Czech Statistical Office, State Administration of Land Surveying and Cadastre). The whole schema of division is shown in Figure 2.

1. category

- Office of the Government of the Czech Republic
- National Security Authority
- National Cyber and Information Security Agency
- State Material Reserves Administration
- State Nuclear Safety Authority
- Czech Telecommunication Office
- Personal Data Protection Office
- Czech Mining Authority
- Energy Regulatory Office
- Digital and Information Agency (not included in survey)

2. category

- Czech Statistical Office
- State Administration of Land Surveying and Cadastre
- Office for the Protection of Competition
- National Sports Agency
- Office for the Supervision of Political Parties and Political Movement
- The Council for Radio and Television Broadcasting
- Industrial Property Office (not included in survey)

Fig.2. Categorization of other central administrative authorities [own]

4.1. Crisis management units

Other central administrative authorities are obligated by law [1] to establish a crisis management unit to ensure and implement activities related to the assurance of preparedness and management of crisis. The survey shows that the other central administrative authorities listed in the first category mostly have an independently functioning crisis management unit - the security/crisis management department headed by the Security Director. Their crisis management units have more personnel, with more table positions are created. In the second category, this function is usually held only by one personnel, most commonly represented by the Security Director, who is also responsible for all, setting up and securing the crisis staff within the framework of crisis preparedness. In the second category ofother central administrative authorities, there were problems with a lack of staff dedicated to crisis management issues. The work of the crisis management unit is carried out mainly by a single staff member, who combines functions from other areas. In the case of security, this includes personnel, administration, physical, information and communication systems, health and safety at work, fire safety and cryptographic protection. The departments thus comprehensively cover the security issues of the other central administrative authorities concerned. The accumulation of tasks may result in reduced crisis preparedness of the office concerned. These departments also often have to deal with a relatively high fluctuation of staff in these positions.

4.2. Crisis management plans

The necessary planning documentation of other central administrative authorities includes the preparation of a crisis plan, which has clearly defined structure and contains a summary of crisis measures and procedures for dealing with crisis situations [1]. Oulehlová [6] noted that also other central administrative authorities must be prepared for both situations, where due to their own deployment of their subordinate units and departments may be threatened by any danger (e.g. flood, leakage of dangerous chemical substances, terrorist attack) or a situation that belongs to their area of responsibility (e.g. gas supply disruption, cyber-attacks). The survey did not provide relevant information on the existence of a crisis plan for all other central administrative authorities interviewed, but it can be assumed that all of them have fulfilled this obligation. According to Government Regulation No. 462/2000 Coll. [7], the crisis plan is updated regularly in four-year cycles in a normal situation. Only the National Cyber and Information Security Office mentioned a regular 4-yearly update, the other offices did not comment on this issue at all and 3 authorities mentioned more frequent updates, which appears to be very improbable, as these were belonging to the 2. category.

As Göghová [8] mentioned, other central administrative authorities are also responsible (co-responsible) for drafting type plans based on the Threat Analysis [9], which identifies threats with an unacceptable risk to the Czech Republic. In view of the dynamically changing security situation and the effects of climate change in connection with the transformation of threats of a natural nature on the territory of the Czech Republic, an update of the Threat Analysis is now being carried out.

Table 1

Responsibility of Other Central Administrative Authorities for Type Plans [own]

Other Central Administrative Authorities	***Type plan***
Office of the Government of the Czech Republic	X
National Security Authority	Information security breach of critical information infrastructure
Czech Telecommunication Office	Disruption of the functionality of major electronic communications systems
Personal Data Protection Office	X
Industrial Property Office	X
Czech Statistical Office	X
State Administration of Land Surveying and Cadastre	X
Czech Mining Authority	X
Energy Regulatory Office	X
Office for the Protection of Competition	X
National Sports Agency	X
Digital and Information Agency	X
Office for the Supervision of Political Parties and Political Movement	X
The Council for Radio and Television Broadcasting	X
State Material Reserve Administration	Large-scale disruption of oil and petroleum products supply
State Nuclear Safety Authority	Radiation accident Leakage of a hazardous chemical from a stationary installation
National Cyber and Information Security Agency	X

It is clear from Table 1 that this could at least co-responsibly affect other central administrative authorities than just 4 out of a total of 17 authorities.

4.3. Other requirements resulting from the Crisis Management Act

The paper further examined the extent of compliance with the Emergency Management Act under Section 9. The authorities responded very diversely to the question of what tasks an institution performs within the crisis management system. Crisis management of other central administrative authorities is primarily focused on the organizational and functional support of the authorities' activities in the event of crisis situations. Offices that were classified in Category 1 answered the question in more depth and in the context of their specific subject matter competence. Most authorities claimed that their security departments ensure the development of security and workplace protection plans as part of crisis preparedness, together with the performance of inspections of the premises. The National Cyber and Information Security Agency, for example, has specific responsibilities for analyzing potential cyber security threats, proactively searching for cyber security incidents and then disseminating information to critical infrastructure entities as part of crisis management. The National Cyber and Information Security Agency has the power to declare a cyber emergency, which is communicated to the general public and through the public media. The Czech Telecommunication Office is another office that fulfils the duties set out in the Crisis Management Act [1] within its scope. For example, its separate security department may issue general authorizations, thereby regulating the conditions relating to the protection of personal data for certain sectors of electronic communications, the use of electronic communications networks and services in crisis situations, etc. Two agencies, the State Nuclear Safety Authority and the State Material Reserve Administration, play an important role, as their subject-matter is directly related to dealing with emergencies. Both of them are in charge of 2 type of plans and thus have a number of other sub-tasks, for example, the State Nuclear Safety Authority has to prepare the National Radiation Emergency Plan in case of a radiation emergency abroad, on the other hand, the State Material Reserve Administration, as the central authority in the field of economic measures for emergency situations and state material reserves, submits a proposal for declaring a state of oil emergency in case of a crisis situation related to oil shortage.

Authorities classified as Category 2 fulfil their duties as defined in the Crisis Management Act [1] marginally. Most of the authorities included in the List have a consultative, educational and monitoring function. The Czech Statistical Office, for example, focuses on the production and distribution of quality, valid and complete statistical data, which is then used by government authorities in preparation for potential security risks and crisis situations. A similar function is performed by the National Sports Agency and the Office for the Protection of Competition, which also collect data in the field of crisis management and provide it on request to ministries and other authorities involved in crisis management.

The questionnaire survey revealed that out of a total of 17 other central administrative authorities, 5 of them actively participate in national and international exercises on a regular basis, namely, State Material Reserve Administration, State Nuclear Safety Authority, National Cyber and Information Security Agency, Office of the Government of the Czech Republic, National Security Authority. The above-mentioned authorities regularly receive invitations to the international CMX exercise, which is organized by the North Atlantic Treaty Organization. Very occasionally, national and international exercises are attended by Czech Telecommunication Office and Energy Regulatory Office. At the national level, regularly exercise through the Zone and Sources exercises only State Material Reserve Administration, State Nuclear Safety Authority and Office of the Government of the Czech Republic. According to the analysis, other central administrative authorities do not participate in the exercise at all thereby also not fulfilling the requirements of the Crisis Management Act [1].

5. Conclusion

Other central administrative authorities are classified as elements of the executive power and are also crisis management authorities. Normative legal acts [1], [2] show that their role is in all phases of crisis management, increasing in the case of a large-scale crisis situation and requiring a coordinated approach of management from the national level. An example is the COVID-19 disease pandemic, which demonstrated the necessity of increasing crisis preparedness in all sectors of society, and at the same time was the first crisis situation for some other central administrative authorities to address.

The article helped to fill a gap in information about other central administrative authorities in national crisis management contexts. The survey provided and also confirmed the necessary division of other central administrative authorities according to their competences in relation to crisis management into two categories, which was made at the beginning of the research. The primary difference was seen in the degree of involvement of the authorities in crisis management issues, which, however, is mainly determined by their subject matter competence. However, the same legal responsibilities also applied to the authorities under category 2, and their implementation should play a key role. The article also identified the problems that are more frequent in the second category of other central administrative authorities and which, in a way, also result from their more reduced subject-matter competence in relation to crisis management.

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Technologies in the Ukrainian Conflict: Reflection and Perspectives from Viewpoint of Combat Unit's Utilization

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Abstract

The aim of the article is to highlight the technologies, which are somehow new or more widely utilized then in times prior to 2022, when the Ukrainian conflict started. The research has been based on an in-depth study of a wide range sources and analysis. The core of the research has been based on logic, mostly methods of deduction and induction also, based on knowledge of tactics of combat units, knowledge of new tools and processes. It describes how they affected tactical level operations and missions. The article proposes recommendations for tactical level units, mostly combat units up to battalion level.

KEY WORDS: *artificial intelligence, multi-domain warfare, network centric warfare, units, unmanned devices, tactics, technologies*

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1. Introduction

In the Ukrainian conflict have been new technologies utilized, which have influenced effectiveness at all levels of command and control. A number of experts have labelled the character of the conflict as "a drone war" or the "first artificial intelligence (AI) war". At the same time, we can observe more news, tools, applications and processes, which have been more or less successfully utilized. By studying various sources, most of the studies analyses and comments on the overall situation [1] are from a higher perspective and does not go down into "tactical unit" level. This specific article is focused on tactical level and consequences from viewpoint of utilization in higher intensity of armed conflict [2]. The information, data and conclusions were analyzed, defragmented into elements and were linked to specific missions and tasks, which are conducting by combat units according to allied doctrine.

New technologies, processes and approaches can significantly influence results of clashes and battles. Facing over-numbering, there is no other chance, then use technology, smart-approach and something new, creating shock, effect or other devices and processes, to increase the "combat potential".

2. Unmanned aerial vehicles

Unmanned aerial vehicles (UAVs) will be in future widely utilized. The utilization of UGV's, based on their characteristics, can be used for strategic, operational or tactical missions. Focusing on low tactical level, we can mention small and mini UAV' s and drones. From viewpoint of "air layer", it is the lowest layer, operating in altitude couple hundreds of meters and on a distance of kilometers, usually not more than 10 kilometers. Enabling observation and impacting the targets, they are able to deliver devices (explosives, sensors etc.) in amount of kilos. Most of them are radio operated or enabling swarming and partial autonomy.

The drones, in appropriate amount, do the "pin-down effect". The enemy is trying to avoid his detection, therefore he limits his movement and maneuver, in consequence of this is limited in occupying advantageous firing positions. This is

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exactly the purpose of tactical activity "cover", what is defined as "A security task to protect the main body by fighting to gain time while also observing and reporting information and preventing enemy ground observation of and direct fire against the main body". UAV's can be utilized also for tasks disrupt, interdict, block and may be others [3]. Some ground units can be replaced by formations of drones or mixed with drones. The limitation is a distance of remote control, electronic warfare operations, battery capacity and weight of a cargo.

As a theoretical example, the swarm [4] of mini 10 UAV´s, each loaded by cargo from 0,5 to 2 kg means, that is able to deliver hand-grenade on target (theoretically lethally impacting area approx. 50 m-depends on type and surface) or for example 60 mm mortar high explosive shell (theoretically lethally impacting area approx. 100 m-depends on type and surface). It means, that enemy platoon, operating in area not more than 500 x 100 m, could be impacted and enemy neutralized.

From perspective of small unit´s tactics, it seems to be beneficial be equipped by "drone unit" on company (mechanized, motorized, infantry) level and with single drones on platoon level / squad level. Definitely, the major role of manned ground unit, is in-replaceable, but UAV´s can be on low tactical level game-changing: enabling to operate on longer and wider distances, having overview better situational awareness, hit enemy in right moment, saving own life's.

3. Antitank weapons

Antitank weapons (ATW) played crucial role during first phase in the Ukrainian conflict. Units stopped approaching enemy and were able to block columns of vehicles. In the close past, the antitank units were in western armies reduced. Ukrainian conflict showed their importance.

ATWs mounted on vehicles enables maneuver and damage effect also. The amount of carrying ATWs is limited, usually amount is around 4 shots. Dismounted unit equipped by ATW is limited with speed, maneuver and physical endurance. On the other hand, can be more "hidden" or can occupy the terrain, which is "no-go" for vehicles. Future warfare will be conducted by various types of vehicles. It means, stopping their movement, similarly as in past, will be crucial [5]. The enemy can be equipped by smart protection, where modern weapons can be detected and neutralized. The combat can be adjusted in various types of terrain, enabling utilization or non-utilization of advantages of various types of weapons. Short-distance combat (in urban, forests) will be also actual, most of modern weapons do not enable fight on shorter distance than 200 m. Therefore, combination of various types will be necessary. Light antitank weapons or RPG´s are not sufficient against modern armored vehicles. They can just partially reduce some abilities, what is manageable to fix by self-maintenance or by logistic units on tactical level. Destroying armored vehicles will be challenge for infantry of future, not only for specialized antitank units. One of many ways is also re-arming of units. Equipping wide specter of units by antitank weapons, with both types- for mounted and dismounted units also. Real resisting modern armored vehicles, stopping their maneuvering and denying their advance should be effectively incorporated again to list of abilities of all combat units.

There exist three perimeters for destroying armored vehicles: close distance, up to 300 meters, typically in forested or urban area. The area is saturated by units, being in clash. The quick actions are essential. Therefore, infantry in first echelon has to be equipped by antitank weapons, small, light, effective, penetrating from sides and from the top also.

Next perimeter, to be placed is middle-range distance, what can be from 300 m to 2 km. It is distance, where enemy usually dismounts or fires from vehicles effectively to our positions. His positions are visible or predictable, the antitank weapons are more sophisticated, usually needing 2-3 members crew. Loitering ammunition can be also alternative, but not the only solution.

The last level needs to be solved by specialized antitank units on distance above 2 km. Usually, commanders sort the targets based on priorities. Enemy units can be in columns or holding important positions (for example by tanks). The loitering ammunition and sophisticated weapons are sufficient.

The structure and equipment of combat units has to cover all three levels of anti-tank warfare. Every squad has to be equipped by small anti-tank weapon, neutralizing enemy effectively. Developed ammunition has to be utilized. On the platoon level, has to be incorporated minimally 1 team, operating with anti-tank weapon covering middle-range level and also loitering ammunition is recommended. On the company level, there has to exist minimally 1 squad, being able to operate on longer distances, including loitering ammunition. The unit has to maneuver by vehicles, so mounted and dismounted tools are necessary.

At levels from battalion above, we can speak about specialized antitank units, focused primarily on destroying armored units, utilizing various tactics and tools, based on combination of anti-tank weapons, also engineer devices, joint fires etc.

4. Unmanned ground vehicles

Unmanned ground vehicles (UGVs) do not play decisive role in current Ukrainian conflict. Despite this fact, they have been used mostly as loaders, transporting causalities or material in and out of the front line. The combat UGV´s were most likely utilized also, but not as major weapon or main effort. The barrier is a control of vehicles. It is safe and resistant wireless control needed. Autonomy is not developed to sufficient level, enabling UGV´s are waiting for their opportunity. In close future, it is highly in-possible, that they will be used for fully autonomous missions in typical conditions of front line battle [6]. The micro-relief [7] and combat identification is challenging [8].

Despite introduced facts, the development is going forward and incorporating easily commanded UGV´s will be reality. We can mention missions, based on following men-operated crews, utilization against enemy with not so strong electronic warfare. Typically, observing [9], transporting or un-crewed stations [10] (radio, meteorological etc.) are sufficient tasks.

For combat units, seems to be beneficial to be equipped by transporting UGV´s, delivering material or immobile persons from "hot spot" to unit´s rear, moving on known path. Cooperation between UAV, UGV and controlled by manned team is also possibility. The company can be the right lever, from which can be transport UGV incorporated.

The common tactical tasks can be secure and guard, including lethal effect-which has to be under 100% control of manned crew. Mostly, lethal weapons are small caliber, because of back-impact. On the other hand, un-crewed rocket launchers or grenade launchers can be helpful, when being part of squad or platoon, mounted in vehicle and after dismounting placed after movement to the specific point.

The other approach, deploying UGV´s as full-blown combat vehicle, is not realistic in close future. Firstly, because of electronic warfare, secondly, because of un-sufficient autonomy. From perspective of small combat units seems to be small fire-supporting UGV the right way and meanwhile, upgrading the levels of autonomy based on lessons from praxis. When the mistake happens, the commander can deny operating the UGV without significant limitation of unit´s tactical task.

5. Fusion of vision technologies

Technologies like night vision and thermal vision are in Ukrainian conflict widely utilized. From the very beginning of the conflict, Ukrainian side was donated by amount of personal night and thermal visions, mostly commercially available. Maneuver units made a lesson, that night and thermal vision gives them tactical advantage. Also was practically tested, that combination of a thermal and a night vision is beneficial, each has his own specifics, advantages and disadvantages. Especially fast and precise detection [11] is the key for combat units and the most of middle-cost civil applications [12] is sufficient for tactical tasks.

Especially a thermal vision should be incorporated in wide scale into combat units. Minimally, every section has to be equipped with this device, but as best every team, and also with night vision. There exist foresights, which can be mounted according to the tasks and conditions or scopes, based on fusion of technologies, it means a night vision and a thermal vision in one, where the pictures are combined. The final result is the united output, which takes the best from both. Based on experiences from current conflict and own experiments, the effectiveness of small arms fires rapidly increases, not only low visibility or hidden enemy (typically approaching enemy).

The fusion of technologies in mounted weapon stations should be standard part of new generation of vehicles. The inputs from own vehicle, other vehicles, UAVs and reports from dismounted element should be drawn into electronical overlay and be part of common operational picture (COP).

The challenge is not only amount and price of this devices, but also training equipment. It is necessary to use for practical training and coordination of fires the targets with appropriate thermal image, shape, camouflage and electro-magnetical image also.

6. Real time sharing

The OODA loop [13] (Observe, Orient, Decide, Act), as an approach, can be utilized at tactical level also. Quick interaction between phases enable facing strong enemy, using "hit and run tactics", what is well applicable in distributed battlefield [14]. The cornerstone to this is real time sharing of information, agility and flexibility in physical domains, information space and cognitive space also. From one viewpoint, the mission command is appropriate approach, on the other hand, the centralization and the intrication of networks is necessary and is increasing. Not only own forces, but also enemy will conduct the network cells and network-centric warfare will be reality in modern batteles. Therefore, the combat units will be also utilized to eliminate the powerful tools of enemy, what are not only weapons as effectors, but information and communication centers also. Creating gaps in a network structure will significantly reduce enemy´s combat potential and after it, can be destroyed by own forces. As in "old times" the artillery preparation of battlefield was common, the "disrupting the networks" is a part of new age battles. Meaning in all scales, from platoon level above.

Support from space domain to other physical domains is a reality. The satellite communication and utilization of images as a part of C4ISR support, contributes on a synergy of forces [15] at the battlefield. The specific realization of this mean can be linking via satellites, support by images and adequate intelligence evaluation supported by applications, sharing GPS. The networks have to be resilient.

Mentioned approach can be not used only in high-intensity conflict, but also in lower intensity conflicts, where the enemy is "visible" for a short while, because in a moment is mixed into local citizens. It means the quick OODA process is necessary at low tactical level is appropriate. For this purpose, the company level should be equipped by devices being able to act quickly and do the right low tactical level decisions and actions, because they should have in their structures other assets (UAV´s, anti-aircraft/drone, anti-tank, maneuver, ect.), being able to work with this data both directions-in and out.

The OODA loop based on connectivity needs, for "act" phase, the power and potential of unit. Unit, which is not able to act, from different reasons, does not deliver intended effect, it means the potential of "network" is limited by the weakest element. It means, it is necessary to prepare units for this kind of warfare, keep them ready and capable for "act".

This is related to frequency of missions and sequence of tactical tasks. The rhythm has to be arranged according to METT-TC and also in order to dis-balance enemy´s battle-rhythm.

7. Multi-domain battle

Cross domain and multi-domain actions are starting to be more common. We can observe some characteristics of multi-domain operations (MDO) in Ukrainian conflict [16] and the conflict shows, that small unit's leaders have to understand wide range of circumstances, tactical and technical details including. They interact with tools, which are utilized for multi-domain battle despite fact, they don´t lead them. They are part of multi-domain operations. Synergy across domains and creating common effect on enemy has to be understood by leaders, including low tactical level.

Practically, the realization of multi-domain battles, is related on planning and conducting of synergic effect by various tools. It is the most difficult level of operations and battles. The basics, from viewpoint of maneuvering units, is combined arms, able to cooperate with aircraft, navy, utilize the outputs from space operation-mostly for intelligence and communication purposes, interacts with various types of aircraft incl. unmanned, co-operates artillery and air defense, operates with unmanned systems, participate psychological operations and cognitive warfare, operates with electronic warfare tools, ect.

Small armies, like Czech army, will be most probably part of multinational formation, following "Multi-domain doctrine". Key tenants of Joint Warfighting Concept (JWC) 3.0 include the following [17]:

- Integrated, Combined Joint Force: The seamless integration of all military Services across all warfighting domains, enabling them to function as a unified force.
- Expanded Maneuver: Fluidly moving through space and time, including but not limited to maneuvering through land, sea, air, space, cyber, the electromagnetic spectrum, information space, and the cognitive realm.
- Pulsed Operations: A type of joint all-domain operation characterized by the deliberate application of joint force strength to generate or exploit advantages over an adversary.
- Integrated Command, Agile Control: Seamless command and control (C2) across all domains, integrating sensors, platforms, and decision-making processes.
- Global Fires: Integration of kinetic and non-kinetic fires to deliver precise, synchronized global effects across all domains
- Information Advantage: The rapid collection, analysis, and dissemination of information using advanced
- technologies.
- Resilient Logistics: The rapid movement of personnel and equipment, timed in accordance with operational requirements.

From longer-term perspective should be discussed advanced abilities in multi-domain operation. Inspired by this approach, more armies will develop their forces with "multi-domain" abilities, including small armies [18]:. The "multi-domain approach" [19] has not be only topic for strategic or operational level, but for all levels and all domains.

Above mentioned will directly influence low tactical level. It means, that battalion and company level has to include elements as: JTACs at the battalion level and JFOs at the company level. The S-2 and S-3 groups has to be able to use various sources and distribute them in real time to the units via robust and resilient communication network. The physical instruments have to be agile, quick deployable and re-deployable and doubled / tripled, because enemy will focus on disrupting our communications. The unmanned vehicles have to be part of units from platoon level above (as was mentioned in chapter 4). The artillery has to be effectively utilized, the JFOs and junior officers are the minimal level, who is able to cooperate on targeting. The effect has to be synchronized and the low tactical level is also "sensor". Own air-defense is the priority, in times of increasing utilizing swarms of drones, loitering ammunition etc. Every single unit has to be protected by anti-aircraft "umbrella". The anti-drone and anti-aircraft squads has to be essential part of all units. At the battalion level, cyber-operations and psychological operations has to be supported via staff officers and understood by troop leaders. They have to incorporate above mentioned tools into their missions and TTP´s. It is necessary to stress, that multi-domain battle is not led by company or battalion level, but these units have to understand bigger picture, be able to participate missions and put partial effort into synergic effect. The plug and play approach is essential, starting from company level. The reason is, that as a contribution to multinational (and also maybe multi-domain) corps is brigade combat team and minimal detached level for related tasks is a company level.

The crucial role plays connection and artificial intelligence by supporting quick decision-making. Networking of all elements is crucial. The commander has to see status of his units and in case of loss of some element, needs to fill the gap in the physical domain, but also in electronic domain. Disrupting of connectivity in all domains will be the key for success in the battle. Then, the gaps in physical and non-physical domains can be utilized for enemy maneuver.

Education and training of cadets in this field is necessary and topic of multi-domain battle has to be incorporated into curriculum of education programs. This topic is new, and development of multi-domain warfare is on the beginning, but new generation of leaders has to be educated in this field, being prepared to operate in multi-domain warfare with own MDO task force in the future.

8. Character of an enemy

In close past, the enemy was considered mostly as an army or a guerilla. Starting from 21st century, in the field of tactical level we can see next actors, like private armies and mercenaries [20], [21], which can play significant role form higher perspective also. Their number is growing and number of contract increasing also. Wagner´s group is good example of well utilized private company. They reached abilities, comparing like tactical level formations of modern armies (similar like brigade or division combat team). They are able to incorporate skilled military veterans and experts and mass of poor fighters also. They are able to utilize them effectively. The combat equipment of war experts can be on the best level, of the poor fighters only the very essential.

Above mentioned means, that the analysis of enemy at lower tactical level will be more related to lower tactical units and small intelligence teams, operating in the area. The capabilities, structure, equipment and amount of personnel of private companies is not defined in doctrines and is worse predictable. Also, their commanders and manners are not such well "readable". It can happen, that regular army units will face techniques and weapons, against which are not trained or familiarized with.

Leaders of small units can face from poor fighters to well trained and equipped veterans. This has significant impact on chosen tactics, but also on morale and attitude of leaders. Their pre-deployment training should include various types of enemy. All of this, creates more pressure on the tactical units, their level of training adaptability, equipment etc. Usually, the structure of regular modern armies is more "complex" a "combined". Still will be valid, that is necessary to identify the weaknesses of enemy and utilize them for success of own actions. Typically, from low tactical viewpoint, it can be lack of artillery, limited aircraft, low personal protection or protection of vehicles, connection related on single distributor etc. The complex portfolio of weapons, combined arms structure, utilization of hi-tech, networking and flexibility in decision-making can be a solution, how to face this types of unpredictable enemy.

9. Conclusions

The Ukrainian conflict provided many lessons to all levels and to all branches. It is visible, which technologies plays and will be play disruptive role in close future. The key findings are related mostly to one two words: complexity and networking. UAV´s are phenomenon no. 1. They directly influence tactics of units. Warfighting by drones in combination of UGV s should be part of tactics. The units should consist from UGVs, UAVs and manned crews. The units have to be equipped by anti-tank and anti-aircraft weapons, what has been partially neglected. Combined units, able to cooperate in multi-domain environment were established in Ukrainian conflict and in case of their high-quality future development and creating network structure, this would be significant change at tactical level. Network centric warfare should be trained as a part of nowadays and future battles, it is reality. The operational environment is and will be more uncertain, the role of leaders and their staffs is to try give some level of certainty to their subordinates, which directly face more lethal and sophisticate challenges.

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The Multi-Domain Approach to Military Operations and its Challenges to Intelligence and Intelligence, Surveillance, Reconnaissance

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Abstract

This paper discusses the multi-domain approach to military operations. Through comparative research and literature review, authors analyze how Western and peer adversary countries, namely the Russian Federation and the People's Republic of China, perceive and implement multi-domain operations. The article also identifies the challenges presented by the multi-domain character of the contemporary and future operating environment to intelligence and ISR. It highlights the crucial role of timely intelligence and surveillance in the diverse and contested operating environment, emphasizing the need for new technologies like artificial intelligence and big data processing.

KEY WORDS: *multi-domain operations, North Atlantic Treaty Organisation, Russian Federation, People's Republic of China; Intelligence Surveillance Reconnaissance, threat, doctrine.*

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1. Introduction

Modern militaries, particularly those within the North Atlantic Treaty Organisation (NATO), have for decades used the term joint when discussing operations coordinated across multiple domains. In the context of joint operations, most military forces have been focused primarily on the physical domains of the operating environment (OE), i.e. land, maritime and air. In practice it means that until recently operations and planning staffs preferred to seek solutions in these traditional domains, and due to multiple factors, they often struggled with relatively new operational domains such as space and cyberspace, and non-physical environments, including the electromagnetic environment (EME) and information environment. As the military conflicts of the last decade have underscored the ever-growing dynamics of evolution of threats and challenges, which the coalition forces will most likely counter in the near future, a perception of the OE as a composite of separate domains is no longer acceptable.

In a multi-domain approach, these domains and environments are interconnected and interdependent, with capabilities in one domain supporting and enhancing operations in others [1, p. 3-3]. In general, it refers to a strategy that integrates capabilities and operations across the domains of the battlespace to achieve military objectives. Interestingly, during their research, the authors also encountered viewpoints suggesting that a multi-domain approach is not a novel concept. This can be exemplified by Sun-tzu's assertion: *"There are not more than five musical notes, yet the combinations of these five give rise to more melodies than can ever be heard. In battle, there are not more than two methods of attack – the direct and the indirect; yet these two in combination give rise to an endless series of maneuvers."* [2] The emergence of this concept, despite not being perceived as exactly novel by some, has nonetheless instigated significant changes and complexities in the way modern warfare is strategized and executed. Today, its influence in reshaping warfare strategies on a global scale is undeniable and its importance in the context of contemporary warfare continues to escalate.

NATO and most of its member states have been gradually considering challenges, opportunities and possibilities related to inevitable implementation of a multi-domain approach. Several concepts have been developed by various nations so far, however, they are often inconsistent or even misunderstood with regard to terminology, scope and policies [3, p. 15].

Despite this lack of consistency, continuous developments of our approaches towards future military operations underscore the need for detailed and comprehensive knowledge of the operating environment or synergistic effects of our targeting. Responding to challenges posed by contemporary and emerging security threats, this approach recognizes that modern conflicts are not limited to a single domain and require coordinated efforts across multiple domains to effectively project power, maintain superiority, and achieve mission success. The complexity and variability of contemporary military operations requires situational awareness about the current developments in the joint operations area and the OE, which must be shared across all command and control (C2) levels with special emphasis on the operational and tactical levels.

In this respect, intelligence is a critical joint function which significantly contributes to comprehensive understanding of the OE which is essential to identify opportunities, anticipate threats, and make informed decisions. It is a key enabler which provides the situational awareness and understanding necessary to achieve military objectives in a highly contested and interconnected battlespace.

2. Methodology and limitations

This paper employs a qualitative research approach, analyzing publicly available information, military doctrine, and strategic communications. The article firstly compares different perspectives of the most prominent proponents of a multi-domain approach, such as the United States of America (USA), the United Kingdom (UK) or NATO, with the aim to identify and clarify differing and similar aspects of the concepts explored. The comparative research was focused predominantly on the most recent doctrinal documents related to multi-domain operations (MDO) released by the abovementioned countries and organization. The authors also performed systematic a literature review in order to analyze how the Western multi-domain approach is perceived and interpreted by peer adversaries/competitors, namely the Russian Federation (RF) and the People's Republic of China (PRC), and how a multi-domain mindset is reflected in military strategies of both countries. The challenges presented by the multi-domain character of the contemporary and future OE to intelligence and intelligence, surveillance, reconnaissance (ISR) were identified through a case study of the multi-domain interrelation in the conflict in Ukraine and analysis of informal interviews conducted within the Czech Armed Forces intelligence and ISR community.

In this article, there are several limitations that should be taken into consideration when interpreting the results:

22. Limited Public Information: While some information about military operations is publicly available, much of it is often restricted or sanitized for security reasons. This limitation sometimes hinders the depth as well as broader context of the research.
23. Changing Nature of Warfare: Warfare and military strategies are constantly evolving in response to technological advancements, geopolitical shifts, and changes in tactics. Keeping up with the latest developments and trends in multi-domain operations can be challenging.
24. Limited Academic Literature: While there is increasing interest in multi-domain operations, academic literature on the topic may still be relatively limited compared to more established fields. Finding scholarly sources to support this research requires thorough searching and critical evaluation of available literature.

3. The implementation of the multi-domain approach in selected countries

The multi-domain approach recognizes that modern warfare extends beyond traditional battlefields and that victory requires superiority across all domains. The main reason for the development of the multi-domain concept was the changing nature of modern warfare, particularly the rise of near-peer competitors, advancements in technology, and the increasingly interconnected and interdependent nature of the global battlespace.

The USA, or more specifically the U. S. Army, became the main proponent of the multi-domain concept during the second decade of the 21st century. In December 2018, the U.S. TRADOC published its Pamphlet 525-3-1 "The U.S. Army in Multi-Domain Operations 2028" [4]. It explained the reasons why the USA had adopted the MDO concept claiming that *"China and Russia exploit the conditions of the operational environment to achieve their objectives the integration of diplomatic and economic actions, unconventional and information warfare (social media, false narratives, cyber-attacks), and the actual or threatened employment of conventional forces"*. [5, p. 1]

The multi-domain approach has gradually become a new paradigm to NATO member countries as well as for NATO itself. However, understanding the multi-domain concept among the USA and NATO countries presents several challenges, including differing definitions, terminology, doctrinal issues, technological solutions and requirements, security and legal aspects etc. This chapter elaborates on different perspectives regarding the multi-domain approach in order to provide the context for identification of challenges associated with intelligence and ISR.

When exploring the U.S. multi-domain approach to operations, it is important to highlight that MDO should not be simply perceived as further evolution of joint operations. In fact, in the U.S. context there are two major concepts of the multi-domain approach – the MDO and Joint All-Domain Operations (JADO). While they are similar in many respects, there are key differences between them.

MDO is a concept that has been primarily developed by the U.S. Army. Having been outlined by the aforementioned Pamphlet 525-3-1, it is doctrinally anchored in the Army's Field Manual (FM) Operations (FM-3.0) published in October 2022. The document defines MDO as *"the combined arms employment of joint and Army capabilities to create and exploit* *relative advantages to achieve objectives, defeat enemy forces, and consolidate gains on behalf of joint force"* [1, Glossary – 10] while also claiming that *"all operations are multidomain operations"*. [1, p. 1-3]

The primary concept of the Army is to succeed through competition in every domain without conflict, thereby discouraging a potential enemy. If this deterrent strategy fails, the Army, in collaboration with Joint forces, aims to infiltrate enemy anti-access and area denial (A2/AD) systems to facilitate strategic and operational maneuvering of U.S. forces [5, p. 1]. MDO describe manoeuvering across these domains as convergence, with tactical commanders needing to understand how their actions shape other domains, and exploiting successes, or guarding against vulnerabilities that may emerge in them [3, p. V]. In order to obtain such understanding, tactical commanders must be able to receive relevant intelligence, therefore in October 2023, the U.S. Army published FM-2.0 Intelligence which describes in detail the role of army intelligence in MDO closely following FM 3-0: "*To provide effective and flexible intelligence support, intelligence professionals must understand multidomain operations. FM 3-0 provides many doctrinal concepts that are important to intelligence professionals."* [6, p. 2-1] The importance of intelligence to MDO is evident from the statement: "*Intelligence drives multidomain operations and multidomain operations enable intelligence"*. [6, p. xi] In this way, the U.S. Army maintains doctrinal complementarity and compatibility.

While MDO focuses on integrating U.S. Army operations across multiple domains to create advantages for friendly forces and disadvantages for adversaries with the goal to enable maneuver and operations across all domains, JADO is a broader concept that encompasses all branches of the military. Unlike MDO, it has not been doctrinally established yet, therefore it should be considered more a vision of future U.S. military operations.

The aim of JADO is to connect every sensor to every shooter in all domains to achieve decision superiority and overmatch against adversaries. It seeks to integrate capabilities across all domains, the electromagnetic spectrum, and the information environment to achieve operational objectives. It is believed that in this way, U.S. forces will be able to create multiple simultaneous dilemmas for an enemy which cannot all be solved and which compel hostile troops and commanders to make difficult or impossible trade-offs [7, p. 3]. The key is synchronizing decisions and effects across all domains in a contested battlespace [8]. This will require an accelerated decision-making process supported by a robust and timely intelligence support to ensure that all actions are integrated, synchronized and integrated at speed and scale needed to gain advantage and accomplish the mission [9, p. 9]. In other words, is a military concept that refers to a seamless integration of operations across all domains of warfare – land, air, sea, space, and cyber to achieve a more effective and efficient joint force. The goal of this concept is to ensure information and operations synchronization across these domains in real-time to outpace adversaries. This approach is seen as a way to maintain a strategic advantage and respond to threats more quickly and effectively.

A crucial enabler to JADO, and actually its tangible implication, is Joint All-Domain Command and Control (JADC2) Strategy. In March 2022, the U.S. Department of Defense (DoD) published "The Summary of the Joint All-Domain Command and Control (JADC2) Strategy" which formulated guiding principles to promote coherence of effort including information sharing capability improvements, Joint Force C2 systems resilient in degraded and contested EME, layered security features or broadly applicable common data standards [10, p. 2]. Also in March 2022, the DoD signed "The JADC2 Implementation Plan" which provides the framework and methodology to achieve the JADC2 strategy and goals [11, p. 21].

So, while both MDO and JADO seek to integrate operations across multiple domains, the key difference lies in their scope and the degree of integration. JADO represents an evolution of MDO, aiming for a fully connected and integrated joint force across all domains, however, it still sees the joint force as the pivotal stakeholder in the future military operations.

The evolution of the global security environment during the second decade of the 21st century has also initiated extensive doctrinal and organisational changes in the British Armed Forces. The British Ministry of Defence has taken a somewhat different approach to multi-domain integration than the USA, consisting of adapting the existing institutional framework to better coordinate the development and effects of emerging military capabilities [12, p. 3]. While the USA has focused on the tactical and operational challenges posed by the PRC in the South Pacific, the UK sees the aggressive foreign policy of the RF and its associated hybrid engagement, particularly in Eastern Europe, as the main threat. The British concept of the multi-domain integration (MDI) is described in the Joint Concept Note 1/20 which was published in November 2020. The core tenet of the MDI is based on the assumptions that it involves partners across the government, while the strategic objectives of the UK will be pursued through its designed alliance with NATO, emphasizing that the North Atlantic Treaty Organization remains a crucial part of this strategy [13, p. 31]. The practical implementation of the MDI concept into the intelligence doctrine was done in August 2023 when the British Ministry of Defence published the 4th edition of the Joint Doctrine Publication 2-00 Intelligence, Counter-intelligence and Security Support to Joint Operations (JDP 2-00). The document emphasizes the fact that "*information is a critical enabler to mission command and a multi-domain approach, as it enables understanding, decision-making, and command and control. The ever-increasing volume of information and data available represents one of the biggest challenges for producing intelligence and will continue to challenge available human analytical capacity"*. [14, p. 20] According to JDP 2-2.00, "*MDI seeks to generate advantage through integration across the three levels of operations (tactical, operational and strategic) and the five operational domains to create multi-domain effect that adds up to far more than simply the sum of the parts. Operations spanning multiple operational domains are an evolution of joint operations, reflecting the introduction of the space, and cyber and electromagnetic domains"*. [14, p. 109]

The UK MDI concept and the US MDO approach share the common goal of integrating operations across all military domains – land, sea, air, space, and cyberspace – for more effective combat operations. However, the specifics of their approaches can differ based on their unique strategic contexts, military structures, and doctrines. From the conceptual perspective, the US's MDO concept is spearheaded by the US Army and emphasizes the integration of capabilities to penetrate and disintegrate enemy A2/AD systems. The UK's MDI approach, while also aiming for operational integration, places a strong emphasis on the cooperation and interoperability with allies, particularly within the NATO framework, and it also involves partners across the whole government spectrum to ensure a coordinated and effective response to shared threats. Concurrently, MDI may also place a greater emphasis on a broader range of operations, including counter-terrorism and peacekeeping missions, and on adversary activities across the political or information domains across the operational variables of the Political, Military, Economic, Information, Infrastructure-Physical, Time (PMESII-PT) model, thus not concentrating only on military capabilities. In addition, there are also different implications for implementation of both concepts. The USA has a larger military with vast resources, and its MDO concept involves significant restructuring and modernization of its forces. The UK, on the other hand, has a smaller military and its MDI approach may focus more on optimizing existing structures and improving coordination between different branches. Both countries recognize the importance of emerging technologies, such as artificial intelligence, machine learning, and cyber capabilities. However, the MDO concept heavily emphasizes the development and deployment of new technologies to gain an advantage in future conflicts. The MDI, while also acknowledging the role of technology, may place a greater emphasis on the integration and best use of current capabilities to improve decision-making, situational awareness, and the speed and precision of military operations.

NATO had been discussing a multi-domain approach for several years until it was formally acknowledged in the Brussels Summit Communiqué of 2021 which mentioned, among others, Russia's growing multi-domain military build-up, threats in a multi-domain environment and commitment of the Alliance to ensure a flexible, agile, and resilient multi-domain force architecture [15]. It was further developed in NATO's Strategic Concept, adopted at the NATO Summit in Madrid in June 2022. According to this document, NATO's multi-domain approach combines military and non-military tools, as well as integrates efforts across different domains to achieve strategic objectives [16]. In the NATO context, it means that MDO prepare, plan, orchestrate and execute coordinated military activities across all operating domains and environments. These actions are synchronized with non-military activities and enable the Alliance to achieve an advantage in shaping, contesting and fighting and presents dilemmas that decisively influence the attitudes and behaviours of adversaries. Thus, it essentially merges both U.S. MDO and UK MDI concepts [9, p. 10].

Despite the common tenets, it should be noted that U.S. MDO concept is premised on the U.S. needing to confront China and Russia simultaneously. European allies, however, do not necessarily see China as a competitor. Other contradicting opinions point out that the U.S. MDO has a similar focus as offensive operations in a conflict, with three main components that are clearly offensive in nature: penetrate, disintegrate, and exploit [17]. This may seem to be a contradiction to NATO primarily defensive posture. However, while the MDO has offensive components, it also emphasizes the importance of defense and deterrence which is then fully in line with NATO policy as evidenced by one of the statements from the Vilnius Summit Communiqué: "*We will individually and collectively deliver the full range of forces, capabilities, plans, resources, assets and infrastructure needed for deterrence and defence, including for high-intensity, multi-domain warfighting against nuclear-armed peer-competitors*". [18] It was the Vilnius summit in 2023 that introduced NATO's most concrete commitments, steps and measures in implementation of a multi-domain concept so far. It was stated that the Allies would be committed to fully resourcing and regularly exercising plans for high-intensity and multi-domain collective defense. A new multinational and multi-domain Allied Reaction Force will provide more options to respond swiftly to threats and crises. NATO's command and control will be strengthened to ensure agility, resilience, and adequate staffing for executing plans. This will enhance the ability to conduct exercises, manage NATO's posture in peacetime and during transitions, and undertake command and control for various missions, including large-scale MDO for collective defense. Work will continue on MDO, enabled by NATO's Digital Transformation, to drive military and technological advantages and strengthen the Alliance's ability to operate decisively across various domains [18].

NATO's approach is not isolated but instead relies heavily on cooperation among member nations. Each nation contributes its unique capabilities across various domains, making the collective defense more robust. This fact does not present only opportunities, but also a plethora of challenges:

1. Surprisingly, there is no internationally agreed definition of 'domain' yet, and understandings of what constitutes a domain vary between countries [9, p. 5].
2. Different stakeholders may interpret MDO differently, which can hinder effective implementation. The USA and its allies do not have a consistent way of describing the multi-domain environment. Without this common nomenclature and terminology, it is difficult to have a common understanding of the battlespace.
3. In many cases, the MDO concept does not seamlessly align with existing national political and military structures. The same applies for legal constraints, because planning and execution of MDO across multiple domains, especially cyberspace and the EME, will require an appropriate legal framework, which still needs to be modified or adopted. This fact has become evident during implementation of new capabilities into national armed forces as well as within multinational cooperation of NATO member states.
4. MDO relies heavily on advanced technologies. Ensuring interoperability and reliability across domains remains a challenge.
5. A capability gap is in the capacity of European Allies in U.S. MDO smaller allied states, deploying forces no larger than brigades, to support operations at echelon.
6. Not all allies require the same level of sophisticated equipment to contribute to MDO, but there are three critical challenges to be addressed: shared situational awareness; coordinating synchronic operations at echelon; and the training burden created by the demands of MDO [3, p. 13–14].

To conclude, although NATO has firmly bound the multi-domain approach in its strategic documents, the Alliance is still in the process of fully integrating and operationalizing this approach. To achieve this, clear direction and guidance from civilian political leaders is essential, along with a common understanding of terms and definitions agreed upon by NATO. This includes developing comprehensive doctrines, capabilities, and training for MDO within the whole Alliance.

4. The Perception of Multi-domain Approach by the Russian Federation and the People's Republic of China

Both the RF and PRC likely view the U.S. MDO concept as a part of broader U.S. strategic intentions, including maintaining global dominance and containing potential adversaries. The concept of MDO is taken up by the Russians as multi-sphere operations (mnogosfernoye operatsii) and by the Chinese as multi or all-domain operations [19, p. 42]. Both countries have already demonstrated a deep understanding of the complexity of MDO by developing their own counter-strategies involving asymmetric warfare, advanced technology investment, and increased focus on information warfare and A2/AD systems (although A2/AD in the Russian context should be rather interpreted as a set of active defensive measures, comprising also offensive capabilities and manoeuvre defence) [20, p. 17].

The RF perceives the U.S. MDO concept as a threat to its national security and strategic interests. Moscow views the concept as an attempt by the United States to maintain its global dominance and to contain Russia's influence. The RF vigilantly observe support of NATO countries to Ukraine, with a special emphasis focused on implementation of new operational concepts. According to Russian sources, the USA exploits the Ukrainian battlespace for testing its MDO strategy, for example by "supporting suppressive and destructive actions against reconnaissance, strike, anti-aircraft, and other combat systems that are carried out simultaneously in several spheres to create numerous difficult-to-resolve problems for the opposing side, which allows identifying vulnerabilities in defense and effectively using the changing situation" [21, p. 126].

The RF has been focusing on developing its own capabilities across multiple domains and geographical regions, including the Baltic, Black and Mediterranean Sea as well as the Artic [18]. A particular emphasis is placed on the whole-of-government approach, ability to repel aerospace aggression with all the strike and defensive capabilities, asymmetric and hybrid warfare tactics, comprising information warfare, radio-electronic combat (i.e. the Russian concept of the electromagnetic warfare), interference in democratic processes, political and economic coercion, malicious cyber activities, and illegal and disruptive activities of Russian intelligence services etc.

To summarize, the RF is using a multi-domain approach to asymmetric warfare against a perceived Western aggressor. This approach focuses on using information to control adversary behavior and shape the strategic environment in Russia's favor. The information environment is seen as the foundation and integrator of all other operational domains, and is therefore critical for achieving asymmetric advantage and Russian success at all levels [9, p. 13].

The PRC acknowledges the existence of the multi-domain approach and most likely has a very accurate understanding of the JADO concept [22]. According to Air Chief Marshal The Lord Stuart Peach *"the PRC has been closely observing the development of the conflict, interprets it in its own way and considers those findings in its strategy"*. [23] It tends to view U.S. military developments through the lens of strategic competition. As such, it is presumed that it sees the MDO and JADO concepts as a potential threat, particularly in the context of the US's focus on the Indo-Pacific region.

The People's Liberation Army (PLA) conceptualizes future warfare as a multidimensional confrontation between competing 'system of systems' which represents a strategic approach that views warfare not simply as a conflict between individual units or platforms, but as a clash between holistic, networked "systems" of weapons, communications, command and control, intelligence, and other military capabilities [9, p. 81]. This approach also emphasizes the integration of different domains of warfare – land, sea, air, space, and cyberspace – into a unified whole, and the use of advanced technology, including artificial intelligence, big data, and automation, to achieve dominance in these domains.

Another PLA concept is represented by 'informationized' warfare which refers to the use of information and communication technologies in modern warfare. It is based on the understanding that information superiority is key to overall military success in contemporary conflicts. In the context of informationized warfare, the side that can gather, process, and use information more effectively will have significant advantages in terms of command and control, intelligence gathering, and the coordination and effectiveness of its forces [24, p. 16].

Therefore, the PRC focus on 'system-of-systems' operations and 'informationized' warfare could be seen as a response to the US's MDO concept, as they share many of the central characteristics of what the West might describe as multi-domain concepts.

5. The Case Study of the Multi-Domain Implication in the conflict in Ukraine

Since the onset of the Russia-Ukraine conflict in 2014, several multi-domain approaches employed by the Russian Federation Armed Forces have been observed. In general, the RF has been utilizing multi-domain concepts to pursue asymmetric 'new-type' and systems warfare, using tactics like 'reflexive control' and disorganisation. The strategy is centered around controlling adversary behavior and shaping the strategic environment in the RF's favor via information use, while also exploiting the adversary's weaknesses to maximize impact with minimal use of the RF's resources. The information environment, which encompasses technological and psychological aspects, have been viewed as a critical foundation that integrates all other operational domains and is thus crucial for the RF to gain an asymmetric advantage and achieve success at all levels of conflict [9, p. 45–65].

This was evident in the Battle of Zelenopillya (2014), where a single Russian Battalion Tactical Group (BTG) commander utilized an array of weapons across multiple domains against Ukrainian forces. The operation stood out due to the strategic integration of organic unmanned aerial vehicles (UAVs), cyber capabilities, and ground forces under the command of a single battalion, resulting in a synergistic effect. The Russian forces initially launched cyber-attacks to disrupt Ukrainian communications and create confusion in decision-making processes. With the Ukrainian C2 system compromised, the Orlan 10 UAV carried out a meticulous target acquisition of the Ukrainian position, which was subsequently followed by a destructive long-range rocket and artillery strike on the Ukrainian unit. This strategy was replicated in subsequent battles involving different BTGs, including the Battle of Ilovaisk (2014), the Battle of Donetsk Airport (2014–2015), and the Battle of Debal'tseve (2015). The incorporation of Surface-to-Air Missiles (SAMs) and UAVs into the BTG underscores the identified synergies between land and air domains. Additionally, the ground-based jammers' EW capabilities, coupled with EW capabilities embedded in UAVs, demonstrated interconnections between the land and electromagnetic spectrum, as well as with the air domain. These confrontations showed that the strategic use of the cyber domain can create early opportunities for success and facilitate simultaneous offensive and defensive operations across strategic, operational levels, and other domains.

On the other hand, also Ukraine has been employing a multidomain approach in the ongoing conflict with the RF to effectively counteract and respond to the multifaceted threats it faces. With the aid of Elon Musk's Starlink satellite internet service, Ukraine has been able to sustain internet connectivity, demonstrating the application of space domain resources. This comprehensive, multidomain approach has been critical in Ukraine's efforts to resist and respond to the multi-pronged offensive. Elon Musk's involvement in the Russia-Ukraine conflict can be analyzed through the concepts of MDO and MDI. Musk's SpaceX company, through its Starlink satellite internet service, has been providing internet connectivity to Ukraine, an example of operations in the space and cyberspace domains [25]. This has allowed Ukraine to maintain vital communications infrastructure despite Russian attacks, enabling both military and civilian coordination and information dissemination.

In terms of MDO, this can be seen as an example of exploiting the space and cyberspace domains to achieve strategic objectives - in this case, maintaining Ukraine's ability to communicate and coordinate despite adversarial actions. It demonstrates how operations in one domain (space) can affect outcomes in another (cyberspace), and how these can impact the terrestrial battlefield.

Looking at it from an MDI perspective, Musk's involvement illustrates how actions in the space and cyberspace domains can be integrated with operations in other domains. The provision of satellite internet connectivity is not a standalone operation but is integrated with Ukraine's broader military and strategic operations, potentially enhancing their effectiveness.

However, it is crucial to note that while this example fits into the concepts of MDO, it is an unconventional application given that Musk is a private individual and SpaceX a private company, not a state military force. Private companies like SpaceX and Starlink are providing capabilities in the space domain that can be leveraged in multidomain operations. As seen in the recent conflict in Ukraine, where Starlink provided satellite internet service, these capabilities can have a direct impact on the terrestrial domain by enabling communication and information sharing in the face of infrastructure disruption.

In the cyberspace domain, private tech companies play a crucial role in providing cybersecurity solutions and services, which can be integral to the success of multi-domain interrelation. These companies can help protect critical infrastructure, secure communication networks, and respond to cyber threats, which are increasingly being used as a form of warfare. Furthermore, the private sector can also contribute to the development and deployment of emerging technologies like artificial intelligence, machine learning, and unmanned systems, which are likely to play a significant role in future multidomain operations. It is worth to mention that commercial satellite capabilities have increased dramatically, offering eyes in the sky for anyone who wants them. Satellite launches more than doubled between 2016 and 2018; now, more than 5,000 satellites circle the earth, some no larger than a loaf of bread. Commercial satellites have less sophisticated sensing capabilities than do their spying counterparts, but civilian technologies are rapidly improving [26, p. 58].

The significance of nonmilitary means has been underlined also in Russian strategic literature, suggesting that gaining "information superiority" is crucial in accomplishing strategic objectives, including military and other aims. A 2013 article, extensively examined, penned by General Valery Gerasimov, the Chief of the General Staff of the Armed Forces of the Russian Federation, proposed that nonmilitary approaches should play a much more substantial role than military strategies in settling interstate conflicts, suggesting a 4:1 ratio. Identifying and leveraging the weaknesses in the information gaps of opponents are deemed critical to realizing desired political and strategic objectives, especially in an asymmetric competition with adversaries possessing greater military strength [27].

In the past, technological breakthroughs such as the Internet and GPS were pioneered by U.S. government agencies and later commercialized by the private sector. Most innovations that impacted national security didn't have extensive commercial applications, so they could be classified from inception and, if necessary, restricted indefinitely. Today, the situation has reversed. Technological innovations are more likely to be "dual use," having both commercial and military applications. They are also much more likely to originate in the private sector, where they are financed by foreign investors, developed by a multinational workforce, and marketed to global customers in both private and public sectors [26, p. 60].

However, the involvement of private entities in multidomain approach also raises a host of legal, ethical, and security issues. These include questions about accountability, the appropriateness of delegating certain military functions to the private sector, and the need to protect sensitive information and technologies. Therefore, as the role of private entities in MDO continues to grow, it will be important to carefully consider these issues and develop appropriate policies and regulations. This raises interesting questions about the role of private entities in multidomain operations and integration, which could be a fertile area for further research and discussion.

6. The challenges presented by the multi-domain operating environment to Intelligence and ISR

Intelligence naturally spans multiple domains, including the joint, interagency, intergovernmental, and international levels. It plays a crucial role in enhancing lethality by offering efficient and adaptable intelligence backup to large-scale combat operations. Nevertheless, in all strategic military contexts, the importance of intelligence support is paramount. The goal of intelligence is to supply commanders and staff with immediate, pertinent, precise, predictive, and customized intelligence. This information is necessary to understand the OE, evaluate the situation, prepare the theater, guide military actions, and secure relative advantage points across the domains and dimensions of the OE as part of the joint force [6].

One aim of MDO is to disrupt adversary decision-making processes and create multiple dilemmas, which also has implications for intelligence and ISR. The MDO concept requires a high level of interoperability, real-time intelligence sharing, and seamless communication among different military units and platforms. As a result, it heavily relies on advanced technologies such as artificial intelligence, machine learning, and big data analytics. In this respect, it is crucial to note that the successful implementation of the MDO concept depends on the ability to effectively integrate and leverage these technologies. The strategic use of artificial intelligence and machine learning can enable rapid processing and analysis of vast amounts of data, leading to improved decision-making and response times. Moreover, big data analytics can provide valuable insights and predictions, enhancing the situational awareness and strategic foresight of military units. However, the potential challenges such as cybersecurity threats, data privacy issues, and technical complexities should not be overlooked. Therefore, while MDO presents a transformative approach to military operations, it also necessitates concerted efforts in technology integration, cybersecurity measures, and policy development.

Understanding the potential benefits and risks of these and other emerging technologies is a crucial task for intelligence community. Intelligence experts need to identify the frontrunners in pivotal technological races and forecast the possible implications. They must analyze how future conflicts will be conducted and won. It must be ascertained how new technologies could address global issues such as climate change. Intelligence staffs need to discern how adversaries will utilize data and technological tools for coercion, atrocity commission, sanction evasion, dangerous weapons development, and securing other advantages [26, p. 60].

The success of MDO also depends on the ability of military personnel to adapt to the new operational environment, where timely information sharing and collaboration are crucial. Because particular adversary operations within multidomain environment can happen so quickly subject matter experts dealing with the current intelligence also need to operate with newfound speed. For instance, on September 1, 2001, U.S. President George W. Bush had less than 13 hours after the World Trade Center attacks to review intelligence and announce a response. Today, the time for presidents to consider intelligence before making major policy decisions may be closer to 13 minutes or even 13 seconds [26, p. 60]. Therefore, training programs and exercises should be designed to enhance the skills and knowledge of military personnel in the areas of network-centric warfare, decision-making, and mission planning.

To better understand the challenges that the multi-domain operating environment presents to Intelligence and ISR, the authors have examined the respective steps of the UK intelligence process (see Figure 1). Military units and organizations use the intelligence process to integrate intelligence support and provide the commander and staff the intelligence needed to facilitate situational understanding, effectively make decisions, and exercise command and control. The intelligence process consists of four steps (direction, collection, processing, dissemination) [14, p. 38]. Each of these steps is influenced by the multi-domain approach in varying ways and degrees. Findings derived from interviews with intelligence specialists suggest that the MDO have the most significant impact on the second step, "Collection", closely followed by the third step, "Processing". The intensity of the blue color on Fig. 1 visualizes the estimated extent of the "multi-domain impact" on the corresponding step within the intelligence process.

When considering the respective steps of the aforementioned intelligence process, the implementation of MDO presents several opportunities and challenges. One of the key advantages of MDO is the capacity for unified planning and direction, where intelligence requirements from disparate domains are integrated to create a comprehensive intelligence collection plan. This consolidation provides a more holistic operational perspective, enhancing strategic decision-making. Furthermore, MDO broadens the scope of data collection, utilizing resources across multiple domains. This diversification not only increases the volume of information gathered but also enhances the quality and relevance of the intelligence. The processing of this data is expedited by leveraging advanced technologies such as artificial intelligence and machine learning, which are central to MDO. In terms of analysis and production, the integration of data from various domains can lead to a more comprehensive intelligence picture, providing a deeper understanding of the operational environment. This ensures that the intelligence produced is both detailed and accurate. Finally, MDO promotes real-time intelligence sharing and seamless communication among different military units and platforms, which significantly improves the speed and efficiency of decision-making processes.

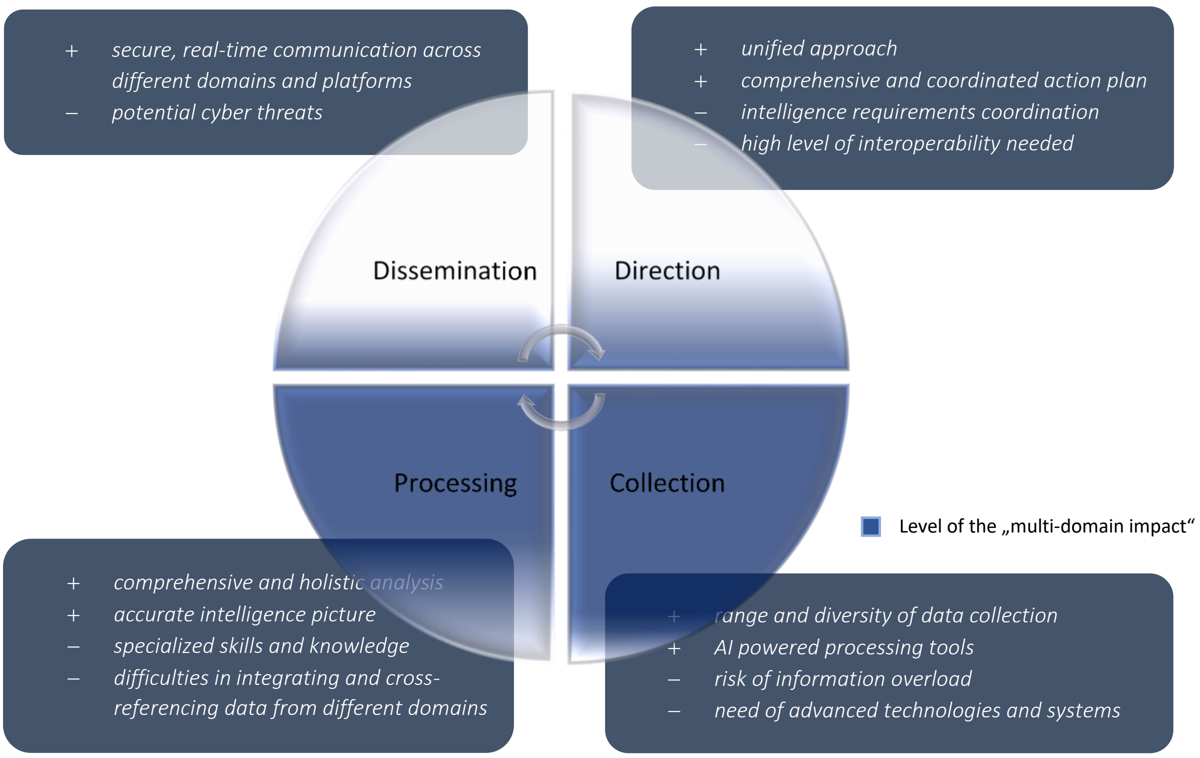

Fig.1. Opportunities (+) and challenges (-) associated with MDO within the intelligence process

However, there are also inherent challenges associated with MDO within the intelligence process. Coordinating intelligence requirements across multiple domains requires a high level of interoperability and coordination, which can be complex. The collection of data from diverse domains can also result in information overload, potentially obscuring relevant intelligence. Processing vast amounts of data from multiple domains necessitates advanced, often expensive technologies and systems, and the analysis of this data requires specialized skills and knowledge. Moreover, ensuring secure, real-time communication across different domains and platforms can be challenging, particularly in the face of potential cyber threats. Thus, robust cybersecurity measures are essential to protect sensitive information. Despite these challenges, the incorporation of MDO into the intelligence process presents a promising avenue for enhancing military operations.

Multi-domain environment is logically affecting also Joint Intelligence Preparation of the Operating Environment (JIPOE) as one of the primary tool used to support joint operation planning, execution and assessment. In this respect, it is not possible to limit the analysis of the contemporary OE only to the physical domains and their relationship to the non-physical ones. Drawing from the authors' extensive experience in NATO multinational intelligence staffs and various intelligence positions across all C2 levels, they contend that the conventional depiction of the OE is inadequate. This depiction, which is heavily reliant on the PMESII-PT model and centers mainly on the physical domains and their connections with the non-physical ones, only offers a narrow understanding of the OE. This is because it does not adequately analyze the synergies and interdependencies that exist between these domains. This applies especially to planning and execution of operations in the non-physical domains, such as electromagnetic operations (EMO), information operations (INFOOPS) or cyberspace operations, where the thorough insight must be obtained in order to identify windows of opportunity in the multi-domain OE, execute faster decision cycles and create synergic effect exploiting collective capabilities available across all the domains.

It is assessed that the current way, in which JIPOE is conducted, provides a solid foundation but it needs to be improved to better accomplish requirements and effectively support of future operations. In order to make JIPOE more relevant and adequate for future military operations, it will be necessary to consider all of the physical and non-physical domains, including the EME, as a combination of tools for achievement of future operational objectives. In other words, it will be very difficult to update and adjust JIPOE processes, if JIPOE primary customers (plans, operations) do not change their pertaining overall perception of the OE. All these aspects will also have to be reflected and described in new or updated doctrinal documents. The application of complex systems through JIPOE can be improved by changing from a categorical description to the interdependency-focused approach, because categories provide descriptions, but interdependencies provides insights [28]. One of the methods, which will have to be introduced and included into JIPOE procedures, is comprehensive risk assessment measuring the impact of threats on multiple assets of the OE. In this way, it will be possible to prioritize the threats, understand interdependencies across the OE or identify centres of gravity more precisely. This intelligence will need to be available in a way that is contextualised to the user. It will also have to be integrated across the C2 to be able to realise windows of opportunity at all levels, thus exploiting the specific conditions and circumstances in the OE.

Despite indisputable benefits of modern technologies, personnel will remain the most critical asset ensuring the cognitive superiority needed for success in future military operations. As of now, education of military professionals in most NATO countries, including members of intelligence staffs, is still focused on tactical level competencies, whereas operational level knowledge is usually gained during their further military career. Such an approach then creates a widening capability gap, because appropriately qualified military personnel is not always readily available. In order to outcompete opponents in future military conflicts, NATO countries should also update their military education programmes and prepare their personnel how to employ joint capabilities across a multi-domain environment. Hence, in addition to the implementation of cutting-edge technologies as well as conceptual and procedural changes, innovative steps must be taken in relation to the development of expertise and knowledge not only of dedicated OE analysts, but also of all potential customers who are expected to request and use intelligence products in support of future military operations.

7. Conclusions

Multi-domain approach to modern warfare is a holistic one, recognizing the interconnected nature of conflicts and the need for integrated, flexible, and adaptive responses to emerging threats. In this respect, intelligence and ISR staffs will be required to counter numerous challenges ensuing from the dynamic character of the OE and the rapid development of technologies. The authors conclude that despite advances in technology, human factors remain crucial in intelligence operations. This includes the recruitment, training, and retention of skilled intelligence analysts, as well as ensuring effective collaboration and communication among intelligence personnel and with operational commanders.

The analysis reveals that peer adversaries are not merely passive recipients of MDO but active participants who shape and redefine the operational environment. They reflect MDO in their strategic thinking, force structuring, and capability development, indicating a profound understanding of modern warfare's demands. The reflections of MDO by peer adversaries underscore the evolving character of modern warfare. Recognizing these reflections is essential for adjusting defense strategies and understanding the changing dynamics of international security. Future research should focus on exploring specific cases of peer adversaries' reflections on MDO to provide more nuanced insights.

The role of intelligence and ISR will be of the paramount importance, because commanders must be provided with timely information they need to make informed decisions and effectively employ forces across various domains., including information overload, cross-domain integration of data and intelligence obtained from multiple domains, or complex synchronization of ISR assets in the diverse and contested OE [29, p. 114]. This will not be possible without implementation of new technologies, such as artificial intelligence and big data processing to enable effective intelligence processing and analysis.

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Degradation of Land Cover in the De-Occupied Territories of Ukraine

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Abstract

The land cover trend analysis helps to identify trends in land cover change, such as changes in the area and structure of natural ecosystems or in anthropogenic impacts on the environment. Such analysis will provide insight into the causes of the dynamics of natural ecosystems and help develop strategies for their conservation and restoration. An analysis of changes in cover in the de-occupied territories is necessary to assess the impact of anthropogenic factors on land use, that is important for making decisions on the rational use of natural resources, especially in the post-war period. The object of the research is the land cover of the Kharkiv region and its changes. The purpose and objectives of the research are to identify negative trends in the land cover of the Kharkiv region as a result of hostilities, using satellite data and open source statistics.

KEY WORDS: *degradation, Kharkiv region, land cover changes, de-occupied territories, agriculture, nature, war.*

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1. Introduction

The North-Eastern region of Ukraine has a strong mining and processing industry and significant agricultural potential. The intensive economic activity is causing significant land cover transformation, which leads to mostly negative consequences for natural ecosystems and the region's economy. Analyzing land cover change trends on the example of the Kharkiv region is an urgent task to understand the dynamics of changes and identify their causes. The analysis of land cover trends is of scientific importance in identifying land cover trends, which will contribute to understanding the causes of changes in natural ecosystems and developing strategies for their conservation and restoration. In addition, the analysis of land cover changes can be important for assessing the impact of anthropogenic and natural factors on land use, which is key in making decisions on the rational use of natural resources, especially in the post-war period.

The fires are a serious threat to people, nature and the economy of Ukraine. The use of geoinformation technologies allows for comprehensive analysis and monitoring of the fire situation, identifying hot spots and the most

vulnerable areas, predicting risks and effectively managing resources during firefighting. Given the increase in the number of fire incidents due to military operations, the using of geoinformation analysis is extremely important for preventing and fighting fires in Ukraine.

The object of the research is the land cover of the Kharkiv region and its changes.

The purpose and objectives of the research are to identify negative trends in the land cover of the Kharkiv region as a result of hostilities, using satellite data and open source statistics. The main objectives of the study are: to analyze statistical data on changes in the land cover of the Kharkiv region for the period 2015-2022; to analyze the state of land cover based on remote sensing materials; to identify trends in the change of certain land covers that have the largest share among all the covers of the Kharkiv region; to assess the impact of hostilities on the state of the Izyum forest and the air as a result of numerous forest fires using satellite data.

2. Method of Investigation

The main methods of our research are the analysis of remote sensing materials, in particular, Sentinal-2 and Sentinal-5P satellite images. To obtain detailed information on land cover changes for the period 2015-2022, we used the web sources Land Cover 2022 [1], Worldcover 2021 Map [2], Global Land Cover 2015 [3].

The mathematical and statistical method was used to process statistical information and obtain index images as a result of processing satellite images and obtaining thematic rasters.

The electronic resource Firms [4] was used to analyze fires. The resource analyses data from the MODIS imaging systems on the Terra, Aqua satellites and Viirs, that are available from the Suomi NPP and NOAA-20 satellites. The MODIS instruments on board Terra and Aqua EOS satellites continuously collect data, providing global coverage every 1-2 days. The MODIS instruments have a swath of 2330 km and have been available since November 2000 (for Terra) and July 2002 (for Aqua) to the present. For MODIS, a pixel is approximately 1 km, and for VIIRS, it is approximately 375 m. Each hotspot of detected active fire represents the center of the pixel that contains one or more fires and other thermal anomalies (e.g. volcanoes). The center point of the pixel doesn’t necessarily represent the coordinates of the actual fire. The fire detection is performed by an algorithm that uses the powerful mid-infrared radiation from the fire. NASA's MODIS algorithm inspects each pixel of the MODIS band and assigns each pixel one of the following classes: missing data, clouds, water, non-fire, fire, or unknown. For the pixels classified as thermal anomalies, latitude and longitude data are provided.

The research used data from the MODIS hyperspectral imaging system. The attribute table provides the following information about each fire: latitude, longitude, channel brightness temperature (in Kelvin), time of data acquisition, satellite, confidence level, data type, fire radiation power, daytime or nighttime fire. For further geoinformation analysis, statistical information for the state of Ukraine for 2022 on all types of fires recorded by the MODIS imaging system in csv format was downloaded from the Firms website. The table was loaded into QGIS by adding a text layer, after which the layer was exported to a shapefile.

3. Investigation Results

The results of the analysis of land cover changes conducted using the Global Land Cover service [3] and statistical data of the Kharkiv region [5] are presented in the graphs (Fig. 1, 2). Land cover trends reflect the interaction of various factors, such as climate change, human activity, development, pollution, and warfare. The knowledge and consideration of these trends is key to developing strategies for biodiversity conservation, provision of environmental services and sustainable economic development.

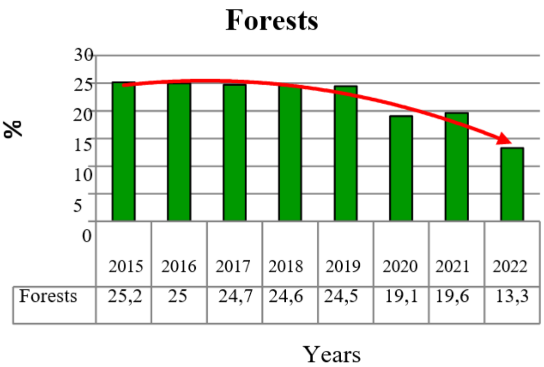

Fig. 1. Graph and polynomial trend line of forest cover change for 2015-2022.

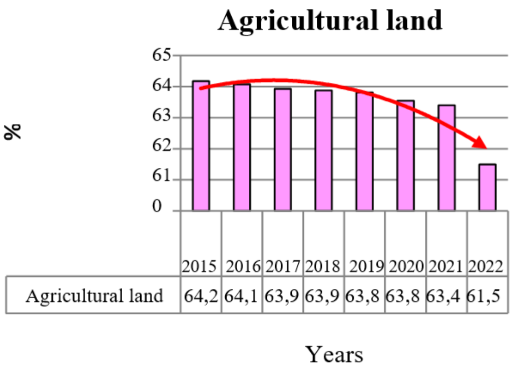

Fig. 2. Graph and polynomial trend line of changes in agricultural land cover in 2015-2022.

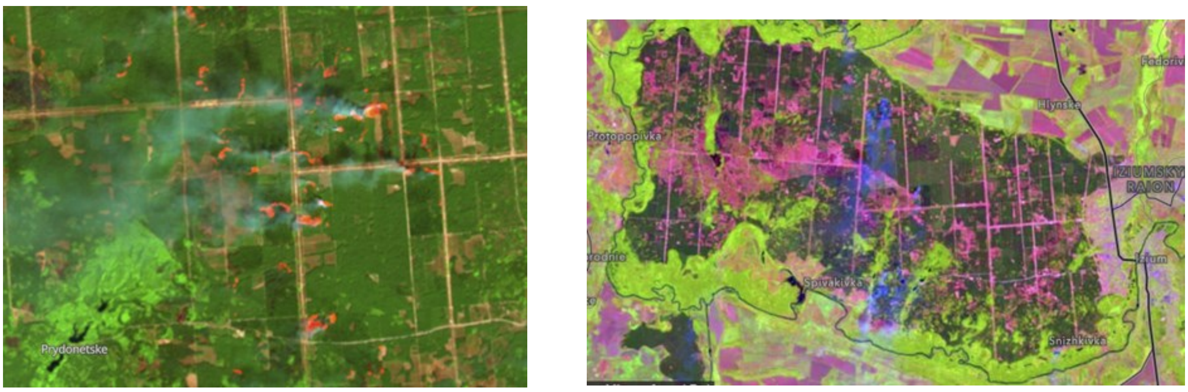

Fig. 3. Sentinal-2 satellite images of 06.05.2022 of forest fires in the Izium forest, Kharkiv region, caused by military operations in the spring of 2022 in natural colors and SWIR combination.

The forests cover a significant area of the Kharkiv region (over 20%) and play an important role in the industrial sector of export production. Following the extremely strong impact of the hostilities in 2022, the forest cover of the Kharkiv region has become a focus of special attention. The Izyum forest in Kharkiv region was severely affected by the military events, suffering extensive damage from fires caused by the fighting. The significant areas of the forest have burned out, especially after the summer fires of 2022, as can be seen on satellite imagery (Fig. 3). In addition, the danger from forest fires is the release of CO_2, a greenhouse gas equivalent that exacerbates climate change. Another dangerous gas is NO_2 - nitrogen dioxide caused by the burning of fossil fuels and biomass.

The Fig. 4 shows a fragment of the Sentinal-5P satellite image, that examines the state of the atmosphere. As a result of the fire, the concentration of nitrogen dioxide in the atmosphere over the forest area is maximum. The image shows the increased concentration in shades of green to brown. The damage caused to the air as a result of emergencies and hostilities during martial law in 2022 was calculated to be in the total amount of UAH 9277642,200 thousand [2].

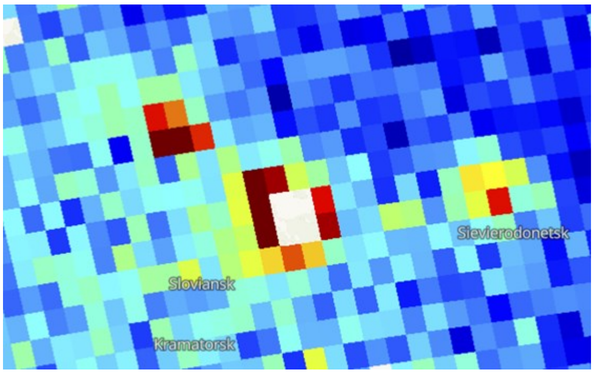

Fig. 4. Increased content of nitrogen dioxide in the atmosphere on the territory of the Izyum forest as of 03.05.2023 according to the Sentinal-5P satellite data.

The results of the analysis of land cover change in Kharkiv region show an extraordinary level of economic development of the region's land. The general trend since 2015 has been a decrease in forests and agricultural land, with a significant reduction in 2022, which is the result of hostilities and their consequences. The military operations lead to a number of mechanical, physical and chemical impacts on the land cover. The vegetation destruction, soil disturbance, and desertification are common consequences of military and technological pressure. In particular, land cover degradation due to military operations has become a major trend in land cover change. The hostilities in the Kharkiv region have severely damaged all natural resources: land areas have been contaminated and polluted with various wastes, the air has been polluted by explosions and fires, water bodies, forest resources and biota have fallen victim to enemy equipment, pollution and deliberate destruction. As a result of the armed aggression of the russian federation against Ukraine, the significant damage has been done to land resources. According to the National Scientific Centre "A.N. Sokolovsky Institute of Soil Science and Agrochemistry", the greatest impact on agricultural land and soil cover is caused by enemy aircraft and artillery (80% of the surveyed areas) [6]. The air, soil, and water pollution can cause significant reductions in yields, food contamination, and threats to human health. During the war, more than 20,000 facilities were damaged or destroyed in the region, 31% of which were in Kharkiv. Of the total number of protected areas in the temporarily occupied territory and in the combat zone, there were 84 protected areas covering an area of 35.1 thousand hectares (46.8% of the total area) in Izium, Kupiansk, Kharkiv, and Chuhuiv districts of Kharkiv region [5].

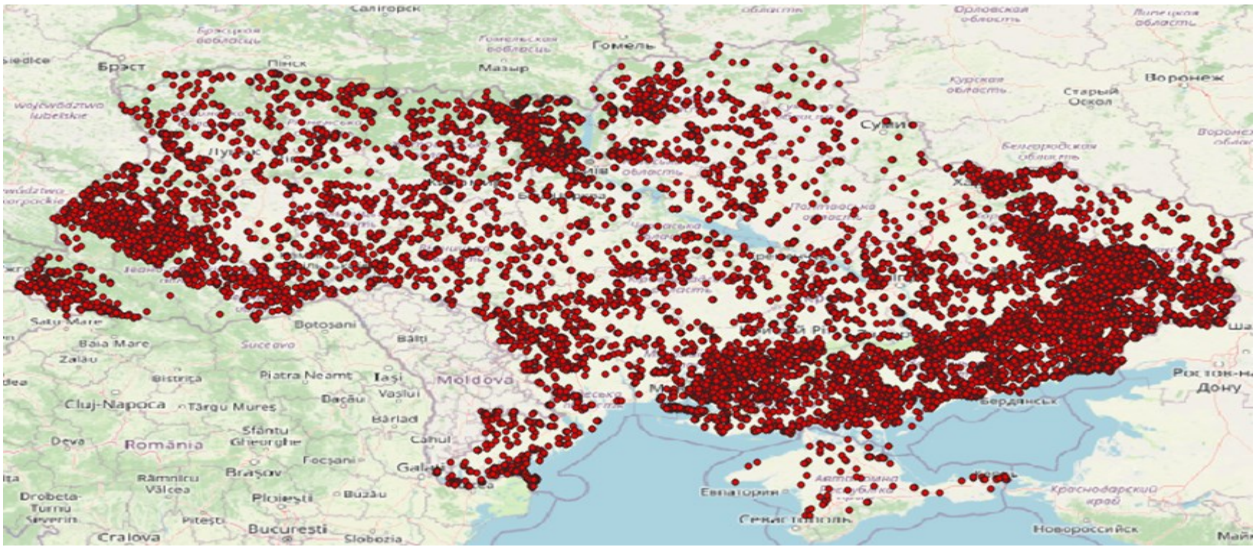

Fig. 5. Array of heat anomaly points from the beginning of the war to the end of the year.

For a more detailed study of land cover changes related to military activities, including the destruction of the humus horizon, soil contamination with metal fragments and explosive residues, and soil contamination with heavy metals, field research and the use of high-resolution aerial or space imagery are needed.

The general statistical information on the fire situation was obtained in QGIS, based on the Firms resource, and displayed through the basic statistics option for 2022: the total number of recorded thermal anomalies was 15327; the initial temperature in Kelvin (K) was converted to °C and contained the following critical values: min 26.85 °C, max 180.65 °C. The next step in the data processing was to select and save the sample of the number of fires for the period from the beginning of the war on 24 February 2022 to the end of the year. There were 14992 such anomalies. Among them, the anomalies with low level of confidence were removed, which are those that are less than 15 K (according to the Firms resource). They mainly include pixels with sun glare. The created sample from the attribute table of all anomaly values above 15 K contains 14709 values of thermal anomalies of high confidence (Fig. 5).

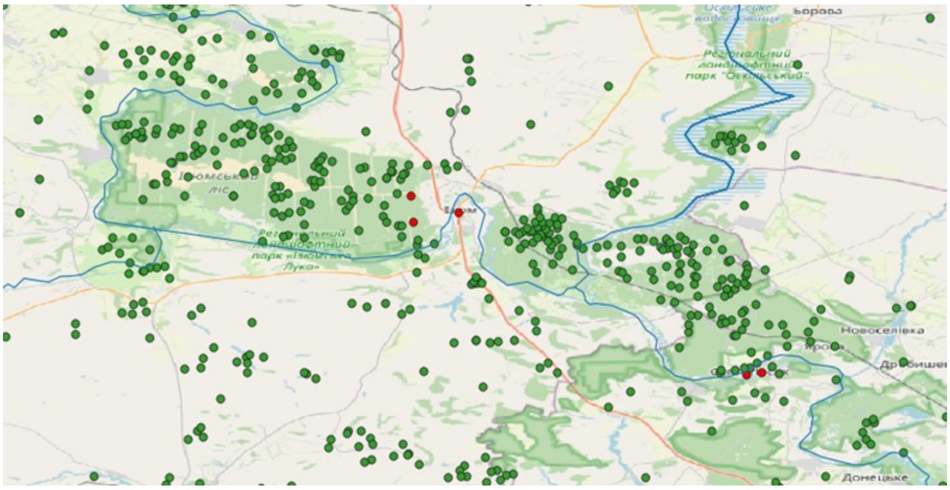

Fig. 6. Map's fragment of classification of thermal anomalies by type (Izium forest area).

Further analysis of the point array involves determining the number of heat anomalies by type. We classify all the anomalies by type and colour the points accordingly: thermal anomalies caused by vegetation burning - green; 2 - thermal anomalies caused by static ground sources - red. Vegetation fires predominate on the territory of the Izyum forest, and, accordingly, most of them are green (Fig. 6).

Fig. 7. Heat map of the fire situation from the beginning of the war to the end of 2022.

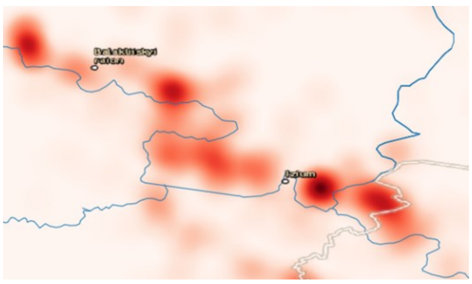

Fig. 8. Fragment of the heat map for the territory of the Izyum forest in Kharkiv region.

To identify the hottest spots in Ukraine, the heat map was created (Fig. 6). The input data is the brightness temperature of the pixels, that are classified into three gradations with uniform distribution: 27.0 - 78.0 (14163 values, the largest number); 78.1 - 129.0 (528 values); 129.1 - 181 (18 values). The heat map shows the 18 hottest points with their temperature values in °C (Fig. 7, 8).

4. **Conclusions**

Thus, the following actions and measures can be recommended to overcome the consequences of the hostilities and restore economic activity:

- to conduct demining the territories of the region's nature reserves and forests;
- to conduct a comprehensive study on the assessment of the degree of contamination of territories and soils;
- to establish the necessary measures to clean up the territory and restore its suitability for agriculture;
- to establish control over the quality of air, soil and water;
- to introduce support from the state and local authorities.

The GIS analysis from the beginning of the war to the end of 2022 revealed 14709 thermal anomalies of high reliability, including maximum value of 180.65 °C and minimum of 26.85 °C. The highest temperatures were recorded at 18 locations between 22.03.2022 and 31.07.2022. Among these 18 outbreaks, the largest number occurred in two months - August/September. The heat map shows the foci and spread of fires across Ukraine, that corresponds to active hostilities during this period.

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Information Warfare Model with Internal Conflict

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Abstract

We construct and study an information warfare model, with an internal conflict integrated into it (interregional migration) based on the example of the Lotka-Voltaire model with cyclical migration, as well as its research using a software tool. For this purpose, the behavior of the spread of one and several information threats within the same community is described, the principle of conflict is described, a model is built and its behavior is studied on various examples, and conclusions are drawn regarding the importance of the influence of internal conflict on the model and regarding methods of predicting the results.

KEY WORDS: *information warfare model, conflict interaction, the Lotka-Voltaire model, stochastic vector.*

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1. Introduction

Nowadays humanity has reached a new stage of its evolution – the so-called "information society". It is characterized by a sharp increase in the importance of the information sphere. And everything that is important to one degree or another creates new threats and dangers. With the emergence of the information sphere and its ever-growing role in our lives, there was a need for its regulation and, most importantly, its protection.

Therefore, the issue of information security is quite important now. Existing information dissemination technologies open up a huge space for the dissemination of various information, including harmful information in the form of propaganda. That is why, during the last decades, tasks to ensure the information order (information security) began to come to the fore. Their list includes problems related to determining the sources, nature, and mechanisms of the emergence and distribution of information flows, as well as various related tasks.

As we know, information can be of a different nature and with sufficient resources, it can be directed and used for various purposes, which are not always positive, but often on the contrary – have harmful and dangerous consequences. A proper understanding of the operation of information dissemination mechanisms is required for proper countermeasures against such threats and timely neutralization of negative effects, or their weakening. At the moment, there are a small number of really effective approaches that produce results. One of approaches is modeling.

The purpose of this work is to first study the model of informational struggle, which is based on the article [1]. The concept of conflict and one of the options for its implementation between indestructible rivals in the form of interregional migration will also be separately considered, in which we will refer to the article [2], [3], [5], [7], [9].

Papers [4], [6], [8] and [10–14] describe, respectively, the basic principles of the theory of continuous evolutionary models with impulse perturbations, and the actual continuous model of information warfare model. And the main task will be the creation of a complex system that will describe the model of information struggle with internal conflict integrated into it (interregional migration) based on the example of the Lotka-Voltaire model with cyclic migration, which is described in [2], as well as its research using a software tool. In the examples (Fig. 4–19), we will conditionally divide the territory into four regions and examine the model's behavior at various coefficients and with different migration directions.

2. "Classic" information warfare model

Let us start with setting the problem in the simplest case [1]. Let us have a social community with the number of N_0, potentially susceptible to the influence of two information streams dissimilar in their content (in the extreme case, information of type 1 (I_1) and type 2 (I_2) are diametrically opposed to each other). We assume at the time $t_0 = 0$ two sources of different information simultaneously begin to broadcast it, as a result of which both information flows spread among the community.

Since I_1 and I_2 are not similar to each other, this process can naturally be considered as an information struggle (competition, rivalry). Our goal now is to build a mathematical model of this struggle, from which it would be possible to obtain the dynamics of its development over time (that is, the dependence on time t of the values $N_1(t)$ and $N_2(t)$ – the number of "adepts" who perceived information, sources "1" and "2"), as well as determine its final result - "winner" or "loser". The winner will be considered to be the one who, by the time the studied community is fully covered by both types of information, has managed to spread his information among a larger number of community members than the opponent, i.e. a value greater than $N_0/2$.

Basic model assumptions. 1) Each of flows I_1 and I_2 is distributed among the community through two information channels:

a) the first of them is "external" in relation to the community. The speed of information propagation through this channel for I_1 is characterized by the parameter $\alpha_1 > 0$, and for I_2 - by the parameter $\alpha_2 > 0$, which are considered independent of time;

b) the second – "internal" channel - interpersonal communication of members of the social community (its intensity for I_1 is characterized by the parameter $\beta_1 > 0$, and for I_2 – by the parameter $\beta_2 > 0$, which are not dependent on time). As a result of such communication, the adepts already recruited by the idea "1" (their number is equal to the value of $N_1(t)$, influencing the members who have not yet been recruited (their number is equal to the value of $(N_0 - N_1(t) - N_2(t))$, contribute their "personal" contribution to the recruitment process. In the same way, the adepts recruited by the idea "2" (their number is equal to the value of $N_2(t)$), influencing the members who have not yet been recruited (their number is also equal to the value of $N_0 - N_1(t) - N_2(t)$), contribute their "personal" contribution to the recruitment process.

2) The rates of change in the number of followers $N_1(t) + N_2(t)$ (that is, the number of which was recruited in a unit of time I_1 and I_2) consist of:

a) rates of external recruitment (they are proportional to the products of parameters α_1 and α_2 on the number of active members $(N_0 - N_1(t) - N_2(t))$, i.e. values α_1 $(N_0 - N_1(t) - N_2(t))$ and α_2 $(N_0 - N_1(t) - N_2(t))$, respectively for I_1 and I_2;

b) rates of internal recruitment (they are proportional to the products of the parameters β_1 and β_2 on the number of active followers $N_1(t)$ and $N_2(t)$ and on those not yet recruited $(N_0 - N_1(t) - N_2(t))$, that is, the values of $\beta_1 N_1(t)$ $(N_0 - N_1(t) - N_2(t))$ and $\beta_2 N_2(t)$ $(N_0 - N_1(t) - N_2(t))$, for I_1 and I_2, respectively.

The number of not-yet-recruited members of the community is equal to N_0 without members who have already received not one, but both types of information (that is, the sum $N_1(t) + N_2(t)$), should be subtracted. As in item 1, the parameters $\alpha_1, \alpha_2, \beta_1$ and β_2 characterize not only the intensity of informational influence, but also the tendency to perceive it at the same time. Thus, the part of the community not yet recruited by the time t (its hypothetical "average statistical" representative, initially neutral in relation to both I_1 and I_2) accepts information faster if the values of $\alpha_1, \alpha_2, \beta_1$ and β_2 are larger. At the same time, even if the influence of I_1 is clearly greater than that of I_2 (i.e. $\alpha_1 > \alpha_2, \beta_1 > \beta_2$), some members of the community still accept I_2 (i.e. there is no complete monopoly of one type of information over another).

Summarizing assumptions 1 and 2, we get the model [1]:

$$\begin{cases} \frac{dN_1}{dt} = \left(\alpha_1 + \beta_1 N_1(t)\right)\left(N_0 - N_1(t) - N_2(t)\right), N_1(t_0 = 0) = N_1(0) \geq 0 \\ \frac{dN_2}{dt} = \left(\alpha_2 + \beta_2 N_2(t)\right)\left(N_0 - N_1(t) - N_2(t)\right), N_1(t_0 = 0) = N_2(0) \geq 0 \end{cases} \tag{1}$$

The system of nonlinear ordinary differential equations (1) (autonomous dynamic system of the 2nd order) is the initial model of the researched process. From it, given the known parameters $N_0, \alpha_1, \beta_1, \alpha_2, \beta_2$ and the initial values of the quantities $N_1(0)$ and $N_2(0)$, it is possible to analytically or numerically find all the required characteristics. Dividing the second equation (1) by the first, we get:

$$\frac{dN_2}{dN_1} = \frac{\alpha_2 + \beta_2 N_2}{\alpha_1 + \beta_1 N_1} \tag{2}$$

Hence, we find the joint solution of system (1) in the form of an integral:

$$\beta_2 N_2(t) = C\left(\alpha_1 + \beta_1 N_1(t)\right)^{\frac{\beta_2}{\beta_1}} - \alpha_2 \tag{3}$$

$$C = \frac{\alpha_2 + \beta_2 N_2(0)}{\left(\alpha_1 + \beta_1 N_1(0)\right)^{\frac{\beta_2}{\beta_1}}}$$

In particular, with zero initial data ($N_1(0) = N_2(0) = 0$) the integration constant is equal to $C = \frac{\alpha_2}{\alpha_1^{\frac{\beta_2}{\beta_1}}}$, and we have for the equation's solution

$$\frac{\beta_2}{\alpha_2} N_2(t) = \left(1 + \frac{\beta_1}{\alpha_1} N_1(t)\right)^{\frac{\beta_2}{\beta_1}} - 1 \tag{4}$$

We also note that it is possible to find a condition for the victory of one type of information over another by introducing the "victory" function V_i [1]:

$$V_i = V_i(\alpha_i, \beta_i, N_i(0), N_0), i = 1,2,$$

where

$$V_i = \beta_i \ln\left(\left(1 + \frac{\beta_i N_0}{2a_i}\right) / \left(1 + \frac{\beta_i N_i(0)}{2a_i}\right)\right)^{-1}$$

Then the participant with the highest value of the victory function will be considered the winner.

3. Examples of the behavior of models in the simple cases

For clarity, we will use a discrete-time model. To do this, we will use the definition of the derivative:

$$\frac{dN_i}{dt} = \frac{\Delta N}{\Delta t} = \frac{N_i^{(n+1)} - N_i^{(n)}}{1}$$

where $n \in (0, \infty)$ is time. We received a discrete form of the model of information struggle (1):

$$\begin{cases} N_1^{(n+1)} = \left(\alpha_1 + \beta_2 N_1^{(n)}\right)\left(N_0 - N_1^{(n)} - N_2^{(n)}\right) + N_1^{(n)} \\ N_2^{(n+1)} = \left(\alpha_2 + \beta_2 N_1^{(n)}\right)\left(N_0 - N_1^{(n)} - N_2^{(n)}\right) + N_2^{(n)} \end{cases} \tag{5}$$

Next, we consider several illustrative examples that demonstrate the behavior of the model for various parameters.

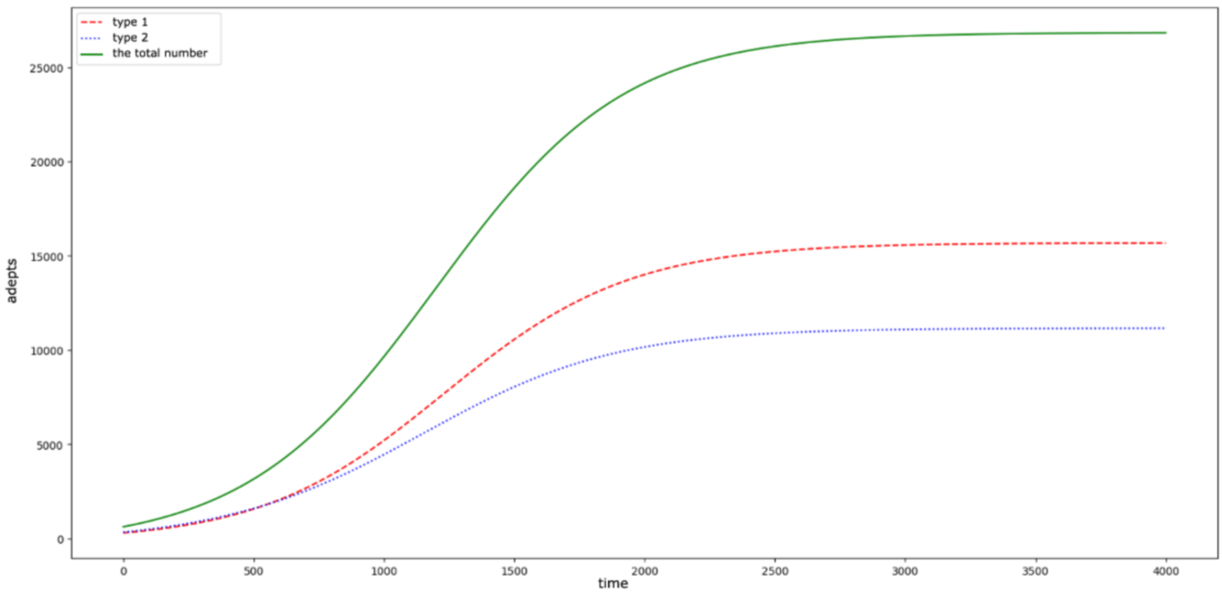

Fig. 1 Model example 1

Consider the behavior of a model with non-zero initial numbers of followers $N_1(0) = 289, N_2(0) = 326, N_0 = 26840$ at parameters values: $\alpha_1 = 0.000015, \alpha_2 = 0.000025, \beta_1 = 0.00000011, \beta_2 = 0.000000089355$. With the help of computer support, we will build a graph and calculate the values of the victory functions

$$V_1 = 3.177659836624433 \cdot 10^{-8}$$
$$V_2 = 2.865215480796103 \cdot 10^{-8}$$

As we can see from Fig.1, the values of the victory function coincided with the results – type 1 information won the fight.

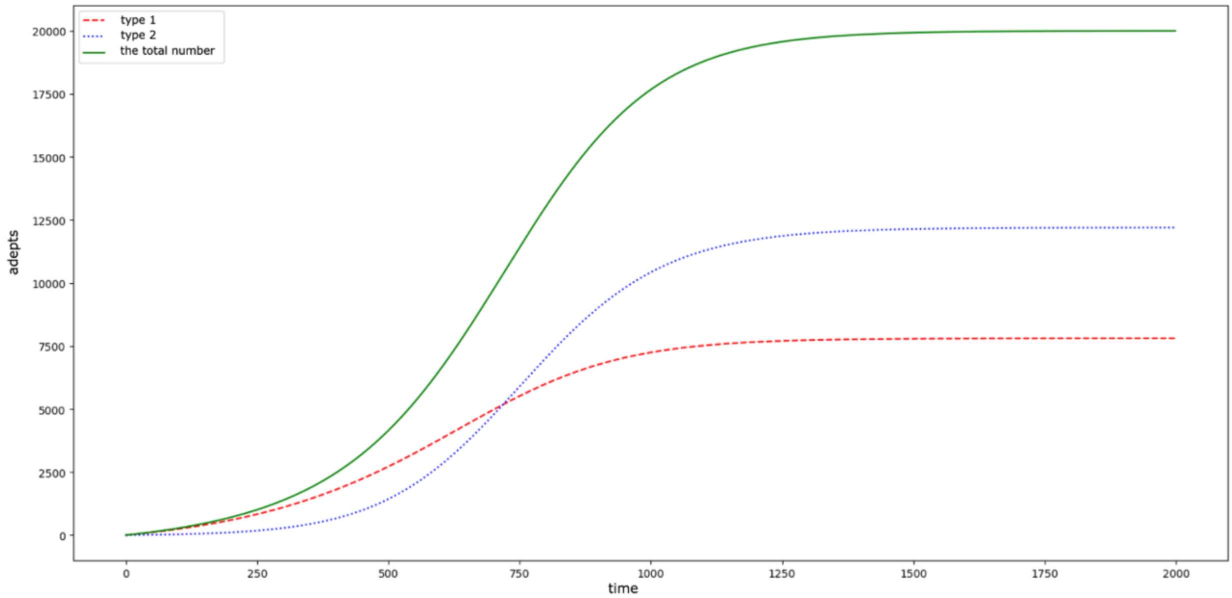

Fig. 2 Model example 2

$\alpha_1 = 0.0001, \alpha_2 = 0.00001, \beta_1 = 0.0000002, \beta_2 = 0.00000045, N_1(0) = 0, N_2(0) = 0, N_0 = 20000$

$$V_1 = 6.569174775061021 \cdot 10^{-8}$$
$$V_2 = 7.363207148164498 \cdot 10^{-8}$$

This example 2 shows a slightly different scenario of the model's behavior: although the final result indicates a clear victory of type 2, at the beginning type 1 held the lead, which indicates the possibility of a change of leadership at any time until the community is covered by followers. It is easy to imagine a situation when information about the intermediate behavior of the model can be important, which even in the case of such a simplified model of the information struggle, suggests that the victory function is not such a useful tool compared to modeling.

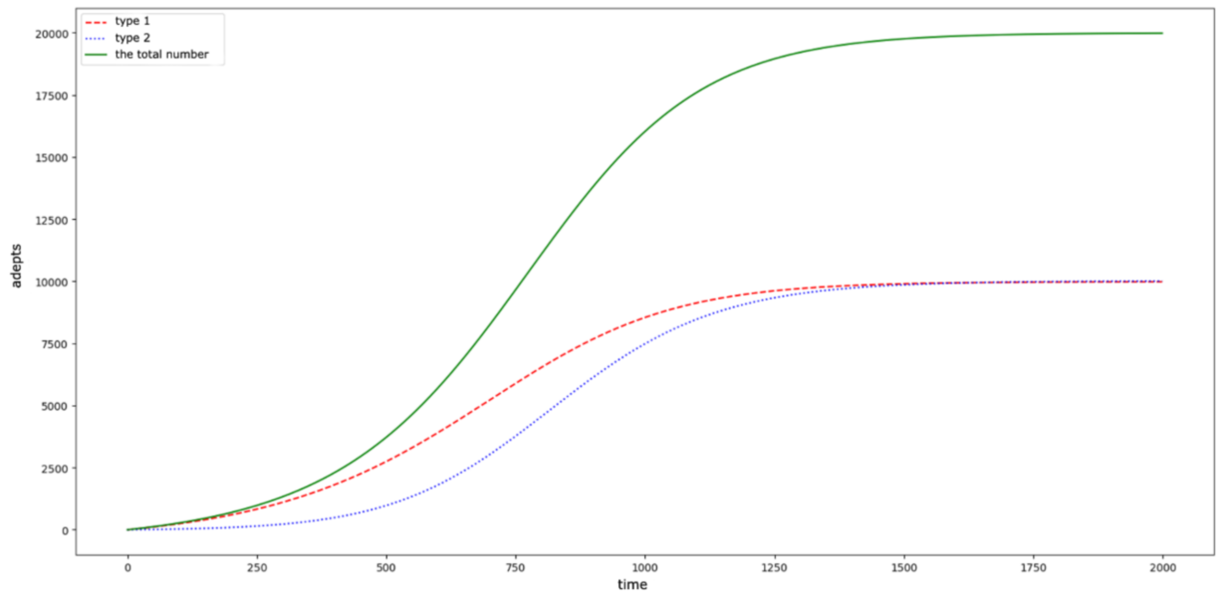

Fig. 3. Model example 3

$\alpha_1 = 0.0001, \alpha_2 = 0.00001, \beta_1 = 0.0000002, \beta_2 = 0.00000039326, N_1(0) = 0, N_2(0) = 0, N_0 = 20000$

$$V_1 = 6.569174775061021 \cdot 10^{-8}$$
$$V_2 = 6.57959947580904 \cdot 10^{-8}$$

In case of example 3, type 1 dominated for a while but eventually caught up with type 2, which was "predicted by the win function." Parity is established, but should intermediate values be completely ignored? If there was a clear lead for a certain period of time, and then there was no one, then did type 1 not get some other achievement besides winning.

Any, including intermediate values, can be important in various tasks, especially when it comes to information security [15,16]. But in any case, it can be said with certainty that it is the modeling of behavior over long intervals that brings the desired results and that the final value does not even come close to describing the general behavior.

4. Model of conflict interaction between complex systems

By conflict we will understand a physical system consisting of at least two substances (opponents) A and B, and a certain field of common interests Ω (the field of common interests consists of "positions", each of which at one moment in time can belong to only one substance or be free), which they are interested in capturing [2], [3]. We consider one of the simplest variants of a complex system, in which the field of common interests is divided into a finite number of separate regions $\Omega_i: \Omega = \cup_{i=1}^{n} \Omega_i, n < \infty$. The goal of each of the opponents A and B is to own as many positions as possible in Ω. This means that A and B can be described by vectors with non-negative coordinates: $A = (A_1, \ldots, A_n)$, $B = (B_1, \ldots, B_n)$, $A_i, B_i \geq 0, i = 1, \ldots, n$, and their initial values describe the starting positions of the opponents and can be both zero and non-zero. At the same time, the numbers A_i, B_i give the quantitative characteristics of the corresponding substances in Ω_i at any moment in time.

The change of vectors A and B caused by conflict interaction gives rise to some dynamic system in discrete time:

$$\{A^N, B^N\} \overset{*}{\rightarrow} \{A^{N+1}, B^{N+1}\}, N = 0,1, \ldots, \quad (6)$$

where A^0 and B^0 characterize the substances at the initial moment of time.

The reflection * denotes the law of this conflict interaction between substances, which is generally unknown. Here we will define it according to our intuitive understanding of the physical meaning of substances A and B within the framework of our problem and according to the conditions imposed by the studied model.

As we wrote earlier our goal is to describe the model of information struggle with internal conflict, by which we understand some interregional interaction as migration, following the example of the Lotka-Voltaire model with cyclical migration [1].

To describe the principle of migration, which will be the law of interaction between substances (within the framework of this problem), we will use the model of conflict interaction in a discrete-time system between two indestructible rivals [3] (the indestructibility of rivals is an important condition, the satisfaction of which corresponds to the assumptions of the model information struggle). We are especially interested in the rule of redistribution of values, described by the formula of non-linear and non-commutative conflict interaction between two vectors, which we will use later.

$$p_i^{(n+1)} = \frac{p_{ai}^{(n)}\left(1+\gamma r_i^{(n)}\right)}{1+\gamma\sum_{i=1}^{I} p_i^{(n)} r_i^{(n)}} \quad (7)$$

This formula describes the change in the quantitative values of the substance p in the regions under the influence of the substance r with a certain coefficient in the field of interest (the total amount of the substance does not change). The result of such an interaction depends on the distribution of substances and the coefficient of their interaction. In the framework of the indestructibility of opponents, this interaction is reduced to the movement (outflow) of substances from one region to another. The magnitude of this outflow depends on the value of the intensity coefficient $\gamma \epsilon [0,1]$, and its sign indicates the direction of movement relative to the magnitude of another substance in the regions. These coefficients do not necessarily have to be equal for the interaction of p with r and r with p, as they describe independent outflows. That is, the first substance can interact with the other more than the second with the first, which makes this formula more universal. With a positive intensity coefficient during the interaction of substances p with r (which is described by formula (2)), some part of substance p in all regions will flow to places where there is more substance r and vice versa. For example, in the case of two regions, in the region with a larger amount of r, the amount of p will increase, and in the second, where it is less, it will decrease by the same amount. With a larger number of regions, the redistribution is less obvious, but the idea of the principle remains.

It is also worth remembering that as a result of such interactions, the total value of each region $\Omega_i = \text{substance}\ r + \text{substance}\ p + \text{free positions}$, but not Ω, can change at each moment of time.

In formula (7), normalized (stochastic) vectors are used for calculations. And since we use natural numbers to describe the amount of substance (members of the community), before and after calculations, the necessary vectors must be normalized and denormalized accordingly:

$$\tilde{p}_i = \frac{p_i}{z}, z = \sum_{i=1}^{I} p_i \quad (8)$$

$$p_i = \tilde{p}_i z \quad (9)$$

where I is the number of regions, p_i is the absolute amount of substance p in the region i, and we is a normalized vector.

Since the basis of our model is still the model of informational struggle within a certain community, we are forced to impose a number of intuitive conventions in order to preserve the possibility of further complicating the model for practical application.

As it was said earlier, the parties to the conflict are 2 types of information I_1 and I_2, the field of interests will be a conditional community. Next, let us "settle" our community on some territory and divide it into regions. This, in addition to satisfying the necessary conditions for the integration of the conflict in the model, brings the problem closer to real practical conditions. Each element of such a community, according to the assumptions made in section 1, can be an adept of information of one of the types or a so-called neutral personality - a neutral. The conflict interaction itself will take place at each moment of discrete time. Adepts of information, as well as the neutrals themselves, will be interacting substances, respectively. However, this is not a conflict between three equal players, since neutrals also play the role of a field of interests, but a conflict between adepts of different types of information and at the same time – a conflict between all adepts and neutrals (because it is natural to assume that neutral members of the community also have respond to changes). Therefore, we will divide the entire interaction into two stages:

(I) The conflict between neutrals and adepts of information in general
(II) Conflict between adherents of different types of information

During the first stage, the redistribution of the vector of neutrals N_0 will take place under the influence of the vector of the sum of followers in each region $\mathrm{N}_{(1+2)}$ and the coefficient α, and the vectors N_1 and N_2 will be influenced by the vector of neutrals and the coefficient γ (if necessary, you can use different interaction coefficients, but we will limit ourselves to one). In the second stage, a standard conflict between two players will take place: the vectors of followers are redistributed under the influence of the opponent's vector and the coefficient β (as above, we can take the coefficient for each interaction).

We will fix the state of our system by three vectors and a moment of time: $N_1^{(n)} = \left(N_{11}^{(n)}, \dots, N_{1i}^{(n)}\right), N_2^{(n)} = \left(N_{21}^{(n)}, \dots, N_{2i}^{(n)}\right)$ are the distributions of the number of all persons, $N_0^{(n)} = \left(N_{01}^{(n)}, \dots, N_{0i}^{(n)}\right)$ is the distribution of neutral persons, $(N_0^{(n)} = N^{(n)} - N_1^{(n)} - N_2^{(n)}$, where $N^{(n)}$ with non-negative coefficients, $n = 0,1, \dots$ describes discrete time, $i \in N_+$ is the number of the conflict region.

The schematic evolution of the vectors will look like this:

$$N_1^{(n)}\left(N_2^{(2)}\right) \xrightarrow{information\ warfare\ model} N_1^{(ń)}\left(N_2^{(ń)}\right) \xrightarrow{the\ conflict\ of\ adepts\ and\ neutrals} N_1^{(n'')}\left(N_2^{(n'')}\right)$$

$$\xrightarrow{the\ conflict\ of\ adepts\ and\ neutrals} N_1^{(n+1)}(N_2^{(n+1)})$$

$$N_0^{(n)} \xrightarrow{information\ warfar\ model} N_0^{(n')} \xrightarrow{the\ conflict\ of\ adepts\ and\ neutrals} N_0^{(n+1)}$$

where n' and n'' mean intermediate moments of evolutionary cycles.

The general algorithm of the program during one round in the cycle will be as follows: First of all, we recalculate the vectors of adepts 1 and 2 of the information type coordinately according to the formulas from chapter 2:

$$\begin{cases} N_{1i}^{(n')} = (\alpha_1 + \beta_2 N_{1i}^{(n)})(N_i^{(n)} - N_{1i}^{(n)} - N_{2i}^{(n)}) + N_{1i}^{(n)} \\ N_{2i}^{(n')} = (\alpha_2 + \beta_2 N_{2i}^{(n)})(N_i^{(n)} - N_{1i}^{(n)} - N_{2i}^{(n)}) + N_{2i}^{(n)} \\ N_{0i}^{(ń)} = N_i^{(ń)} - N_{1i}^{(ń)} - N_{2i}^{(ń)} \end{cases}$$

Next, we will conduct a conflict interaction between all adepts and neutrals. To do this, we first form the vector of adepts $N_{1+2}^{(n')} = N_1^{(n')} + N_2^{(n')}$ (addition is coordinate-wise). We will describe this conflict with the following transition:

$$\begin{pmatrix} N_1^{(n')} \\ N_2^{(n')} \\ N_0^{(n')} \end{pmatrix} \xrightarrow{A} \begin{pmatrix} N_1^{(n'')} \\ N_2^{(n'')} \\ N_0^{(n'')} \end{pmatrix}$$

where *A* consists of three operations that we described earlier: $A = D^{-1} * D$, D and D^{-1} normalization and denormalization operations, respectively (formulas (8) and (9)), and * is the law of conflict interaction. Therefore, calculations will be made according to the following formulas:

$$N_{0i}^{(n+1)} = \frac{N_{2i}^{(ń)}\left(1 + \alpha N_{1+2i}^{(ń)}\right)}{1 + \gamma \sum_{i=1}^{I} N_{0i}^{(ń)} N_{1+2i}^{(ń)}}, N_{1i}^{(n̈)} = \frac{N_{1i}^{(ń)}\left(1 + \gamma N_{0i}^{(ń)}\right)}{1 + \gamma \sum_{i=1}^{I} N_{1i}^{(ń)} N_{0i}^{(ń)}}, N_{2i}^{(n̈)} = \frac{N_{2i}^{(ń)}\left(1 + \gamma N_{0i}^{(ń)}\right)}{1 + \gamma \sum_{i=1}^{I} N_{2i}^{(ń)}}, i = 1, \dots, I$$

Now we need to conduct a conflict between different adepts:

$$\begin{pmatrix} N_1^{(n'')} \\ N_2^{(n'')} \end{pmatrix} \xrightarrow{B} \begin{pmatrix} N_1^{(n+1)} \\ N_2^{(n+1)} \end{pmatrix},$$

$$B = D^{-1} \ast D$$

Here by $\acute{*}$ we understand the following redistribution:

$$N_{1i}^{(n+1)} = \frac{N_{1i}^{(n'')}\left(1+\beta N_{2i}^{(n'')}\right)}{1+\beta \sum_{i=1}^{I} N_{1i}^{(n'')} N_{2i}^{(n'')}}, N_{2i}^{(n+1)} = \frac{N_{2i}^{(n'')}\left(1+\beta N_{1i}^{(n'')}\right)}{1+\beta \sum_{i=1}^{I} N_{2i}^{(n'')} N_{1i}^{(n'')}}$$

After that, we will recalculate the vector of all persons by region and finish the round.

5. Examples

In this section, we will consider the behavior of the created model by simulating its behavior with the help of the program. For greater visibility of the influence of internal conflict on the model of information struggle, we will take the parameters for the basic model from example 1 (Fig.1). It described an unequivocal victory of type I_1, both by the value of the victory function and by constant leadership.

Let the number of regions I be 4 and the initial distributions are as follows: $N_1^{(0)} = (31, 97, 73, 88), N_2^{(0)} = (34, 94, 122, 76), \mathrm{N}^{(0)} = (6746, 3464, 9790, 6840)$ $(N_1(0) = 289, N_2(0) = 326, N_0 = 26840)$. And then we will consider the behavior of the model with different coefficients of conflict interaction and, most importantly, with different signs because although the magnitude of the interaction is important, it is not as much as the direction of migration.

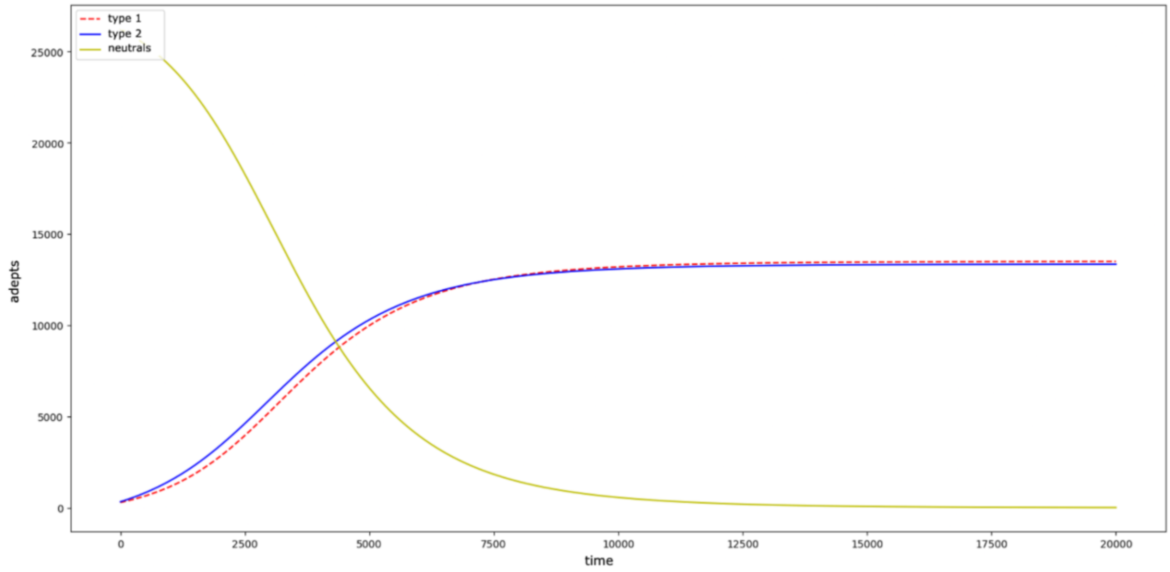

Fig. 4. General behavior of the model

5.1. The case with zero coefficients

First, consider the case when all coefficients α, β, γ are zero – that is, there is no conflict, but the division into regions remains.

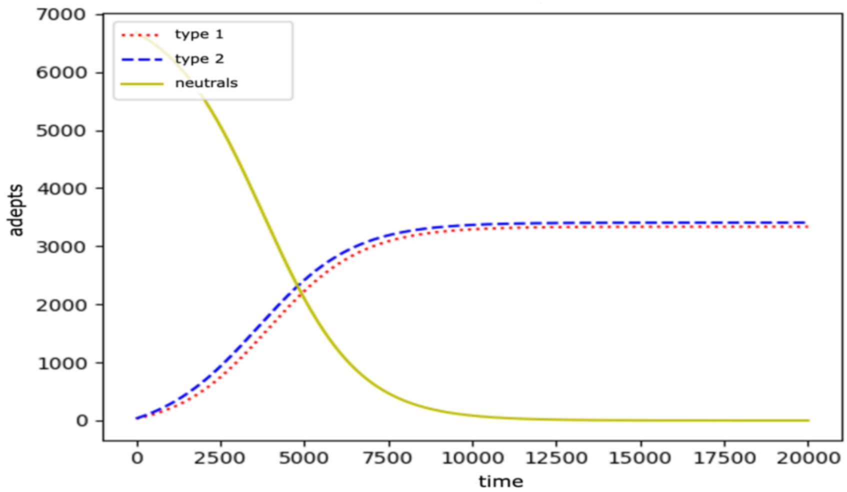

Fig. 5. Region 1

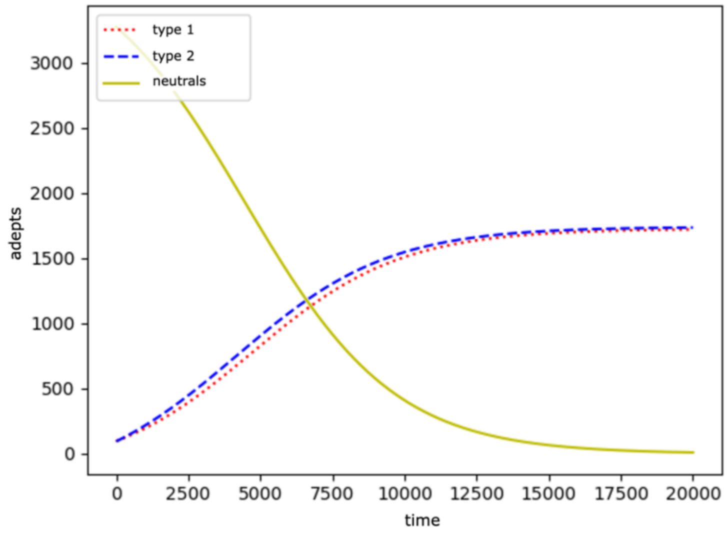

Fig. 6. Region 2

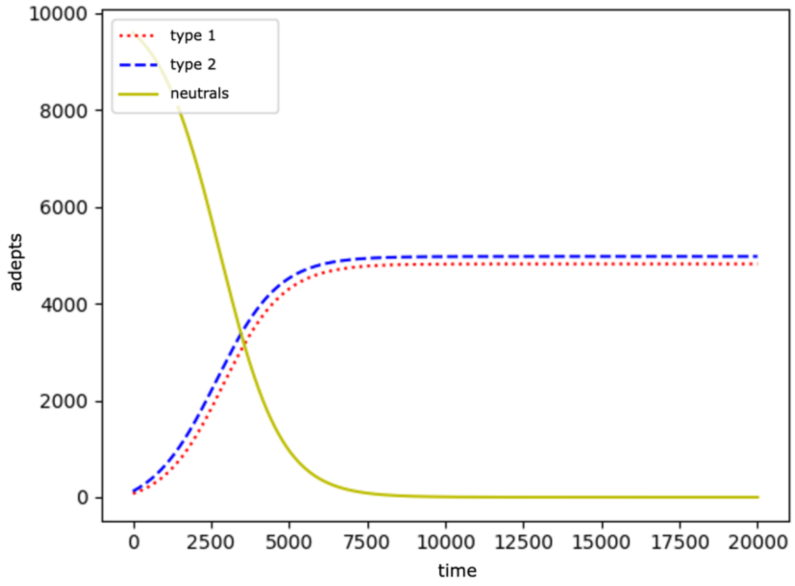

Fig. 7. Region 3

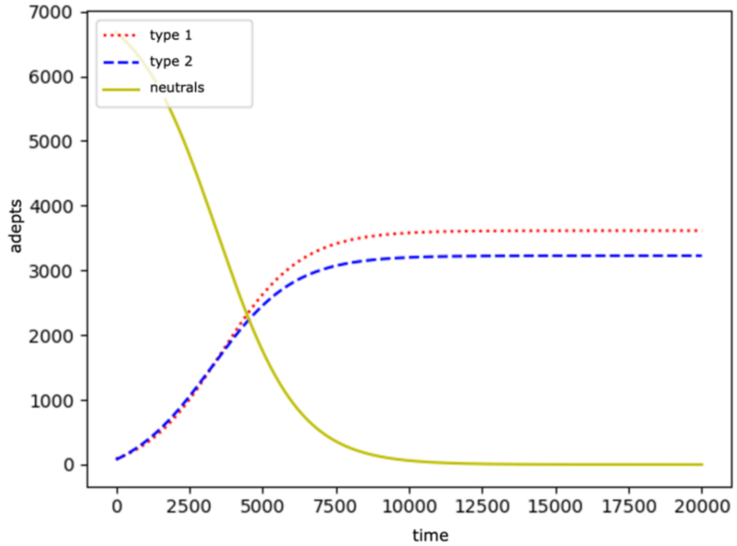

Fig. 8. Region 4

According to the absence of conflict, we obtained four independent models of information struggle (Fig. 5–8), which in turn affect the behavior of the model as a whole depending on its size, which can be seen in the graphs. Despite the slight advantage of I_2 in regions 1, 2, and 3, with the third region being the largest among all, it was still not enough to overcome the larger victory of I_1 in region 4. Therefore, overall, as we can see, the victory belongs to I_1, although this time, only within 1%.

This coincided with the result in section 1, but it is more of a coincidence because the behavior of the model is significantly different – there is a change of leadership and the final results differ by 1%. For clarity, if only the vector $N_2^{(0)} = (104, 24, 172, 26)$ is changed, I_2 victory can be obtained, with a larger permanent advantage without changing the leadership (Fig. 9).

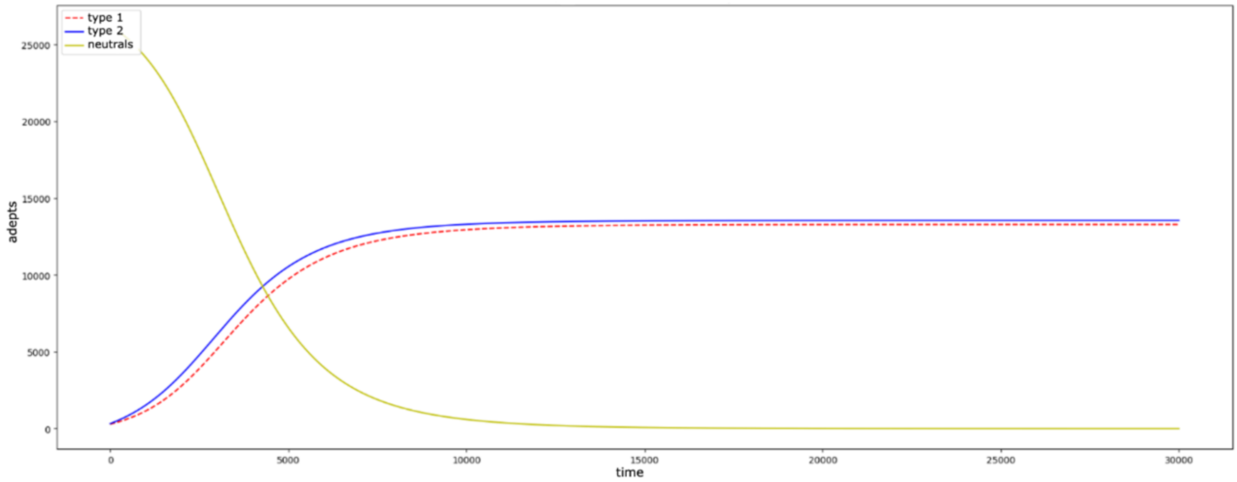

Fig. 9. General behavior of the model

However, this does not mean that the results of such a model cannot be predicted. For each region, it is enough to find the value of the win functions for each type of information and, taking into account the size of the corresponding region relative to the size of the entire community, calculate the corresponding total values.

5.2. The case with "natural conflict"

Now we take the coefficients in such a way that Adepts migrate to regions with a large number of Neutrals but few rivals in order to be able to recruit more individuals, and Neutrals migrate to regions with few Adepts in order to "have a calmer life." For example, $\alpha = -0.75, \beta = 0.5, \gamma = -0.8$

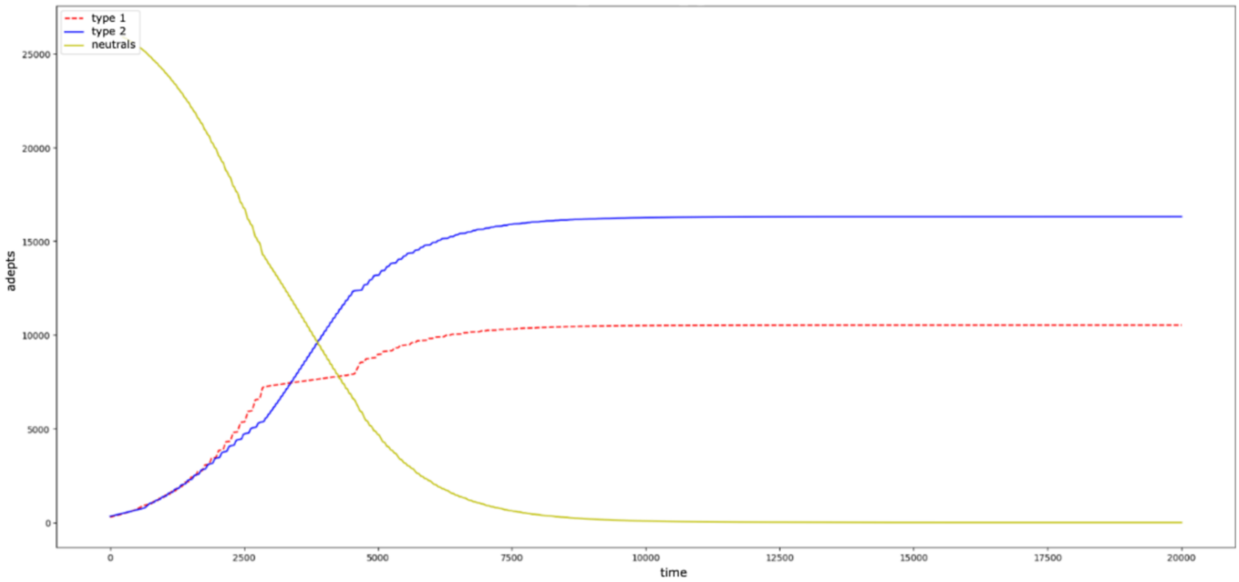

Fig. 10. The behavior of the model

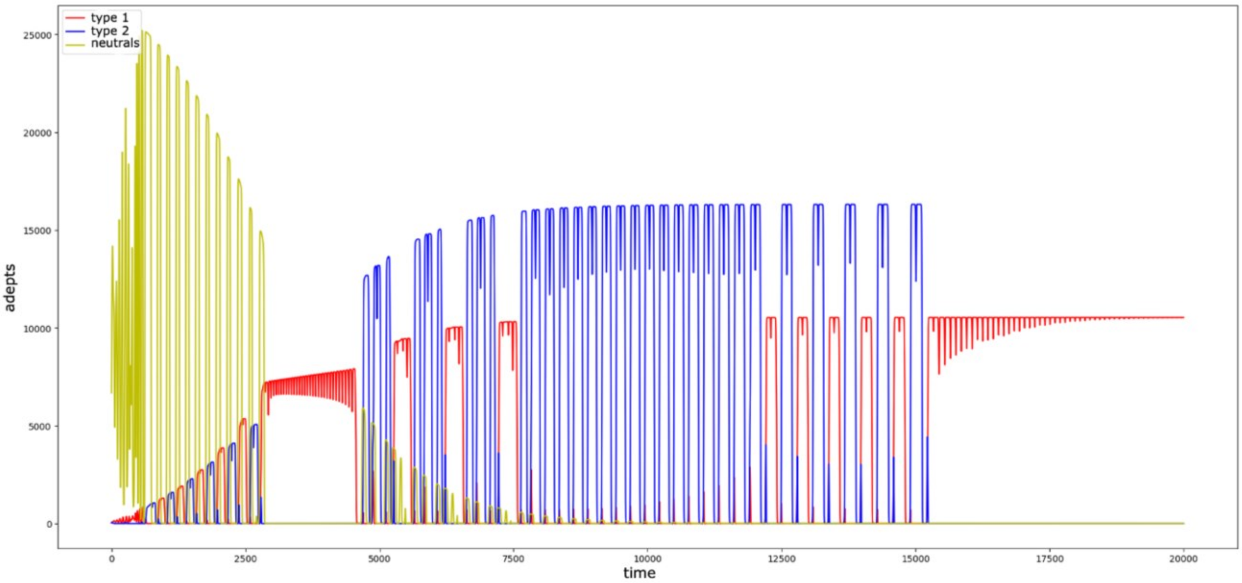

Fig. 11. Region 1

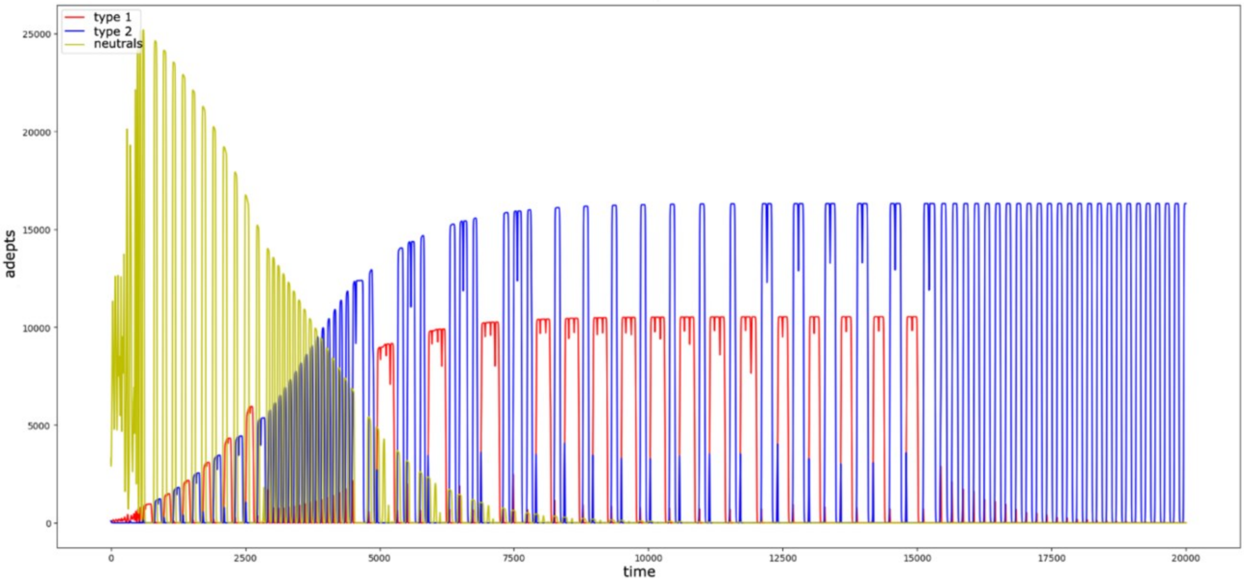

Fig. 12. Region 2

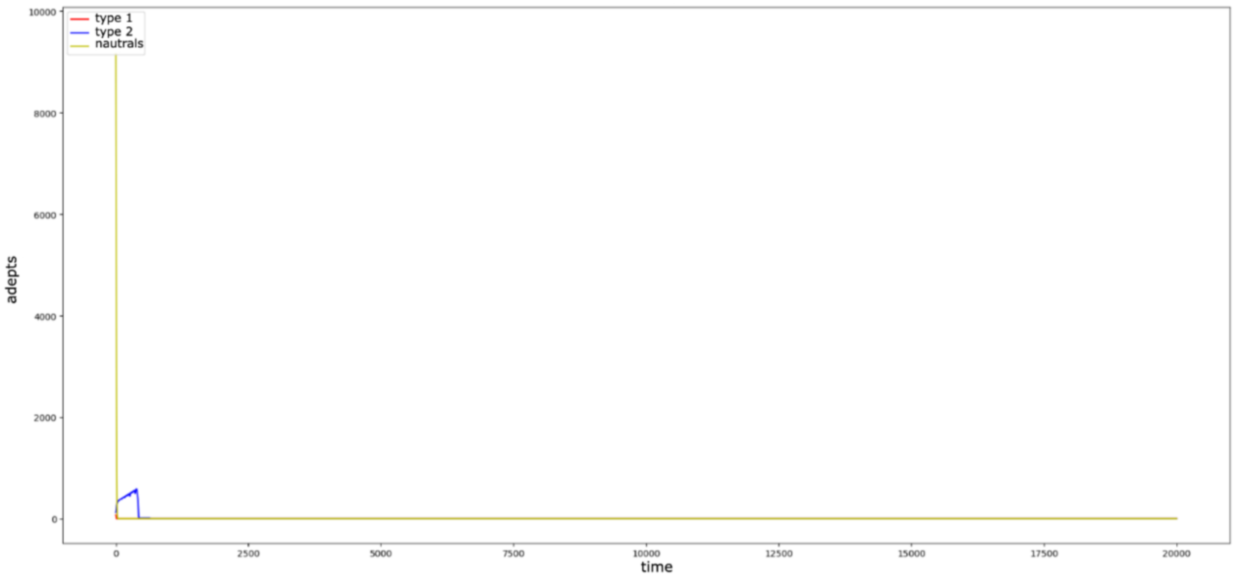

Fig. 13. Region 3

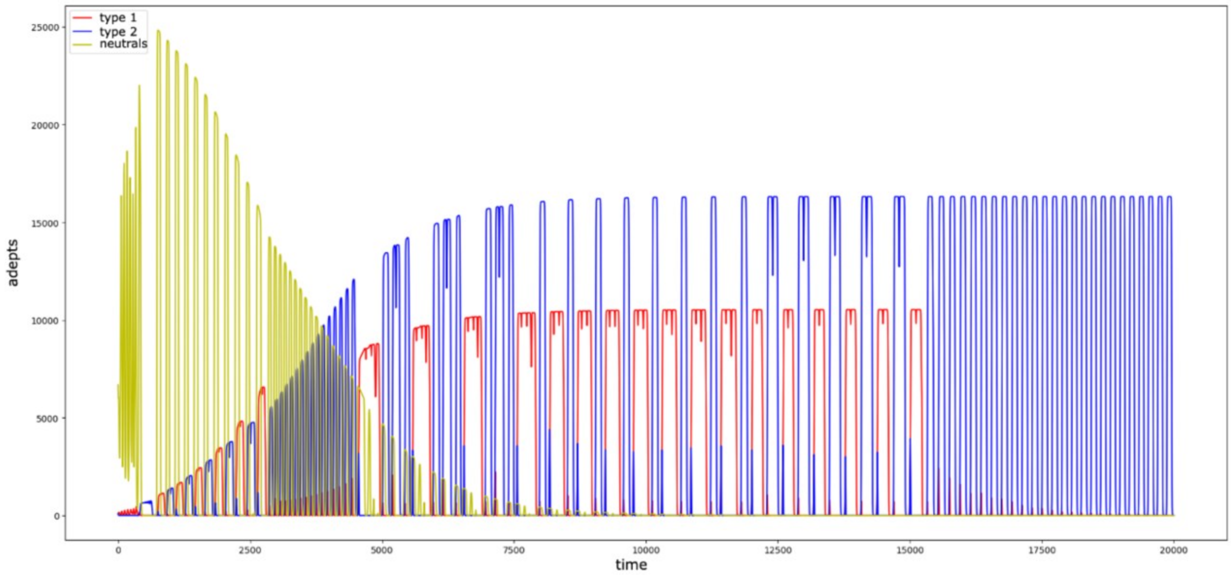

Fig. 14. Region 4

This time the results are much more interesting. From the general behavior of the model (Fig. 10), it can be seen that the second type of information won by an absolute margin. It can also be said that at the beginning I_1 still held the leadership for some time, until its growth rate decreased significantly, and in I_2, on the contrary, it increased strongly. And in general, in contrast to the model of information struggle, the growth rates here vary, which is clearly visible in the first third of the graph.

Now let us analyze the situation in each region in particular. First of all, it should be said that the third region almost immediately ceased to exist – all its resources were distributed among other regions at the very beginning, despite the fact that it is the largest among all.

In the other three regions, migration fluctuations occur throughout time, which only in the case of region 1 faded over time. In their behavior, four parallel stages for each region can be distinguished.

The first of them lasted from time 0 to ≈ 2900. During it, neutrals constantly migrate between these three regions, and at certain times they completely emigrate from each region, but return after some time (this is especially noticeable in region 2 and 4). At the same time, there is a rapid increase in the number of followers of the two types in each region.

The second stage ended around the time of 4500. During it, each region was dominated in the number of adherents of one information. What is more, all the neutrals emigrated from region 1 at this stage (which later returned), and I_1 adepts appeared instead. Although there was no competition for them here, the lack of neutrals also prevented them from spreading, which lasted until the end of the stage. This was the reason for the decline in growth, which in the future led to losses. In regions 2 and 4, the situation is completely opposite. Thanks to additional neutrals from region 1, I_2 adepts, despite little competition, were able to significantly expand their ranks, which explains the sharp increase in their pace.

The third stage is the longest, it ended around 15300. Here, all neutrals will already be recruited, and therefore the winner will be determined, which can be seen on the graph of the general behavior. However, within individual regions, everything is not so obvious. Adepts still migrate between regions, and the only thing that speaks of the superiority of I_2 adepts is the larger amplitude of oscillations in all regions and the almost complete displacement of I_1 in region 1 in the segment (7600;12100).

Only during the last stage, the behavior of the model become stable in all regions. In regions 2 and 4, the leadership is finally secured by the followers of I_2, and the migration fluctuations of I_1 fade away, going to zero. Region 1 is completely anchored by adepts I_1, whose quantity fluctuations also fade, but at the level of 10528, which is their final value. The oscillations of I_2 did not disappear, which can be explained by the presence of two regions for migration, where they dominate, as well as by different periods of oscillations that did not coincide.

The cases when the coefficients $\alpha > 0$ and $\beta \leq 0$ (as well as $\alpha = 0$ and $\beta > 0$) are essentially analogous since they mean that neutrals migrate to places where there are more adepts and adepts to where there are few neutrals. Although this does not correspond to natural conflicts, it fully supports migration. The sign of γ in a certain sense will also not change the model much, as it does not affect the interaction with neutrals. The behavior of the model will of course change, but the oscillatory migrations, like the example above, will remain.

5.3. The case $\alpha, \gamma > 0, \beta \geq 0$

It can be interpreted as the migration of neutrals to where there are many adepts, and the adepts to where there are many neutrals, and the adepts themselves also migrate to where there are many competitors. Briefly, this behavior can be described as migration.

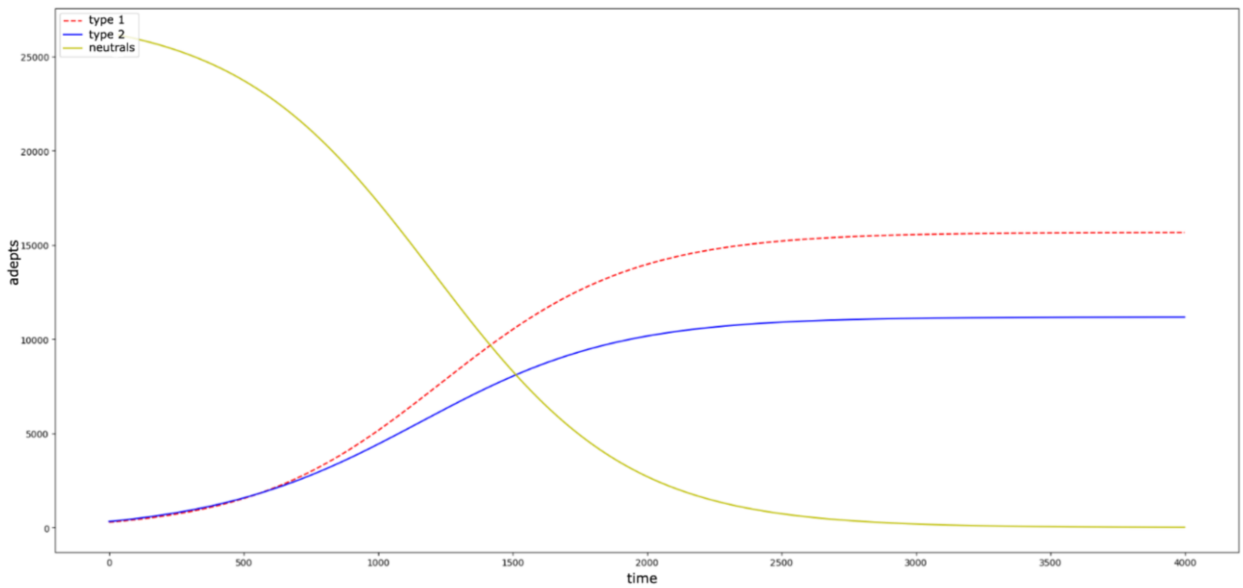

Fig. 15. The behavior of the model

It was established experimentally that for this model of information struggle, regardless of the values of the coefficients, if they are positive, the model behaves practically the same, namely:

The behavior in the regions resulted in the outflow of all resources to region 3 in a small number of cycles, which turned the model into a standard information struggle model.

There is nothing surprising in this, because, according to the parameters, all community members moved toward each other. Since the most significant region is the third, it became the goal of migration.

If $\alpha, \beta > 0$, and $\gamma \leq 0$, then the model behaves in the same way, except for the case when $-1 \leq \gamma < \Gamma, \Gamma \approx -0.5$ (the value of Γ was determined experimentally and requires further clarification and research). Then, the model again behaves relatively the same, regardless of the coefficients α and β. However, now due to the conflict between followers, some part of I_1, instead of migrating to region 3, migrated to the empty region 4, where they remained (information threat propagation model). This allowed I_2 to win in the main region 3, which still held practically the entire community. When increasing $|\gamma|$ the part of I_1 that did not migrate to region 3 also increases, while at $\gamma = -1$ the adepts completely separated in regions 3 and 4, thereby forming two models of information threat propagation.

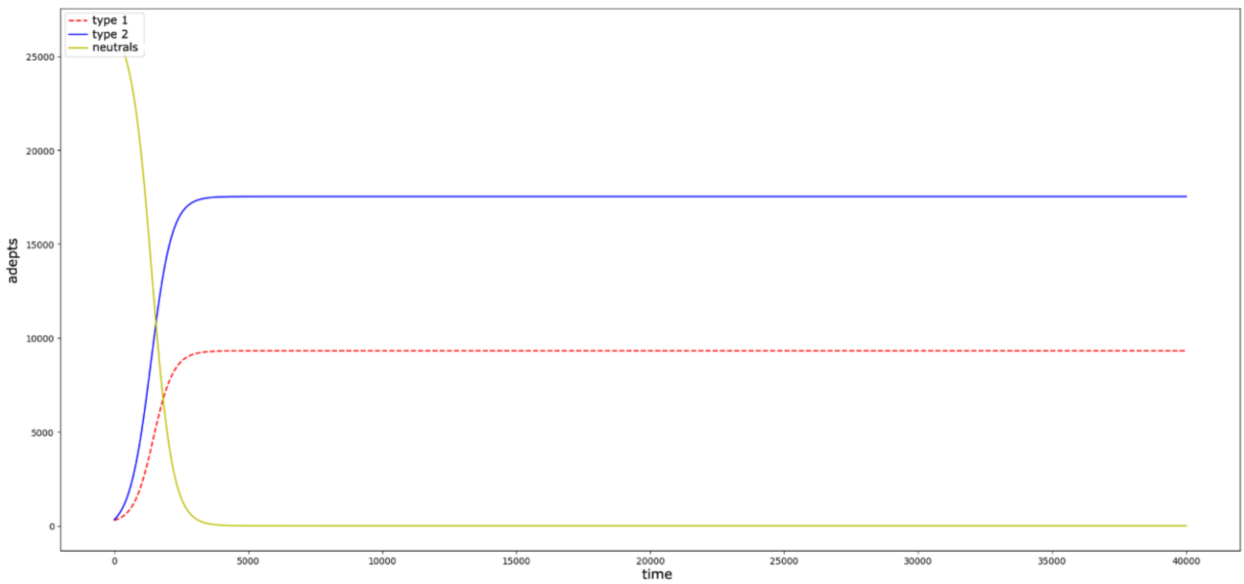

Fig. 16. The case when $\alpha, \beta > 0, \gamma \leq 0$

5.4. The case $\alpha \leq 0, \beta < 0$

The interpretation of such an example is as follows: neutrals migrate to places where there are few adepts, and adepts migrate to places where there are few neutrals.

This time, as a result of a series of experiments, it was established that regardless of the values of coefficients α, β, the behavior of the model, in general, does not change at all, but the behavior by regions changes significantly.

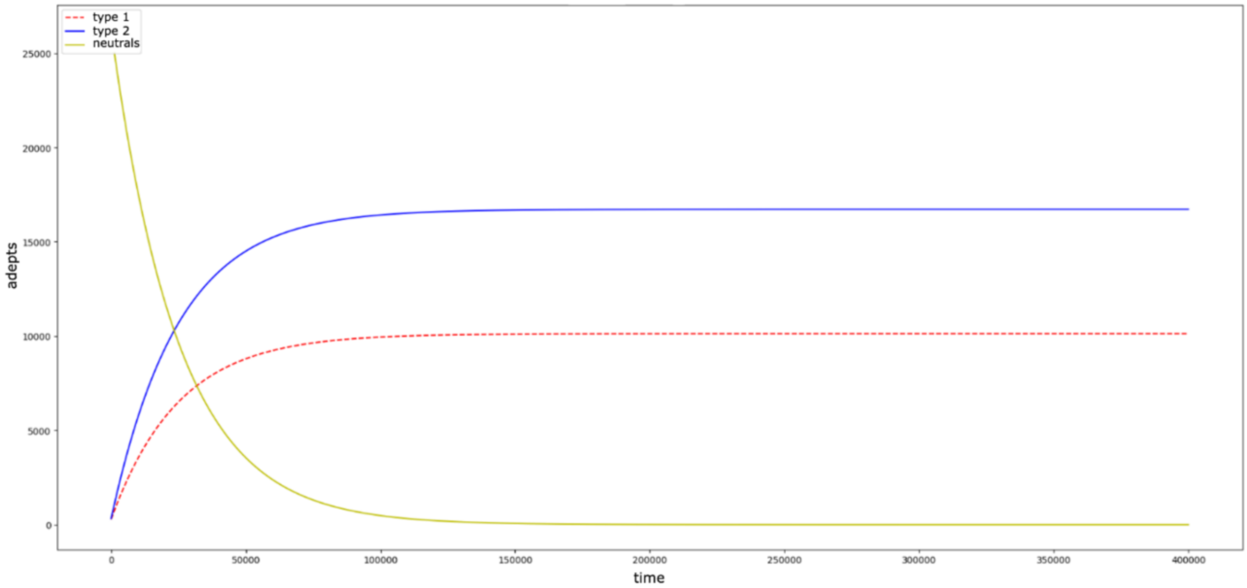

Fig. 17. The case when $\alpha \leq 0, \beta < 0$

The situation is similar to example C, namely, depending on γ, the behavior of the model in the regions gradually changes from the information struggle model in region 2 at $\gamma = 1$ to the information threat spread model in regions 2 and 3 at $\gamma = -1$ (Fig. 17).

5.5. The case $\alpha = 0, \beta = 0, \gamma \neq 0$

In this case, a conflict only between followers of different types of information.

When $\gamma < 0$, adepts of different information migrate to rival-free regions, and due to the lack of migration among neutrals, such migration is reduced to a complete separation of adepts in regions where there are free members of the community who do not migrate anywhere. The behavior in each region is a model of information threat spreading: 1 (I_1), 2 (I_1), 3 (I_2), 4 (I_1). Meanwhile, the behavior in general also does not change significantly depending on the value of the coefficient.

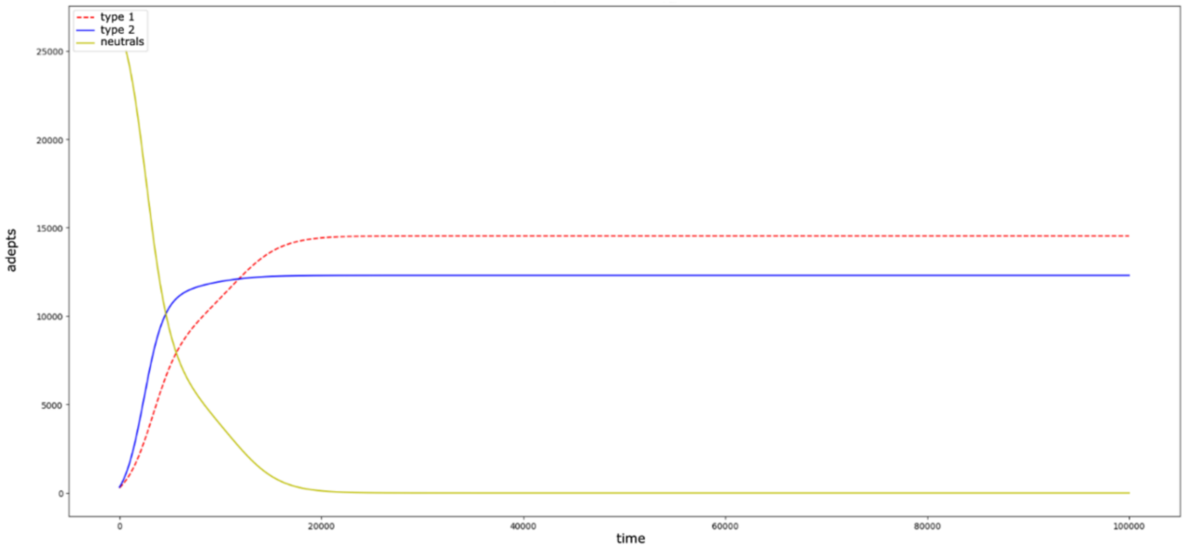

Fig. 18. The case when $\alpha = 0, \beta = 0, \gamma < 0$

When $\gamma > 0$, adepts migrate towards each other, and therefore all members of the community are concentrated in the largest region. Although there are still a large number of neutrals in other regions, under the influence of external channels of information dissemination, they also, albeit relatively slowly, become recruited, after which they migrate to meet other adepts in region 3. Depending on the value of the coefficient, the behavior of the model does not change in general and fully corresponds to the behavior in the third region - the information warfare model.

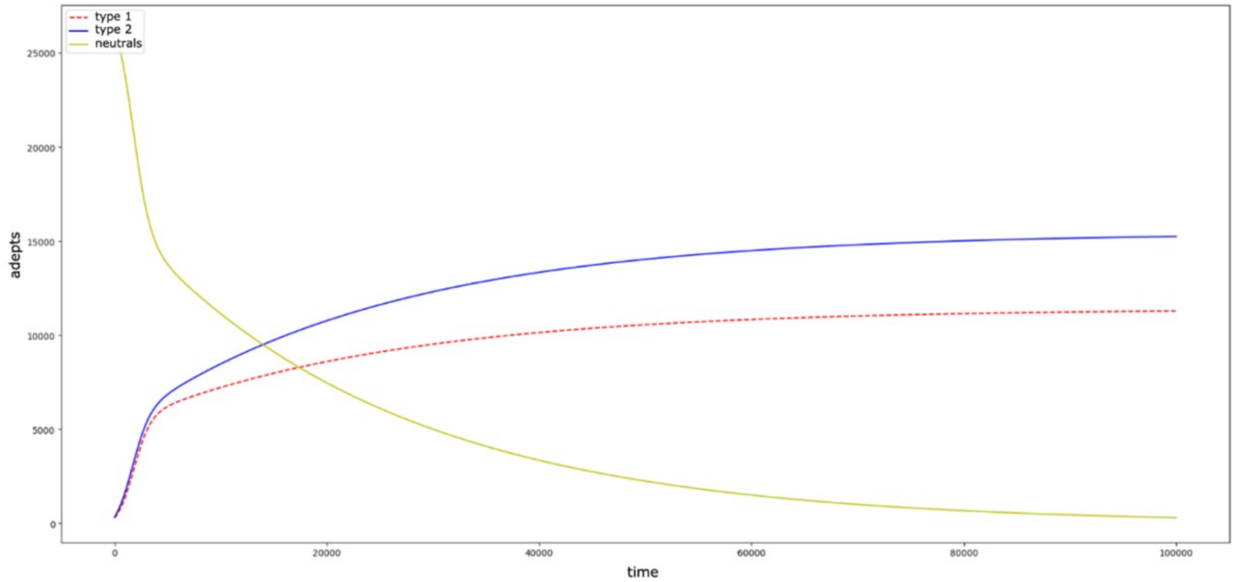

Fig. 19. The case when $\alpha = 0, \beta = 0, \gamma > 0$

6. Conclusions

Having studied the model of information struggle separately, it was found that the opposing parties have (including depending on the "capacity" of the social community) many opportunities to achieve victory. Depending on the coefficients of external and internal intensities, as well as, in a certain feature, the initial values, different scenarios of the model's behavior unfold: permanent leadership, leadership change, and parity. However, in each such situation, it is possible to predict the final results with sufficient accuracy using the win function.

The integration of internal conflict into the model brings significant and interesting changes in its behavior. First of all, it was found that the greatest influence is not the values of the interaction coefficients, but their signs, which determine the directions of migration. The division into regions also has a significant impact, and depending on the initial divisions, the language also changes.

In some cases, the internal conflict turns the model into a standard model of information struggle, such as with all positive coefficients of interaction. In such a situation, the model does not differ at all from the same one, but without division into regions and with the absence of conflict. Or, with appropriate coefficients, it is possible to separate rivals in separate regions, thereby reducing their behavior to a standard model of the spread of an information threat.

But the most interesting results were obtained when studying the behavior of the model with coefficients that describe natural conflict. It completely changes the behavior of the system. And as we have seen, these changes vary from a slowdown in the general process of "capturing" of the entire space to an increase in the behavior in general, and the behavior in the regions is characterized by constant migration fluctuations with stable and non-stable periods, different amplitudes.

It is obvious that when introducing a conflict, determine the final result, knowing only the starting conditions, if possible, then only in certain special cases. Predicting the behavior of the natural conflicts that are most important for research is impossible, and the only way to do this is through computer simulations using a sufficient number of iterations.

Therefore, in the presence of an internal migration conflict, the behavior of the information struggle model cannot be predicted without proper modeling. Even the behavior at $t \to \infty$ is not obvious – it can be both constant and fluctuating. Therefore, further research into this problem is extremely important.

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Drone Swarming and its Use in Minefield Laying Using Mathematical Methods

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Abstract

The work deals with the modelling of minefields using smaller swarms of different shapes. The aim of the work is to use mathematical methods to obtain clearer data on the possibilities of creating minefields using unmanned vehicles. On the basis of the minefield density parameters and the probabilities of hitting a mine according to the theory of at least once recurring phenomenon, possible variations of minefield laying are determined. The contribution of this work lies in presenting the real possibility of laying minefields in a completely new way. The calculations performed are identical to those performed for standard minefields.

KEY WORDS: *Drone, swarming, UAV, military, minefield, mines, minelaying, engineer support, density, probability*

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1. Introduction.

Significant technological advances in autonomous vehicles and drones are changing the dynamics of modern conflicts. The war in Ukraine has provided evidence of how this technology can change the course of combat. Even well-equipped militaries, such as the Russian Federation, face challenges posed by the deployment of autonomous unmanned vehicles. Their ability to carry out long-range attacks with minimal risk to their own forces gives a new dimension to military operations. [1]

However, drones are not just a tool of attack. They are also used to scout and track enemy movement and targets. Their ability to quickly and efficiently gather battlefield information allows command staffs to better navigate and make strategic decisions in real time [2]. In the area of mine warfare, autonomous assets are revolutionizing the field. Minefields built with unmanned assets enable faster and more flexible deployments. Analytical models and mathematical methods can be used to optimize mine placement and maximize the effectiveness of minefields, increasing the ability to resist enemy advances and defend strategic positions. [3]

While technological advances bring new possibilities for warfare, it is important to recognize their ethical and humanitarian implications. Care must be taken to protect civilians and minimize unwanted collateral damage. The use of autonomous means should be subject to firm ethical principles and legal frameworks in order to minimize the risk of uncontrolled attacks and negligence in military operations. [1]

2. Significance of minefields and current methods of their establishment

In contemporary conflicts, mines have always been deployed in areas of anticipated enemy movement. Although mines are relatively simple devices, their cheap production, high efficiency and mass proliferation make them a problem not only for the attacking troops, but also for troops operating within the area, unfortunately, for civilians, as civilian casualties have already exceeded 1 000 since the beginning of the war in Ukraine. [4], [5] To inflict casualties on the enemy by merely concealing a prepared mine or explosive charge below ground level is always advantageous to the defender, as it inflicts casualties on the enemy with only a small load. The prevalence and relative popularity of mines is evidenced by the accompanying illustration (e.g. Fig.1), which graphically shows the area potentially mined.

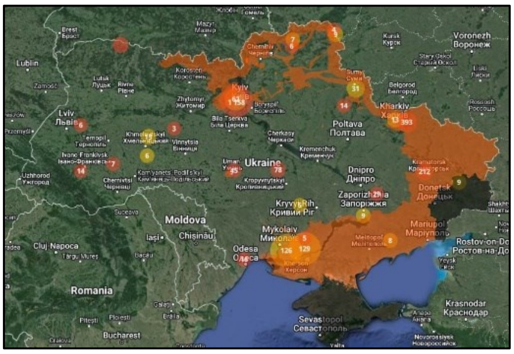


Fig.1. Undermined areas in Ukraine [4]

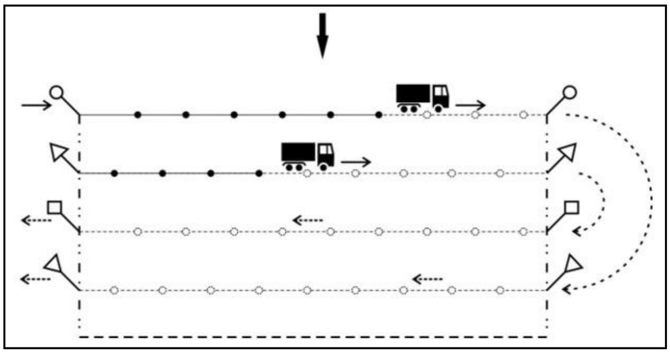


Fig. 2. Laying minefields using vehicles [7]

The data is taken as of February 2024. It is estimated that an area of 156 000 km^2 is undermined. This represents roughly 25% of the area of Ukraine and, for a better idea, almost three times the area of Croatia or twice the area of the Czech Republic. Nevertheless, more than 6 000 000 inhabitants remain in the designated areas and therefore increasing numbers of civilian casualties can be expected. [6]

In modern armies, where engineer units are also active, standardised methods for laying individual mines and large minefields have been established over time. Current mine laying methods are divided into arranged and scattered methods. It is this factor that will play an important role in the future. A minefield is considered to be an arranged minefield when individual mines are laid in a grid, checkerboard, or other shape that is determined in some way. Thus, the minefield is systematically laid, and all mines that have been placed in the minefield are traceable by means of a record and drawing of the minefield. An arranged minefield can be created by vehicles (e.g. Fig. 2) or by military personnel. In an arranged minefield, individual mines can be embedded in the ground to create an embedded minefield. Scatter minefields, on the other hand, are very non-deterministic. It is a method of minelaying in which proxies (rockets, helicopters, mortars) are used to barrage and block large areas in a very rapid time. It is the speed of minelaying and the difficulty of detection that is one of the serious threats to the assault troops, but also to the population. Landmines placed by a scatterable system are mostly laid on the surface of the ground (unless one of the landmines falls from a great height into softer soil). [7], [8]

The scattered method is characterised by irregular minefield edges. This is due to the unsystematic deposition caused by the means that can be characterized as the totality of the engineer, artillery, rocket launcher, and aerial systems used to bring mines to the mined area and to scatter them on the terrain. Scatterable minefields are located and their resulting shape can only be inferred from the characteristics of the carrier's trajectory. It is reported that 50% of all mines in a scattered minefield (e.g. Fig. 3) are located in ¼ of the area [7]. As an example of the scattered method, one can mention the Rosomacha minelaying kit (e.g. Fig. 4), which is a newly introduced quadrupedal vehicle to the Armed Forces of the Russian Federation, carrying SKM-A (Specialnyj komplekt minirovanija) throwers in the rear. Each launcher is fitted with four cartridges. This quadricycle is capable of dispersing small mines, identical to those used for dropping from helicopters or other self-propelled vehicles of the UMZ series. [9]

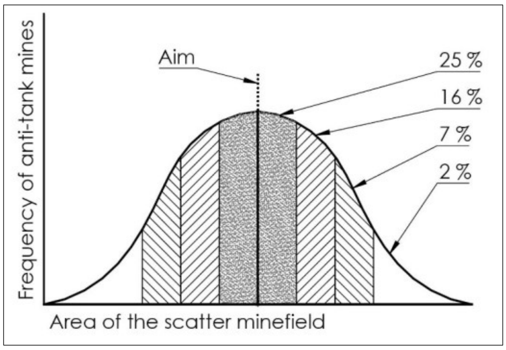


Fig. 3. Placement of mines in a minefield established in a dispersal manner [7]

Fig. 4. Minelaying off-road quad Rosomacha [9]

3. Drone swarming and its use in minefield

A swarm or fleet of Unmanned Aerial Vehicles (UAVs) consists of aerial robots, commonly known as drones, that collaborate to fulfill a particular objective. Each drone in the swarm is powered by a set number of rotors, allowing it to perform vertical take-offs, landings, and hovering maneuvers (VTOL). Drone flight can be controlled either manually via remote control or autonomously through onboard processors. Drones are frequently utilized for military purposes. Affordable drone swarms present a valuable opportunity for groundbreaking research and future commercial ventures that will benefit people in their daily activities and professional tasks. [10]

The concept of drone swarms – clusters of small, affordable drones that can collectively overcome enemy defences – is gaining traction. Equipped with weapons, even small drones can be highly destructive, especially in large numbers. These swarms, which can be remote-controlled, autonomous, or accompany other military assets, leverage advancements in artificial intelligence and drone miniaturization to multiply their effectiveness on the battlefield. Such swarms, inspired by natural swarms of insects, can adapt their size to the specified task and have the potential to redefine future warfare. They can operate as coordinated units of various types and sizes, achieving strategic objectives together. This evolving technology poses both a promising opportunity and a significant threat in national defence scenarios. [11]

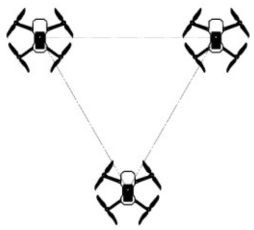


Fig. 5. Triangular swarm

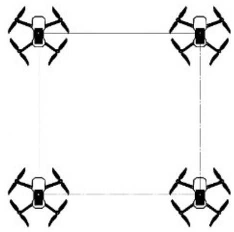


Fig. 6. Square swarm

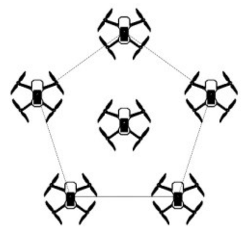


Fig. 7. Pentagon swarm

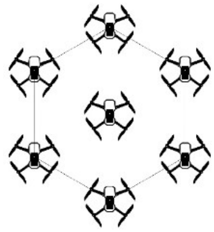


Fig. 8. Hexagon swarm

Individual drones in the swarm are programmed to form a pattern. The drones can fly in a straight line behind each other, fly in a grid or checkerboard pattern, or any other determined pattern. Assuming the use of a swarm of unmanned aerial vehicles, the appropriate grouping appears to be: Triangular (e.g. Fig. 5); Square (e.g. Fig. 6); Pentagonal (e.g. Fig. 7); Hexagonal (e.g. Fig. 8).

4. Mathematical expression of minefield density

The basic formula for calculating the minefield density is equal to [12]

$$D = \frac{m}{L}, \tag{1}$$

where: D – minefield density; m – number of mines in the minefield; L – minefield length.
This value indicates the number of mines per meter of minefield length. It is the ratio of the number of mines laid in the minefield to the actual length of the minefield established. Minefield density expresses the saturation of a section of terrain with mines and should not be confused with barrier density, which expresses the saturation of an area with barriers of various types, including non-explosive barriers. [12]

The density of the minefield is selected according to the type and effectiveness of the mines used, and the combat effectiveness of the minefield is directly dependent on its value. In view of this link, principles for the selection of minefield densities are established in accordance with the requirements for the combat effectiveness of minefields. For anti-tank minefields made of anti-track mines, a value of 0.75 – 1 is given. The second type is full-width mines. Such mines are activated by means other than pressure and are therefore more effective because their activation area (the entire vehicle profile) is increased. For full-width mines, the quoted value is set at 0.2 – 0.4. Minefields formed by anti-personnel mines are not calculated because their use, manufacture and retention are prohibited in Czechia under the Ottawa Treaty. [12], [13]
The activation zone of the mine is not included in the calculations as the shape of the mine will not affect its effectiveness. An alternative formula

$$D = \frac{n}{a}, \tag{2}$$

where: n – number of minefield rows; a – distance between mines in the row
can also be used to determine the minefield density. [12]

In terms of practice, it has some advantages over the first formula. In particular, the mine commander knows the minefield density in advance and can make an informed determination of the distances between mines. It is rather difficult to determine the value of the distance between mines in a row, because it is only possible to enter directly into the formula if these distances between mines are always the same. If the distance between mines is different on each rows of the minefield, the average distance must be added [12]

$$\emptyset\, a = \frac{a_1 \times X_1 + a_2 \times X_2 + \cdots + a_n \times X_n}{X_1 + X_2 + \cdots + X_n}, \tag{3}$$

where: $\emptyset a$ – average distance between mines in a row; $a_1, a_2, a_3, \dots, a_n$ – distance between mines in each row; $X_1, X_2, X_3, \dots, X_n$ – frequency (number) of occurrence of series with the corresponding distance value.
If the mine distance in each row is different, the density of the minefield could also be determined as the sum of the densities of each row according to the formula [12]

$$D = D_1 + D_2 + \cdots + D_n = \frac{1}{a_1} + \frac{1}{a_2} + \cdots + \frac{1}{a_n}. \qquad (4)$$

If all the above formulas are used for a given minefield, the calculated values may differ slightly (irrelevant for the needs of armies). Formulas (2) and (4) consider only the actual course of the minefield and do not consider the distances of mines from the control lines (right and left boundaries of the minefield). In contrast to formula (1), it is usually the distances between the control lines (minefield length) that are decisive. Partial differences in the calculated values are particularly evident for minefields of small length. [12]

Established minefields, which are arranged, are laid to cover the most suitable area when enemy combat vehicles enter the area. It is disadvantageous to construct such a minefield in a uniform grid, where the mines form regular quadrilateral formations (square, rectangle). In a theoretical passage of enemy combat vehicles through a minefield with an angle of attack of 90° and the specified directional vector, the combat vehicles would pass between mines without activating any mines. Therefore, mines are laid in a checkerboard formation where the mines on the second row of the minefield are offset by half the length between the mines on the first row. This ensures an increased probability of enemy combat vehicles raiding the mine activation zone or directly onto the mine. Existing methods of laying arranged minefields are therefore limited strictly to simple shifts between mines in a row. The only data that can be changed are the number of mines in the row (distance between mines in the row) and distance between rows. [7], [12]

It can be seen that existing methods are limited in the design of minefields, which still represent one of the key elements of modern warfare. It is therefore necessary to continually address the modernisation of laying minefields. A much more serious problem that can be observed in the war in Ukraine is the high vulnerability and conspicuousness of the units that place these minefields. Due to the high effectiveness of minefields and their considerable spread, both sides in the conflict are aware of their dangers. This exposes the units placing the minefields to the threat of being ambushed and subsequently attacked (e.g. by artillery or attack drones).

The use of remotely deployable scatterable minefields is a promising alternative, although their uneven distribution of anti-tank mines may not fully achieve the intended effect. With the rapid advancement of UAVs, employing these drones as carriers for mine deployment is becoming an increasingly viable option. Leveraging the swarming capabilities of drones enhances their potential use in the armories of many countries. To maximize the effectiveness of UAVs in laying arranged minefields, applying mathematical methods to maintain structure and consistency in mine placement is essential.

5. Mathematical expression of minefield combat effectiveness

Minefield combat effectiveness is a value indicating the probable number of combat equipment destroyed (intercepted) or casualties inflicted. It is directly dependent on the density of the minefield, the type of mines laid, and the characteristics of the equipment engaged. Thus, if we consider that a minefield formed by swarming UAVs will be composed entirely of full-width mines, the combat effectiveness of the minefield will depend on the overall width of the vehicle and the direction of approach of the vehicle into the minefield. [12]
The formula for the combat effectiveness of a minefield is based on the theory of the probability of a phenomenon occurring at least once in n trials [12]. This probability does not consider additional data such as the probability of a target entering a particular minefield, the probability of detecting a minefield, etc.

$$P_{1,n} = 1 - (1 - P_1)^n, \qquad (5)$$

where: P_1 – probability of the target hitting a mine in the first row.
The formula is usable only under the assumption that the composition of the individual series does not change and therefore the probabilities are always the same. If we want to know the opposite phenomenon (how many combat vehicles pass through the minefield), we just need to modify the formula [12]

$$P_p = (1 - P_1)^n. \qquad (6)$$

The probability of a target striking a mine is determined by the characteristics of the anti-tank mine. Assuming that mines laid by UAVs will be full-width, the formula is equal [12]

$$P_1 = \frac{w}{a}, \qquad (7)$$

where: w – width of the combat vehicle; a – distance between mines in the row.
In case a minefield is modelled that does not have regular rows (i.e. the densities of the individual rows change), a general formula is needed to calculate the combat effectiveness of the minefield

$$\prod_{k=1}^{i-1} (1 - P_k) \times P_i, i = 1, 2, 3, \dots n\,. \qquad (8)$$

6. Calculations of minefields created by a swarm of drones

The initial model used a square-shaped swarm to simulate a minefield laid over a 100-meter wide area. The layout involved arranging smaller swarms sequentially without side-by-side overlap. Each smaller swarm, depicted as a square with a circle inside, ensured coverage. Simple shading indicated areas covered by two adjacent swarms, while double hatching denoted coverage by all neighboring swarms. There were six such swarms, each consisting of 9 drones equipped with an anti-tank mine, totaling 54 mines. Density calculations utilized all available formulas. The minefield had 54 mines, was 100 meters long, consisted of 6 rows, with a 12.5-meter distance between mines in a row.

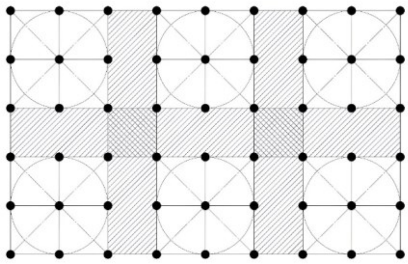


Fig. 9. A minefield made up of square swarms of UAVs

$$D = \frac{m}{L} = \frac{54}{100} = 0.54$$

Using the general density formula (1), it was calculated that the model minefield using square drone swarms reaches a density of 0.54, which exceeds the requirements for minefields consisting of full-width mines (0.3 – 0.4).

$$D = \frac{n}{a} = \frac{6}{12.5} = 0.48$$

Using the formula for determining the density of a minefield using the distances between mines and the number of rows (2), it was found that the density corresponds to a value of 0.48, which is a tolerable deviation from the previous formula, as slight differences are possible for smaller minefields

$$D = \frac{1}{12.5} \times 6 = 0.48.$$

When calculating the density of each row (4), we get the same result as in the case of the formula using the number of rows and distances between mines in the row. To calculate the combat effectiveness, it is necessary to know the width of the vehicle entering the minefield. As an example, a random battle tank with a width of 3.75 m will be given for all calculations

$$P_1 = \frac{w}{a} = \frac{3.75}{12.5} = 0.3.$$

Knowing the probability P_1 of a target hitting a mine, we can calculate the probability of traversing the entire minefield. The probability that the target (combat vehicle) hits a mine increases with each row of the minefield. For a given minefield characteristic of 6 rows, the probability of hitting a mine is 0.8824 which, when converted to a percentage, gives a rounded probability of 88.24%

$$P_{1,6} = 1 - (1 - 0.3)^6 \cong 0.8824 = 88.24\%.$$

Substituting in the modified formula gives the opposite effect, or what is the probability that a combat vehicle of width w will overcome a minefield of 6 rows. When rounded and converted to percentages, it gives 11.76%

$$P_p = (1 - P_1)^n = (1 - 0{,}3)^6 = 0.1176 = 11.76\%.$$

However, as mentioned in the paragraphs above, minefields cannot be laid in a grid without overlapping rows. The entire minefield would have to be laid at a certain angle towards the enemy. A 45° angle would ensure that the each row would form an already functioning minefield. But even a 45° angle is not entirely effective. A sharper angle of between 25° and 35° appears to be a suitable angle for a minefield grid. A perpendicular entry of the combat vehicles into the minefield would increase many times the number of mines that would be on a collision course with the combat equipment. This method is a target for future research. As in the previous case, the minefield created by triangular swarms was modelled. Due to the ideal shape, where the rows overlap and thus meet the functionality requirements. The minefield, containing 48 anti-tank mines, was modeled using 10 swarms of 6 drones each. To maintain the grid and address gaps, rotating some swarms is recommended. However, the triangular layout cannot perfectly meet the minefield requirements, particularly at the edges. These edge gaps could link to additional mine-laid areas. Density was calculated using all applicable formulas. The minefield is 100 meters long, has 6 rows, and the mines are spaced 12.5 meters apart.

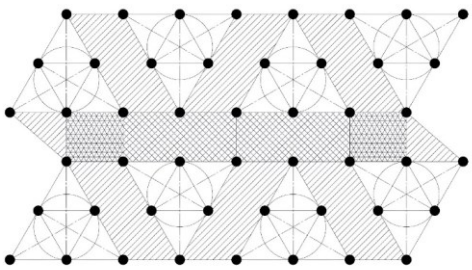


Fig. 10. A minefield made up of triangular swarms of UAVs

$$D = \frac{m}{L} = \frac{48}{100} = 0.48.$$

Using the general density formula (1), it was calculated that the model field using triangular drone swarms reaches a density of 0.48, which exceeds the requirements for minefields consisting of full-width mines (0.3 – 0.4). Using formula (2) to calculate the density yields the same result as for a minefield modelled from quarter swarms. The difference between the two models is known more in practical application, since the basic formulas assume knowledge of the basic rules for laying minefields (and hence for the principle of overlapping rows in succession)

$$D = \frac{n}{a} = \frac{6}{12.5} = 0.48.$$

Summing the densities on each row separately, the resulting value will be identical to the value calculated through formulas (1) and (2)

$$D = \frac{1}{12.5} \times 6 = 0.48.$$

When calculating the probability of hitting a target on a mine in a minefield, we use the same parameters

$$P_1 = \frac{w}{a} = \frac{3.75}{12.5} = 0.3.$$

Since the calculation of the probability of hitting a target on a mine considers only the distance of mines in the row and the total number of rows, the resulting value will be similar to the previous modelling

$$P_{1,6} = 1 - (1 - 0{,}3)^6 \cong 0.8824 = 88.24\%.$$

When substituted into the probability formula, the value settles at 88.24%. The inverse phenomenon, i.e., what is the probability that a given technique will pass through the minefield, equals 11.76%

$$P_p = (1 - P_1)^6 = (1 - 0{,}3)^6 \cong 0.1176 = 11.76\%.$$

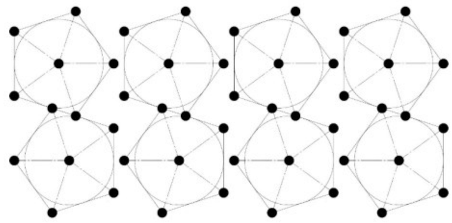
The pentagonal swarm was another model focused on minefields made of regular pentagons. In contrast to the previous modelling, it shows phenomena not observed in triangular or square grids. In fact, the distances between mines in a row will vary depending on the type of row. In total, 8 smaller swarms of 6 drones in each swarm were modelled. The first row of these swarms faced right, while the second row of swarms faced left. Using the basic density formula (1), a value of 0.48 was obtained

$$D = \frac{m}{L} = \frac{48}{100} = 0.48.$$

Since there are two rows in the pattern (third and eighth row of the minefield), which have different distances between mines, it is necessary to use the formula (3) for calculating the average distance between mines. Using this formula, the average distance between mines is 23.04 m

$$\emptyset\, a = \frac{25.6 \times 8 + 12.8 \times 2}{8 + 2} = \frac{230.4}{10} = 23.04\ m.$$

This value can already be applied to the formula for calculating the minefield density using the number of rows and distances between mines in a row (2). In this case, the measured value was equal to 0.434



$$D = \frac{n}{a} = \frac{10}{23.04} = 0.434.$$

Using the formula (4) for calculating the density of each row, a value of 0.46875 was obtained

$$D = 8 \times \frac{1}{25.6} + 2 \times \frac{1}{12.8} = 0.46875.$$

When trying to calculate the combat effectiveness of a minefield, we run into the problem of differing probabilities of hitting a mine in each row of the minefield. For this reason, it is not possible to use the basic formula for calculating combat effectiveness (5). First, the probability of hitting a mine in each row must be determined. This is obtained using formula (8), which was developed for this work. The width of the combat vehicle is the same as in the previous models (3.75 m)

$$P_n = \begin{cases} \frac{w}{a_1} = \frac{3.75}{25.6} \cong 0.1465; n = 1,2,4,5,6,7,9,10 \\ \frac{w}{a_2} = \frac{3.75}{12.8} \cong 0.2930; n = 3,8. \end{cases} \tag{9}$$

Table 1.

Combat effectiveness of minefield established by pentagon swarms

Rows - n	**Probability of hitting a mine in the row**	**Number of vehicles entering row**	**Number of vehicles entering row**	**Probability of hitting a mine in row n**	**Cumulative losses in the rows**	**Cumulative losses in the rows (%)**
Row 1	0.1465	1	100	0.1465	0.1465	14.65
Row 2	0.1465	0.8535	85.35	0.1250	0.2715	27.15
Row 3	0.2930	0.7285	72.85	0.2134	0.4849	48.49
Row 4	0.1465	0.5151	51.51	0.0754	0.5604	56.04
Row 5	0.1465	0.4396	43.96	0.0644	0.6248	62.48
Row 6	0.1465	0.3752	37.52	0.0550	0.6797	67.97
Row 7	0.1465	0.3203	32.03	0.0469	0.7267	72.67
Row 8	0.2930	0.2733	27.33	0.0801	0.8067	80.67
Row 9	0.1465	0.1933	19.33	0.0283	0.8350	83.50
Row 10	0.1465	0.1650	16.50	0.0242	0.8592	85.92

Fig. 11. A minefield made up of pentagonal swarms of UAVs

The total combat effectiveness of the minefield is in the table 1 at the end of row 10. The combat effectiveness value of the pentagonal grid is 85.92%.

Complex calculations for military use are impractical. The calculation of combat effectiveness serves mainly to inform commanders for decision-making, as predicting enemy movement in a minefield is uncertain. Simplifying this calculation is advisable by using a procedure similar to previous models (triangular and square grids). The average probability of a target hitting a mine in a row can be calculated similarly to how average minefield length is determined by summing the probabilities per row and dividing by the total number of rows

$$\emptyset P_1 = \frac{P_{n1} \times X_1 + P_{n2} \times X_2}{X_1 + X_2} = \frac{0.1465 \times 8 + 0.2930 \times 2}{8 + 2} \cong 0.1758. \tag{10}$$

To perform the necessary calculations, we obtain a value for the average combat effectiveness fixed at 0.1758. This value can already be inserted into the standard formula for calculating combat effectiveness (5)

$$P_{1,10} = 1 - (1 - 0.1758)^{10} \cong 0.8553 \cong 85.53\ \%.$$

The resulting value of combat effectiveness equals 85.53% which is almost the same value as the more complicated (but more accurate calculation – 85.95%).

Like the pentagonal grid, the hexagonal grid features rows without an orderly arrangement due to varying mine distances. The grid consists of 8 rows with 20-meter minimum distances and 5 rows with 40-meter minimum distances. For simulations, 8 groups of 7 drones each were utilized. The figure shows areas of "dead" space, with different hatching patterns indicating coverage by two, three, or four neighbouring drone swarm.

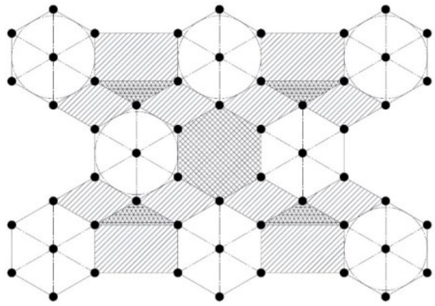


Fig. 12. A minefield made up of hexagonal swarms of UAVs

These "dead" zones would distort the total distance between the left and right boundaries of the minefield. It is therefore necessary to introduce an average minefield length. A closer examination of the figure of the model hexagonal grid shows that the first five and last five rows of the minefield have a standard length of 100 m. The middle three rows of the minefield, however, are truncated and are two mines (one on each side of the minefield) shorter in length, and therefore their total length equates to a minefield of 60 meters.

The formula for calculating the average length showed a value of 90.77 m

$$\emptyset\, L = \frac{n_1 \times L_1 + n_2 \times L_2}{n} = \frac{10 \times 100 + 3 \times 60}{13} = \frac{1180}{13} = 90.77\ m. \tag{11}$$

This value would be further used in the basic formula (1) to calculate the density using the number of mines and the length (average length) of the minefield. The resulting density value is equal to 0.617

$$D = \frac{m}{L} = \frac{56}{90.77} = 0.617.$$

As with the previous modelling, it is necessary to determine the average distance between mines, as the minefield series are not the same (3). The resulting value of the average distance between mines in a row is equal to 27.69 m

$$\emptyset\, a = \frac{40 \times 5 + 20 \times 8}{5 + 8} = \frac{360}{13} = 27.69\ m.$$

This value can be plugged into the formula (2) for calculating the minefield density

$$D = \frac{n}{a} = \frac{13}{27.69} = 0.469.$$

Using the formula for calculating the density in each row (4), we get a result of 0.525

$$D = 5 \times \frac{1}{40} + 8 \times \frac{1}{20} = 0.125 + 0.4 = 0.525.$$

The calculation of combat effectiveness is based on the same principles as the calculation of combat effectiveness for the pentagonal structure.

$$P_n = \begin{cases} \dfrac{w}{a_1} = \dfrac{3.75}{40} = 0.09375; n = 1,3,7,11,13 \\ \dfrac{w}{a_2} = \dfrac{3.75}{20} = 0.1875; n = 2,4,5,6,8,9,10,12. \end{cases}$$

Table 2.

Combat effectiveness of minefield established by hexagon swarms

Rows - n	**Probability of hitting a mine in the row**	**Number of vehicles entering row**	**Number of vehicles entering row (%)**	**Probability of hitting a mine in row n**	**Cumulative losses in the rows**	**Cumulative losses in the rows (%)**
Row 1	0.09375	1	100	0.09375	0.09375	9.38
Row 2	0.1875	0.9063	90.63	0.16992	0.2636	26.37
Row 3	0.09375	0.7363	73.63	0.06903	0.3327	33.27
Row 4	0.1875	0.6673	66.73	0.12512	0.4578	45.78
Row 5	0.1875	0.5422	54.22	0.10166	0.5595	55.95
Row 6	0.1875	0.4405	44.05	0.08260	0.6421	64.21
Row 7	0.09375	0.3579	35.79	0.03356	0.6756	67.56
Row 8	0.1875	0.3244	32.44	0.06082	0.7345	73.45

Row 9	0.1875	0.2635	26.35	0.04942	0.7859	78.59
Row 10	0.1875	0.2141	21.41	0.04015	0.8260	82.60
Row 11	0.09375	0.1740	17.40	0.01631	0.8423	84.23
Row 12	0.1875	0.1577	15.77	0.02956	0.8719	87.19
Row 13	0.09375	0.1281	12.81	0.01201	0.8839	88.39

As with the pentagonal structure of the swarm laying the minefield, we can calculate the combat effectiveness in the same way as with the previous model (10)

$$\emptyset\, P_1 = \frac{0.09375 \times 5 + 0.1875 \times 8}{5 + 8} = 0.1514.$$

To perform the necessary calculations, we obtain a value for the average combat effectiveness fixed at 0.1514. This value can already be inserted into the standard formula for calculating combat effectiveness (5)

$$P_{1,13} = 1 - (1 - 0.1514)^{10} \cong 88.17\ \%.$$

The resulting value of combat effectiveness equals 88.17% which is almost the same value as the more complicated (but more accurate calculation – 88.39%).

7. Discussion

To model minefields laid using UAV swarms, it is necessary to understand the main principles that apply to their creation. This work has brought a basic understanding to the area under discussion. The scope and application of drones is wide and will therefore be further researched. When modelling individual minefields using the specified patterns, these patterns need to be placed so that they do not overlap where a potential drone may already be. At the same time, there must not be a phenomenon where there are mines at different distances from each other in the same row of mines. Thus, within a row, it must be the case that the mines are always equidistant from each other. If this condition is met, it is possible to model multiple rows with different distances of mines from each other, but only ever within the respective row. According to the authors, it is possible that there is a pattern that may not appear orderly at first glance, but at the same time the mines are placed within them according to given parameters and not randomly as is the case with minefields laid in a scatter pattern. Such a pattern should manifest itself in patterns that are not laid in a grid but are rotated about their axis. Patterns of 7 or more points (heptagons, octagons, ...) were not used for the modelling of minefields because the more the number of sides in a circle increases, the more the shape resembles a circle.

However, it is possible that future research will consider these patterns. The primary motivation for researching unmanned mine-laying is to accurately track the positions of anti-tank mines via modern drones equipped with GPS. This capability enhances the efficiency of minefield recovery, allowing for the safe retrieval of unactivated mines post-conflict and potentially preventing civilian casualties. Additionally, the research seeks to move away from traditional minefield layouts, such as checkerboard or grid patterns, by exploring non-standard formations like pentagonal arrangements. These patterns, while precisely configured, appear irregular and help to avoid the predictability of conventional mine templating.

8. Conclusion

The results of the calculations suggest that it is possible to create minefields using UAVs in a swarm. The density values of the modelled minefields comply with the prescribed standards and also meet the requirements for their establishment. There were no marginal differences between the modelled examples. The measured deviations do not show a significant difference between the models. The contribution of this work lies in the description and outlining of the possibilities to lay minefields differently than the established procedures.

Calculations and modelling show that minefields using unmanned vehicles are a possible alternative, although their prevalence is so far low. In light of the experience of the war in Ukraine, it is certain that minelaying will become a routine part of future forces operating with unmanned vehicles. Pressure to protect units is increasing, which is spurring research in this area.

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Evaluation of Modern Approaches to Crisis Management

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Abstract

Decision-making is an important function of crisis management as a resolution technique for the negative impacts of crisis phenomena. There are several models and concepts of crisis management in the world, which were compared in the study and an evaluation table of crisis management models was developed. The main objective of the study was to evaluate modern approaches to crisis management (crisis management models) with the intention of providing recommendations on the practical application of these models in crisis management for the development of the crisis management system within government agencies. The comparative analysis was carried out using the rules, relationships and regularities that apply in complex management models.

KEY WORDS: *crisis; crisis management; models; comparative analysis; rescue services.*

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1. Introduction

Crisis phenomena have a negative impact on the natural development of human society. The issues of their prevention and, consequently, their resolution is becoming more and more topical. Emergencies, especially natural disasters, have a special place in the crisis management system. They can affect large populations and have a negative impact over a wide area [1]. Their consequences usually have a negative impact not only on population and the environment, but also on the material resources and cultural heritage located in the affected area. In the case of large-scale natural disasters, the functioning and stability of the country's entire economy can be threatened and disrupted [2].

Decision-making is an important function of crisis management, and we can refer to it as multi-criteria decision making, and its importance increases during the resolution of crisis phenomena. It is a complex and demanding process that is influenced by the nature of the crisis phenomenon itself. Crisis managers and the various public authorities and institutions involved in dealing with crisis phenomena are under pressure from the media and the public, who demand a rapid and effective response to emergencies and the minimization of damage and loss [3]. The role of public administrations, with an emphasis on local government, in dealing with emergencies is extensive and complex [4].

The main objective of the study was to evaluate modern approaches to crisis management (crisis management models) with the intention of providing recommendations on the practical application of these models in crisis management for the development of the crisis management system within government agencies. Various quantitative and qualitative methods and tools were used to achieve the objective of the study, with the main emphasis on comparative analysis, which was used to compare different approaches (models) of crisis management, following the principles that the model should reflect the characteristics of the modelled reality.

2. The Theoretical Background

At the beginning of the study, it is necessary to define the basic terms and concepts related to the problems addressed. They will form part of the theoretical basis for increasing the effectiveness of crisis management processes, for assessing the conditions of the above-mentioned activities and, ultimately, for optimizing the decision-making processes at the local government level. The choice of individual terms and their concepts was influenced by several facts.

Various crisis phenomena have affected mankind since the very beginning [5]. In the course of time, with the development of society and technical and technological innovations of various kinds, the frequency of crisis phenomena has increased. This means that the probability of their occurrence has also increased, which is why the issue of crisis management, which is a specific part of public administration, has become more complicated.

To manage individual crisis phenomena, it is necessary to understand the behavior of complex systems, their functions, and interconnections. In the case of natural disasters, it can be difficult to predict their occurrence and overall course. For this reason, the existence of a specific type of management, known as crisis management, is essential. In general, there are three basic perspectives on the definition of crisis management [6]:

25. functional approach - crisis management is characterized as a specific activity aimed at solving a crisis using specific principles, methods and tools aimed at overcoming negative impacts and restoring the system,
26. institutional approach - crisis management is perceived as a system of institutions and staff, dealing with the analysis of the possibilities of crises in each system, their causes and possible impacts and the identification of measures and tools to prevent them and to eliminate negative consequences in the event of their occurrence.
27. theoretical approach - crisis management is defined as a logically arranged set of knowledge about possible crises, their causes, and consequences at the level of security of the state, society, economic activities, and properties, as well as about the principles, possible methods, and measures for their solution.

In a broader sense, crisis management out of wartime can therefore be a set of management activities of crisis management bodies, which are aimed at analyzing and evaluating security risks and threats, planning, taking preventive measures, organizing, implementing, and controlling the activities carried out in preparation for crisis situations and in their resolution. State administration bodies, including local state administration, are involved in crisis management. Local state administration bodies represent a hierarchically lower level of state administration. They consist of authorities that are directly subordinated to a central government body, and which have established an independent governing body with a country-wide scope of activity. Competent authorities use different models or crisis management schemes in crisis management, which are different in terms of the overall management system and individual processes. Selected models will be further analyzed in the following chapter.

3. The Models of Crisis Management

The basic theoretical model of crisis management is ***the "Šimák - basic model"*** which consists of four crisis management processes - prevention, crisis planning, response and recovery [7]. In the prevention phase, the most important step is the identification and assessment of all current risks and threats, followed by the development of crisis forecasts and crisis scenarios. The primary goal of prevention is to prevent the occurrence of negative consequences of crisis phenomena through various measures and activities. A separate and no less important phase of crisis management in the preparatory phase is crisis planning, in which crisis and contingency plans are developed with the main purpose of protecting society and common values [7]. The protection of society has created the conditions for a link between the prevention of severe natural hazards and the planning documents of the municipal authorities of cities [8].

After the period of preparation for crisis phenomena and the occurrence of a crisis phenomenon, there follows the period of resolution of crisis phenomena. The immediate response to an emerging crisis requires the immediate deployment and coordination of the forces and resources needed to deal with the crisis. This phase follows the immediate gathering of information about the crisis phenomenon and its correct assessment and evaluation. The immediate response is carried out through rescue operations and various activities with the primary objective of preserving human life, material assets, the environment and cultural heritage. The recovery phase is mainly developmental in nature, allowing the system to return to its original stabilized (pre-crisis) state. The feedback loop is of great importance in the basic model of crisis management. It represents a means of improving and strengthening crisis management at its various levels [7].

Some authors refer to the described theoretical model of crisis management in the form of a cycle. These approaches usually identify from four to eight phases of the crisis management process applied in cycle form [9], propose six phases of crisis management [10], or present a simplified four-phases modified model of crisis management [11]. In practice, generally, all of the above models are implemented sequentially in several stages. The models allow for the implementation of new organizational, administrative, and technological elements in the prevention, crisis planning and preparedness phases, respectively, in an effort to improve and make crisis management more effective at all levels of management.

In general, it can be concluded that the above crisis management system respects the specificities, principles, as well as the legal environment and historical experience of the countries in which it has been developed. This crisis management system primarily uses organizational structures of a line-state nature and is made up of specific public authorities, i.e. the national administration (central and local) and the municipalities (regional and local). An integral part of the crisis management system is its executive branch, whose members must be able to deal with even the most complex crisis phenomena.

The other model of crisis management prevalent in the OECD is ***the "Baubion model"***, according to which crisis management consists of three basic phases [12]:

1. crisis readiness (pre-crisis),
2. response to reduce the damage (during a crisis),
3. feedback (post-crisis).

Crisis management is also a core task of NATO. As part of the implementation of an adequate response to emerging crisis phenomena of a natural or military nature, NATO applies ***the "Marinov model"***, which represents the strategic concept of crisis management in NATO [13]. The model assesses the current situation and develops a comprehensive response through a six-phase crisis management process:

4. identification of the risk factors with subsequent warning of the population and notification of specific authorities and institutions involved in crisis management,
5. a comprehensive assessment of the crisis phenomenon,
6. planning phase,
7. adequate response phase [14],
8. implementation of other necessary measures to minimise the negative consequences of crisis phenomena of a natural or military nature,
9. transition to a phase in which the threat no longer poses a danger to NATO member countries.

The "Marinov model" allows crisis staffs and committees within NATO institutions to coordinate their work and provide information to the North Atlantic Council. The different phases are not precisely defined in terms of timing and organization, they may overlap, and their duration depends on the specific situation.

The "Jaques model" of crisis management is based on a holistic perspective presenting crisis management as a continuous and coordinated management activity using non-linear elements. Prevention and preparedness for crisis phenomena are as important as the activities to be implemented in the response phase. Feedback has a crucial role in implementing new elements in the preparation and management of future crises [15]. The "Jaques model" is characterized by its non-linear structure, emphasizing that the different phases of crisis management should not be seen as sequential steps, but as a set of interrelated crisis management actions and activities.

In less developed parts of the world, crisis management models are adapted to the financial, material and personnel capacities of countries. For these countries, a model that allows a smooth transition from general crisis management to natural risk management for sustainable development is preferable. ***The "Hamani model"*** represents a model of crisis management in countries on the African continent, a form of integration between local authorities and the community located in the affected area [16]. The main objective of the "Hamani model" of crisis management is to improve the resilience and cooperation of the civilian population in dealing with natural disasters. The model provides relevant standardized information for each type of hazard, such as floods, earthquakes, and landslides. The overall effectiveness of the model is conditioned by a rigorous analysis of the territory.

The complex procedure of solving crisis phenomena is characterized by ***the "Šimák - complex model"***. The complex procedure of solving crisis phenomena is much more complex than the basic theoretical model of crisis management. In addition to the type of crisis phenomena, it is also necessary to consider its severity and the environment in which it takes place [7]. This model is based on the basic model, which has been extended in order to adapt to the conditions and to deal with the likely crisis phenomena. Sources of crisis phenomena, whether in natural, social, technological, economic, or other processes, can give rise to crisis phenomena. The intensity of the impact of the negative factors of crisis phenomena can be influenced by a comprehensive process of proper risk assessment. Risk assessment is a process of verifying the intensity of impact of crisis factors and their level of acceptability [17]. If the intensity of the threat of a crisis phenomenon exceeds the level of its acceptability, or if negative factors act, a crisis phenomenon will occur.

The crisis phenomenon is followed by the crisis response phase. First of all, it is necessary to warn the population and notify specific persons by activating the warning and notification network. These networks ultimately support the initial rescue efforts, which are an elemental part of the response [18]. The technical means used for warning and notification can be of different nature, such as siren networks, radio and television broadcasts, public address systems, local information means of municipalities and cities, automated notification systems and last but not least, public electronic communication networks. The implementation of the necessary measures is directly followed by the actual handling of the crisis phenomena by the Integrated Rescue System components and the components of the legal persons and business entities owning the premises in which the crisis phenomenon has occurred. Crisis management consists of two elementary activities, namely the elimination of the negative consequences of crisis phenomena and the prevention of new crisis phenomena. The last phase in both the basic crisis management model and the complex crisis management process is recovery, the tasks, and activities of which are the responsibility of the statutory representative of the institution that has been affected by the negative consequences of the crisis event. In part, recovery can also be carried out by the forces and means that participated in the rescue work [7] (Šimák, 2016).

The "Ristvej model" is a simplified model of crisis management introduced in the project "Community Based Comprehensive Recovery". This four-phases model [19] is based on a six-phases crisis management cycle [10].

To evaluate the current state of crisis management concepts and models, Table 1 was created, listing the options and criteria. The variants represent selected crisis management models, and the criteria are characteristics of these models. The evaluation table of crisis management models was prepared primarily in cooperation with experts on crisis management in the conditions of the Slovak Republic, including specialists and experts from institutions dealing with the issue of crisis management. The selection and formulation of the evaluation criteria, or characteristics of individual models, was influenced by several factors. The evaluation criteria were designed to consider, in particular, the structure and practical application of the selected crisis management models. All evaluation criteria are qualitative in nature. The only exception is the criterion assessing the number of phases/steps of the crisis management model. This criterion is of a quantitative nature as it can be expressed numerically.

Table 1.

Crisis Management Models Assessment Table

Criteria	Model Baubion	Model Marinov	Model Jaques	Model Hamani	Model Šimák – basic	Model Šimák – complex	Model Ristvej
No. of steps	**2**	**6**	**4**	**5**	**4**	**7**	**4**
Users	OECD	NATO	Crisis management bodies in the public administration	Less developed countries	Crisis management bodies in the public administration	Crisis management bodies in the public administration	Crisis management bodies in the public administration
Subsidiarity	NO	NO	YES	YES	YES	YES	YES
Algorithm structure	Linear	Linear	Non-linear	Non-linear	Non-linear	Non-linear	Non-linear
Applicability for crisis phenomenon	YES	YES	NO	YES	YES	YES	YES
Limitations	Legal	Subordination of military forces	The paradox of vulnerability	Acquisition of input data	Failure to accept the wider context	Loss of flexibility	Overlapping of activities in the model phases
WHO crisis phenomenon classification	Natural-climatic, economic, military conflicts	Natural-climatic, military conflicts	Natural-climatic	Natural-climatic, anthropogenic	Natural-climatic, anthropogenic	Natural-climatic, anthropogenic	Natural-climatic, anthropogenic

4. Discussion

To improve the quality of crisis management processes in the OECD context, an adaptation of the legal environment is essential. Countries that are members of the OECD are contractually obliged to comply with the recommendations and guidelines, but these are not legally obligatory. At present, there are not legally obligatory and transparent country-specific strategies for the crisis management system in the OECD. The "Baubion model", alone among the selected crisis management models, also assesses risks in selected regions based on historical context. Other advantages of this model are the joint approaches developed between the different agencies for public information and the flexibility of multi-purpose teams to deal with crisis phenomena of different nature, whether natural, military, or economic.

The "Marinov model" allows crisis staffs and committees within NATO institutions to coordinate their work and provide information to the North Atlantic Council. The individual phases are not precisely defined in terms of time and organization, they may overlap, and their duration depends on the specific situation. Crisis management in NATO, similarly to crisis management in the OECD, has a specific role compared to other models, because it involves not only individual countries, but also about institutions that consist of contributions from individual member states. In addition to the military domain, crisis management in NATO has a political dimension. It is the particular individual interests of the politicians and leaders of NATO member states that can have a negative impact on flexibility, especially in responding to emerging crises, and ultimately prolong the actual resolution of crises. Article 5 of the Washington Treaty deals with the principle of collective defense, where the member states agreed that an armed attack against one or more of them in Europe or North America would be considered an attack against all, and therefore agreed that if such an armed attack occurred, each of them would apply the principle of individual or collective defense. This obligation only applies in the case of an attack on one of the allies. The principle of collective defense does not deal with a potential military operation in which a NATO member would participate voluntarily. A positive aspect of the "Marinov model" of crisis management is the coordination and cooperation with other international crisis management organizations (UN and OECD), as well as the preparation of studies on political problems and the monitoring of trends in the development of the political situation in the world.

The "Jacques model" of crisis management deals with crisis management in the context of interdependent activities that need to be carried out in the different phases of crisis management. This model is characterized by its non-linear structure, which emphasizes that the individual phases of crisis management should not be seen as successive steps, but as a series of interrelated branches of crisis management. The peculiarity of the "Jaques model" is that it is the only one among the selected models of crisis management that does not follow the principle of subsidiarity. The model streamlines strategic relations, increases their effectiveness, and ultimately optimizes decision-making processes in crisis management. We can consider the so-called shortcoming of this model as the paradox of vulnerability. Each of the four phases of the model is subdivided into three further sub-phases. Too many individual activities in the model can make it ineffective and unworkable in certain practical conditions. We can consider the "Hamani model" as one of the best crisis management models. This generic model is intended for less developed countries, especially for the countries of the African continent. For the first time, the "Hamani model" was applied in the conditions of Algeria. The main goal of the model is to improve the resilience and cooperation of the civilian population in solving crisis phenomena of a natural and environmental nature. The model provides relevant standardized information for each type of threat, such as floods, earthquakes, and landslides. The overall effectiveness of the model is conditioned by a rigorous territorial analysis. The technological attributes of the "Hamani model" represent its positives, and at the same time they are also its shortcomings. On the one hand, the model can work with ARCGIS map data, on the other hand, obtaining input data in such a format represents a significant problem for African countries, and it is not possible to apply this technological innovation in all areas [20]. In the future, it would be necessary to adapt the model for the specifics of the territory of these countries. While the "Šimák - basic model" of crisis management is based on the generalized long-term experience of developed countries, the comprehensive process of solving crisis phenomena is much more complex. In addition to the type of crisis phenomena, it is also necessary to consider their intensity and the environment in which they occur. The "Šimak - complex model" is based on the basic model and is extended in such a way that it can adapt to the conditions and solve a probable crisis phenomenon. The complex process of solving crisis phenomena creates conditions for linking the prevention of serious natural hazards with the planning documents of local government bodies [21]. In practice, it is important to focus on the overall analysis of vulnerability and the structural causes of the emergence of crisis phenomena, as a natural disaster, even of a small scale, can have a significant impact on the population and nature with a long-time duration of the entire recovery phase. In contrast to the basic theoretical model, the complex procedure for solving crisis phenomena is relatively detailed, which may result in a loss of flexibility and a reduced ability to respond operationally (for example, at lower levels of crisis management).

The "Ristvej model" of crisis management is similar in many respects to the "Šimák - basic model" of crisis management from the point of view of the selected criteria in the evaluation table. However, the difference lies in the understanding of the recovery phase, which in this model is understood as resolution and reconstruction. Resolution and reconstruction are seen as an extension of the phase of reaction to the crisis phenomenon, as these activities already begin in the reaction phase. The resolution and reconstruction represent the restoration of the basic functions of the system, while the recovery phase also includes activities related to the restoration of the entire activities of society the original stabilized (pre-crisis) state. A limiting factor for the use of the model in the response phase is the mixing of activities in the response, resolution and reconstruction and recovery phases.

5. Conclusions

Not all approaches and models can be applicable to diverse crisis phenomena and in various regions of the world. Each of the shortlisted crisis management concepts and models has its own specific status, principles, and environment in which the individual phases of crisis management are applied. The crisis management system must respect the specificities of the principles as well as the legal environment and historical experience of the countries in which it could potentially be applied. An integral part of the crisis management system must be its executive branch, whose members must be able to deal with even the most complex crisis phenomena. The various bodies and institutions of the executive branch of the crisis management system may include: (1) professional staff (members of rescue units and specialised organisations, members of the armed forces used to deal with the aftermath of a crisis and members of legal entities, whose activities and professional focus are the same as those of the staff of the relevant crisis management organisations); (2) non-professional staff (voluntary employees and employees who have been subject to a labour obligation under a special law).

The crisis management executive must be able to intervene immediately at a specific location [22] with the necessary human and technical capacity and appropriate technology [23]. It is essential that all crisis management actors have clearly defined competences to be able to intervene in any environment. The effectiveness and efficiency of emergency responders in the response phase of crisis phenomena is contingent on the existence of capable responders in individual countries, while the very applicability of crisis management concepts and models is also valid. The capacities necessary to deal with crisis phenomena must be trained and prepared in the prevention and crisis planning phase [24]. Their deployment and the coordination of their activities are part of the response phase, with the emphasis on effective and efficient handling of crisis phenomena.

The assessment of selected concepts and models of crisis management can be considered as contributions of the study. Through analysis and comparison, theoretical bases for increasing the effectiveness of crisis management processes were identified, with emphasis on activities in the phase of response to crisis phenomena. However, there is a need for further research, such as optimization of the organization and decision-making processes at the local government level. Emphasis should also be placed on creating the most effective environment for the cooperation of all those involved in the crisis management process.

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Geographical Distribution Analysis of Field Hospitals Along the Frontline: 2SFCA method-based approach

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Abstract

The purpose of this article is to develop mathematical-geographical model to study the accessibility of fields hospitals along a frontline based on 2SFCA methodology. Invented P2SFCA model compares destinations proportionally and customizes the distance decay function for the needs of wounded soldiers. It is empirically shown that P2SFCA model distributes the same amount of accessibility as 2SFCA model but allocates it differently. Obtained model could be further used in decision making processes to better ensure the safety of wounded soldiers.

KEY WORDS: *2SFCA; field hospitals; spatial accessibility; frontline; proportional distances; minimal distance decay function.*

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1. Introduction

When it comes to health care availability we can monitor multiple parameters to monitor the situation in a given location. Among the most basic ones are hospital capacity, which measures how many patients can particular hospital treat in a predetermined amount of time, and patient's demand, which describes how many patients will visit given hospital in a specific amount of time.

Measuring hospital capacity can be achieved by different means, for example, by calculating the number of hospital beds, hospital physicians or hospital size. On the other hand, it is more difficult to estimate patient's demand as it involves unknown variables. For example, only a portion of ill patients will go to a hospital. Furthermore, patients can usually choose between several hospitals and will decide which one to visit based on variable criteria. However, even when patients decide between multiple hospitals, they can visit only one hospital at a given time.

For this reason, mathematical-geographical models were developed to estimate patient's demand (where groups of patients are considered instead of individual patients) in a simplified manner. Furthermore, 2SFCA models aggregate ratios of hospital capacities to patients' groups demand to measure health care availability in an investigated area. Special meaning is assigned to the distance between hospitals and patient groups.

2SFCA models were used under different settings to address various civilian needs. However, it seems that these models are yet to be deployed for military use. Nevertheless, there is a clear difference between civilian patients and military patients. This article then investigates a theoretical background for a potential application, where 2SFCA models are utilized in a military environment. As a consequence, a new modified 2SFCA model (named P2SFCA) was obtained and it analyses geographical distribution of field hospital along a frontline.

Primary objective of P2SFCA model is to introduce dynamical definition of the search radius by proportional comparison of distances. Its main advantage is that it better mirrors the real-world situation and offers more precise results. Additionally, distance decay function that generally appears in 2SFCA model is customized to better suit the military needs.

Modern warfare utilizes modern technology, bombardment and swift tactical attacks to deal with an opponent as is illustrated, for example, by Gulf War (see the official US government site [1]).

However, stalled progress of Ukrainian recently showed, that even in modern conflicts can prolonged frontline appear. Therefore, analyzing deployment of field hospitals along a front line still has its place in modern military preparedness. Improved effectiveness of field hospital distribution could then lead to saved lives. P2SFCA model could be later introduce into multi-criteria decision-making processes that compare multiple factors such as accessibility, costs, terrain and others.

2. Literary review

Original simple 2SFCA model was developed in [2] based on previous research and it geographically compares supply (hospital capacities) and demand (patients' demand) in two steps. Studied area is subdivided into smaller regions and the method works in two steps. First, supply/demand ratios are calculated for each hospital based on the localized demand, i.e. based on the regions that fall into hospital's scope. Next, for each region are considered hospitals that are sufficiently close and their supply/demand ratios are aggregated to calculated the accessibility index for that region.

In [3] weights were introduced to represent friction of distance into the model, i.e. regions that are closer to the hospital put higher demand on the hospital than regions that are farther away. This is nowadays called distance decay function and article [3] works with stepwise functions. Article [4] introduced continuous Gaussian distance decay function. At present, by 2SFCA models we usually refer to the models introduced in [3] and [4] (that is also the terminology that we will use). However, in literature we sometimes find these models under the name E2SFCA (that is the original terminology proposed by [3]).

These models were originally used to measure healthcare accessibility (see also [5-9]), however, in the last ten years they were used to investigate other scenarios such as earthquake shelter distribution [10] (see also [11] as well), fire stations distribution [12], supermarket accessibility [13], and water supply accessibility [14].

Field hospitals are sometimes used in emergency situation such as natural disasters or earthquakes. Optimal allocation of such hospitals saves civilian lives and tax payer's money. Mathematical algorithms were developed to optimize the allocation in [15], [16]. Furthermore, several countries recently utilized field hospital to relief overcrowded hospitals during the pandemic. As a consequence, effective distribution of said hospitals was investigated as well, see, for example, article [17]. Following this, article [18] developed algorithm that optimizes field hospital allocation during a pandemic by minimizing 2SFCA based coefficient in the studied area.

Above mentioned references illustrate an interest in investigating field hospitals, their geographical distribution and availability for civilian purposes. However, authors of this article do not know about similar scientific paper that would cover military requirements.

3. P2SFCA model

2SFCA model with Gaussian decay developed in [4] works in the following manner. Studied area is subdivided into smaller regions. Each region i is assigned its demand P_i (e.g. number of patients, number of people living in the region, …) and each hospital j is assigned its capacity S_j (e.g. number of physicians [19], number of ICU beds [20], floor area, …). Distances $d_{i,j}$ (e.g. planar distance, walking distance, mean travel time, …) between regions i and hospitals j are calculated. For each hospital j is then calculated its R_j - supply/demand ratio as

$$R_j = \frac{S_j}{\sum_{d_{i,j} \leq d_0} P_i f\left(d_{i,j}\right)},$$

where d_0 is maximal radius, from which would people still consider traveling to the hospital and $f(x)$ is Gaussian distance decay given as

$$f_G(d_{i,j}) = \begin{cases} \dfrac{\mathrm{e}^{-\frac{1}{2}\left(\frac{d_{i,j}}{d_0}\right)^2} - \mathrm{e}^{-\frac{1}{2}}}{1 - \mathrm{e}^{-\frac{1}{2}}} & \text{if} \quad d_{i,j} \leq d_0 \,, \\ 0 & \text{if} \quad d_{i,j} > d_0 . \end{cases}$$

In the second step, A_i - accessibility index is calculated for each region i as

$$A_i = \sum_{d_{i,j} \leq d_0} R_j f\left(d_{i,j}\right).$$

Region's demand P_i is scaled in denominator of R_j with distance decay function $f(d_{i,j})$, that can be explained by the following reasoning: The portion of patients that would consider traveling to the hospital is decreasing with increasing distance. This is natural in certain scenarios as some patients with, for example, flu, would not decide to travel to far away hospital and rather stay at home. On the other hand, this means that there will be some situations where patients will not travel anywhere. However, for the purposes of this article, patients represent seriously wounded soldiers that do need medical attention. Hence, P2SFCA model utilizes modified distance decay function

$$f(d_{i,j}) = \begin{cases} 1 & \text{if} \quad d_{i,j} = \min_l \left(d_{i,l}\right), \\ \dfrac{\mathrm{e}^{-\frac{1}{2}\left(\frac{d_{i,j}}{d_0}\right)^2} - \mathrm{e}^{-\frac{1}{2}}}{1-\mathrm{e}^{-\frac{1}{2}}} & \text{if} \quad \min_l \left(d_{i,l}\right) < d_{i,j} \le d_0, \\ 0 & otherwise. \end{cases}$$

Here every patient considers traveling at least to the closest hospital. Hospitals, that are further away than the closest one are considered only when they are located in maximal radius d_0. Gaussian decay function is then employed for these hospitals. Additionally, P2SFCA model utilizes modified coefficients A_i and R_j given as

$$R_j = \frac{S_j}{\sum_i P_i f\left(d_{i,j}\right) H(i,j)}, \qquad A_i = \sum_j R_j f\left(d_{i,j}\right) H(i,j),$$

where

$$M_{k,i} = \left\{ d_{i,j} \middle| \frac{\min_l (d_{i,l})}{d_{i,j}} \ge 1 - \frac{1}{k} \right\} \cap N_{k,i},$$

$k_0 \ge 1$ is maximal integer that satisfies $\left|M_{k_0,i}\right| = k_0$ and $H(i,j) = \begin{cases} 1 & \text{if } d_{i,j} \in M_{k_0,i} \\ 0 & \text{if } d_{i,j} \notin M_{k_0,i} \end{cases}$. Here $\left|M_{k,i}\right|$ denotes number of elements in the set $M_{k,i}$ and $N_{k,i}$ set of k smallest distances from region i.

In this way, hospitals are filtered for the second time. Their distances are compared with the closest hospital proportionally through ratio $\frac{\min_i(d_{i,j})}{d_{i,j}}$ which has to satisfy certain condition $\ge 1 - \frac{1}{k_0}$ and only k_0 closest hospitals are taken. The condition ensures that only limited number of hospitals are considered and that if we consider more hospital then their distances have to be in smaller range.

This can be explained on a following example. When the closest hospital is 10 kilometers away then we consider n hospitals only when the farthest hospital satisfies that its distance is $d_{i,j} \le \frac{10n}{n-1}$. Meaning that if we consider $n = 3$ hospitals then the farthest one can be at most 15 kilometers away (12.5 kilometers for $n = 5$ and 11.7 kilometers for $n = 7, \dots$). On the other hand, if the closest hospital is 100 kilometers away, then we consider $n = 3$ hospitals when the farthest one is at most 150 kilometers away. In a sense, this condition scales the number of hospitals considered dynamically. In fact, this is supposed to better represent humans' decision process where values are compared between each other and not with respect to a theoretical maximal distance.

Proposed P2SFCA model can be mathematically described in the following fashion as well. Let D be a matrix created from distances $d_{i,j}$. Furthermore, assume that $\widetilde{D}$ is another matrix, containing ordered rows of D that are increasing from left to right and let us denote its elements as $\tilde{d}_{i,j}$. Finally, let $\sigma_i(j)$ be a system of bijections such that $d_{i,j} = \tilde{d}_{i,\sigma_i(j)}$ for all i and let there be a function

$$H\left(\tilde{d}_{i,j}\right) = \begin{cases} \tilde{d}_{i,j} & \text{if} \quad \dfrac{\tilde{d}_{i,1}}{\tilde{d}_{i,j}} \ge 1 - \dfrac{1}{j}, \\ 0 & \text{otherwise.} \end{cases}$$

Then we can calculate coefficients A_i and R_j for P2SFCA model as

$$R_j = \frac{S_j}{\sum_i P_i f\left(H\left(\tilde{d}_{i,\sigma_i(j)}\right)\right)}, \qquad A_i = \sum_j R_j f\left(H\left(\tilde{d}_{i,\sigma_i(j)}\right)\right).$$

4. Methodology

Classic 2SFCA model is compared with newly established P2SFCA model on two datasets. Strictly theoretical data were generated based on the system proposed in [9], where model's performance is tested on various small case scenarios and both models are compared. Two classes of nodes are generated, one representing hospitals and another representing groups of patients. Distances between nodes, hospitals' capacities and patients' groups demands are then generated and varied to obtain several scenarios. Finally, it is observed how scenario's parameters impact each model.

Another set of simulated data was utilized as well. A segment of Ukrainian frontline (roughly 160 km long measured from one endpoint to another, whereas the curved path measures twice that long; segment is depicting the situation at the end of January 2024, see [21]) was taken and locations for field hospitals and military units were simulated. Military units were represented by their position centroids with the distance to the closest unit ranging from 3 to 7 kilometers. Overall, 57 units and 6 hospitals were generated. Each hospital was assigned semi randomized capacity (from 10 to 25 for each hospital with overall capacity 105) and similarly each military unit was assigned semi randomized number of seriously wounded soldiers representing patients' demand (from 0 to 4 with the total number being 75). Distances between hospitals and military units were calculated in ArcGIS pro software. Finally, accessibility indices A_i for both 2SFCA and P2SFCA are compared in map and statistically with maximal radius d_0 taken as 50 kilometers.

Wilcoxon Signed Rank (WSR) Test [22] is applied in MATLAB software (function *signrank*) to statistically compare accessibility indices A_i for both models. WSR Test is non-parametric test with the null hypothesis that two random samples have the same median against the alternative that their medians are different.

5. Model evaluation

This section presents models' analysis where we compare both models on strictly theoretical data and on simulated data.

5.1. Theoretical data

Three scenarios are considered and they schematics are visualized on Figure 1 a), b) and c). Here circles represent demand points (military units) and squares represent supply points (field hospitals). As was already mentioned, P_i represents number of wounded soldiers in group i and S_j capacity of hospital j. These values are taken as fixed in Figure 1 a), b) and for Figure 1 c) they are summarized in Table 3. Distances $d_{i,j}$ between nodes P_i and S_j are taken as fixed for Figure 1 b), where they are written next to the edges. Distances $d_{i,j}$ for Figure 1 a), b) are summarized in Table 1 and 3. Maximal (cut off) distance was taken as $d_0 = 1$ for all scenarios.

Scenario a) is the same as in [9], [23] and it was considered for historical continuity. Scenario b) is similar to the scenario considered in [9] and illustrates possible issues with P2SFCA model that occurs if the number of supply points (field hospitals) is bigger that the number of demand points (military units). This is expected to be an unrealistic but theoretical situation. Scenario c) illustrates how indices A_i depend on distances $d_{i,j}$ across different settings.

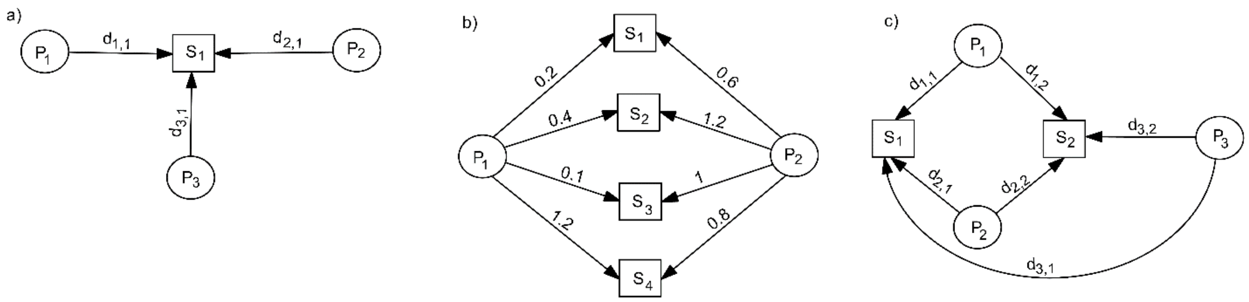

Fig. 1. Three scenarios a), b), c) and their schematic representation.

Scenario a) assumes that $P_1 = P_2 = P_3 = 100$ and $S_1 = 20$. This is the same as with the analogous scenario in [9]. In the scenario, there is only one supply point and its supply/demand ration R_1 is given in Table 1, where spatial accessibility indices A_i are calculated as well. In situation a) I there are $d_{1,1} = d_{2,1} = d_{3,1} = 0.8$ which mathematically ensures for both models that all accessibility indices A_i are equal. Furthermore, when there is just one supply point S_1then P2FCA model has $f(d_{1,1}) = f(d_{2,1}) = f(d_{3,1}) = 1$ and consequently indices A_i(P2SFCA) are mathematically equal for situation a) II as well. Finally, means of A_i are mathematically equal for all situations a) I, a) II and all models 2SFCA, P2SFCA. Moreover, this is true even when A_i(2SFCA) are different in situation a) II.

Table 1.

Accessibility indices A_i and parameters for scenario a).

		$d_{1,1}$	$d_{2,1}$	$d_{3,1}$	R_1	A_1	A_2	A_3	mean(A_i)
I	2SFCA	0.8	0.8	0.8	0.219	0.067	0.067	0.067	0.067
	P2SFCA				0.067	0.067	0.067	0.067	0.067
II	2SFCA	0.8	0.1	0.6	0.107	0.033	0.105	0.062	0.067
	P2SFCA				0.067	0.067	0.067	0.067	0.067

Scenario b) assumes that $P_2 = 100$ a $S_1 = S_2 = S_3 = S_4 = 20$ and its indices R_j, A_i are summarized in Table 2. Here it has to be emphasized that $R_2 = 0$, which is a theoretical consequence of hospital S_2 being too far from all demand points. As a consequence, hospital S_2 is not considered by any demand point and therefore $H(1,2) = H(2,2) = 0$, which results in division by zero in the process of evaluating R_2. However, this can happen with 2SFCA model as well and the situation is avoided by setting $R_2 = 0$.

Scenario b) highlights a theoretical difference between 2SFCA and P2SFCA models. Model 2SFCA considers unlimited number of supply points S_j if they are inside of maximal radius. On the other hand, P2SFCA model works with only a limited number of closest supply points that have sufficiently similar distances. Therefore, in scenario b) are sets $M_{k_0,i}$ given as $M_{k_0,1} = \{d_{1,1}, d_{1,3}\}$, $M_{k_0,2} = \{d_{2,1}, d_{2,4}\}$. Furthermore, P2SFCA model gives more weight to the closes node, which in scenario b) results in $f(d_{2,1}) = 1 > 0.581 = f_G(d_{2,1})$. This disparity grows remarkably when the distance of the closest node tends to d_0.

Table 2.

Accessibility indices A_i and parameters for scenario b).

	R_1	R_2	R_3	R_4	A_1	A_2	mean(A_i)
2SFCA	0.131	0.249	0.203	0.660	0.524	0.276	0.400
P2SFCA	0.103	0.000	0.200	0.660	0.298	0.303	0.301

Scenario c) illustrates more complex situation with varied parameters for three versions of distances and two versions of supply and demand. Scenarios assume that $P_2 = 100$, $S_1 = 20$, $d_{3,1} = 0.8, d_{3,2} = 0.3$ and choices for other parameters are summarized in Table 3 together with their R_j and A_i.

Table 3.

Accessibility indices A_i and parameters for scenario c).

Scenarios		$d_{1,1}$	$d_{1,2}$	$d_{2,1}$	$d_{2,2}$	P_1	P_3	S_2	R_1	R_2	A_1	A_2	A_3	mean(A_i)
I	2SFCA	0.2	0.4	0.5	0.3	100	100	20	0.103	0.078	0.160	0.141	0.100	0.134
	P2SFCA					100	100	20	0.118	0.071	0.176	0.154	0.071	0.134
II	2SFCA					150	50	80	0.088	0.315	0.338	0.342	0.307	0.329
	P2SFCA					150	50	80	0.091	0.295	0.328	0.359	0.295	0.327
III	2SFCA	0.4	0.8	0.6	0.9	100	100	20	0.118	0.148	0.140	0.091	0.167	0.133
	P2SFCA					100	100	20	0.174	0.087	0.200	0.114	0.087	0.134
IV	2SFCA					150	50	80	0.103	0.762	0.315	0.177	0.708	0.400
	P2SFCA					150	50	80	0.121	0.408	0.245	0.427	0.408	0.360
V	2SFCA	0.2	0.5	0.5	0.2	100	100	20	0.079	0.103	0.147	0.153	0.101	0.134
	P2SFCA					100	100	20	0.1	0.2	0.1	0.2	0.1	0.133
VI	2SFCA					150	50	80	0.078	0.372	0.335	0.408	0.182	0.308
	P2SFCA					150	50	80	0.1	0.8	0.1	0.8	0.1	0.333

Scenarios c) I and c) II describe the situation where the distances are mostly smaller (as compared to the maximal distance) and it can be seen that both R_j, A_i as well as means of A_i have similar values (with differences from 1 to 3%). In both of these scenarios there are $M_{k_0,1} = \{d_{1,1}, d_{1,2}\}$, $M_{k_0,2} = \{d_{2,1}, d_{2,2}\}$, $M_{k_0,3} = \{d_{3,2}\}$ where the distance $d_{3,1}$ not considered in P2SFCA has for 2SFCA $f_G(d_{3,1}) = 0.304$ smaller impact that is additionally compensated by other terms, for example, by $f(d_{2,2}) = 1 > 0.888 = f_G(d_{2,2})$. Moreover, the disparity between functions $f(d_{i,j})$ and $f_G(d_{i,j})$ is further lessened by smaller distances in I and II.

Scenarios c) III and c) IV cover the situation where the distances are larger (as compared to the maximal distance) and it can be seen that the values of R_j, A_i are occasionally similar (A_2 in III and A_3 in IV) however mostly different (with difference going up to 8% in III and 35% in IV). However, even in this situation have means of A_i similar levels (difference 0% in III a 4% in IV). Sets $M_{k_0,i}$ are the same for scenarios I, II, III, and IV and their impact is limited. Hence, the dissimilarity (between scenarios I, II and III, IV) seems to be caused solely by the change in distances.

Scenario c) V and c) VI depict the situation where $M_{k_0,1} = \{d_{1,1}\}$, $M_{k_0,2} = \{d_{2,2}\}$, $M_{k_0,3} = \{d_{3,2}\}$ and the impact of sets $M_{k_0,i}$ is bigger whereas the distances are similar to scenarios I and II. Here it is possible to note again that R_j, A_i are occasionally similar (A_3 in V and R_1 in VI) but mostly different (with difference going up to 10% in V and 43% in VI). Overall impact on means of A_i is again smaller (difference 0% in V a 2% in VI).

5.2. Simulation

Accessibility indices A_i for each military unit were calculated and their elementary statistics are summarized in Table 4. Minimums, means, and medians are similar for both models. However, maximums differ by one. Furthermore, Figure 2 shows normalized histogram comparing both sets of indices.

Table 4.

Elementary statistics

	min	max	mean	median	std
2SFCA	0.483	2.522	1.388	1.315	0.486
P2SFCA	0.521	3.534	1.475	1.293	0.874

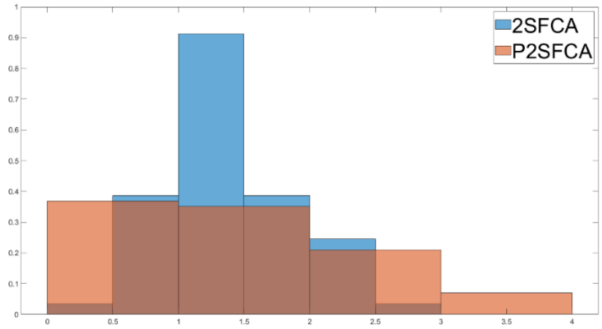

Fig. 2 Normalized histograms comparing accessibility indices A_i for both 2SFCA and P2SFCA.

It can be observed that A_i for 2SFCA model center around its peak with 45.6% of values between 1 and 1.5. On the other hand, indices A_i for P2SFCA model have similar levels for indices between 0 and 1 and between 1 and 2. Additionally, there is no peak standing out for P2SFCA model and the values are spread more uniformly.

WSR Test was performed to compare accessibility indices for both models with *p*-value=0.5918. As a consequence, null hypothesis that both sets of indices have the same median cannot be rejected.

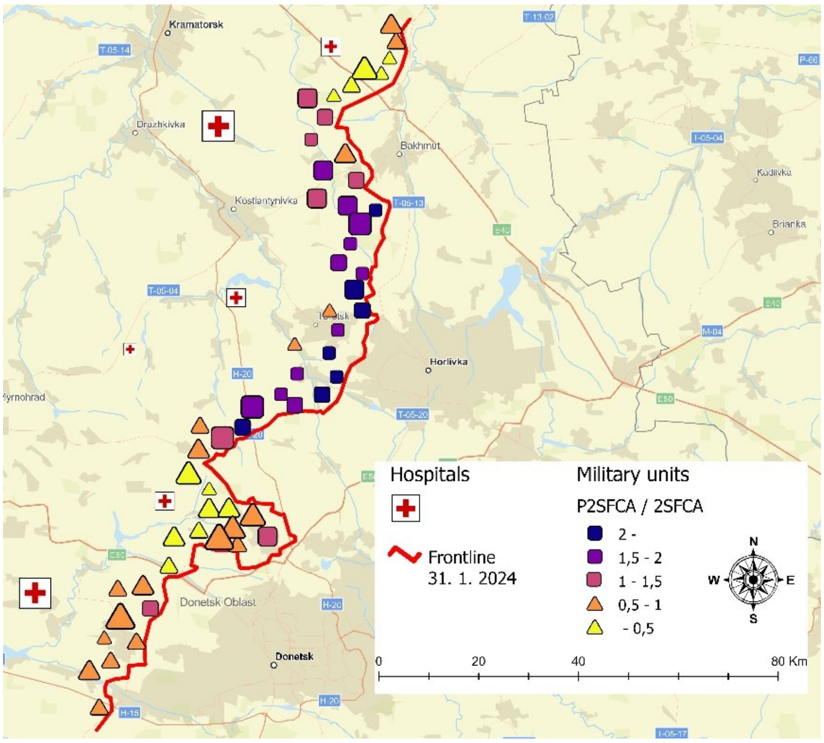

Fig. 3 Segment of Ukrainian frontline with simulated military units (triangles and squares) and field hospitals. Symbols' size represents hospital capacity and patient's demand (number of seriously wounded soldiers). Triangles mark military units for which is $P2SFCA < 2SFCA$ and squares mark units for which is $P2SFCA > 2SFCA$.

Figure 3 shows geographical distribution of both models. Triangles mark military units for which is $P2SFCA < 2SFCA$ (here and subsequently $P2SFCA$ denotes coefficient A_i for P2SFCA model and analogous notation is used for $2SFCA$) and squares mark units for which is $P2SFCA > 2SFCA$. It can be noted that the lower and upper portion of the frontline contains triangles and the middle portion contains squares. Furthermore, color indicates how many times is P2SFCA model smaller/bigger as compared with 2SFCA model. It is possible to visually identify two (yellow) regions on Figure 3, where $2 * P2SFCA < 2SFCA$ and scattered group of (blue) squares where $P2SFCA > 2 * 2SFCA$.

6. Conclusions and limitations

A new modified P2SFCA model and sets $M_{k_0,i}$ were developed for a better simulation of a humans' decision process. In fact, it seems to be a common knowledge that when humans have to decide between multiple options then they decide by comparing these choices among each other. This is indeed one of the features of P2SFCA model. On the other hand, classic

2SFCA models searches only in a strict radius. Classic 2SFCA model was already extended several times in multiple ways to better represent the real-world situation, see, for example, [7], [23], [24], [25], and [26]. However, dynamical modifications to the search radius were, as far as the authors know, considered solely in [9], [28].

Additionally, modified function $f(d_{i,j})$ was considered to better suit the needs of military and better represent the requirements of wounded soldiers. Similar analysis was performed and applied in other studies for classic 2SFCA model, see, for example, [3], [14], [27], [20]. However, Gaussian $f_G(d_{i,j})$ decay function is often times utilized as well, see, for example, [4], [10], [18], [28], [29]. Other resources focus on calculation of distances and how it is performed. However, in military settings, it is important to consider how the distance is calculated on a battlefield, see also [31], [32], [33], [34], [35].

Analysis of theoretical and simulated data showed, that P2SFCA model results in different indices A_i but means or medians remain similar. Hence, it seems that P2SFCA model distributes similar amount of accessibility throughout the region differently than 2SFCA method. This highlights military units that could be overlooked by 2SFCA and on the other hand it shows that certain units are in a better situation than is showed by 2SFCA model. In this situation, it is expected that P2SFCA model offers more precise information as opposed to 2SFCA model because it mirrors the actual situation on the battlefield better. Further improvements are necessary by customizing the model for the military doctrine of the studied army, see also [30].

Nevertheless, additional research is necessary before P2SFCA model could be deployed for military purposes. Proposed simulation works with the number of wounded soldiers that are station along frontline. In actual application, statistical models could be employed to infer this number for each military unit. However, additional consultations about military doctrine with military experts are necessary before this could be done. Furthermore, particular needs of any given army are dictated not only by their military doctrines but by the adversary as well. 2SFCA model was studied under the assumptions that there is a clear frontline between armies. However, military conflicts in the 20th century showed that this does not have to happen (see [35]). Hence, further generalization of 2SFCA model are necessary for different types of conflicts (if 2SFCA model can be applied at all).

Finally, practical applications of 2SFCA based models could lead to improved decision-making process such as in

- Field hospitals location selection: Location selection algorithm based on P2SFCA model could show where to place field hospitals to improve their efficiency (see also [8], [10]).
- Analysis of actual situation: Software tools analyzing real time data could highlight problematic situations in need of attention.
- Doctrine improvement: Analysis could highlight problematic parts of current military doctrine and lead to further improvements.

In this way, P2SFCA model could be utilized together with other optimization algorithms that consider other parameters of the problem under consideration in a multi-criteria model, see, for example, [18].

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Multicriterial Analysis and Comparison of Air-to-Air Fighter Jets

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Abstract

Fighter aircraft are the dominant tools for gaining the desired level of air control. As the crisis over Ukraine since 2022 showed, air superiority in congested airspace plays a crucial role. The aim of this article is to present the methodological approach to compare different aircraft dedicated to air-to-air roles. For this purpose, the Multi-Criteria Decision-Making Method, based on the analytical hierarchy process, was used to identify the most suitable military fighter aircraft for air-to-air operations. To demonstrate the method, four operational representatives of the North Atlantic Treaty Organization countries were selected to compare specific aircraft types.

KEY WORDS: *multicriterial analysis, analytical hierarchy process, fighter aircraft, decision-making*

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1. Introduction

Fighter aircraft have historically played a crucial role in establishing the desired degree of control in the air. From an operational management perspective, achieving this position is necessary for success on the contemporary battlefield. The unfolding conflict in Ukraine serves as the evidence supporting this principle. Initial offensives conducted by the Russian Federation targeted at various strategic locations, including air bases, air defense sites, and airspace surveillance systems. Despite the inability to completely neutralize the Ukrainian air forces on the ground, ongoing confrontations between aircraft of the two opposing factions persist. [1]

The delivery of air power can be defined in terms of roles, missions, and sorties. This study will be further elaborated and focused only on Counter-Air Operations conducted to obtain and maintain the required degree of Control of the Air. The desired level of Control of the Air will allow the actual operation to be conducted under the required degree of freedom for ground units and other components in the required time and space. Achieving this level is ongoing, but further action is required to maintain this state [2]. The most important factor affecting the probability of fulfilling the task is the human factor, followed by the technological level of development and the aircraft capabilities [3]. All these factors should be included in the phase of developing plans and stating the standards, thus it is important to the strengths and weaknesses evaluation [4]. When evaluating any object, the first phase is to establish the requirements. In the case of modern fighter aircraft, the trend is that one aircraft can play different roles, such as a multi-role aircraft or a swing-role [5].

The aim of this study is to introduce a systematic approach to the selection and comparison of suitable tactical aircraft for Counter-Air operations. To achieve this objective, it is essential first to identify the fundamental capabilities and characteristics of the aircraft that are critical to the performance of these missions. Evaluation criteria will then be derived from these parameters. The criteria will be selected based on the historical development of tactical aircraft, their operational deployment, potential tactics, principles of air warfare, technical advances, and the capabilities of current platforms. A multi-criteria method will be developed to incorporate the significant number of sub-criteria that determine an aircraft's readiness level. The effectiveness of this method will then be demonstrated through a comparative analysis of a few selected aircraft.

The purpose of this study is not to evaluate aircraft for specific operations in a specific location or to select the appropriate aircraft for a specific military or government agency. Its primary focus is to evaluate the disposition of Counter

Air Operations only, without regard to aircraft characteristics that are not analytically critical to this effort. An example would be acquisition cost or cost per flight hour. Calculating the cost per flight hour or mission accomplishment is highly complex and can vary from nation to nation. Therefore, this study does not address the price in general.

2. Method of Investigation

The operational deployment of fighter jets involves a wide range of factors that significantly impact on the feasibility of deployment under specific conditions and mission requirements. These factors, such as information support, maintenance complexity, operational economics, logistics support, and navigation performance, must be considered in practice. However, this study focuses on assessing the effectiveness of air dispositions in achieving success in air-to-air operations, specifically in conducting air combat. Therefore, the study will not explore the factors mentioned above or consider scenarios where adversaries have equal capabilities in certain variables to isolate the analysis of aircraft dispositions.

The study employed the Multi-Criteria Decision-Making Method (MCDM) [6], which is based on the analytical hierarchy process (AHP) [7], to identify the most appropriate military fighter aircraft for air-to-air operations.

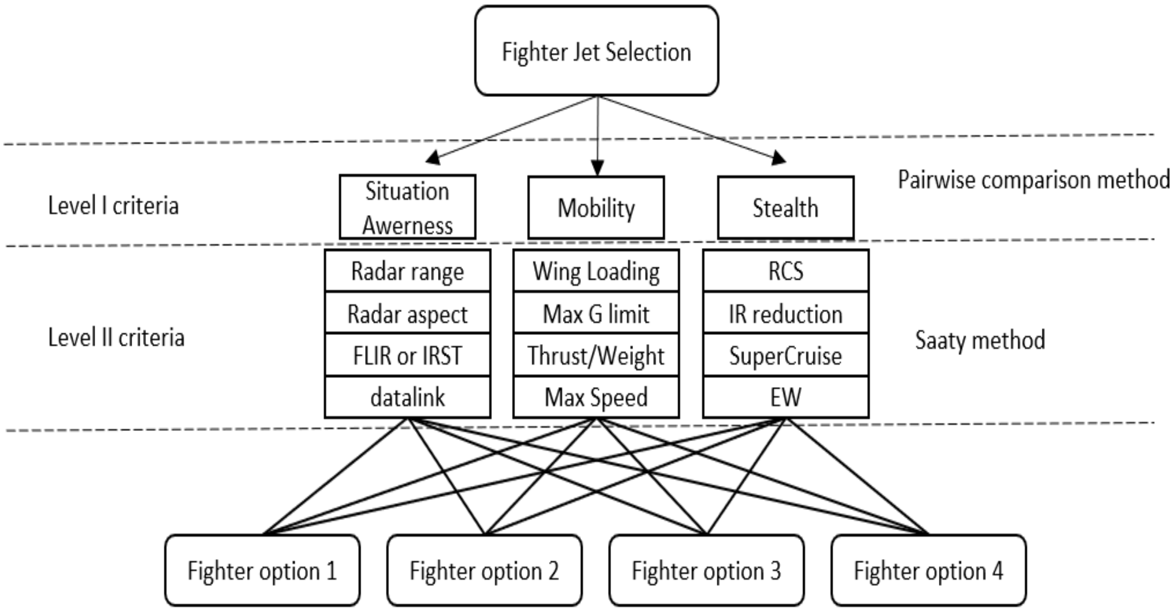

Fig. 1. Analytic hierarchy structure

The analytical hierarchy method was used to establish three primary criteria, and their weights were determined by a group of experts using Fuller's pairwise comparison method. At the second level, experts identified four criteria for each category from the primary criteria. Based on the evaluation by the expert team, the weights of these criteria were determined using the Saaty method [8]. The structure of the AHP is illustrated in Fig. 1.

2.1. Level I Criteria

The identified Level I Criteria defining modern Air-to-Air Fighter Jets, including the 5th GEN fighters, were chosen upon Senior Matter Experts (SME). The pairwise comparison method using Fuller's triangle was used to determine the weights of these criteria. Air Force SME's task was to choose which pair of criteria was more critical. The SME compared the pairs of criteria sequentially, with the number of pairs defined by formula (1). For the example of three Level I criteria ($k = 3$), the number of pairs is $N = 3$.

$$N = \binom{k}{2} = \frac{k(k-1)}{2} \tag{1}$$

From Fuller's pairwise comparison method and the SME's evaluation, the weights are assigned by scoring, where the preferred criteria are awarded 1 point. In the case of a situation where the SME prefers both criteria equally, both criteria in a pair receive 0.5 points. The final weight v_i of the i-th criterion is defined by formula (2), where n_i indicates how many preference points the criterion received. The results of SME are presented in Table 1.

$$v_i = \frac{n_i}{N}; \quad i = 1, \dots, k \tag{2}$$

Table 1.

The results of SME evaluation (data are rounded)

Level I criteria	
Situation Awareness (SA)	$v_{SA} = 0.50$
Stealth	$v_{Stealth} = 0.34$
Mobility (MOB)	$v_{MOB} = 0.16$
Sum	**1.00**

2.2. Level II Criteria

Level II Criteria for each category were chosen after analysing the avionics capability, aerodynamic characteristics, performance, and other aircraft qualities. The armament characteristics were intentionally omitted due to limited access to valid data and variations in the types of munitions used for each aircraft worldwide. In this case, Saaty's matrix with a nine-point scale was used for pairwise comparison of these criteria. The weights v_{jA}, v_{jB} and v_{jC} of the individual criteria were then calculated as the ratio of the geometric mean in the given row and the sum of the geometric means for all criteria in the Saaty matrix (see Table 2).

Table 2.

Situation Awareness (SA)

	Radar range	**Radar aspect in azimuth and vertical**	**FLIR or IRST**	**NATO compatible datalink**	**Geometric Mean**	v_{jA}
Radar range	1.000	7.000	5.000	0.200	1.627	0.248
Radar aspect in azimuth and vertical	0.143	1.000	0.250	0.143	0.267	0.041
FLIR or IRST	0.200	4.000	1.000	0.125	0.562	0.086
NATO compatible datalink	5.000	7.000	8.000	1.000	4.091	0.625
					Σ=6.547	**1.00**

Stealth

	Radar Cross Section	**IR reduction**	**Super Cruise**	**Electronic Warfare Capability**	**Geometric Mean**	v_{jB}
Radar Cross Section	1.000	3.000	2.000	0.200	1.047	0.171
IR reduction	0.333	1.000	0.167	0.143	0.298	0.049
SuperCruise	0.500	6.000	1.000	0.143	0.809	0.132
Electronic Warfare Capability	5.000	7.000	7.000	1.000	3.956	0.647
					Σ=6.111	**1.00**

Mobility (MOB)

	Wing Load	**Max G limit**	**Thrust to Weight Ratio**	**Maximal Speed**	**Geometric Mean**	v_{jC}
Wing Load	1.000	0.333	0.250	0.125	0.319	0.056
Max G limit	3.000	1.000	0.333	0.200	0.669	0.117
Thrust to Weight Ratio	4.000	3.000	1.000	0.333	1.414	0.248
Maximal Speed	8.000	5.000	3.000	1.000	3.310	0.579
					Σ=5.712	**1.00**

3. Investigation Results

Four representative aircraft from the North Atlantic Treaty Organization countries were selected to compare specific aircraft types [9], [10]. This selection was made to demonstrate the functionality of the method. This selection can be further supplemented or modified for possible specific use at the national or international level.

The data on specific aircraft were taken from publicly available sources, mainly the English version of Wikipedia. The authors are fully aware of the imperfections of this data. However, again, the method can be supplemented with accurate and often classified data for any specific use. The purpose of the paper is to establish a methodological approach to the Multicriterial Analysis [11] for comparing different types of aircraft where a comparison was made between four representatives currently in service within the NATO.

The selected types of aircraft deployed in the North Atlantic Alliance include:

1. JAS-39 C Gripen.
2. Dassault Rafale C.
3. Eurofighter Typhoon.
4. F-35 Lightning II.

For the analytical approach and the final evaluation, it was necessary to transverse the data for each Level II criteria to value them in a points scale. The scoring principle is described in Table 3.

Table 3.

Situation Awareness (SA)

	criterion	*scale*	*JAS-39C*	*Rafale*	*Eurofighter*	*F-35*
f_{1A}	Radar range	Highest value = 100 points Zero value = 0 points	93	100	80	100
f_{2A}	Radar aspect in azimuth and vertical	360° + 360° = 100 points 0° = 0 points	33	36	55	70
f_{3A}	FLIR or IRST	Both = 100 points Only one = 50 points None = 0 points	100	100	100	100
f_{4A}	NATO compatible datalink	Yes = 100 points No = 0 points	100	100	100	100

Stealth **score**

	criterion	*scale*	*JAS-39C*	*Rafale*	*Eurofighter*	*F-35*
f_{1B}	Radar Cross Section	Lowest value = 100 points Highest value = 0 points	50	0	0	100
f_{2B}	IR reduction	Yes = 100 points No = 0 points	100	100	100	100
f_{3B}	SuperCruise	Yes = 100 points No = 0 points	0	100	100	100
f_{4B}	Electronic Warfare Capability	Yes = 100 points No = 0 points	100	100	100	100

Mobility (MOB) **score**

	criterion	*scale*	*JAS-39C*	*Rafale*	*Eurofighter*	*F-35*
f_{1C}	Wing Load	Lowest value = 100 points Highest value = 0 points	27	31	30	20
f_{2C}	Max G limit	Highest value = 100 points Zero value = 0 points	100	100	100	100
f_{3C}	Thrust to Weight Ratio	Highest value = 100 points Zero value = 0 points	73	94	100	83
f_{4C}	Maximal Speed	Highest value = 100 points Zero value = 0 points	80	90	100	80

After examining the characteristic data, the final result was calculated for each criterion in the category using the formula (3), where the weights v_{SA}, v_{Stealth} and v_{MOB} are the weights calculated in Fuller's pairwise comparison method in Table 1.

$$\mathrm{SCORE} = v_{\mathrm{SA}} \cdot \mathrm{Sum(SA)} + v_{\mathrm{Stealth}} \cdot \mathrm{Sum(Stealth)} + v_{\mathrm{MOB}} \cdot \mathrm{Sum(MOB)} \quad (3)$$

The sum for each Level II category is calculated as specified in formula (4), where weights v_{jA}, v_{jB} and v_{jC} were calculated using the Saaty matrix (see Tab. 2) and f_{jA}, f_{jB} and f_{jC} were determined from Tab. 3.

$$\mathrm{Sum(SA)} = \sum_{j=1}^{4} v_{jA} \cdot f_{jA}, \qquad \mathrm{Sum(Stealth)} = \sum_{j=1}^{4} v_{jB} \cdot f_{jB}, \qquad \mathrm{Sum(MOB)} = \sum_{j=1}^{4} v_{jC} \cdot f_{jC}. \quad (4)$$

4. Conclusions

Thanks to the methodical comparison of aircraft for air-to-air operations, the final ranking of the aircraft was determined. In the category of stealth and situational awareness, the F-35 stood out the most, thanks to its 5th generation aircraft concept. Conversely, the remaining aircraft were tied in these categories. On the other hand, the F-35 fell short in mobility, where the aircraft lost points due to its higher surface load and lower top speed. However, the F-35 outperformed the other aircraft in the overall rating. This result underlines the importance of the 5th generation aircraft, where the emphasis is on information superiority on the battlefield, which is achieved through powerful radars and the Stealth concept in general. The Rafale and Eurofighter had similar score gains. The Gripen fell slightly behind due to its outdated airborne radar and single-engine concept. The resulting scores are shown in Table 4. In conclusion, the concept of 5th generation aircraft is an essential element of the modern battlefield concept, and the philosophy of the relevance of information superiority for air-to-air engagements has been demonstrated by comparison using multicriterial analysis.

Table 4.

MCA Results

aircraft type	SCORE
F-35 Lightning II	**95.9**
Dassault Rafale C	**91.0**
Eurofighter Typhoon	**90.1**
JAS-39 C Gripen	**86.7**

Limitations

A limitation of the study is the source of valid data, where certain specific data are very often classified. The authors mainly relied on publicly available sources. For further specific use at the level of a particular army, the data can be further specified as categories can be expanded to include additional criteria for comparison.

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Predictive Estimates in Population Models with Variable Dynamics Under Uncertainties

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Abstract

In this paper, we investigate the predictive estimates of the model which at the initial time interval describes a slower population growth, and later turns into a model with a rapid growth of such a population. For considered problem, with unknown initial conditions and parameters of differential equations, however for a known number of persons in the population at certain moments of time, we obtain the predictive sets at a given time under certain conditions and substantiate the formulas for calculating the minimum and maximum number of persons in the population.

KEY WORDS: *predictive estimate, uncertainty, population model, nonlinear equation, variable dynamics, information spreading.*

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1. Introduction

Mathematical models of population processes provide a framework for understanding the dynamics of populations over time. These models utilize mathematical equations to describe birth rates, mortality rates, immigration, and emigration, among other factors [1], [2]. By incorporating variables such as carrying capacity and environmental influences, these models can simulate the growth or decline of populations under various conditions, aiding in predicting future trends and informing decision-making in fields such as ecology, epidemiology, and economics.

In population processes, uncertainties manifest in various forms [3], including unknown parameters, which refer to incomplete knowledge about factors influencing population dynamics such as birth rates or mortality rates. Furthermore, error in observations introduces uncertainty [4], as inaccuracies or limitations in data collection methods can distort our perception of population trends, complicating efforts to accurately model and predict population behavior.

Population models with a fuzzy structure are also insufficiently studied. This type of uncertainty has been studied in works [5] – [7].

Mathematical models for describing population processes can take various forms, each tailored to capture specific aspects of population dynamics. Here are some different types of mathematical models commonly used:

Agent-Based Models: In agent-based models, populations are simulated as collections of individual agents, each with its own characteristics, behaviors, and interactions. These models are useful for capturing heterogeneity within populations and exploring emergent phenomena arising from individual-level interactions.

Spatial Models: These models incorporate spatial dimensions to analyze how population processes vary across geographical regions. They are valuable for studying patterns of migration, population distribution, and the spread of infectious diseases.

Stochastic Models: Stochastic models introduce randomness into population processes, acknowledging inherent variability and uncertainty. They are particularly useful for studying small populations, rare events, or systems subject to random fluctuations.

Nonlinear Differential Equations Models: Nonlinear differential equations are powerful tools for modeling population processes, allowing for a more realistic representation of complex dynamics such as feedback mechanisms, saturation effects, and interactions between different population groups.

We propose to use the model, which at the initial time interval describes a slower population growth, and later turns into a model with a rapid growth of such a population.

Initial Phase of Slower Population Growth: In the initial time interval, the population model may exhibit characteristics of slow growth. This phase could be influenced by factors such as limited resources, environmental constraints, or low reproductive rates. For example, a population may initially have a small number of individuals, undergoing gradual growth as individuals reproduce and the population expands to fill available niches. During this phase, the population growth rate may be moderate, and the population size increases steadily over time.

Transition to Rapid Growth: As the population approaches a critical threshold or experiences changes in its environment, it may undergo a transition to rapid growth. This transition could occur due to various factors, such as favorable environmental conditions, increased availability of resources, or changes in reproductive behaviors. For example, if a population's predators decline in number or if abundant food sources become available, individuals may experience reduced mortality rates or increased reproductive success, leading to accelerated population growth. This transition often involves nonlinear dynamics, where small changes in conditions can trigger disproportionately large responses in population growth rates.

Predictive estimates from a system of nonlinear differential equations are essential for understanding the dynamics of population growth, particularly when the model depicts transitions from slower to rapid growth phases. By providing insights into future trends and potential impacts [8], [9], predictive modeling informs policy, management, and planning efforts aimed at promoting sustainable development and addressing the challenges associated with population growth.

In this article, we explore modeling population processes with dynamics transitioning from slow to rapid using nonlinear differential equations to describe the processes. For each type of process behavior, a specific equation with parameters and initial conditions is proposed. We will also propose a method for obtaining predictive estimates of the dynamics of such models.

2. The Mathematical Background

Today, a significant number of publications are dedicated to the study of the behavior of dynamic systems. Such interest is caused by the variety of applications to real processes that are described using the mathematical apparatus of dynamic systems. The information spreading in social networks [10], the change in the number of patients during epidemics [11], the dynamics of the number of people with stress syndrome [1], [12] can be modeled with the help of hybrid dynamic systems. The most common models, which are studied, for example in [13] – [17], are logistic or more generalized Volterra models. With rapid population growth, it is recommended to use Gompertz models [18-22]. Given the known initial conditions and parameters of the models, such an analysis is reduced to solving Cauchy problems for linear or nonlinear differential equations.

In the case when the initial conditions or parameters of the models are unknown and belong to certain sets, it is not possible to obtain accurate predictive estimates, which forces us to look for the predictive sets at a given time under certain conditions. With unknown initial conditions and parameters of differential equations, however, for a known number of persons in the population at certain moments of time, formulas are given for calculating the minimum and maximum number of persons in the population.

3. Main Results

Let functions $x_1(t)$ and $x_2(t)$ be solutions of the system

$$\begin{aligned} &\frac{dx_1}{dt} = \gamma_1(t)x_1(t)(N - x_1(t)), \quad x_1(0) = x_0, \quad 0 < t < t_1, \\ &x_1(t_1) = x_2(t_1), \\ &\frac{dx_2}{dt} = (b(t)u(t) + \gamma_2(t)\ln\frac{x_2(t)}{N})x_2(t), \quad t_1 < t < T. \end{aligned} \tag{1}$$

Assume that the functions $\gamma_1(t), \gamma_2(t), u(t)$ are integrable with the square on the corresponding intervals, and a function $b(t)$ is continuous on $[t_1, T]$.

Proposition 1. *Equation system (1) has a unique solution that is continuous and differential almost everywhere (a. e.).*

Proof. Without limiting the generality, we will assume that $N = 1$.

Let's put $\varphi_1(t) = \dfrac{x_1(t)}{1-x_1(t)} = -1+(1-x_1(t))^{-1}$, $\varphi_2(t) = \ln x_2(t)$. Functions $\varphi_1(t)$ and $\varphi_2(t)$ are differential a.e. and almost everywhere satisfy the equations

$$\begin{gathered}\frac{d\varphi_1(t)}{dt} = \gamma_1(t)\varphi_1(t),\ \varphi_1(0) = -1+(1-x_1(0))^{-1} \\ at\ x_1(0) \neq 1 \quad and \quad for\ \ 0 < x_0 < N, \\ \varphi_2(t_1) = \ln x_1(t_1)(1-x_1(t_1))^{-1}, \\ \frac{d\varphi_2}{dt} = b(t)u(t) + \gamma_2(t)\varphi_2(t).\end{gathered} \tag{2}$$

We can write the solution of system (2) in the form

$$\varphi_1(t) = \varphi_1(0)\exp\int_0^t \gamma_1(\tau)d\tau, 0 \le t \le t_1,$$

$$\varphi_2(t) = \varphi_2(t_1)\exp\int_{t_1}^t \gamma_2(\tau)d\tau + \int_{t_1}^t \exp\int_\tau^t \gamma_2(s)ds \cdot b(\tau)u(\tau)d\tau,$$

therefore, the solution of system (1) is functions $x_1(t) = \dfrac{\varphi_1(t)}{1+\varphi_1(t)}$, $x_2(t) = \exp\varphi_2(t)$. □

Further, let x_0 be an unknown value that belongs to interval $[x_0^-, x_0^+]$, where $x_0^- > 0$, $x_0^+ < 1$.

Let also $x_1(s_k)$ be the given values with errors $v_k, k = \overline{1,m}$ at the points $s_1, s_2, ..., s_m$, $0 < s_1 < s_2 < ... < s_m < t_1$ with some value $x_0 \in [x_0^-, x_0^+]$. Also assume that we observe some given values

$$y_k = x_1(s_k) + v_k, k = \overline{1,m}, \text{ and } v_k^- \le v_k \le v_k^+.$$

Let us introduce the set $G_y = \left\{x_0 : x_0^- \le x_0 \le x_0^+, v_k^- \le y_k - x_1(s_k) \le v_k^+, k = \overline{1,m}\right\}$, and also the sets $G_y^{(1)}$ and $G_y^{(2)}$

$$G_y^{(1)} = \left\{x_1(\bar{t}, x_0) : x_0 \in G_y, s_m < \bar{t} \le t_1\right\},$$

$$G_y^{(2)} = \left\{x_2(t, x_1(t_1, x_0)) : x_0 \in G_y, t_1 < \bar{t} < T\right\}.$$

The sets $G_y^{(1)}$ and $G_y^{(2)}$ are called the sets of predictive estimates for values $x_1(\bar{t})$ and $x_2(\bar{t})$, respectively.

Proposition 2. *The set* G_y *has the form*

$$G_y = [\alpha, \beta] \cap [x_0^-, x_0^+] = [\max(\alpha, x_0^-), \min(\beta, x_0^+)] = [\alpha^-, \alpha^+].$$

Proof. From the inequality $v_k^- \le y_k - x_1(s_k) \le v_k^+$, according to the relation $x_1(s_k) = \dfrac{\varphi_1(s_k)}{1+\varphi(s_k)}$, we obtain such inequalities

$$\frac{y_k^-}{1+y_k^-} \le \varphi_1(s_k) \le \frac{y_k^+}{1+y_k^+},$$

where $y_k^- = y_k - v_k^+$, $y_k^+ = y_k - v_k^-$.

Since $\varphi_1(s_k) = x_0 \exp\int_0^{s_k} \gamma_1(\tau)d\tau,$ then for x_0 the ratios $\gamma_k^- \le x_0 \le \gamma_k^+, k = \overline{1,m}$ are valid, and here

$$\gamma_k^- = \frac{y_k^-}{1+y_k^-}\exp\left\{-\int_0^{s_k} \gamma_1(\tau)d\tau\right\}, \quad \gamma_k^+ = \frac{y_k^+}{1+y_k^+}\exp\left\{-\int_0^{s_k} \gamma_1(\tau)d\tau\right\}.$$

In this way, we get that $x_0 \in [\alpha, \beta]$, $\alpha = \max\limits_{1\le k\le m} \gamma_k^-, \beta = \min\limits_{1\le k\le m} \gamma_k^+$. □

Consequence 1. *The sets* $G_y^{(1)}$ *and* $G_y^{(2)}$ *have the form* $G_y^{(1)} = [\delta_1^-, \delta_1^+]$, $G_y^{(2)} = [\delta_2^-, \delta_2^+]$, *where* $\delta_1^- = x_1(\bar{t}, \alpha^-)$, $\delta_1^+ = x_1(\bar{t}, \alpha^+)$, $\delta_2^- = x_2(\bar{t}, x_1(t_1, \alpha^-))$, $\delta_2^+ = x_2(\bar{t}, x_1(t_1, \alpha^+))$.

Suppose that the function $\gamma_1(t)$ is unknown and belongs to the set

$$\Gamma = \left\{ \gamma_1 : \int_0^{t_1} q^2(t)(\gamma_1(t) - \bar{\gamma}_1(t))^2 dt \le 1 \right\}, \quad (3)$$

where $\bar{\gamma}_1(t)$ is a well-known function integrable with the square, the function $q^2(t)$ is continuous on $[0,t_1]$ and such that the following inequality holds: $q^2(t) \ge q^2 > 0$.

We put that $x_0 \in [x_0^-, x_0^+]$. Let us denote by

$$\Gamma_y = \left\{ (x_0, \gamma_1) : x_0^- \le x_0 \le x_0^+, \gamma_1 \in \Gamma, v_k^- \le y_k - x_1(s_k) \le v_k^+ \right\}.$$

Definition 1. An interval $[x_1^-(\bar{t}), x_1^+(\bar{t})]$ is called a *set of predictive estimates* for the values $x_1(\bar{t})$, where $x_1^-(\bar{t}) = \min_{(x_0,\gamma_1)\in\Gamma_y} x_1(\bar{t}, x_0, \gamma_1)$, $x_1^+(\bar{t}) = \max_{(x_0,\gamma_1)\in\Gamma_y} x_1(\bar{t}, x_0, \gamma_1)$, $x_1(\bar{t}, x_0, \gamma_1)$ is the solution of system (1) at the initial value x_0 and the function γ_1. Similarly, for the predictive interval $[x_2(\bar{t}, x_1^-(t_1)), x_2(\bar{t}, x_1^+(t_1))]$ is called a set of predictive estimates for the values $x_2(\bar{t})$.

Proposition 3. *The following equalities*

$$x_1^-(\bar{t}) = 1 - (1 + \varphi_1^-(\bar{t}))^{-1}, \quad x_1^+(\bar{t}) = 1 - (1 + \varphi_1^+(\bar{t}))^{-1}, \quad (4)$$

hold, where $\varphi_1^-(\bar{t}) = \exp L^-(x_0, \gamma_1)$, $\varphi_1^+(\bar{t}) = \exp L^+(x_0, \gamma_1)$, and $L^-(x_0, \gamma_1) = \min_{\Gamma_y} L(x_0, \gamma_1)$, $L^+(x_0, \gamma_1) = \max_{\Gamma_y} L(x_0, \gamma_1)$, $L(x_0, \gamma_1) = \ln \varphi(0) + \int_0^{\bar{t}} \gamma_1(\tau) d\tau.$

Proof. Since $x_1(\bar{t}) = \dfrac{\varphi_1(\bar{t})}{1 + \varphi_1(\bar{t})} = 1 - (1 + \varphi_1(\bar{t}))^{-1}$, where $\varphi_1(\bar{t}) = \exp L(x_0, \gamma_1)$, then this representation yields equalities (4). □

Remark 1. Since $x_0 = \dfrac{\varphi(0)}{1 + \varphi(0)}$, then the set Γ_y can be written as

$$\bar{\Gamma}_y = \left\{ (\psi_0, \gamma_1) : \psi_0^- \le \psi_0 \le \psi_0^+, \gamma_1 \in \Gamma, \right.$$
$$\left. \theta_k^- \le L_k(\psi_0, \gamma_1) \le \theta_k^+, \quad k = \overline{1,m} \right\},$$

where $L_k(\psi_0, \gamma_1) = \psi_0 + \int_0^{t_k} \gamma_1(\tau) d\tau$, $\psi_0 = \ln \varphi(0)$, $\psi_0^- = \ln \dfrac{x_0^-}{1 - x_0^-}$, $\psi_0^+ = \ln \dfrac{x_0^+}{1 - x_0^+}$, $\theta_k^- = \ln \dfrac{y_k^-}{1 + y_k^-}$, $\theta_k^+ = \ln \dfrac{y_k^+}{1 + y_k^+}$.

Remark 2. In order to find predictive sets for the value $x(\bar{t})$, one needs to find the minimum and maximum value of a linear functional $L_1(\psi_0, \gamma_1) = \psi_0 + \int_0^{\bar{t}} \gamma_1(\tau) d\tau$ on the convex and closed set $\bar{\Gamma}_y$.

Proposition 4. *Let x_0 and γ_1 belong to the set Γ_y, the functions $b(t), u(t)$ and $\gamma_2(t)$ are given. Then the predictive set for the value $x_2(\bar{t})$ as $t_1 < \bar{t} < T$, has the form $[x_2^-(\bar{t}), x_2^+(\bar{t})]$, where $x_2^-(\bar{t})$ and $x_2^+(\bar{t})$ are found from the solution of system (1) at $x_2(t_1) = x_1^-(t_1)$ and $x_2(t_1) = x_1^+(t_1)$, respectively.*

The proof of this statement follows from the representation $x_2(\bar{t}) = \exp \varphi_2(\bar{t})$ and equality $x_2^-(\bar{t}) = \exp \varphi_2^-(\bar{t}), x_2^+(\bar{t}) = \exp \varphi_2^+(\bar{t})$, where

$$\varphi_2^{\mp}(\bar{t}) = x_1^{\mp}(t_1) \exp \int_{t_1}^{\bar{t}} \gamma_2(\tau) d\tau + \psi(\bar{t}),$$

$$\bar{\psi}(t) = \int_0^{\bar{t}} \exp \int_{\tau}^{t} \gamma_2(s) ds \, b(\tau) u(\tau) d\tau.$$

Remark 3. If the predictive sets for the values $x_1(\bar{t})$ and $x_2(\theta)$ are given in the form of intervals $[x_1^-, x_1^+]$ and $[x_2^-, x_2^+]$, then the guaranteed predictive estimates and guaranteed predictive errors are calculated by the formulas (see, for example, [21])

$$\hat{x}_i = \frac{1}{2}(x_i^+ + x_i^-), \quad \sigma_i = \frac{1}{2}(x_i^+ - x_i^-), \quad i = 1,2.$$

Definition 2. Let Γ_y^- and Γ_y^+ be such sets that such sets connected by embedding $\Gamma_y^- \subset \Gamma_y \subset \Gamma_y^+$. The predictive sets for $x_1(\bar{t})$ and $x_2(\Theta)$, corresponding to the sets Γ_y^- and Γ_y^+ are called the *lower* and *upper predictive sets*.

Suppose that

$$F(\psi_0, \gamma_1) = (\psi_0 - \overline{\psi})^2 \sigma_0^{-2} +$$

$$+\int_0^{t_1} (\gamma_1(t) - \overline{\gamma}_1(t))^2 q^2(t) dt + \sum_{k=1}^{m} (L_k(\psi_0, \gamma_1) - \overline{\theta}_k)^2 \sigma_k^{-2},$$

where $\overline{\psi} = \frac{1}{2}(\psi_0^+ + \psi_0^-), \sigma_0 = \frac{1}{2}(\psi_0^+ - \psi_0^-), \overline{\theta}_k = \frac{1}{2}(\theta_0^+ + \theta_0^-), \sigma_k = \frac{1}{2}(\theta_k^+ - \theta_k^-).$

Further, consider the sets $\Gamma(\beta_i) = \{(\psi_0, \gamma_1) : F(\psi_0, \gamma_1) \le \beta_i\}$, $i = 1,2.$

Let's choose β_1 and β_2 in such a way that $\Gamma(\beta_1) \subset \Gamma_y$ and $\Gamma(\beta_2) \supset \Gamma_y$. We need to find the lower and upper prediction sets in this case.

Let's introduce a notation $(\hat{\psi}_0, \hat{\gamma}) \in Arg \min_{\psi_0, \gamma_1} F(\psi_0, \gamma_1).$ First, we show that the following statement holds.

Proposition 5. *This equality holds*

$$F(\psi_0, \gamma_1) = F(\hat{\psi}_0, \hat{\gamma}) + F_1(\psi_0 - \hat{\psi}, \gamma_1 - \hat{\gamma}),$$

where $F_1(\psi, \gamma) = \psi_0^2 \sigma_0^{-2} + \int_0^{t_1} \gamma^2(\tau) d\tau + \sum_{k=1}^{m} L_k^2(\psi_0, \gamma) \sigma_0^{-2}.$

Proof. Consider a function $g(\tau) = F(\hat{\psi}_0 + \tau(\psi_0 - \hat{\psi}_0), \hat{\gamma} + \tau(\gamma_1 - \hat{\gamma}))$ and expand such a function into a Taylor series at a point $\tau = 0.$ Then we obtain

$$g(\tau) = g(0) + \frac{1}{2} g''(0) \tau^2.$$

Note that since $(\hat{\psi}_0, \hat{\gamma})$ is the minimum of the function $F(\psi_0, \gamma),$ then $g'(0) = 0.$ Since

$$g(\tau) = (\tau \tilde{\psi}_0 - \overline{\psi})^2 \sigma_0^{-2} +$$

$$+\int_0^{\bar{t}} (\tau \tilde{\gamma}(s) - \overline{\gamma}_1(s))^2 q^2(s) ds + \sum_{k=1}^{m} (\tau L_k(\tilde{\psi}_0, \tilde{\gamma}) - \overline{\theta}_k)^2 \sigma_k^{-2},$$

where $\tilde{\psi}_0 = \psi_0 - \hat{\psi}_0, \tilde{\gamma}(s) = \gamma_1(s) - \hat{\gamma}(s),$ then

$$\frac{1}{2} g''(0) = \sigma_\psi^{-2} \tilde{\psi}_0^2 + \sum_{k=1}^{n} L_k^2(\tilde{\psi}_0, \tilde{\gamma}) \sigma_k^{-2} + \int_0^{t_1} \tilde{\gamma}^2(s) q^2(s) ds.$$

From here we obtain the necessary equality. □

Consequence 2. *We can write sets* $\Gamma(\beta_i)$ *in the form*

$$\Gamma(\beta_i) = \{(\psi_0, \gamma) : F_1(\psi_0 - \hat{\psi}_0, \gamma_1 - \hat{\gamma}) \le \beta_i - F(\hat{\psi}_0, \hat{\gamma})\}.$$

Proof. We obtain that at $\tau = 1$

$$g(1) = g(0) + \frac{1}{2} g''(0).$$

Since $g(1) = F(\psi_0, \gamma_1),$ from the fact that $\frac{1}{2} g''(0) = F_1(\psi_0 - \hat{\psi}_0, \gamma_1 - \hat{\gamma})$ we obtain the necessary equality. □

Lemma 1. *The following equalities hold*

$$\max_{\Gamma(\beta_i)} L(\psi_0, \gamma) = L(\hat{\psi}_0, \hat{\gamma}) + \delta_2(\beta_i - F(\hat{\psi}_0, \hat{\gamma}))^{\frac{1}{2}},$$

$$\min_{\Gamma(\beta_i)} L(\psi_0, \gamma) = L(\hat{\psi}_0, \hat{\gamma}) + \delta_1(\beta_i - F(\hat{\psi}_0, \hat{\gamma}))^{\frac{1}{2}},$$

$$i = 1,2, \quad \delta_1 = \min_{\Gamma_0} L(\psi_0, \gamma), \quad \delta_2 = \max_{\Gamma_0} L(\psi_0, \gamma),$$

$$\Gamma_0 = \{(\psi_0, \gamma) : F_1(\psi_0, \gamma) \le 1\}.$$

Proof. Obviously, if we make a substitution $\psi_0 - \hat{\psi}_0 = \tilde{\psi}_0,\ \gamma_1 - \hat{\gamma} = \tilde{\gamma},$ we get the relation

$$\max_{\Gamma(\beta_i)} L(\psi_0, \gamma) = \max_{\Gamma_1(\beta_i)} L(\psi_0, \gamma) + L(\hat{\psi}_0, \hat{\gamma}) =$$

$$= (\beta_i - F(\hat{\psi}_0, \hat{\gamma}))^{\frac{1}{2}} \max_{\Gamma_0} L(\psi_0, \gamma) + L(\hat{\psi}_0, \hat{\gamma}),$$

where $\Gamma_1(\beta_i) = \{(\psi_0, \gamma) : F_1(\psi_0, \gamma) \le \beta_i - F(\hat{\psi}_0, \hat{\gamma})\}$.

We obtain similar relations for $\min_{\Gamma(\beta_i)} L(\psi_0, \gamma).$

Thus, in order to find predictive estimates, it is necessary to find values $\hat{\psi}_0$ and $\hat{\gamma}$, as well as expressions for δ_1 and δ_2.

Since $(\hat{\psi}_0, \tilde{\gamma}) \in Arg \min F(\psi_0, \gamma_1),$ then these values can be found from the equation

$$\frac{d}{d\tau} F(\hat{\psi}_0 + \tau v_0, \hat{\gamma} + \tau v_1)\Big|_{\tau=0} \equiv 0$$

for arbitrary numbers v_0 and functions $v_1(t)$ integrable with the square on $(0, t_1)$. □

Lemma 2. The following equality is valid

$$\frac{1}{2}\frac{d}{d\tau} F(\hat{\psi}_0 + \tau v_0, \hat{\gamma} + \tau v_1)\Big|_{\tau=0} = (\hat{\psi}_0 - \overline{\psi})\sigma_0^{-2} v_0 +$$

$$+\int_0^{t_1} (\hat{\gamma}(s) - \overline{\gamma}(s)) v_1(s) ds +$$

$$+\sum_{k=1}^{m} (L_k(\hat{\psi}_0, \hat{\gamma}) - \overline{\theta}_k)\sigma_k^{-2} L_k(v_0, v_1),$$

where $L_k(v_0, v_1) = v_0 + \int_0^{t_1} \chi_{[0,t_k]}(s) v_1(s) ds,$ χ is the characteristic function of the interval $[0, t_k]$.

The proof of this Lemma 2 follows from the form of the functional $F(\psi_0, \gamma_1)$.

Proposition 6. *A pair of values $\hat{\psi}_0$ and $\hat{\gamma}(s)$ is a unique solution of a system*

$$\begin{cases} (\hat{\psi}_0 - \overline{\psi})\sigma_0^{-2} + \sum_{k=1}^{m} (L_k(\hat{\psi}_0, \hat{\gamma}) - \overline{\theta}_k)\sigma_k^{-2} = 0, \\ (\hat{\gamma}(s) - \overline{\gamma}(s)) + \sum_{k=1}^{m} (L_k(\hat{\psi}_0, \hat{\gamma}) - \overline{\theta}_k)\sigma_k^{-2} \chi_{[0,t_k]}(s) = 0. \end{cases}$$

Proof. We get these equations if we take into account the expression for the derivative of the function $F(\psi_0, \gamma)$ obtained in the Lemma 2, as well as the arbitrariness of the number v_0 and the function $v_1(s)$.

The uniqueness of the solution of these equations follows from the fact that the quadratic functional $F(\psi_0, \gamma)$ reaches a minimum at a unique point. □

Consequence 3. *The following equality is valid*

$$\hat{\psi}_0 = \left(\sigma_0^{-2} + m\sum_{k=1}^{m} \sigma_k^{-2}\right)^{-1} \left(\sum_{k=1}^{m} \overline{\theta}_k \sigma_k^{-2} - \sum_{k=1}^{m} \sigma_k^{-2} x_k\right),$$

$$\hat{\gamma}(s) = \overline{\gamma}(s) - \sum_{k=1}^{m} (\hat{\psi}_0 + x_k)\sigma_k^{-1} \chi_{[0,t_k]}(s) + \sum_{k=1}^{m} \overline{\theta}_k \sigma_k^{-2} \chi_{[0,t_k]}(s),$$

where numbers $x_k, k = \overline{1,m},$ can be found from the system of equations

$$x_j + \sum_{k=1}^{m} x_k \min(t_k, t_j)\sigma_k^{-2} =$$

$$= \sum_{k=1}^{m} \sigma_k^{-2} \overline{\theta}_k \min(t_k, t_j) - \sum_{k=1}^{m} \min(t_k, t_j)\hat{\psi}_o, j = \overline{1,m}.$$

Proof. The system of linear algebraic equations with respect to variables x_k can be obtained if we put $x_k = \int_0^{t_k} \hat{\gamma}(s) ds.$

Note that in order to find the values δ_1 and δ_2 it is necessary to calculate $\min L(\psi_0, \gamma)$ and $\max L(\psi_0, \gamma)$ on the set $\Gamma_0 = \{(\psi_0, \gamma) : F_1(\psi_0, \gamma) \le 1\}$.

Since the minimum and maximum of these expressions are reached on the boundary of the set Γ_0, there exist Lagrange multipliers λ_1 and λ_2 such that

$$\min L(\psi_0, \gamma) = L(\hat{\psi}(\lambda_1), \hat{\gamma}(\lambda_1)),$$

$$\max L(\psi_0, \gamma) = L(\hat{\psi}_0(\lambda_2), \hat{\gamma}(\lambda_2)),$$

where $\hat{\psi}_0(\lambda_i), \hat{\gamma}(\lambda_i)$ are the extremum points of the function $\mathcal{L}(\psi_0, \gamma) = L(\psi_0, \gamma) + \lambda F_1(\psi_0, \gamma)$ which can be found from the condition

$$\left. \frac{dg_i(t)}{dt} \right|_{t=0} \equiv 0.$$

$\forall v_0, v_1 \quad g_1(t) = \mathcal{L}(\hat{\psi}_0(\lambda) + tv_0, \hat{\gamma}(\lambda) + tv_1),$ and Lagrange multipliers λ_1, λ_2 can be found from the equation $F_1(\hat{\psi}_0(\lambda), \hat{\gamma}(\lambda)) = 1$. □

Let $u(t) = 0$, $\gamma_2(t)$ be an unknown function with the form

$$\gamma_2(t) = (\theta, g(t)) = \sum_{k=1}^{m} \theta_k g_k(t),$$

where $g_k(t)$ are known piecewise continuous functions, $\theta = (\theta_1, ..., \theta_m)^T$ is a vector of unknown parameters. Suppose that the values $y_k = x_2(\tau_k) + v_k,\ k = \overline{1, N},\ t_1 < \tau_k < T$ are given, v_k are unknown values which belong to the interval $I_k = [v_k^-, v_k^+]$.

Definition 3. The set

$$G(\theta) = \{\theta : v_k^- \le y_k - x_2(\tau_k) \le v_k^+, k = \overline{1, N}\}$$

is called the *posterior set* of parameters θ.

Introduce the values $y_k^- = \ln\ln \dfrac{y_k - v_k^+}{\overline{\varphi}_2(t_1)}$, $y_k^+ = \ln\ln \dfrac{y_k - v_k^-}{\varphi_2(t_1)}$, $g_k = \int_{t_1}^{\tau_k} g(\tau) d\tau$, $g_0 = \int_{t_1}^{T} g(\tau) d\tau$. Let θ^+ and θ^- denote the solutions of linear programming problems

$$\max_{\theta \in \bar{G}(\theta)} (\theta, g_0) = (\theta^+, g_0),\ \min_{\theta \in \bar{G}(\theta)} (\theta, g_0) = (\theta^-, g_0),$$

where $\bar{G}(\theta) = \{\theta : y_k^- \le (\theta, g_k) \le y_k^+, k = \overline{1, N}\}$.

Definition 4. The expressions

$$\hat{x}_2(T) = \frac{x_2^+(T) + x_2^-(T)}{2}, \quad \sigma_g = \frac{x_2^+(T) - x_2^-(T)}{2},$$

are called the *guaranteed predictive estimate* (GPE) of the value $x_2(T)$ and the *guaranteed predictive error* (GPEr) respectively, where $x_2^+(T) = \max_{\theta \in G(\theta)} x_2(T), \quad x_2^-(T) = \min_{\theta \in G(\theta)} x_2(T).$

We show that the following statement holds.

Theorem. Assume that the values $y_k, k = \overline{1, N}$ are given with their errors v_k, which belong to the interval I_k. Then equalities hold

$$\hat{x}_2(T) = \frac{1}{2}[\exp \varphi_+(T) + \exp \varphi_-(T)],$$

$$\sigma_g = \frac{1}{2}[\exp \varphi_+(t) - \exp \varphi_-(T)],$$

where $\varphi_+(T) = \varphi(t_1) \exp\{(\hat{\theta}, g_0) + \sigma(\theta)\}$, $\varphi_-(T) = \varphi(t_1) \exp\{(\hat{\theta}, g_0) - \sigma(\theta)\}$, $\hat{\theta} = \frac{1}{2}(\theta^+ + \theta^-)$, $\sigma(\theta) = \frac{1}{2}[(\theta^+, g_0) - (\theta^-, g_0)]$.

Proof. Note that inequalities $v_k^- \le y_k - x_2(\tau_k) \le v_k^+$ can be written as $y_k - v_k^+ \le x_2(\tau_k) \le y_k - v_k^-$. Since $x_2(\tau_k) = \exp \varphi_2(\tau_k)$, then for $\varphi(\tau_k)$ we obtain the inequality

$$\ln(y_k - v_k^+) \le \varphi_2(\tau_k) \le \ln(y_k - v_k^-).$$

Taking into account that $\varphi_2(\tau_k) = \varphi_2(t_1) \exp(\theta, g_k)$ we get that (θ, g_k) satisfies the inequalities $y_k^- \le (\theta, g_k) \le y_k^+$.

Moreover, $\max_{\theta \in G(\theta)} x_2(T) = \max_{\theta \in G(\theta)} x_2(T) = \exp \max_{\theta \in \bar{G}(\theta)} \varphi_2(T) = \exp \varphi_2(t_1) \exp \max_{\theta \in \bar{G}(\theta)} (\theta, g_0)$ and

$$\max_{\theta \in \bar{G}(\theta)} (\theta, g_0) = \frac{1}{2}\left((\theta^+, g_0) + (\theta^-, g_0)\right) + \frac{1}{2}\left((\theta^+, g_0) - (\theta^-, g_0)\right) = (\hat{\theta}, g_0) + \sigma(\theta).$$

Similarly, we obtain the expressions $\min_{\theta \in \bar{G}(\theta)} (\theta, g_0) = (\hat{\theta}, g_0) - \sigma(\theta)$, which means $\min_{\theta \in G(\theta)} x_2(T) = \exp \varphi_-(T)$. Taking these equalities into account, we obtain expressions for $\hat{x}_2(T)$ and σ_g. □

Remark 4. It follows from Theorem that in order to find the GPE $x_2(T)$ and the GPEr $x_2(T)$, it is necessary to find the GPE and the GPEr of the scalar product (θ, g_0) under the condition that the parameter θ belongs to the set $G(\theta)$.
Next, we find approximate the GPE and the GPEr for the value (θ, g_k).

We approximate the set $\bar{G}(\theta)$ by a set $G^-(\theta) = \left\{\theta : \sum_{k=1}^{N} (\hat{y}_k - (\theta, g_k))^2 q_k^{-2} \le 1\right\}$, where $\hat{y}_k = \frac{1}{2}(y_k^+ + y_k^-)$, $q_k = \frac{1}{2}(y_k^+ - y_k^-)$.

Lemma 3. *The following embedding holds* $G^-(\theta) \subset \bar{G}(\theta)$.

Proof. The inequalities $y_k^- \le (\theta, g_k) \le y_k^+$, $k = \overline{1, N}$, can be written in the form $\left|\hat{y}_k - (\theta, g_k)\right| \le q_k$, $k = \overline{1, N}$. From the condition $\sum_{k=1}^{N} \left|\hat{y}_k - (\theta, g_k)\right|^2 q_k^{-2} \le 1$ it follows the condition $|\hat{y}_k - (\theta, g_k)| \le q_k$, which means that $G^-(\theta) \subset \bar{G}(\theta)$. □

Further, let us introduce a matrix $P = \sum_{k=1}^{N} q_k^{-2} g_k g_k^T$. Let us denote by $\hat{\theta}$ the solution of the system of linear algebraic equations $P\hat{\theta} = \sum_{k=1}^{N} q_k^{-2} g_k \hat{y}_k$. Assume that $\det P \ne 0$. Then we show that the following statement holds.

Proposition 7. Approximate guaranteed posterior estimate of the expression (θ, g_0) has the form $(\hat{\theta}, g_0)$. At the same time, the approximate guaranteed posterior error of such an estimate can be written in the form

$$\sigma_H = (P^{-1} g_0, g_0)^{\frac{1}{2}} (1 - F(\hat{\theta}))^{\frac{1}{2}},$$

where

$$F(\theta) = \sum_{k=1}^{N} (\hat{y}_k - (\theta, g_k))^2 q_k^{-2}.$$

Proof. Let $\hat{\theta}$ denote the minimum point of the function $F(\theta)$. From the condition $F'(\hat{\theta}) \equiv 0$ we obtain that $\hat{\theta}$ satisfies the equation $P\hat{\theta} = \sum_{k=1}^{N} q_k^{-2} g_k \hat{y}_k$. Note that the set $\bar{G}(\theta)$ can be written as $\bar{G}(\theta) = \{\theta : F(\theta) \le 1\}$. From the expansion in the Taylor series at the point $\hat{\theta}$ we obtain that

$$F(\theta) = F(\hat{\theta}) + \left(P(\theta - \hat{\theta}), (\theta - \hat{\theta})\right).$$

From here we get

$$\frac{1}{2}\left(\max_{\theta \in \bar{G}(\theta)} (\theta, g) + \min_{\theta \in \bar{G}(\theta)} (\theta, g)\right) = (\hat{\theta}, g),$$

$$\sigma = \frac{1}{2}\left(\max_{\theta \in \bar{G}(\theta)} (\theta, g) - \min_{\theta \in \bar{G}(\theta)} (\theta, g)\right) =$$

$$= \max_{(P\theta, \theta) \le 1} (\theta, g) \left(1 - F(\hat{\theta})\right)^{\frac{1}{2}} = (P^{-1} g, g) \left(1 - F(\hat{\theta})\right)^{\frac{1}{2}},$$

which had to be proved. □

Remark 5. We can get a similar approximate estimate of the scalar product (θ, g_0) and its error when we approximate a set $\bar{G}(\theta)$ by a set

$$G^+(\theta) = \left\{\theta : \sum_{k=1}^{N} (\bar{y}_k - (\theta, g_k))^2 q_k^{-2} \le N\right\}.$$

In this case $\bar{G}(\theta) \subset G^+(\theta)$, and for the approximate guaranteed posterior error we obtain the expression

$$\sigma_H^+ = \left(P^{-1} g_0, g_0\right)^{\frac{1}{2}} \left(N - F(\hat{\theta})\right)^{\frac{1}{2}}.$$

Remark 6. In the case, when the approximate estimates of the scalar product (θ, g_0) and the approximate estimates of errors $\sigma(\theta)$ are given, then the approximate predictive estimate $x_2(T)$ is given in the form

$$\hat{x}_2^{(H)} = \frac{1}{2}\left(\exp \varphi_+^{(H)}(T) + \exp \varphi_-^{(H)}(T)\right),$$

where $\varphi_+^{(H)}(T) = \varphi(t_1) \exp\{(\theta, g_0)_H + \sigma_H(\theta)\}$, $\varphi_-^{(H)}(T) = \varphi(t_1) \exp\{(\theta, g_0)_H - \sigma_H(\theta)\}$, $(\theta, g_0)_H$ is the approximate estimate to (θ, g_0), $\sigma_H(\theta)$ is the approximate error of such an estimate.

Let us further consider the case when $u(t) \ne 0$, and $\gamma(t)$ is a known function.

Let's choose a function $u(t)$ from the condition $y_k = \varphi(s_k), k = \overline{1,N}$, $s_1 < s_2 < ... < s_N$, $s_k \in (t_1, T)$, y_k are given numbers.

Proposition 8. The set U for functions, for which the condition $y_k = \varphi(s_k), k = \overline{1,N}$, holds with given numbers y_k, has the form
$U = \{u : u(t) = u_0(t) + v(t)\}$,
where $u_0(T) = \sum_{k=1}^{N} x_k \Phi_k(t)$, x_k can be found from the system of linear algebraic equations $\sum_{j=1}^{N} b_{kj} x_j = c_k, k = \overline{1,N}$, and $v(t)$ is an arbitrary function from space $L_2(t_1, s_N)$ that satisfies the condition

$$\int_{t_1}^{s_N} \Phi_k(t) v(t) dt = 0, k = \overline{1,N},$$

where $\Phi_k(t) = \exp \int_t^{s_k} \gamma(\tau) d\tau$, $b_{kj} = \int_{t_1}^{s_N} \Phi_k(t)\Phi_j(t)\chi_k(t)\chi_j(t)\, dt$, $c_k = \bar{y}_k - \varphi(t_1)\Phi_k(t_1)$, $\bar{y}_k = \ln y_k$, $\chi_k(t) = \begin{cases} 1, t \in (t_1, s_k) \\ 0, t \notin (t_1, s_k) \end{cases}$.

Proof. Let us rewrite the condition $\varphi(s_k) = y_k$ in the form $\int_{t_1}^{s_k} \Phi_k(t) u(t) dt = c_k, k = \overline{1,N}.$ The solutions of such a system have the form $u(t) = u_0(t) + v(t)$, where $u_0(t) = \sum_{j=1}^{N} x_j \Phi_j(t) \chi_j(t)$, which had to be proved. □

4. Numerical Experiment

Following the form of predictive sets, established by formula (3), the proposed algorithm is tested on synthetic data. We assume that the parameters of the model are stationary. We observe the state x_1 of the first equation of system (1) on the interval $t \in [0,4]$, then on the interval $t \in [4,5]$ we plot the dynamics of the first equation of system (1), which we no longer observe, then on the interval $t \in [5,10]$ we predict x_2 according to the specified parameters of our system (1). The experiment was conducted using Python's libraries *pandas, numpy, math* and *matplotlib.pyplot*.

In formula (3) we put

$\gamma_1 = 0.1$,
$\bar{\gamma}_1 = 0.25$,
$q = 10$,
$\gamma_2 = 0.3$
$u = 0.3$,
$b = 0.5$,
$x_0^- = 0.001$,
$x_0^+ = 0.02$.

Let's find guaranteed estimates for the above parameters

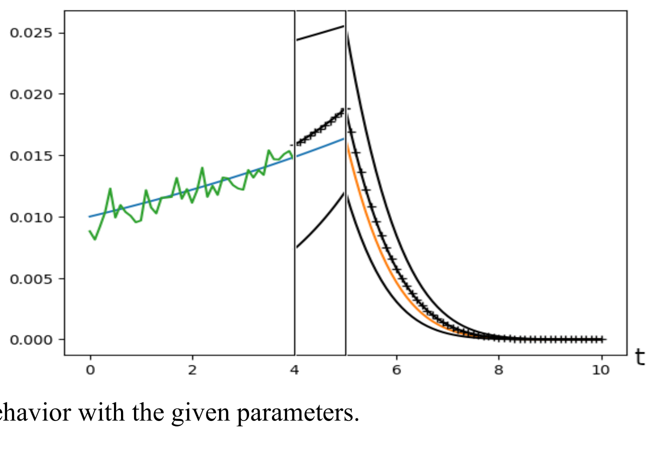

Fig. 1. Graph of system (1) behavior with the given parameters.

On Fig. 1 $x_1(t)$ is in blue, $x_2(t)$ is in orange, observation of $x_1(t)$ is in green. The black dashed curve shows the estimation error, the other black curve shows the predicted estimates of x_1 and x_2.

5. Conclusions

The research provides formulas for calculating predictive estimates of the number of individuals in the population with unknown non-stationary parameters included in the right-hand sides of special nonlinear differential equations. The obtained results can be applied in the tasks of analyzing the dynamics of the number of persons who received certain information, the dynamics of the number of persons with stress syndrome, the dynamics of the number of sick persons during epidemics.

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Intensity Model and Traffic Quality Assessment of the Selected Section of the D1 Highway

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Abstract

This study focuses on analysing the traffic indicators on selected sections of the D1 highway in the direction from Humpolec to Rančířov, with a particular emphasis on the Pávov transportation hub. Data from the nationwide traffic census of 2020 were utilized for calculations, including average daily traffic intensity, average daily load, and transport performance on each section. The capacity of each section was determined and compared to the overall traffic intensity, revealing potential congestion points.
The analysis covers sections 5-8019, 6-8609, 6-1131, 6-1133, 6-1146, 6-1147, and 6-1020, demonstrating a high level of traffic intensity, particularly in terms of heavy motor vehicle traffic volume. The distribution of traffic flow before exit 104 in Větrný Jeníkov into sections 6-1131 and 6-1133 could significantly alleviate temporary traffic congestion. Considering a Mechanized Infantry Brigade comprising 1 320 vehicles, the calculated convoy length would be approximately 70.562 meters, assuming a simple distance of 50 meters between vehicles. This study provides valuable insights for military convoy movement planning and highlights the importance of considering highway traffic conditions for strategic deployments.
The aim of the article is to propose a commercial solution for securing the onward movement of alliance units based on the analysis of traffic intensity in the selected sector of the D1 highway.

KEY WORDS: *D1 Highway, traffic analysis, military convoy movement, transportation hub, traffic congestion, Mechanized Infantry Brigade.*

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1. Introduction

Transport is the intentional movement of means of transport with passengers and goods along transport routes [1], so it is a means of fulfilling mobility needs. It characterizes transport as "the movement of people and goods from a starting point to a designated place" and includes all tools for moving, means of transport, infrastructure, energy and more. [2]. The product of transportation is transportation (relocation), and we therefore understand transportation as relocation through transportation. From the logic of the matter, "it is not possible to store the transport product and cover fluctuations in demand from stocks. These must have transport in the capacity of infrastructure and mobile means" [1].

The transport network is defined by transport routes in the territory, which is composed of transport points. Ending or starting the transport is realized at the transport point, which is a place on the transport routes. From the point of view of passenger transport, a transport point is a point of embarkation, exit or transfer, and for freight transport it is a point of loading, unloading or transhipment of goods.

If an important traffic point is located at the intersection of traffic routes, then it is a traffic node [3]. Transport infrastructure, which is defined by Act No. 183/2006 Coll., on territorial planning and building regulations, defines transport infrastructure "*as transport land, transport structures and related facilities*". At the same time, it is defined that enabling the movement of means of transport along the transport network must be achieved by organizational and technical provision of the transport infrastructure.

Act No. 111/1994 Coll. on road transport defines road transport as "*a set of activities that ensure the transport of people (line passenger transport, shuttle transport, occasional passenger transport, taxi service), animals and goods (freight transport) by vehicles, as well as the movement of vehicles themselves on highways, roads, local roads and publicly accessible purpose-built roads and open terrain*."

Road transport has an irreplaceable place in the transport of people and cargo, and with increasing demands for the implementation of the „Just in Time" method, the demand for the availability and possibility of basic communication routes grows. The current security situation requires carrying out analyses of traffic especially in the west-east direction, especially when using the backbone road D1. Highlands region, the South Moravian region and the Zlín region were selected for the analysis of the current level of permeability.

Mapping the condition of roads is an important activity, which subsequently influences the creation of maintenance, repair and investment plans, also from the perspective of the host country's support for the armed forces of the Allied units.

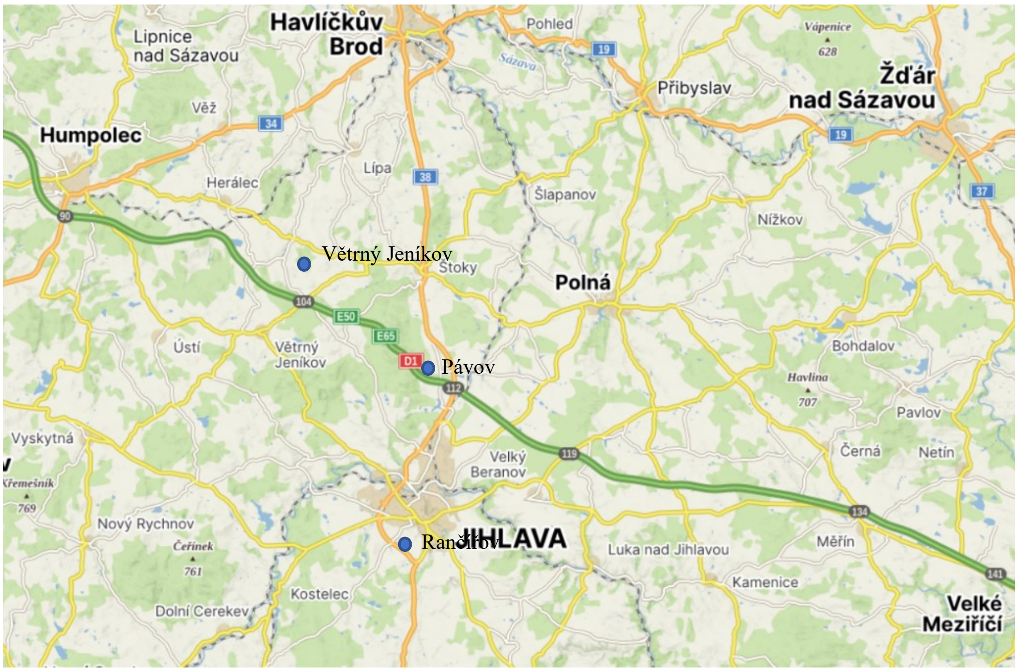

Fig. 1. Highway section D1 Humpolec – Jihlava

In the article, the movement of vehicles in the selected section was modelled, where Pávov represents the traffic point where the highway is left and transport begins in the direction of Rančířov. The authors presented the results of basic statistical data collected during vehicle runs in selected regions of the Czech Republic and the Větrný Jeníkov – Pávov - Měřín (see Fig. 1) section in the period from September to December 2023. The focus of the work is limited to road transport in terms of transport mode and transport infrastructure in terms of transport components. The selected profile of the analysed section is in the range of 691 – 427 meters above sea level.

2. Structure of road transport and indicators of road transport and infrastructure

The road network in the Czech Republic covers the territory of thirteen regions and the capital city of Prague. The total length of road infrastructure in the Czech Republic is 55,761.3 km.

As of 1 January 2022, there are 4.976.5 km of roads in the territory of the Highlands region. The D1 highway crosses the Vysočina region for a length of less than 92.5 km (1.8 %), the I. class road measures 425 km (8.4 %), the II. class almost 1.629 km (32 %) and road III. class of less than 2.937 km (57.8 %). Highlands region therefore owns almost 90 % (4.566 km) of the road network in the region.

As of 1 January, 2022, there are 6.149 km of highways and roads in the territory of the South Moravian Region. Motorways cross the region for a length of less than 74 km (1.2%), class I roads (excluding expressways) measure 646 km, class II roads. class 1.627 km and road III. class of almost 3.800 km. [4].

Condition of road surface II. and III. classes in individual regions rated in the interval of excellent, good, satisfactory, unsatisfactory and emergency.

2.1. Indicators of road transport and infrastructure

Traffic indicators, transport performance, weight of transported cargo, traffic intensity and traffic performance, describe the load on the road network and the impact of traffic on the road transport infrastructure.

Transport capacity in freight transport is calculated by the cost of transporting one ton of cargo over a distance of one kilometer and is calculated according to the formula:

$$P = \sum_{i=1}^{m} q_i lz_i \tag{1}$$

where: P is the transport capacity in freight transport in units of tonne-kilometre (tkm), and q_i is the weigh of i-th cargo transport in tons, lz_i is the transport distance of the *i-th* weight of the cargo in kilometres [4]. The symbol m denotes the number of vehicles [4].

The volume of transported goods is calculated according to the formula:

$$Q = \sum_{i=1}^{m} q_i lz_i \tag{2}$$

where Q is the volume of transported goods - in our case, and q_i is the volume of i-th transpot in a single trip [4].

Traffic intensity is an indicator that tracks the number of vehicles that pass a certain section in a 24-hour time limit. Data collection is carried out through traffic surveys or using automatic traffic counters.

Transport performance evaluates the movement of means of transport (i.e. how many kilometres they travel) regardless of the result of the transport (i.e. the number of people transported or the amount of goods). It is mainly used to determine the capacity of roads and public transport.

Since the mathematical description of the behavior of vehicles on the road is very complicated, we will only focus on the description of one vehicle that drives repeatedly.The formula:

$$^1L = \ ^1L_1 + \ ^1L_0 = nl_Z + \sum_{i=1}^{m} l_{oi} \tag{3}$$

represents the transport work (total distance travelled) of one vehicle for a given operating time [km], $^1L_1$ is the distance travelled by one vehicle on a regular line according to the timetable, or distance travelled with passengers in irregular traffic [km], ^1L_O is the distance travelled by one vehicle without passengers (parking and stopping the vehicle) [km], n is the number of connections of one vehicle during the time of operation on the line, l_Z is the operational length of the line [km], l_{oi} is the distance of the i-th port, i =1, 2, ..m, or parking trips of one vehicle [km], m is the number of port and parking trips [5].

2.2. Analysis of the density of the transport infrastructure of selected regions of the Czech Republic for the transport of armed forces

The assessment of the density of the transport network is calculated depending on the length of the infrastructure and the size of the region. The calculated values are in the following table 1.

Table 1.
Density of transport infrastructure in km/km^2 [4]

	Highway	The expressway	Class I road	Road II. classes	Road III. classes	Railway	In total
Czech Republic	0.010	0.006	0.073	0.185	0.433	0.121	0.828
Highlands region	0.014	0.000	0.063	0.239	0.432	0.092	0.839
South-Moravian region	0.019	0.004	0.059	0.204	0.196	0.109	0.590

2.3. Analysis of selected sections when deploying alliance units

Sections of the D1 highway were selected, which may affect the movement of allied units, especially with a focus on the Pávov traffic point. Data from the national transport census 2020 were used for the calculations. The indicators that were calculated are the following: average daily intensity of the section, average daily load and transport performance on the given section. Subsequently, the capacity of the section was determined and compared with the overall intensity of the section. This revealed the congestion of the given section. Data from the previous intensity analysis were used for the calculations.

2.3.1. Analysis of section 1: Humpolec – Větrný Jeníkov – Jihlava, exit 112

The calculation of this section consists of two sections 5-8019 and 6-8609 (see Fig. 2). The intensity in the given section of interest is described in Table 2.

Table 2.
Fifty-fold hourly intensity for extravillan fivesatiraze and for peak hourly intensity intravillan [6]

Counting section	**5-8019**	**6-8609**
Fifty-fold traffic intensity (heavy motor vehicles) – vehicles/hour	716	760
Peak hourly traffic intensity (heavy motor vehicles) vehicles/hour	0	0
Fifty-fold traffic intensity (all motor vehicles in total) – vehicles/hour	3134	3306
Peak hourly traffic intensity (all motor vehicles in total) vehicles/hour	0	0
Value for heavy goods vehicles	21 779	220823

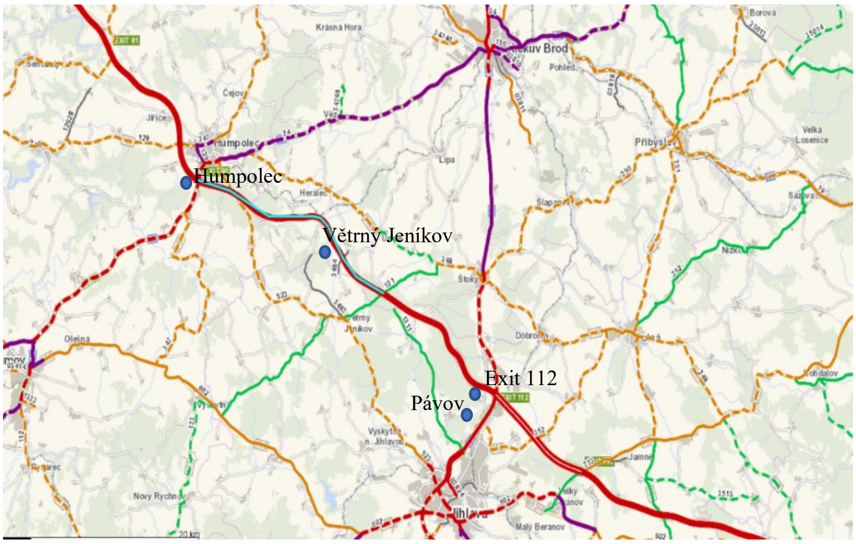

Fig. 2. Highway section D1 Humpolec – Větrný Jeníkov

Counting traffic in the section is implemented for different types of vehicles - light trucks (useful weight up to 3.5 t / total weight up to 7.5 t) without trailers and with trailers (LN), medium trucks (useful weight 3.5 – 10t / gross weight 7.5 – 20t) without trailers (SN), medium trucks (useful weight 3.5 – 10t / gross weight 7.5 – 20t) with trailers (SNP), heavy trucks (useful weight over 10t / total weight over 20t) without trailers (TN), heavy trucks (useful weight over 10t / total weight up to 20t) with trailers (TNP), trailer sets of trucks (NSN), bus (A), articulated buses (AK), tractors without trailers (TR), tractors with trailers (TRP), total heavy motor vehicles (TV), passenger and delivery vehicles without trailers and with trailers (O), single wheel motor vehicles (M), all motor vehicles total (SV) and heavy trucks (TNV).

The following table 3 calculates the annual average of daily traffic intensities (RPDI) for all days, working days and holidays, excluding holidays.

Table 3.
Counting traffic in the section 5-8019 [6]

Annual average traffic intensity		LN	SN	SNP	TN	TNP	NSN	A	AK	TR	TRP	TV	O	M	SV
RPDI – all days	VHC/day	3 773	974	383	248	517	8 018	74	0	0	0	13 967	21 457	27	35 471
RPDI – Mo - Fr	VHC/day	4 121	1 143	447	291	603	9 352	78	0	0	0	16 035	20 767	24	36 826
RPDI - days off, no holidays	VHC/day	2 821	463	191	118	258	4 005	66	0	0	0	7 922	24 966	40	32 928

Hourly traffic intensity is also related to the previous table, where fifty-fold traffic intensity (heavy motor vehicles) is calculated - vehicles/hour, where in our case it is 716 vehicles in total heavy motor vehicles and in the category all motor vehicles total it is a number of 3.134. In the category of heavy trucks, it is a value of 21.779 for Value TNV, based on the number of vehicles per day.

Reducing the load on roads, especially in exits 112 and 104, variants of reducing the intensity of freight traffic were proposed, since freight traffic makes up the majority of the mass load on the roads.

Another area of interest is Větrný Jeníkov, which represents an important traffic point.

The most critical part of the movement is Exit 112 – Jihlava, when the convoy leaves the D1 highway and continues along road 38 (see Fig. 3).

Fig.3. Map of the movement from Exit 112- Jihlava – Rančířov.

If we evaluate the basic traffic indicators, we proceed along the route from the D1 highway to the village of Rančířov, when we analyzed sections 6-1131, 6-1133, 6-1146, 6-1147 and section number 6 -1020, table 4.

In the given case, the main factor is the fifty-fourth and peak hourly intensity, which is based on the intensities measured for the whole year for individual days and in a 60-minute interval.

Table 4.

50-hour intensity for extravillan 50-hour intensity and for intravillan peak hourly intensity [6]

Counting section	**6-1131**	**6-1133**	**6-1135**	**6-1146**	**6-1147**	**6 -1020**
Fifty-fold traffic intensity (heavy motor vehicles) – vehicles/hour	524	524	521	352	290	231
Peak hourly traffic intensity (heavy motor vehicles) vehicles/hour	437	437	435	294	243	193
Fifty-fold traffic intensity (all motor vehicles in total) – vehicles/hour	2434	2434	2825	1383	1134	920
Peak hourly traffic intensity (all motor vehicles in total) vehicles/hour	2032	2032	2359	1154	947	768
Value for heavy goods vehicles	5964	5964	5734	4377	3809	3361

Directorate of Roads and Highways statistical data is an important part of military movement planning, but immediate situational awareness can be enhanced by the use of Movement Control Teams, or a corresponding UAV. Modern UAVs have tracking functions and can contribute to surveillance activities in the implementation of convoy movements. The use of noiseless means enables monitoring of areas of interest – intersections, bridges and tunnels with very low costs.

Testing of unmanned aerial vehicles (UAV) for traffic tracking and analysis is conducted worldwide [7]. Khan et al. [8] systematically reviewed the research studies conducted in UAV traffic monitoring and analysis up to 2016. The development of 5G technologies made it possible to abandon traffic monitoring for fixed-trajectory UAVs. [7]

Table 5.

Counting traffic in the section 6- 8609 [6]

Annual average traffic intensity		**LN**	**SN**	**SNP**	**TN**	**TNP**	**NSN**	**A**	**AK**	**TR**	**TRP**	**TV**	**O**	**M**	**SV**
RPDI – all days	VHC/day	4 084	1 099	453	295	423	8 408	85	0	0	0	14 847	22 497	68	37 412
RPDI – Mo - Fr	VHC/day	4 487	1 298	532	348	496	9 866	89	0	0	0	17 116	21 902	60	39 078
RPDI - days off, no holidays	VHC/day	3 004	514	223	138	208	4 131	74	0	0	0	8 292	25 749	97	34 138

Hourly traffic intensity is also related to the previous table 5, where fifty-fold traffic intensity (heavy motor vehicles) is calculated - vehicles/hour, where in our case it is 760 vehicles in total heavy motor vehicles and in the category all motor vehicles total it is a number of 3,306. In the category of heavy trucks, it is a value of 22,832 for Value TNV, based on the number of vehicles per day.

The analyzed section assumes an exit from the backbone road D1, exit 112 Jihlava, where there is an intersection on section 6-8609, which should not create cross and interweave collision points.

The offered option is to use road 1311 and leave D1 at exit 104 Větrný Jeníkov. If we evaluate the basic traffic indicators, we proceed along the route from the D1 highway to the village of Rančířov, when we analysed sections 6-1131, 6-1133, 6-1146, 6-1147 and section number 6 -1020. In the given case, the main factor is the fifty-fourth and peak hourly intensity, which is based on the intensities measured for the whole year for individual days and in a 60-minute interval.

If we take into account the busyness of the D1 highway, it appears as a possibility to use the exit 104, Větrný Jeníkov.

Table 6.

Counting traffic section 6-6830 [6]

Annual average traffic intensity		**LN**	**SN**	**SNP**	**TN**	**TNP**	**NSN**	**A**	**AK**	**TR**	**TRP**	**TV**	**O**	**M**	**SV**
RPDI – all days	VHC/day	48	12	2	15	2	12	5	0	0	9	105	564	8	677
RPDI – Mo - Fr	VHC/day	56	15	3	19	3	15	6	0	0	11	128	591	8	727
RPDI - days off, no holidays	VHC/day	27	4	1	5	1	4	2	0	0	3	47	496	8	551

Hourly traffic intensity is also related to the previous table 6, where fifty-fold traffic intensity (heavy motor vehicles) is calculated - vehicles/hour, where in our case it is 12 vehicles in total heavy motor vehicles and in the category all motor vehicles total it is a number of 81. In the category of heavy trucks, it is a value of 71 for Value TNV, based on the number of vehicles per day.

3. Creation of traffic flow

A traffic stream is the movement of vehicles behind one another or in lanes next to each other in one direction, so it can consist of several traffic streams. The basic characteristics of the traffic flow are the intensity of the traffic flow, the density of the traffic flow, the time interval between the vehicles and the distance between the vehicles.

The intensity of the traffic flow is the number of traffic units that will pass through a certain transverse profile of the road in 1 direction during the selected time period: I - [car. /h], the traffic flow density represents the number of vehicles that are present in 1 direction on the selected length of road at a given moment: H [vehicles/km]. Another factor is the time gap between the vehicles, which is the time that elapses between the passages of the fronts of two consecutive transport units (vehicles) determined by the traffic profile, and the length gap of the vehicles is the distance between the fronts of the following vehicles at a certain moment.

Hourly traffic intensity is also related to the previous table, where fifty-fold traffic intensity (heavy motor vehicles) is calculated - vehicles/hour, where in our case it is 12 vehicles in total heavy motor vehicles and in the category all motor vehicles total it is a number of 81.

In the category of heavy trucks, it is a value of 21.779 for Value TNV, based on the number of vehicles per day.

4. Traffic flow models

Traffic flow models are used to investigate the behavior of vehicles driving behind each other, i.e. forming a traffic flow. The macroscopic approach is symbolized above all by the so-called fundamental relationships between the speed, density and intensity of the traffic flow. The calculation is made according to the formula:

$$I = V * H \tag{5}$$

where: V- speed [km/hour], H- density [vehicles/km], I- volume [vehicles/hour].

In the calculations of traffic flow models, the Greenshields relationships from 1935 are used, where the relationship between speed and volume and the relationship between speed and density are taken into account.

The trailing vehicle model is defined as the interrelationship between the driving of the vehicle and the driving of the vehicle in front of it. To determine the driving parameters of the vehicle, we use the position x [m], the speed of the vehicle [m/s], the acceleration a [m/s^2] and ryvem j [m/s^3].

We use the position x which depends on the time x=x(t). The speed v and acceleration a can be calculated by means of derivation.

$$v = \frac{dx}{dt} \ ; \ a = \frac{d^2x}{dt^2} = \frac{dv}{\mathrm{dt}} \ ; j = \frac{d^3x}{dt^3} = \frac{d^2v}{dt^2} = \frac{da}{dt} \tag{6}$$

The leading vehicle sets the rhythm of the movement, which is transmitted to the following vehicle. This process has a domino effect on subsequent vehicles. If we evaluate the level of traffic quality according to the technical conditions in the selected section of the road infrastructure, we evaluate the edges and nodes, we start from the document Technical conditions189 – the determination of traffic intensity, which is determined in six levels according to the capacity of a larger number of vehicles than the expected load. Considering the fact that the specified section is satisfactory, we continued with the evaluation of two indicators: the delay time [s] and the number of vehicles.

To determine the traffic intensity, we used the results of the national traffic census for roads of the second and higher classes. The layout of the grade crossing is a key factor for capacity assessment, which is assessed at the points of disconnection, connection and interweaving of vehicles. In this regard, we can also mention the resistance of the network, which can be expressed by the capacity, which represents the simple number of vehicles able to pass through an edge or a node. Here we evaluate the increase in travel time compared to an empty road. The capacity of the road or intersection can be set for one lane as a flat rate in the range of 1.800 to 2.000 vehicles per hour.

The traffic flow models will of course also take into account the commander's requirements, which means that the movement will be carried out unit by unit. The next calculation is based on the division on the main phase, which calculates the relationship between entrances to the intersection and the use of shifting lanes, which have a major impact on the non -collision passage through the intersection.

We have chosen one direction (1) which uses entrances AB (a) and CD (b), the other entrance (2) includes entrances EF (c) (see Fig. 4). A draft signal plan is prepared for each intersection and load levels. Due to the nature of the traffic load used, which does not change over time, it is not possible and necessary to design dynamic control (6).

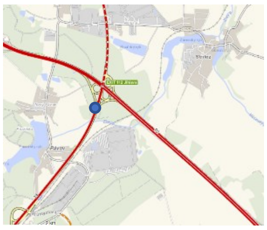
Fig. 4 (a) Section 6-1131 intersection AB


Fig. 4(b) Section 6-1135 – intersection CD

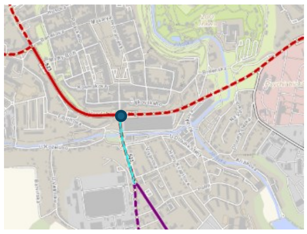
Fig. 4(c) Section 6-7481 – EF (9)

The basic parameters for intersections are Selected cycle time of 80 seconds and Split time-vehicle-vehicle of 4 second. The traffic load of the entire network 4.540 vehicles/h, network extent of 2 intersections and speed between intersections 50 km/h. An optimization algorithm was performed, where we evaluated the optimal time to leave the intersection with a vehicle length of 10 meters for a selected section of the track when commercial traffic stops. If we include the values of normal traffic on the section 6-1135 - intersection CD, the values will be significantly different and with normal commercial traffic and 20 vehicles in the convoy. The numbers and types of vehicles are shown in figure 5.

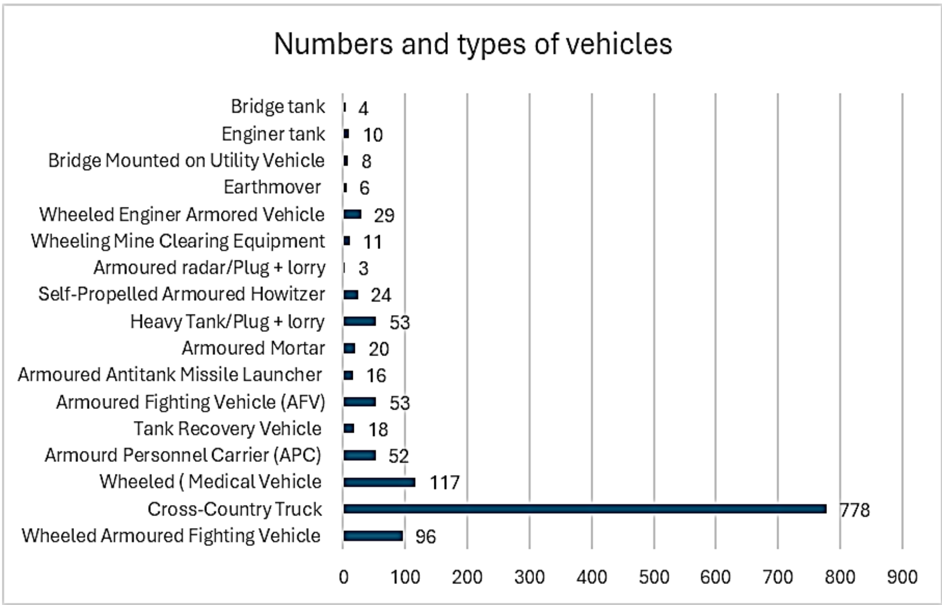

Fig. 5. Overview of transported equipment

5. Conclusions

The analysis of traffic indicators of selected sections of the highway in the direction D1 – Humpolec- Větrný Jeníkov – Jihlava – Rančířov consists of sections 5-8019, 6-8609, 6-1131, 6-1133, 6-1146, 6-1147 and 6-1020 and shows a high level of traffic intensity in selected indicators fifty-four times traffic intensity (heavy motor vehicles) – vehicles/hour and peak hourly traffic intensity (heavy motor vehicles) vehicles/hour. The main recommendation is to use two exits, which means that also using exit 104 Větrný Jeníkov for sections 6-1131 and 6-1133 would significantly reduce the temporary pressure on traffic intensity. If we assume that the Mechanized Infantry Brigade has 1.320 vehicles in its structure, when calculating the length of individual types of vehicles, the length of the column would be 9.975 meters, while keeping a simple distance between vehicles of 50 meters, the length of the column of vehicles would be 60.835 meters, i.e. the calculated total length of the brigade would be 70.562.2 meters.

The Brigade Road March has its own specifics, which are determined by the dimensions of the vehicles and their weight. Limiting factors include speed. Speed limits are described in Table 8.

Table 8.

Estimated speeds of convoys on roads

Features of the road	**Mechanized units**	**Motorized units**
Motor ways	50	60
Rapid roads	40	50
Small roads	30	40
Slow roads	20	30

The Intervals are the timings fixed between the Elements within a Unit Column usually 05 minutes and the gaps are the timings fixed between the Columns (Packages, Battalions or Separate Convos): usually 15 to 30 minutes.

Fig.6. The structure of the Střechov rest area [6]

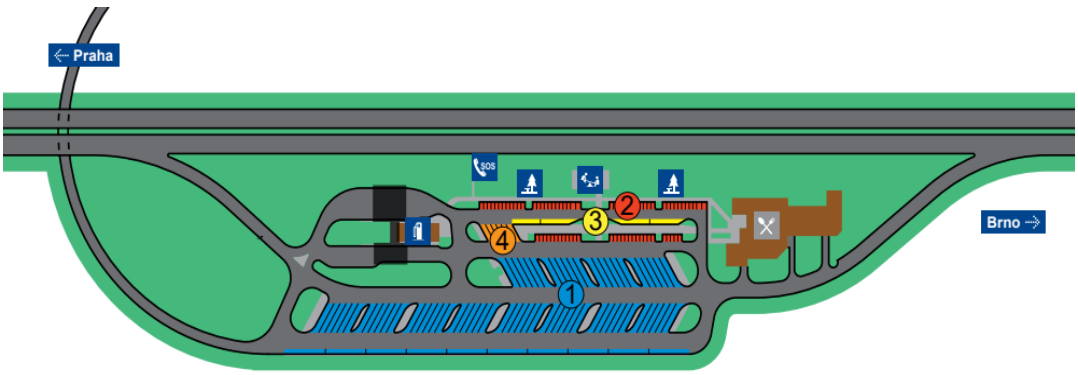

Fig.7. The structure of the Střechov rest area [11]

One of the solutions within the framework of support activities by the host state is the use of the Střechov rest area, which has parking spaces for 98 trucks, 76 passenger vehicles, 4 buses and 6 parking spaces for vehicles with trailers, caravans, and motorhomes.

The rest stop is 52 kilometres in the direction of Prague and is also equipped with a gas station and a restaurant (see Fig. 6). The use of rest periods that are managed by the Roads and Highways Directorate requires an understanding of the fact that support by the host state is not only the responsibility of the Ministry of Defense of the Czech Republic, but of the state, which as an active member of NATO should use all capacities for the safe practice of onward movement in the conditions of the Czech Republic.

The rest area is equipped with catering facilities and a gas station. It can be assessed that the use of the rest area, which is 230 kilometres from the Rozvadov border crossing and 180 kilometres from the Breitenau border crossing, could meet the requirements for a Convoy Support Centre according to the Bi-SC Capability Codes and Capability Statements, which require providing real life support and services (accommodation, catering, sanitary facilities, medical) for up to 750 personnel and sufficient refuelling capacity and parking spaces for 350 vehicles per day (see Fig. 7). These advantages collectively contribute to a more effective and successful operation [9,10].

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Temporal Discontinuity of Defence Investment and Implementation in the Bucharest Nine Countries

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Abstract

This study analyses the timing of acquisitions in B9 countries and shows the time lag that exists between investment and the ability to live up to the technology ordered. Delays in defence acquisitions are observed in the government decision-making and contract execution phases, highlighting the complexity of the procurement process. Despite significant investments, not all countries show an increase in defence capabilities. Acquisition of sophisticated systems appears to be the most time consuming, with significantly greater delays than for simpler systems.

KEY WORDS: *acquisitions; military investments; delays; military equipment; defense capability.*

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1. Introduction

The current security situation is one of the main determinants that influence the level of armaments [1], [2]. Although authors define other important economic factors, such as economic growth, the size of the public sector, or the level of debt, security factors are the primary reason for increasing the amount of resources that are spent on increasing defence capabilities [3]. Currently, in the consequences of the past incidents of 2014, when Russia illegally annexed Crimea, and 2022, when it invaded neighbouring Ukraine, there is a massive increase in military spending in an attempt to increase defence capabilities [4]. The increasing spending is related to both increasing the number of personnel in the armed forces and investing in new equipment, which is an important prerequisite for increasing military capabilities. It is the specifics of the process of purchasing new military equipment that can be identified as one of the limits to the increase in defence capabilities, where the increase in the absolute amount of military expenditure, as well as the increase in the volume of investment, is delayed in the increase in defence capabilities. The time lag in the implementation of defence acquisition can be divided into two basic periods. The first period is associated with the government's decision that a given military equipment can be acquired for the armed forces, and then how the purchase will be implemented. Specifically, there is a delay associated with the process of selecting suitable equipment, where time is needed to specify the need, select the best options and sign the contract. Research in the field of public sector investment confirms that delays caused by the selection but also by other administrative processes are more frequent in public investments [5].

The second period is from the signing of the contract until the delivery of the last piece of ordered military equipment. This period is dependent on a number of variables, the technical level and type of military equipment, whether the military equipment is produced in the country or exported, whether the purchase includes the development of the equipment. For military investment spending in more complex military systems, the lag can increase due to the complexity of the production process or limited production capacity. Defence procurement attracts much attention from politicians and academics because large projects are regularly delayed and their costs far exceed initial estimates.

Delay problems are often associated with the introduction of new technologies. Overall, the defense procurement environment is complex, characterized by uncertainty and significant resource constraints resulting from constantly evolving threat perceptions, limited dissemination of information about new technologies, and defense-related spending [6].

Increasing defence capabilities is a trend throughout the North Atlantic Alliance. The Russian Federation is considered one of the biggest threats due to the aggression in Ukraine. This fact increases the importance of NATO's eastern flanks, specifically the states of the so-called eastern wing. The eastern wing states take the name of the Bucharest Nine (B9), which includes Bulgaria, Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania and Slovakia. This grouping was formally established in November 2015 in Bucharest on the initiative of Romania and Poland. In the following paper, we focus on the problem of the lag effect of defence investments on the defence capabilities of the Bucharest Nine countries. The aim of the paper is to show the time lags of investments on selected projects, which are presented both on specific examples and on aggregated data that are statistically analyzed.

2. Method of Investigation

The research is intended to show the existence of a time lag between the implementation of the investment and its impact on defence capabilities. First, the existence of a relationship between the volume of investment will be investigated and then specific investments in weaponry for the B9 countries will be explored. The statistical analysis will be based on a simple correlation between the volume of investment spending and the Global Military Index (GMI) and then between the volume of investment spending and the Weapons indicator, which is part of the GMI index. The data on investment size for each country comes from the Military Balance+ database, which contains this information for each country and which is based on published data from NATO. The GMI is an established index that quantifies the size of each country's military strength. The GMI score is the sum of the scores from the subcategories evaluated, which are military spending, military personnel, and military equipment. Since the indicator already includes the category of military expenditure, of which investments are a part, the existence of the relationship may be partially distorted. Nevertheless, for us the presence of the other categories is important and due to the fact that military spending in the total GMI score is only one third, we will ignore this fact. Since our primary focus is on military equipment, we will focus separately on the relationship between military investment and the weapons indicator, which is part of the overall GMI score. The weapons indicator is based on data from the Military Balance+ database.

This indicator rates the number of pieces of equipment in each category and their firepower. A limitation of this indicator is that it does not reflect the age and quality/modernity of the equipment. Despite this limitation, we look at the relationship between investment and the change in the weapons indicator. In the context of time lags, which we want to address first, we will examine the relationship between the indicators and the current value of the index. We will then look at the relationship between investment and the indices with a three-year lag and then a five-year lag. In order to illustrate the lag in equipment investment, investment purchases will be presented for each B9 country, by focusing on the time horizon of the entire process from the signing of the purchase to the delivery of the last piece of equipment. Information on each procurement and its process is drawn from the closed Military Balance+ database.

3. The Relationship Between Investment and Defence

The trend in the volume of military investment for each of the B9 countries is shown in Figure 1. This figure shows the growth in the volume of investment after 2014 for all countries except Hungary. In 2019, we find a significant positive fluctuation in investment volume for Romania.

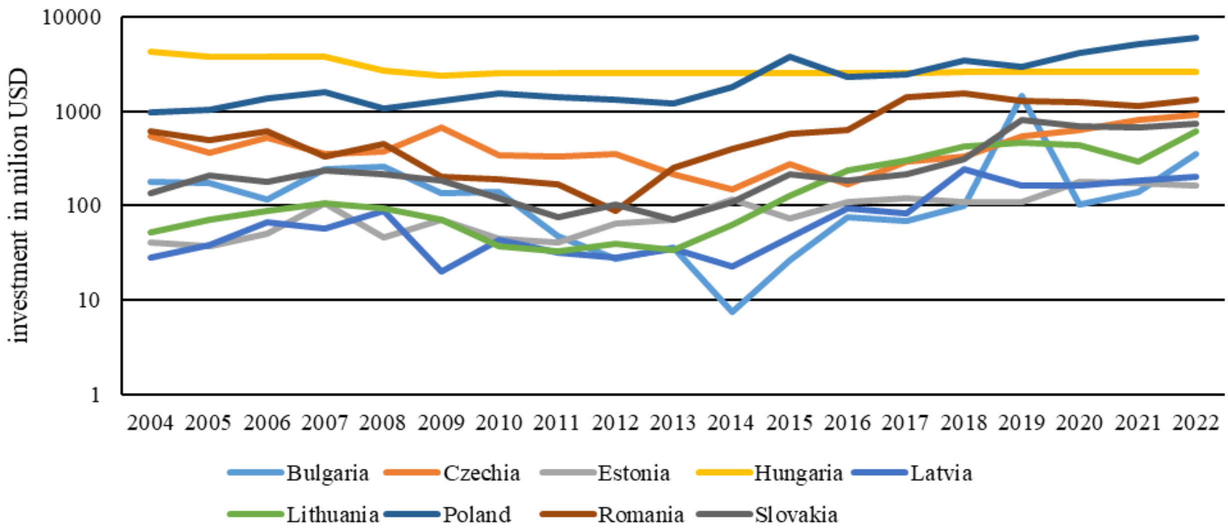

Fig. 1 Military investment 2004-2022 (USD million)
Source: own, data from database Military Balance+ (2024) and GMI index

This fluctuation is due to a large acquisition, which was a unique one-off and for which public budgets were particularly allocated. The importance of investment is both in maintaining existing capabilities and in acquiring new capabilities, respectively greater strength. Figure 2 shows the value of the GMI from 2004 to 2022. Apart from the significant reduction in the value of the GMI for Bulgaria from 2004 to 2012, we do not observe significant fluctuations in the value of this index, despite the fact that, as we have shown earlier, the volume of investment funds has been increasing in recent years.

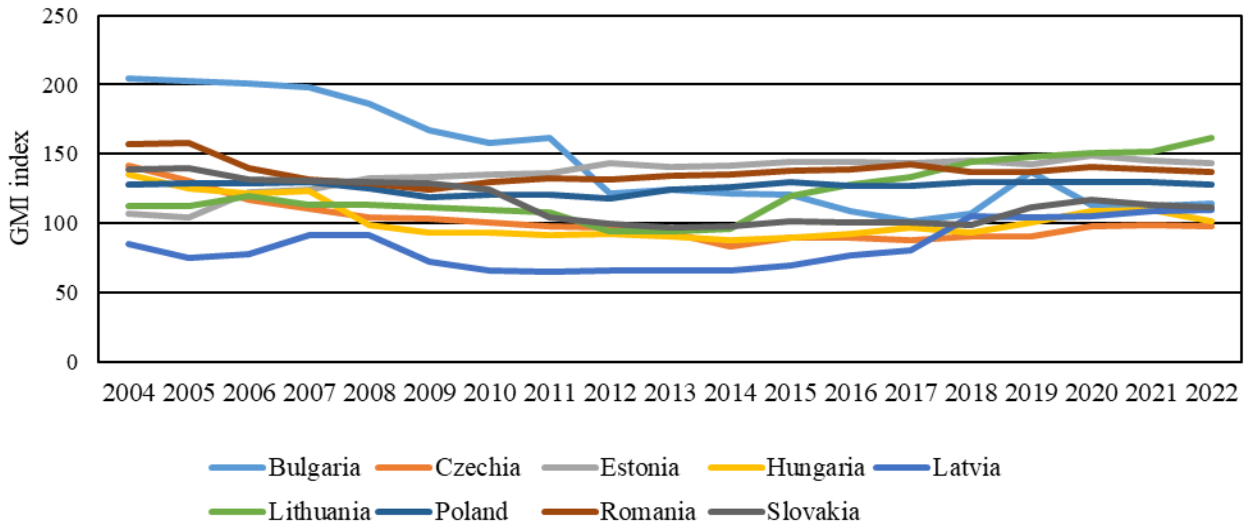

Fig. 2 Global Military Index (GMI) score 2004-2022
Source: own, data from database Military Balance+ (2024) and GMI index

Figure 3 shows the change of the weapon indicator from 2004 to 2022. As with the GMI, we can observe a downward trend in this category for Bulgaria since 2004. On the other hand, in terms of arms strength, Latvia is becoming stronger. However, as we have already mentioned, there may be a time lag over time which we will focus on based on the existence of a statistical relationship.

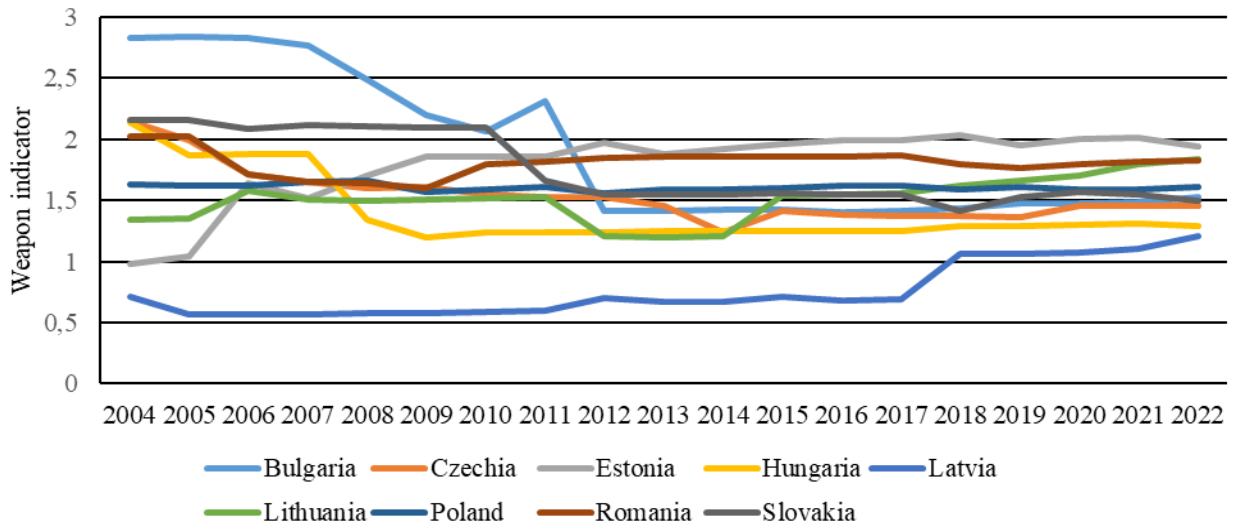

Fig. 3 Weapon indicator score 2004-2022
Source: own, data from database Military Balance+ (2024) and GMI index

Table 1 illustrates for each of the B9 countries the relationship between the GMI index value and the volume of investment. The relationships are observed both with no time lag, a time lag of three years and a time lag of five years. From the observed values, we cannot draw a generally valid relationship for all countries under study. However, we can note that there is a group of three countries, namely Poland, Romania and Slovakia, for which the change in the volume of investment in defence capabilities is not observed either right away or with any time lag. This raises the question of the effectiveness of the resources spent, or the fact that old equipment has been completely phased out in large numbers and new equipment has not yet been put into service. In contrast, a significant relationship between the volume of investment and the GMI index can be observed for the Czechia, Estonia, Hungary and Lithuania. The lag does not appear to be significant in relation to the GMI index, but since we focus on investment and defence capability, Table 2 will be more helpful from this perspective.

Table 1.
Correlation coefficients between change in investment volume and defence capabilities, represented by the GMI

	Relationship without time delay	Relationship with a time delay of 3 years	Relationship with a delay of 5 years
Bulgaria	0,02	-0,01	0,43
Czechia	0,51	0,76	0,57
Estonia	0,62	0,58	0,48
Hungaria	0,97	0,76	0,45
Latvia	0,89	-0,12	-0,40
Lithuania	0,93	0,80	0,47
Poland	0,07	0,24	0,19
Romania	0,31	0,27	-0,19
Slovakia	-0,01	0,17	0,19

Source: own, data from database Military Balance+ (2024) and GMI index

Table 2.
Correlation coeffiicients between change in investment and defence capability as represented by the Weapons Indicator

	Relationship without time delay	Relationship with a time delay of 3 years	Relationship with a delay of 5 years
Bulgaria	-0,05	0,05	0,26
Czechia	0,46	0,76	0,59
Estonia	0,54	0,57	0,43
Hungaria	1,00	0,82	0,58
Latvia	0,89	0,10	-0,38
Lithuania	0,76	0,77	0,48
Poland	-0,14	-0,14	-0,33
Romania	0,10	-0,17	-0,26
Slovakia	-0,37	-0,12	0,16

Source: own, data from database Military Balance+ (2024) and GMI index

In Table 2 we see once again that for Poland, Romania and Slovakia changes in investment are not reflected in the strength of arms. Thus, it is likely that they are only upgrading existing old equipment but not developing new capabilities. A significant relationship between investment and weapon indicator with a three-year lag is evident for the Czechia, Estonia, Hungary and Lithuania. Consequently, for almost half of the B9 countries, spending on weapons is only delayed in terms of defence capabilities. The existence of a relationship is only a partial confirmation of the existence of a lag. To better illustrate the problem, in the next section we present specific acquisitions including their timeframe.

4. Case Studies on Time Lags in Selected Acquisitions in B9 Countries

Defence acquisitions in general attract a lot of attention from politicians and academics as well as the general public, one of the reasons being the long time delays in their implementation and the increase in costs beyond initial estimates. The field of defence procurement is very complex, dependent on the security environment and the political situation, which is linked to the unpredictability of budgets in peacetime, military technologies and equipment are largely not commercially available and are developed according to the current customer requirement, which is linked to long time delays for complex technological solutions. It was mentioned in the introduction of the article that the time lag in the implementation of defence acquisitions can be viewed in two dimensions.

The first period is "pre-acquisition" and is related to certain political decisions about how and when we will meet the needs of the armed forces; there is also a choice of what form, e.g., in the Czech Republic, G2G cooperation has been used recently in major acquisitions. There can be many years of delay in this 'pre-acquisition' phase.

The second period/phase is characterised by the period from the signing of the contract to its completion. This period is dependent on a number of variables, mainly the technical level of the equipment supplied (whether it includes development) and the type of military equipment, it is also important whether the equipment in demand is produced in-country, and last but not least, it is largely influenced by the current security situation, with manufacturers operating in peacetime mode, i.e. manufacturers do not hold large stocks of raw materials, components and finished products [7].

An overview of selected acquisitions for the B9 countries with their timing will follow in the text. For each B9 member, their current political and security approach to acquisitions is first discussed; in the wake of the Russian invasion of Ukraine, the vast majority of members have reassessed their strategic security documents, long-term acquisition plans, and related acquisitions. The tables focus on the period/stage from the signing of the contact to the scheduled delivery of the last item (also graphically), showing both domestic and export acquisitions. It is clear from the data that the more sophisticated the system, the longer it takes to deliver; for aerospace systems, this can be more than 10 years.

4.1. Bulgaria

Bulgaria joined NATO in 2004, three years before it acceded to the European Union (EU). As early as 2021, the country is focusing on rearmament and modernisation of existing equipment, and further focusing on artificial intelligence and cyber capabilities. A new *National Defence Strategy* for the Republic of Bulgaria was published in autumn 2023. The time horizon of the strategy is “until 2033”, leaving the possibility to be updated according to changes in the security environment. The document stresses that Bulgaria's defence is only possible within the framework of NATO's collective defence and the European Union's Common Security and Defence Policy, it follows that the fulfilment of allied commitments is crucial for the country's defence. The document also states that Russia is the greatest threat to the country's national security, regardless of the outcome of the war in Ukraine [8]. Currently, Bulgaria's airspace is protected by the NATO Air Policing Mission due to the limited number of fighter aircraft in the country, with new F-16 Block 70/72 aircraft replacing the outdated MIG-29s. The progress of this acquisition is shown in table 3, along with other selected acquisitions that focus on the integration of new technologies and a higher level of interoperability (transition to Western technology).

Table 3.

Overview of selected acquisitions in Bulgaria

Classification	Designation	Original Qty	Order Date	First Delivery	Contract Completion	Period of realization (Y)	In-country production
FGA	F-16 C/D Block 70/72	8	2019	2025	2027	9	No
FSGHM	MMPV 90	2	2020	2025	2027	8	Yes
MHO	Alkmaar	2	2019	2020	2020	2	Yes

Designation	Year																			
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
F-16 C/D Block 70/72																				
MMPK corvettes																				
Alkmaar																				

Source: own processing, data from database Military Balance+ (2024)

Legend:

- Order date
- From first delivery to contract completion
- Order date and first delivery same year
- Not classified end of contract

4.2. Czechia

Czechia has been a member of NATO since 1999 and a member of the EU since 2024. In the long term, Russia will pose the most serious security threat to Czechia and its allies. The war in Ukraine has confirmed the absolute necessity of our active membership in NATO. The priority task for the armed forces is therefore to build a well-armed, equipped, trained and combat-sustainable force deployable in collective defence operations. The defence and security industry is one of the pillars of defence, particularly in ensuring security of supply and combat sustainability of the armed forces [9]. The Armed Forces, of which the Army of the Czech Republic is the main fighting force, are built on an all-military principle and with an emphasis on a combination of technological maturity and robustness. The main objective of the acquisitions is to acquire modern combat systems, including unmanned systems, and to have the ability to operate with precision-guided munitions at long range. The acquisition effort is presented in Table 4.

Table 4.

Overview of selected acquisitions in Czechia

Classification	Designation	Original Qty	Order Date	First Delivery	Contract Completion	Period of realization (Y)	In-country production
IFV	CV9030	246	2023	2026	2030	8	Partly
AH	AH-1Z Viper	4	2019	2023	2024	6	No
LTH	UH-1Y Venom	8	2019	2023	2024	6	No
155mm SPH	CEASAR	52	2021	2024	2026	5	Partly
AUV	TITUS	62	2019	2022	2023	5	Partly
FGA	F-35A Lightning II	24	2024	2031	2034	11	No

Designation	Year																			
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
CV9030																				
AH-1Z Viper																				
UH-1Y Venom																				
CEASAR																				
TITUS																				
F-35A Lightning II																				

Source: own processing, data from database Military Balance+ (2024)

4.3. Estonia

Estonia has a small active armed force and has relied on NATO membership as a security guarantee since 2004. Russia has long been Tallinn's main security concern; as a result of the Russian invasion of Ukraine, it has increased defence spending and transferred large amounts of military equipment to Ukraine. The current National Defence Development Plan for 2031, adopted in December 2021, focuses on improving territorial defence and increasing capabilities such as anti-tank defence, strengthening naval and surveillance systems [10]. Estonia is acquiring missile artillery systems from the US, medium-range air defence systems with Latvia and air defence systems with Poland. It has also joined the German-led European Sky Shield initiative, which aims to strengthen air defence capabilities across the region. Upgrade spending is also intended to improve infrastructure and readiness, see Table 5 for an overview of selected acquisitions.

Table 5.

Overview of selected acquisitions in Estonia

Classification	Designation	Original Qty	Order Date	First Delivery	Contract Completion	Period of realization (Y)	In-country production
155mm SPH	K-9 howitzer	12	2018	2020	2023	6	No
PBF	Patrol 19 WP SAR	3	2022	2023	2023	2	Yes
MANPADS	Mistral 3	n.k	2018	2020	2020	3	No
227mm MRL	M142 HIMARS	6	2022	2024	n.k	více 3	No
APC	Arma	n.k	2023	2024	2025	3	No
MANPADS	Piorun	100	2022	2023	2025	4	No

Designation	Year																			
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
K-9 howitzer																				
Patrol 19 WP SAR																				
Mistral 3																				
M142 HIMARS																				
Arma																				
Piorun																				

Source: own processing, data from database Military Balance+ (2024)

4.4. Hungary

Hungary has been a NATO member since 1999 and a member since 2004. Hungary has long had a different stance on the war in Ukraine from that of the EU; the country's leadership, headed by Orbán, is pro-Russian, hence the different views on security and foreign policy objectives. Hungary's security strategy notes that the security environment is deteriorating, but also characterises mass migration as a key problem for Hungary [11]. On the other hand, the Hungarian defence forces are being modernised, with purchases of NASAMS air defence systems and PzH 2000 artillery, for example. Modernisations are focused on Western equipment to ensure cooperation within NATO and the EU. An overview of selected acquisitions is given in Table 6.

Table 6.

Overview of selected acquisitions in Hungary

Classification	Designation	Original Qty	Order Date	First Delivery	Contract Completion	Period of realization (Y)	In-country production
IFV	KF41 Lynx	209	2020	2022	2027	8	Yes
Medium TPTA	KC-390 Millennium	2	2020	2023	2024	5	No
MBT	Leopard 2A7+ (2A7HU)	44	2018	2023	2025	8	No
MR SAM	NASAMS III	26	2020	2023	2023	4	No

Designation	Year																			
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
KF41 Lynx																				
KC-390 Millennium																				
Leopard 2A7+ (2A7HU)																				
NASAMS III																				

Source: own processing, data from database Military Balance+ (2024)

4.5. Latvia

Latvia has been a NATO member since 2024 and, like the other Baltic States, relies on the security guarantees that NATO membership brings. Russia is Latvia's primary security concern and following Russia's invasion of Ukraine, Latvia has increased its defence spending. Since 2023, a new National Security Concept has been in force, which focuses on and emphasises societal resilience, comprehensive defence and the importance of border protection. Furthermore, Latvia plans to significantly increase the size of its armed forces. Latvia has recently increased its artillery capability with used howitzers from Austria and is acquiring medium-range air defence together with Estonia, see Table 7 for an overview of other acquisitions.

Table 7.

Overview of selected acquisitions in Latvia

Classification	Designation	Original Qty	Order Date	First Delivery	Contract Completion	Period of realization (Y)	In-country production
IFV	Patria 6x6 (XA-300)	200	2021	2021	2029	9	No
MHO	Imanta	3	2020	2021	2024	5	No
155mm SPH	M109A5ÖE	147	2017	2017	2018	2	No
ARV	FV107 Scimitar	74	2019	2020	n.k	over 2	No

Designation	Year																			
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Patria 6x6 (XA-300)																				
Imanta																				
M109A5ÖE																				
FV107 Scimitar																				

Source: own processing, data from database Military Balance+ (2024)

4.6. Lithuania

Lithuania has been a member of NATO since 2004 and, like the other Baltic states, relies on its NATO membership. In 2021, the country adopted a new national security strategy that reflects the deteriorating security environment in the region – Russia is the country's dominant security concern. In response to Russia's attack on Ukraine, Lithuania is increasing defense spending, and revising the parliament's 2018 10-year program for the development of the national defense system. At the same time, Vilnius wants to improve preparedness and reform the mobilization system, so the government has raised the upper limit on the number of conscripts. The government is planning major improvements to its defense infrastructure, and the country has joined the German-led European Sky Shield. Vilnius is modernising other parts of its defence capacity, notably the purchase of CAESAR artillery systems, see Table 8 for further developments. In early 2023, the head of the armed forces announced plans to transform a mechanised infantry battalion into a tank battalion [12].

Table 8.

Overview of selected acquisitions in Lithuania

Classification	Designation	Original Qty	Order Date	First Delivery	Contract Completion	Period of realization (Y)	In-country production
AUV	JLTV	200	2021	2021	2023	3	No
155mm SPH	CEASAR	18	2022	2026	2027	6	No
Medium TPTH	UH-60M Black Hawk	4	2020	2024	2025	6	No
120 mm Mortar	Expal 120-MX2-SM	n.k	2022	2023	2024	3	No
155mm SPH	PzH 2000	21	2015	2016	2019	5	No
IFV	Boxer (Vilkas)	91	2016	2017	2024	9	No

Designation	Year																			
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
JLTV																				
CEASAR																				
UH-60M Black Hawk																				
Expal 120-MX2-SM																				
PzH 2000																				
Boxer (Vilkas)																				

Source: own processing, data from database Military Balance+ (2024)

4.7. Poland

Poland has been a member of NATO since 1999, and the main pillars of Polish defence policy include ground defence and NATO membership. The 2017-32 Defence Concept focuses primarily on preparing the armed forces to deter Russian aggression.

Table 9.

Overview of selected acquisitions in Poland

Classification	Designation	Original Qty	Order Date	First Delivery	Contract Completion	Period of realization (Y)	In-country production
155mm SPH	Krab	96	2016	2019	2024	8	Partly
FGA	F-35A Lightning II	32	2020	2024	2030	11	No
MBT	M1A2 SEPv3 Abrams	250	2022	2025	2026	5	No
LR SAM	M903 Patriot	48	2023	2026	2029	7	No
MBT	Hyundai Rotem K2	180	2022	2022	2025	4	No
FGA	FA-50 Fighting Eagle	48	2022	2023	2028	7	No
239mm MRL	K239 Chunmoo	218	2022	2023	2027	6	No

Designation	Year																			
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Krab																				
F-35A Lightning II																				
M1A2 SEPv3 Abrams																				
M903 Patriot																				
Hyundai Rotem K2																				
FA-50 Fighting Eagle																				
K239 Chunmoo																				

Source: own processing, data from database Military Balance+ (2024)

Russia is thus characterised as a direct threat to Poland, a position that is accentuated in the context of a Russian invasion of Ukraine in February 2022. Other important tasks of the Polish armed forces include protecting the border with Belarus. Poland is one of the leading contributors of military assistance to Ukraine within Europe. Warsaw is gradually increasing defence spending and supporting modernisation projects. There are plans to increase the number of personnel to 300,000 by 2035, as well as to establish new divisions. Already in 2019, a technical modernization plan for the period 2021-35 was published; modernization efforts include, for example, the F-35A fighter aircraft; a summary of other acquisitions is provided in Table 9 [13]. Poland continues to work on strengthening its defence industrial base, much of which is now consolidated in the state-owned PGZ holding company.

4.8. Romania

Romania has been a member of NATO since 2004, and the Romanian armed forces are structured to provide territorial defence, support NATO and EU missions.According to the National Defence Strategy 2020-2024, the main security threats include Russia's increased presence in the Black Sea, hybrid warfare, cyber-attacks and terrorism. Bucharest has said it is increasing defence spending to 2.5% of GDP in 2023. The military inventory is largely made up of Soviet-era equipment, which limits its capabilities, so as part of the armed forces transformation programme, updated in 2022, the authorities are seeking to modernise and upgrade the military to NATO standards. In 2023, Romania agreed to purchase F-35 Lightning II fighter jets and Bayraktar TB2 drones from Turkey; see Table 10 for a summary of other acquisitions.

Table 10.

Overview of selected acquisitions in Romania

Classification	Designation	Original Qty	Order Date	First Delivery	Contract Completion	Period of realization (Y)	In-country production
227mm MRL	M142 HIMARS	54	2018	2021	2024	6	No
SAM	M903 Patriot PAC-3 MSE	28	2017	2020	2026	9	No
FGA	F-16 Fighting Falcon	32	2022	2023	2024	3	No
IFV	Piranha V IFV	227	2018	2020	n.k	over 3	Partly
Medium TPTA	C-130H Hercules	2	2022	2023	2023	2	No

Designation	Year																			
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
M142 HIMARS																				
M903 Patriot																				
F-16 Fighting Falcon																				
Piranha V IFV																				
C-130H Hercules																				

Source: own processing, data from database Military Balance+ (2024)

4.9. Slovakia

Slovakia has been a member of NATO since 2004 and has been working to modernise its armed forces and replace outdated equipment.

Table 11.

Overview of selected acquisitions in Slovakia

Classification	Designation	Original Qty	Order Date	First Delivery	Contract Completion	Period of realization (Y)	In-country production
IFV	CV9035	152	2022	2025	2028	7	Partly
IFV	Patria AMV	76	2022	2023	2027	6	Partly
FGAA	F-16 C/D Block 70	14	2018	2024	n.k	over 7	No
Medium TPTH	UH-60M Black Hawk	9	2015	2017	2020	6	No

Designation	Year																			
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
CV9035																				
Patria AMV																				
F-16 C/D Block 70																				
UH-60M Black Hawk																				

Source: own processing, data from database Military Balance+ (2024)

Bratislava signed a defence cooperation agreement with the US in 2011 and, under the Foreign Military Financing Programme, Slovakia has been allocated funds to help replace some of the military equipment sent to Ukraine after the Russian invasion (Germany supplied, for example, the MBT Leopard 2A4).

Since 2023, there has been a change of political direction in Slovakia (government and president) and an unclear view of the conflict in Ukraine, partly reminiscent of the situation in Hungary. Part of the Slovak defence industrial base is organised within the state-controlled holding DMD Group, including KONSTRUKTA Defence, which produces ground systems. The most anticipated acquisition is the delivery of F-16 C/D Block 70 aircraft, which are expected to arrive this year; other acquisitions are listed in Table 11.

5. Conclusions

An examination of acquisition timelines in the B9 countries shows common trends, particularly in terms of extending the lead time for advanced military systems. Delays in defence acquisitions occur at two distinct times: the government decision-making phase and the contract execution phase until delivery of the ordered military equipment. These delays, which in some cases last several years, underline the complex nature of the defence procurement process.

On the one hand, the research conducted in this paper shows that investment does not always translate into increased defence capabilities. Among the Bucharest Nine countries studied, Poland, Romania and Slovakia do not show any change in the volume of investment. On the other hand, countries such as the Czechia, Estonia, Hungary and Lithuania show a significant change in investment spending only with a three-year delay. Statistically, a comparison of the change in investment volume and the change in defence capability does not support the generally valid claim of a lag.

On the other hand, it is possible to show, using specific examples for each of the Bucharest Nine countries, a delay in the purchase of more complex military equipment. One of the key factors contributing to these delays is the way the defence industry operates, with some manufacturers maintaining a relaxed approach to the supply chain, which limits their ability to produce quickly or increase production volumes. In the wake of the Russian invasion of Ukraine, demand for military equipment has increased rapidly, and the arms industry is trying to respond by moving to 'wartime' production with government support, for example the French company Nexter has increased production of 155mm howitzers to 8 systems per month (it was producing 2 systems per month in 2022).

From the data used in the article on the length of individual military acquisitions, it is clear that in general the most time consuming are the sophisticated systems, these are mainly in the categories of fighter aircraft, battleships, aircraft carriers, submarines, one example for all is the delivery time of the F-35 Lightning II, which is around 10 years, from ordering and until the last unit is delivered.

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The Impact of Military Expenditures on the Indebtedness of the Czech Republic and Lithuania

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Abstract

While several studies have examined the relationship between military expenditures and economic growth, only few studies have focused on the nexus between these expenditures and indebtedness. The authors have been focused on the analysis of the impact of military expenditures on the indebtedness of the Czech Republic and Lithuania over the period 1999-2022. The aim of the paper is to investigate whether the increase in military expenditures has an impact on the countries' indebtedness. The authors have used nine variables characterizing the economic development to identify the relationship between the trends in military expenditures and economic indebtedness based on the results of the estimated models. The results of the correlation analysis showed the expected effect only in the case of Lithuania. The results of the estimated ARDL model did not show the effect of military expenditures on the countries´ indebtedness.

KEY WORDS: *military expenditures, indebtedness, correlation analysis, ARDL model.*

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1. Introduction

The development of the economic environment characterized by gross domestic product, inflation, budget deficit or the level of indebtedness is one of the so-called economic determinants of military expenditures, which is the subject of a number of empirical studies examining the influence of defined factors on the size of military expenditures. The changing security situation in Europe brings a natural pressure for an increase in military expenditures, which, however, especially for many European economies suffering from government budget deficits, naturally leads to an increase in the country's indebtedness. The authors of this paper build on previous research and through an estimated ARDL model analyze the relationship between military expenditures and indebtedness of the Czech Republic and Lithuania over the period 1999-2022 by using nine variables characterizing the economic development. The analysis itself follows the work of Smyth and Narayan (2009) that focused on observing the effect of military expenditures on the external indebtedness of 6 Middle Eastern countries, where a panel study confirmed the relationship between these variables. Sheikh et al. (2013) further observed the relationship between defense expenditures and debt for two rival neighboring countries, Pakistan and India, concluding that funding of significant military expenditures strongly affects the debt of both countries. The following findings by Azam and Feng (2015) confirm the negative impact of military expenditures on external debt accumulation for 10 selected Asian countries. Similarly, empirical results from a study by Khan et al. (2021) found that military expenditures by 35 arms-importing countries increase foreign indebtedness. Çolak and Özkaya (2020) also confirmed the weakening impact of military expenditures on economic performance and indebtedness of 12 transition economies. To analyze the relationship between military expenditures and the size of economic indebtedness of the Czech Republic and Lithuania, the authors of the paper use nine variables characterizing the economic development of the two countries analyzed in order to identify the relationship between the trends in military expenditures and economic indebtedness based on the results of the estimated model.

Results from studies which observe the relationship between military expenditures and external debt are mixed. The contribution of this study is that it continues with the newest findings for two countries in the period where it has not been statistically analyzed.

2. Method of investigation

For the analysis itself, the authors of the paper use correlation analysis and the ARDL model (Pesaran and Shin, 1999) examining the link between the indebtedness of the economy and selected economic characteristics, namely military expenditures, GDP, exports, imports, total government spending, total investment, foreign investment and inflation.

Economic variables were chosen to estimate the model in accordance with the findings of the above mentioned studies. It is examined whether the increase in military expenditure affects the level of indebtedness of both countries. In general, the effect of military expenditures on indebtedness can be expected for several reasons. First of all, military expenditures are financed by the government budget as a pure public good. It can be expected that if there is a need to increase military expenditures, the need for financing by foreign borrowing may arise from some point. The other input variables chosen were imports and exports, which also affect external indebtedness as a consequence of foreign trade transactions. The authors also address the relationship between overall macroeconomic stability and external indebtedness by considering GDP, total investment, consumer price index and inflation rate.

The authors used an autoregressive distributed lag model ARDL(p, q_1, q_2, ..., q_k), where p is the number of lags of the dependent variable Y_t, $q_1, q_2, \dots, q_k$ are numbers of lags of explanatory variables X_{it}, $i = 1,2,\dots,k$. The model can be written as

$$Y_t = \alpha + \sum_{i=1}^{p} \gamma_i Y_{t-i} + \sum_{j=1}^{k} \sum_{i=0}^{q_j} \beta_{j,i} X_{j,t-i} + \varepsilon_t, \tag{1}$$

where ε_t is a one-dimensional zero mean error term. The model can be transformed into a long-run representation that demonstrates the dependent variable's response to a change in the explanatory variables over time (Baltagi, 2011; Mills, 2019). The long run estimates are given by (Pesaran and Shin, 1999; Pesaran et al. 2001)

$$\hat{\theta}_j = \frac{\sum_{i=1}^{q_j} \hat{\beta}_{j,i}}{1-\sum_{i=1}^{p} \hat{\gamma}_i}. \tag{2}$$

The ARDL approach not only provides a dynamic description but also allows for testing of cointegration. The cointegrated system of time series can be estimated as an ARDL model (Pesaran and Shin, 1999) with the advantage that variables in the cointegrating relationship can be either $I(0)$ or $I(1)$ without needing to specify which are $I(0)$ or $I(1)$. For cointegration analysis, we use the form of (1) in differences.

$$\Delta Y_t = \sum_{i=1}^{p-1} \gamma_i^* \Delta Y_{t-i} + \sum_{j=1}^{k} \sum_{i=0}^{q_j-1} \beta_{j,i}^* \Delta X_{j,t-i} - \hat{\phi} EC_{t-1} + \varepsilon_t, \tag{3}$$

where $EC_t = Y_t - \hat{\alpha} - \sum_{j=1}^{k} \hat{\theta}_j X_{j,t}$, and $\hat{\phi} = 1 - \sum_{i=1}^{p} \hat{\gamma}_i$. (Pesaran et al., 2001) proposed a methodology for testing existence of long-run relationship between independent variable and regressors. For so called bounds testing they use the following representation of (3)

$$\Delta Y_t = \sum_{i=1}^{p-1} \gamma_i^* \Delta Y_{t-i} + \sum_{j=1}^{k} \sum_{i=0}^{q_j-1} \beta_{j,i}^* \Delta X_{j,t-i} - \rho Y_{t-1} - \alpha - \sum_{j=1}^{k} \delta_j X_{j,t-1} + \varepsilon_t. \tag{4}$$

The test for existence of long-run relationship is a test of $\rho = 0$ and $\delta_1 = \delta_2 = \cdots = \delta_k = 0$. The distribution of the test statistic based on (4) depends on the fact whether the regressors are $I(0)$ or $I(1)$. (Pesaran et al., 2001) provide critical values for the cases where all regressors are $I(0)$ and the cases where all regressors are $I(1)$. These critical values are used as bound for the more typical cases where the regressors are a mixture of $I(0)$ and $I(1)$.

3. Investigation Results

Based on previous research, the paper analyze the relationship between military expenditures and indebtedness of the Czech Republic and Lithuania over the period 1999-2022 by using selected variables characterizing the economic development (government indebtedness, military expenditures, GDP, exports, imports, total government spending, total investment, foreign investment and inflation). To investigate mainly the association between military expenditures and external debt in the context of the two above mentioned countries the authors used data from the time period 1999-2022, that is sufficient time frame to examine the relationship. The main source of the data of variables was International Monetary Fund. Table 1 contains the basic descriptive characteristics of the studied variables.

Table 1.

Descriptive statistics

Czech Republic	**n**	**Mean**	**Min**	**Max**	**Median**	**$Q_{0.25}$**	**$Q_{0.75}$**	**St. deviation**	**Skewness**	**Kurtosis**
Debt	24	18.53	- 1.26	29.92	19.75	13.61	26.5	9.39	- 0.63	- 0.73
Milex	24	1.37	0.95	1.89	1.32	1.07	1.72	0.34	0.32	- 1.49
GDPpc	24	33588.19	24026.62	41061.76	33998.56	30067.44	37528.05	5226.36	- 0.28	- 1.1
Export	24	7.19	- 9.83	29.68	7.05	4.09	9.83	8.08	0.37	1.12
Import	24	7.03	- 11.08	25.59	6.5	3.09	11.73	7.56	- 0.21	0.76
Gov.exp	24	42.85	38.98	49.12	42.5	41.01	44.43	2.45	0.73	- 0.03
Total.invest	24	28.76	25.01	32.39	28.77	26.69	30.44	2.33	0.11	- 1.5
Foreing.invest	24	5.05	0.9	10.34	4.54	3.47	5.96	2.61	0.64	- 0.64
Inflation	24	2.87	0.12	15.1	2.3	1.46	3.19	2.98	2.84	9.03

Lithuania	n	Mean	Min	Max	Median	$Q_{0.25}$	$Q_{0.75}$	St. deviation	Skewness	Kurtosis
Debt	24	23.24	7.89	40.86	27.01	10.68	33.14	11.69	- 0.07	- 1.79
Milex	24	1.32	0.76	2.52	1.16	1.05	1.54	0.47	0.89	- 0.25
GDPpc	24	26542.95	13285.19	39896.01	26427.33	20636.11	32446.92	8187.15	0	- 1.21
Export	24	7.95	- 16.37	21.21	9.81	3.87	13.78	9.23	- 1.05	0.73
Import	24	7.56	- 28.65	19.9	10	5.12	14.53	10.88	- 1.65	2.87
Gov.exp	24	35.86	32.1	43.71	34.56	33.42	37.13	3.32	0.99	- 0.34
Total.invest	24	21.1	12.66	32.31	20.06	19.16	22.2	4.29	0.58	0.5
Foreing.invest	24	3.53	- 0.96	7.91	3.46	2.23	4.71	2.19	0.17	- 0.57
Inflation	24	3.12	- 1.08	18.86	1.9	1.09	3.85	4.19	2.37	5.94

Notes: *(n* – number of measurements, Mean – arithmetic mean, Min – minimum value, Max – maximum value, Median – median, $Q_{0.25}$ – lower quartile, $Q_{0.75}$ – upper quartile, St. deviation – sample standard deviation, Skewness – skewness, Kurtosis – kurtosis*)*.Variables description (Debt – government indebtedness, Milex – military expenditures, GDPpc – gross domestic product per capita/per person, Export – export of goods and services, Import – import of goods and services, Gov.exp – government expenditures, Total.invest – total investment, Foreign.invest – investment from foreign countries, Inflation - rate of increase in prices)

The development of indebtedness is displayed in Figure 1 and the development of military expenditures is shown in Figure 2. In the first decade we could observe stagnant debt-to-GDP ratio. With the global economic crisis in 2008, the debt burden of both countries increased significantly. The moderate economic growth in 2010-2011 subsequently helped to reduce the rate of growth of the debt of both countries. In 2019, the negative impact of the Covid pandemic can be observed in both countries. In the case of military expenditure, a gradual decline in the amount as a percentage of GDP can be seen in both countries since 2004. This trend has been intensified since 2008 by the aforementioned global economic crisis. A reversal of the trend has been observed since 2014, when NATO countries declared at the Wales Summit their commitment to reach 2% of GDP for defence spending. Given the security threats related to the Crimea annexation, a more significant increase in the military-to-GDP ratio can be identified especially in the case of Lithuania.

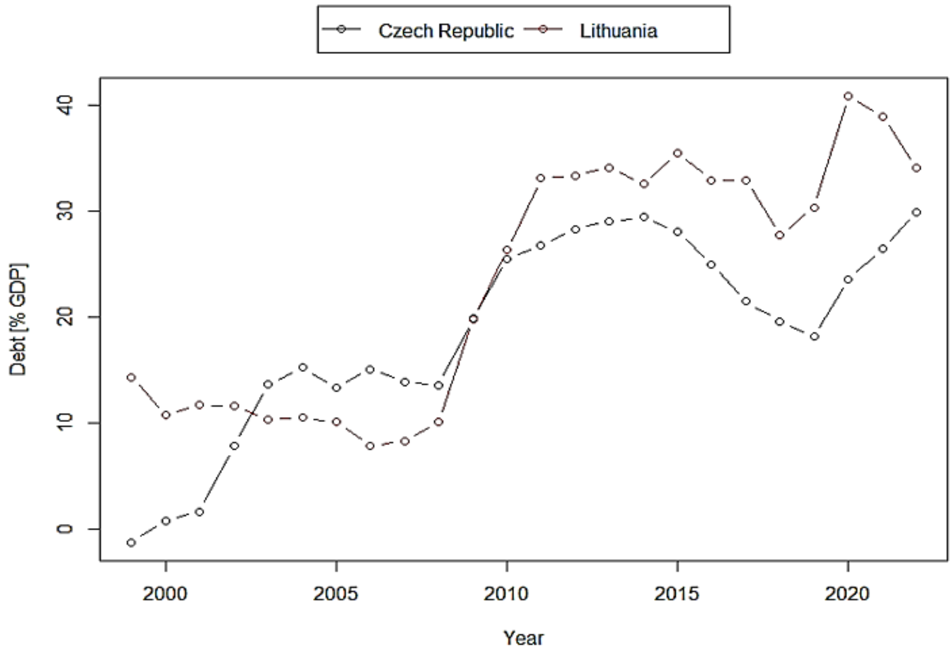

Fig. 1. The graphic interpretation of indebtedness

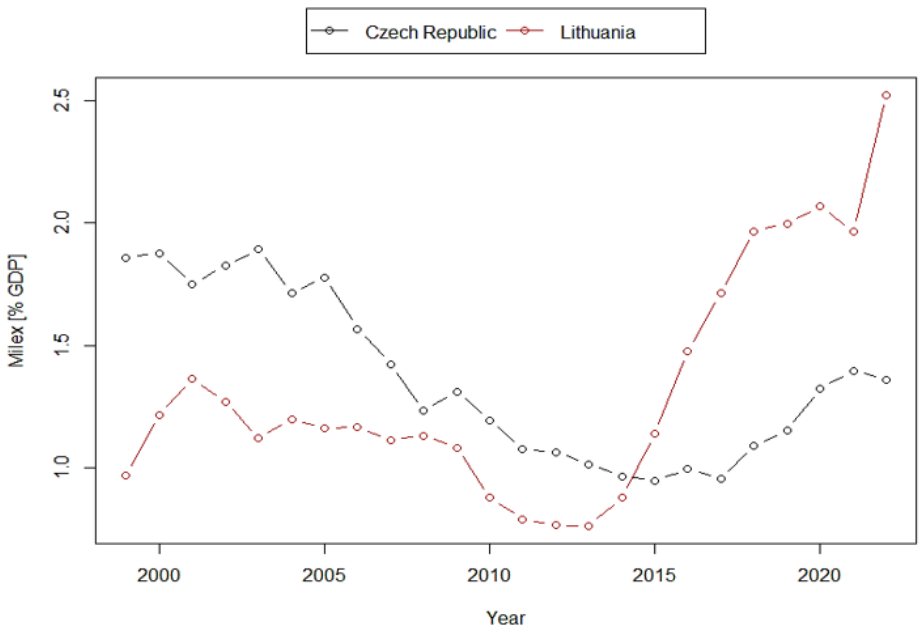

Fig. 2. The graphic interpretation of MIL Expenditure

The authors used correlation analysis and the ARDL model to analyze the relationship between the size of military expenditures and the selected variables. The strength of the effect of the given variable is determined by the size of the circle and its colour indicates a positive or negative effect. The aim of this paper is to observe the relationship between the level of military expenditure and indebtedness, therefore this relationship is characterized in a more detail. The results of the correlation analysis in case of the Czech Republic, see Figure 3, did not confirm the expected relationship between military expenditures and the country's indebtedness, with the correlation coefficient taking negative values. In the case of Lithuania (see Figure 4), the correlation coefficient is positive (statistically significant at the 0.10 level), confirming the expected link between the increase in military expenditure and the country's increasing indebtedness.

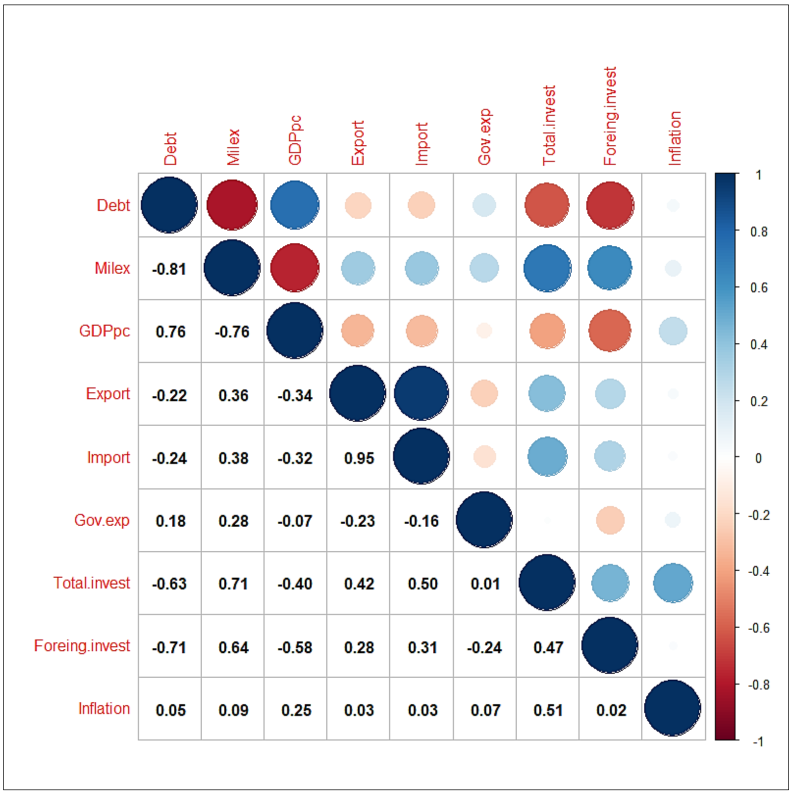

Fig. 3 Correlation matrix (Czech Republic)

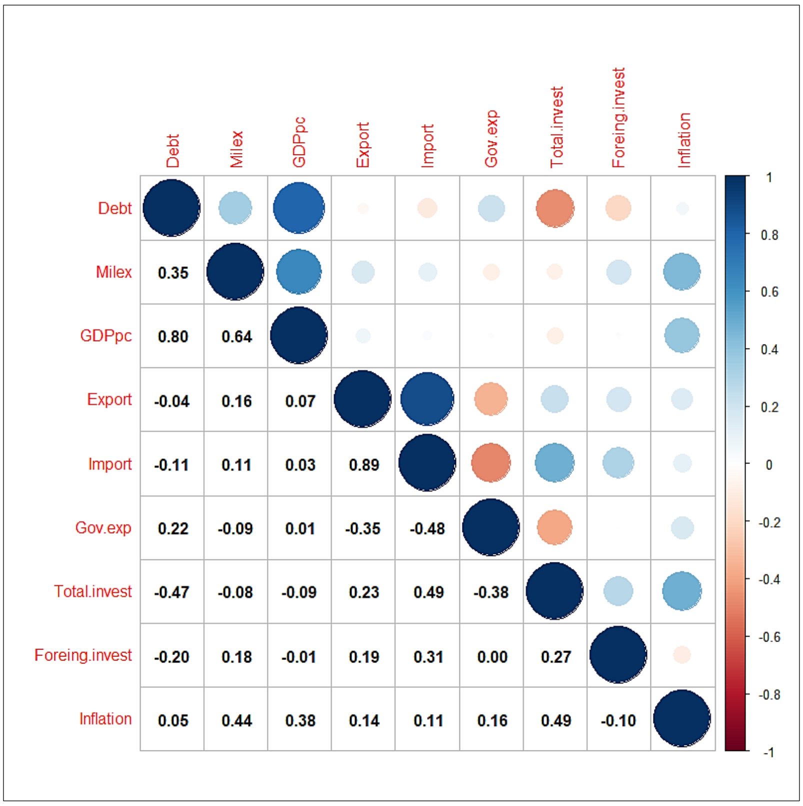

Fig. 4 Correlation matrix (Lithuania)

Table 2 shows the estimation of the ARDL model (1). For both countries, the full model and the reduced final model are developed. In the full model and reduced, all the parameters were displayed and the significance of each variable was assessed, standard errors are in brackets. Then the final model was determined for each country separately using so called "backward selection".

Table 2.

ARDL model (standard errors in parenthesis)

	Czech Republic		Lithuania	
	Full model	Final model	Full model	Final model
Variable	Coefficient		Coefficient	
DEBT$_{t-1}$	0.72462 **	0.698103 ***	0.65584	0.82880 ***
	(0.27614)	(0.10789)	(0.65420)	(0.09381)
MILEX$_{t}$	- 7.11827	- 5.390785 *	- 3.71278	- 4.55817 ***
	(7.87031)	(2.96711)	(10.77828)	(1.15491)
MILEX$_{t-1}$	- 9.72046		- 1.62447	
	(12.72141)		(18.92986)	
GDPpc$_{t}$	- 0.00187	- 0.000765 *	- 0.00036	0.00032 **
	(0.00109)	(0.00036)	(0.00224)	(0.00015)
GDPpc$_{t-1}$	0.00211	0.0008 **	0.00095	
	(0.00122)	(0.00035)	(0.00214)	
EXPORT$_{t}$	0.67003		0.12665	
	(0.48743)		(0.47518)	
EXPORT$_{t-1}$	- 0.00989		0.17485	
	(0.33775)		(0.29009)	
IMPORT$_{t}$	- 0.44863		- 0.03752	0.15076 **
	(0.48703)		(0.51274)	(0.05533)
IMPORT$_{t-1}$	- 0.11759		- 0.10176	
	(0.32862)		(0.32215)	
GOV_EXP$_{t}$	0.74372	0.672861 ***	0.84719	1.12856 ***
	(0.40149)	0.181045	(0.77018)	(0.23099)
GOV_EXP$_{t-1}$	0.88808	0.518215 **	- 0.09681	- 0.56380 **
	(0.56825)	0.190175	(0.61202)	(0.20891)
TOTAL_INVEST$_{t}$	1.08182		- 0.34109	- 0.51589 **
	(0.85779)		(1.23783)	(0.13931)
TOTAL_INVEST$_{t-1}$	0.16611		0.04395	
	(0.67092)		(0.97143)	
FOREING_INVEST$_{t}$	0.45275		0.15443	
	(0.40575)		(0.58273)	
FOREING_INVEST$_{t-1}$	0.81035		- 0.13791	
	(0.48096)		(0.96340)	
INFLATION$_{t}$	- 0.63850		- 0.01382	
	(0.46097)		(0.66196)	
INFLATION$_{t-1}$	0.60040		- 0.76952	
	(0.60031)		(1.11481)	
C	- 89.96887 *	- 37.6099 ***	- 19.43910	- 8.36432
	(40.22844)	(7.56578)	(62.79131)	(6.46435)
R^2	0.992	0.982	0.989	0.985
R^2_{adj}	0.964	0.975	0.950	0.978

***$p < 0.01$, ** $p < 0.05$,* $p < 0.10$

Table 3 illustrates the estimation of the long-run equilibrium relationship. This table contains the results only for the reduced final model for the two studied countries. In the case of the Czech Republic, the long-run equilibrium relationship can be estimated using military expenditures, GDP and government expenditures, nevertheless, GDP is not statistically significant. In the case of Lithuania, a model including military expenditure, GDP, imports, government expenditure and total investment can be used for the long-run relationship, but imports, government expenditure are not significant.

Table 3.

ARDL – long-run relationship (standard errors in parenthesis)

Variable	Czech Republic Coefficient		Lithuania Coefficient	
$MILEX_t$	- 17.85635	***	- 26.62486	*
	(5.39144)		(14.13578)	
$GDPpc_t$	0.00012		0.00188	***
	(0.00031)		(0.00046)	
$IMPORT_t$			0.88062	
			(0.56681)	
GOV_EXP_t	3.94530	***	3.29881	
	(1.03362)		(2.11988)	
$TOTAL\_INVEST_t$			- 3.01335	**
			(1.31053)	
C	- 124.57840	***	- 48.85700	
	(42.15665)		(51.96093)	

***p < 0.01, ** p < 0.05,* p < 0.10

The results of the estimated ARDL model show the following equations describing the long-run relationship between these variables.

Czech Republic

$$EC_t = DEBT_t - (-17.8564\, MILEX_t + 0.0001\, GDPpc_t + 3.9453\, GOV\_EXP_t - 124.5784)$$

Lithuania

$$EC_t = DEBT_t - (-26.6249\, MILEX_t + 0.0019\, GDPpc_t + 0.8806\, IMPORT_t + 3.2988\; GOV\_EXP_t - 3.0133\, TOTAL\_INVEST_t - 48.8570)$$

In the case of the Czech Republic, the relationship between indebtedness and military expenditures, GDP and government spending is demonstrated. However, the expected negative effect of an increase in military expenditures and an increase in the country's indebtedness has not been demonstrated in the long run. In the case of Lithuania, it is possible to observe the relationship between indebtedness and military expenditures, GDP, import size, government spending and total investment. However, as in the case of the Czech Republic, the expected link has not been established in terms of the impact of military expenditures on the country's indebtedness.

Table 4 shows the dynamics of the model describing the short-run relationship between debt and the estimated variables. In the case of the Czech Republic, the short-run significant variable is GDP per capita and government expenditure, whereas in the case of Lithuania, only government expenditure is statistically significant in the short-run.

Table 4

ARDL – short-run relationship (standard errors in parenthesis)

Variable	Czech Republic Coefficient		Lithuania Coefficient	
Δ $GDpc_t$	- 0.000765	***		
	(0.00022)			
Δ GOV_EXP_t	0.672861	***	1.12856	***
	(0.11145)		(0.10661)	
$CointEq_{t-1}$	- 0.301897	***	- 0.17120	***
	(0.02787)		(0.01703)	

***p < 0.01, ** p < 0.05,* p < 0.10

F-bound test for the Czech Republic 18.75, the critical values are 2.79 for $I(0)$ and 3.67 for $I(1)$. F-bound test for Lithuania 10.731, the critical values are 2.39 for $I(0)$ and 3.38 for $I(1)$. Based on these results, the existence of cointegration can be assumed.

4. Conclusions

Military expenditures as a part of government spending belong to the economic category of variables in which, especially in the case of the European NATO countries, can be noted a significant change in their size depending on the change in the security environment. This trend can be observed in both analyzed countries, especially in connection with the conclusions of the NATO Summits in Wales (2014) and consequently in Vilnius (2023). The increase in military expenditures associated with the growth of military capabilities brings with it different economic effects, which can have positive effects on the economic development of a country, e.g. the multiplier effect, but also negative effects, e.g. the growth of the state budget deficit or the indebtedness of a country. The authors of the paper focused on the analysis of the impact of military expenditures on the country's indebtedness. They aimed to confirm whether rising military expenditures are one of the factors influencing the indebtedness of the economy. The results of the correlation analysis showed the expected effect only in the case of Lithuania. The results of the estimated ARDL model did not show the effect of military expenditures on the countries´ indebtedness.

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Analysis of Trends in Defence Funding in the Member States of the North Atlantic Alliance

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Abstract

The aim of the article is to analyse the impact of the development of security threats on the financing of the defence capabilities of NATO states. The author is based on the theory of defence financing as a public good and the analysis of empirical data on the development of defence spending and the negative impact of the "free rider". In the first part, attention is paid to the theoretical definition of defence from the point of view of economic theory, and in the second part to the analysis of defence expenditures in NATO member countries. The author draws on the works of renowned authors such as [2, 6, 14, 15]. In the first and second parts of the article, the author chose a positive approach. The author of the article conducted a literature search of theoretical literature and relevant political and legal documents of NATO, EU, Czech Republic and Slovak Republic. For the purpose of analysing the impact of security threats on military spending, the author analysed trends in NATO member states' defence spending in the context of the "free rider" impact on the state's defence capability.

KEY WORDS: *security, defence, state, alliance, conflict, defence spending, threats.*

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1. Introduction

Ensuring the security and defence of the state has always been one of the topics that attracted the attention of not only politicians, soldiers and security experts, but also economists [2, 10, 17, 35]. After long years of peace, due to the gradual deterioration of the global and regional security environment and the deepening of some security problems, issues of ensuring the security of states and the defence of their freedom, sovereignty, independence, territorial integrity and interests, as well as the defence and protection of their citizens, have become issues in recent years again very urgent [13, 14, 16].

The reason was mainly the continuous increase in tension in international relations, especially after the Russian annexation of Crimea in 2014 and Russian support for the separatist republics in the Ukrainian Donbas, the intensification of geostrategic competition, the growth of tension in relations between the great powers and the growth of several military, but mainly non-military security threats, which undoubtedly contributed to the deterioration of the security situation in several regions of the world [15]. The emergence of several new, primarily asymmetric, security threats in the form of international terrorism, illegal mass migration, proliferation of weapons, cyber-attacks on public and private computer networks and systems, etc. [17], together with the implementation of subversive hybrid activities, interference and influence through disinformation campaigns and propaganda [15], by foreign state and non-state actors with the aim of disrupting the functioning of democratic societies significantly influenced the view of ensuring the security and defence of states [18]. The sharp deterioration of the security situation on the European continent occurred after the military invasion of Ukraine by Russian Federation troops on February [1, 33], Walker [33]. Therefore, never in the past have peace, peaceful development, prosperity, and maintenance of the standard of living of the inhabitants of our planet, including the citizens of NATO member states, been so significantly dependent on the level of ensuring their security [16].

Therefore, in recent years, many political, legislative, organizational, economic, security and other measures aimed at increasing the level of their security and resistance to new threats had to be adopted in NATO member countries (but not only in them). For the reasons mentioned, in several countries in recent years they have changed, or updated security, defence

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and military strategies (for example, in the Czech Republic in 2023, in the Slovak Republic in 2021, the security, defence and military strategies were updated). At the level of the Alliance, a new NATO strategic concept was adopted at the Madrid Summit in 2022 [22]. In addition, several new agreements on mutual cooperation (for example with the European Union [7–9], initiatives and programs aimed at increasing defence spending, modernization and building new military capabilities were adopted at the NATO level before and after the outbreak of the conflict in Ukraine and capacity, growth in R&D investment, etc. (for example NATO Innovation Fund [23]), Defence Innovation Accelerator for the North Atlantic [24].

In connection with the above, the aim of this contribution is a theoretical view of the financing of defence as a public good (financed from public finances) in combination with empirical data in the form of the amount of defence expenditure allocated in the evaluated period in the member countries of the North Atlantic Alliance. In the first part of the paper, attention is paid to the theoretical definition of defence from the point of view of economic theory, and in the second part to the analysis of defence expenditures in the member countries of the North Atlantic Alliance. When preparing the paper, the author is based on the works of foreign authors: [10, 17, 27, 29, 30], as well as domestic authors [2, 12, 17, 27], who in their researches and works deal with issues of the economy and defence financing.

2. Theoretical Basis of Financing the Defence of the State

Ensuring defence, as a public good and an integral part of the public sector, is one of the primary tasks of every state. At the same time, it also belongs to the most expensive economic activities of the state. The issue of ensuring the defence of the state and its inhabitants is not only a political and military issue, but also an economic issue [2, 11, 12, 17, 32].

Historical experience confirms that the demands for economic support for the defence of the state and its citizens have constantly grown with the development of human society. This is also why, from the entire wide spectrum of factors acting to ensure defence needs, the economy represents one of the decisive factors. It represents the base of the defence of the state, because it secures it with the necessary resources. It can be concluded that the dependence of the construction of the defence force of the state on the economy has become much stronger over time, especially due to scientific and technical development, globalization, uncertainty, and the emergence of new asymmetric security threats [10].

Limited and scarce economic resources must be allocated to peace and defence and, depending on the situation or the nature of the threats, they must try to optimize the choice between defence and peace spending. This is also why the problems of the economic security of defence and its financing require incomparably greater interest than until now. The economic security of the state's defence should be stable, because in times of crisis and uncertainty, the feeling of danger is even more intense and the demand for defence and security grows [17].

Defence provision is a typical example of public goods. The benefits of these goods are so dispersed among the population that no single company or consumer has the economic motivation to provide them comprehensively and systematically. In this context [27], also claim that nothing is more important for society than its security and defence. Defence as a collective good cannot be divided into partial units because each individual consumes it as a whole. The benefit (benefit) that an individual derives from it does not reduce the benefit (benefit) for other members of society. Therefore, according to many authors, the marginal costs of additional consumption in defence are zero [28, 29, 31].

Regarding defence spending in the professional, security, military or economic literature, whether domestic or foreign, there is no single, unified and generally accepted definition or precise interpretation of the concept of defence spending. In addition, in the literature it is possible to meet the designation of military expenditure, arms expenditure or army expenditure, which, however, basically also include expenditure related to the defence of the state and it depends on the specific author who uses the term in his work. However, the terms defence spending and military expenditure are most often encountered.

In general, defence spending can be characterized as current and capital spending that states spend on ensuring their defence, that is, on the armed forces, on their maintenance and operation, training, on conducting operations on their own territory and outside the territory of the state, modernization, military research and development, infrastructure, military aid, salaries, social and health insurance for military and civilian personnel, etc. The amount of defence spending reflects the nature of the state's defence policy and its security, but mainly defence and military strategy. It provides information on the defence efforts of the state, the construction of the defence system of the state and, in particular, on the construction and development of the capacities and capabilities of the armed forces of the given state. At the same time, the amount of defence spending reflects the economic possibilities of the state [2, 11, 12, 17, 32].

Defence spending significantly affects the provision of peaceful life and the preparedness of the armed forces as the most important tool of the state to ensure defence, but also the creation of necessary material reserves, the development of military production, research and development of new military equipment, weapons and weapon systems, the preparation of the population and territory for defence, etc. Defence spending, by its size and nature, limits the possibilities of meeting the peaceful needs of society. The use of the concept of defence spending is primarily associated with the distribution of public funds from the state budget to ensure the implementation of individual goals and objectives in the overall system of ensuring the defence of the state [2, 12, 32].

In individual countries, this system is made up of several interconnected elements (e.g.: armed forces, land, air, naval, special forces, etc., national guard, border guard, intelligence services, defence industry, defence infrastructure, specialized state administration institutions, strategic stocks and reserves, civil defence, etc.), which act in favour of guaranteeing the defence of the state. In this context, certain costs arise in every state, the monetary expression of which is defence spending. The amount of defence spending often also reflects how strong, or to what extent the country perceives the probability of the realization of threats against it, or the amount of aggression it wants to provoke. It also provides an idea of how much funding should be provided for defence in the coming fiscal years. Their height also reflects the landscape's ability to finance the activities of the armed forces [17, 28, 29].

Odehnal [26] presents a comprehensive literature review on the definition and influence of free riders on defence financing within the Alliance and the analysis of parasitic states. The non-excludability and indivisibility of benefits from collective defence necessarily leads to an unequal sharing of the costs of common defence among Alliance members. This aspect is a natural phenomenon, the so-called free riding. On the one hand, large, economically stronger states usually spend resources on defence at a certain agreed level (2% of GDP), possibly even a higher volume of resources. On the other hand, the governments of smaller countries usually do not comply with the agreed limit on the volume of resources. They take advantage of the so-called joint defence club membership financed by richer and larger allies. The resources "saved" in this way can be diverted by these governments to other needs that will help them get more preferential votes in the next election. Department of Defence budgets become the government's "last resort" for other spending with a higher voter preference. The willingness of properly contributing states to bear a greater burden of common defence when partners do not fulfil their obligations is not limitless. A breach of mutual trust arises between the partners and leads to contradictions, subsequently to the inefficiency of defence spending and the weakening of the defence capabilities of the member states and the loss of the coalition's ability to act.

3. Investigation Results

A certain easing of tension in international relations at the beginning of the second decade of the 21st century, caused the member states of the North Atlantic Alliance to gradually start reducing defence spending again. Since all NATO member states that sent their military units to operations Iraqi Freedom (2003–2011) in Iraq and Enduring Freedom (2001–2014) in Afghanistan (replaced in 2014 by operation Resolute Support) gradually withdrew their troops in the first years of the second decade or significantly reduced the number of their units and soldiers in Iraq and Afghanistan, this reduction was also reflected in their defence budgets (see Fig. 1). The reduction primarily concerned expenses associated with the training, deployment, replacement, maintenance, and withdrawal of military forces in military operations outside the states' own territory.

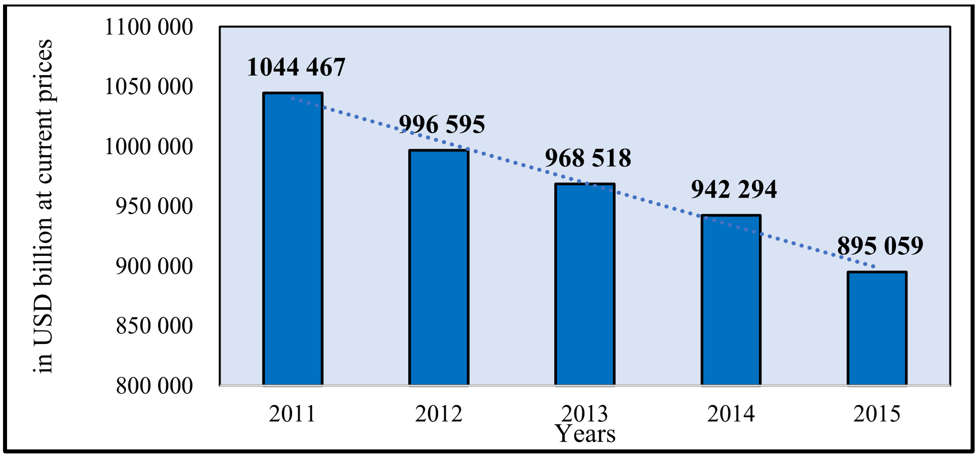

Fig. 1. Trend of defence spending development in NATO member countries in 2011–2015 (in USD billion at current prices) Source: [20]

The turnaround in development occurred mainly under the influence of the crisis events following on the one hand, the change of regime in Ukraine and the subsequent annexation of Crimea by the Russian Federation, and on the other hand, the successful offensive of the Islamic State in Syria and Iraq. In the first case, in November 2013, after former Ukrainian President Viktor Yanukovych did not sign an association agreement with the European Union and the police cracked down on pro-European demonstrators, mass demonstrations and violence in Freedom Square in Kyiv took place in December 2013, leading to the recall President Yanukovych and his government and the election of Oleksandr Turchynov as the interim president of Ukraine and the appointment of a new, pro-European government headed by Arseniy Yatsenyuk [3]. Subsequently, in March 2014, after a disputed referendum on the status of Crimea, initiated by the pro-Russian leadership of Crimea, which did not recognize the new Ukrainian government formed after anti-government riots, the overwhelming majority of voters voted for its annexation to Russia. The Republic of Crimea and the city of Sevastopol were declared subjects of the Russian Federation. However, neither Kiev nor most of the international community recognized this move. The crisis in Ukraine continued in April 2014, when pro-Russian activists declared an independent Donetsk People's Republic and Luhansk People's Republic in eastern Ukraine [5].

From an international perspective, the Ukraine crisis has caused the most serious crisis in mutual relations (not only) between NATO and Russia since the end of the Cold War and has led to the adoption of a large number of political, economic, security, military, organizational and legislative measures on both sides, including the imposition of a large number of sanctions and retaliatory sanctions. From a military-security point of view, the Russian annexation of Crimea and other military activities (e.g. large-scale military exercises of the Russian armed forces near the borders with the Baltic countries, violations of the airspace of NATO member states by Russian bombers and fighter jets or territorial waters by Russian submarines, etc.) in a significant way increased the sense of threat especially in those member states of the Alliance that are directly adjacent or lie close to the borders with Russia and Ukraine.

In the second case, the Islamic State organization, during the civil war in Syria, gained control over large parts of Syria from April 2013 and, after a rapid offensive in the summer of 2014, also over parts of the territory of neighbouring Iraq. After capturing Mosul, Iraq in June 2014, the organization declared a caliphate based on a strict interpretation of Islamic Sharia law in the conquered territories. The organization belongs to Sunni Islam and strongly opposes followers of Shiite Islam and other religions. Islamic State has become known for committing brutal terrorist attacks and war crimes, including mass executions of captured soldiers and civilians. In the conquered territories, he committed general violations of human rights and brutally oppressed all religious groups that do not follow their strict version of Islam, committing extensive violence mainly against Shiites, Yazidis and Christians, but also against Sunnis who were in opposition. These activities have reached such a scale in Syria and Iraq that the United Nations and human rights organizations accuse the Islamic State of committing ethnic cleansing and genocide.

After 2014, a broad international coalition headed by the USA was formed against the Islamic State, which led attacks on its territory in a joint action until 2019. Other activities leading to the liberation of territories controlled by the Islamic State were led by Russia and Turkey. The campaigns and activities of individual actors were relatively successful, and by the end of 2018, the vast majority of the territory was liberated from militants [35]. The above-mentioned matters required not only the initiation of preparations for the re-updating of security, defence and military strategies, but also the preparation and adoption of new military doctrines and concepts at the national and joint alliance level, aimed at increasing the level of defence against military and non-military threats. These activities and measures were, of course, also reflected in the countries' defence budgets in the form of an increase in defence spending (see Fig. 2). It is evident from (see Fig. 2 that after 2015 there is a turn in the development of military expenditures. In 2019, spending is approaching 2011.

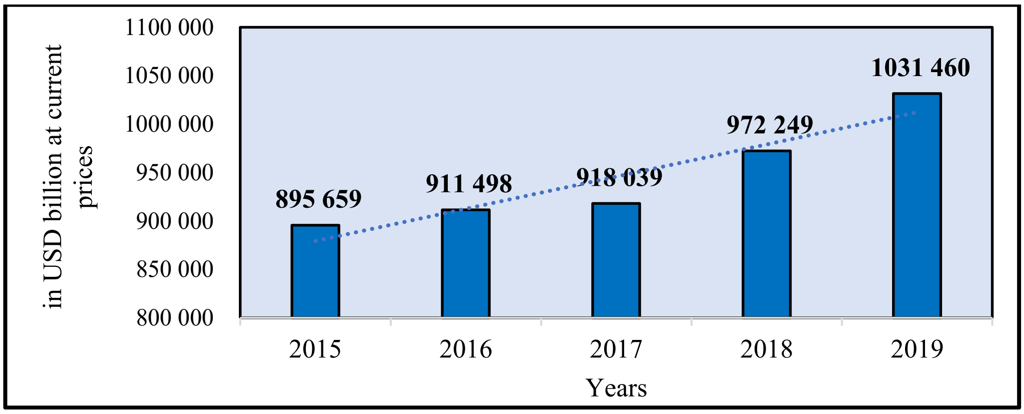

Fig. 2. Defence spending development trend in NATO member countries in 2015–2019 (in USD billion at current prices) Source: [21]

The growth of defence spending in the member states of the Alliance continued – primarily in connection with the Russian threat – in the following years as well. Several sharp statements by former US President Donald Trump to European allies also have a certain share in this, as he repeatedly accused the leaders of European NATO member states of abusing the benefits of collective defence and at the same time called on them personally or through their ministers of defence and foreign affairs to increase their defence spending to the level of at least 2% of GDP [6]. At the same time, he warned them that if they do not increase their defence spending, the United States will reconsider its current approach to guaranteeing security and defence on the European continent [4]. On his account on the social network Twitter, he even stated his idea that allies should prospectively spend up to 4% of GDP on defence [19]. NATO Secretary General Jens Stoltenberg also commented on the mentioned problem several times, who repeatedly emphasized that NATO is based on the principle of solidarity one for all and all for one. If on the one hand everyone enjoys the protection of NATO, on the other hand everyone must also contribute with their obligations towards NATO. He added that he understands that increasing the defence budget is not easy and that the issue of increasing funds for the army is currently extremely sensitive. "The current crisis in Ukraine clearly proves that defence still matters. Defence costs something, but if we didn't secure it, it would cost us even more," declared the head of the North Atlantic Alliance. When presenting the Alliance's new plans, he also appealed, primarily to the Alliance's European members, to fulfil the alliance's commitment to spend 2% of GDP on defence [31].

However, the primary reason for the growth of defence spending in NATO member states was really diverse Russian activities causing concern among the allies (for example, the gathering of troops on the border with Ukraine, cyber-attacks, disinformation campaigns, propaganda, misuse of energy supplies, etc. The culmination of these activities was the military invasion of Ukraine February 24, 2022, which, on the one hand, represents the return of a high-intensity international armed conflict to the European continent, and on the other, an additional impetus for NATO to increase the intensity of its efforts to ensure a higher level of collective defence Ukraine has fully realized the necessity of having adequate military capabilities and capacities necessary for its own defence, as evidenced by the growth of defence expenditures allocated by the regions from their state budgets (see Fig. 3).

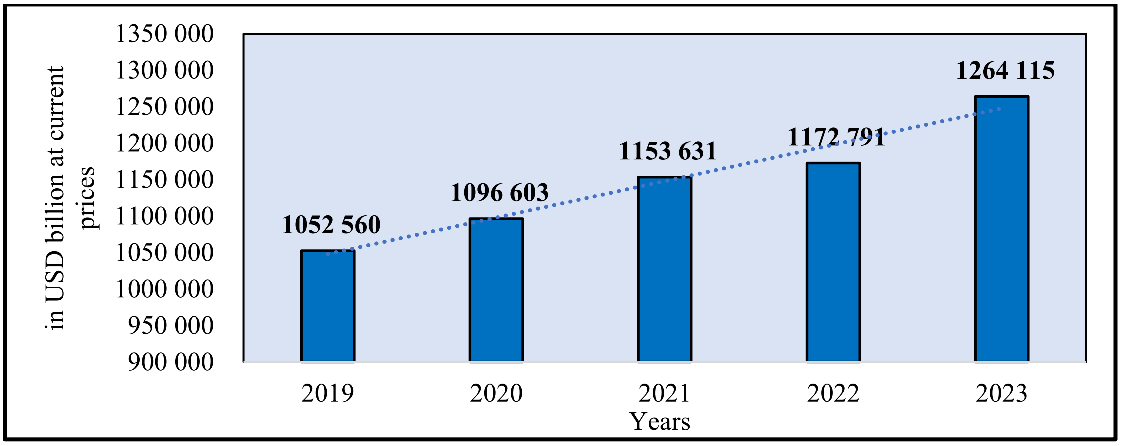

Fig. 3. Defence spending development trend in NATO member countries in 2019–2023 (in USD billion at current prices) Source: [23]

Research results [27] confirmed through macroeconomic analysis that the governments of most Alliance member countries, satisfied with a long-term period of peace, decided not to fulfil their obligations and allocate resources for other purposes. They took the position of free rider. They left the burden of financing the coalition defence mainly to the USA. In 2011, 2013, 2014, only Great Britain and the USA fulfilled their obligations. In 2012 only the US and in 2015 the US, Great Britain and Poland. As the only relatively new member of NATO and the only country of the former Warsaw Pact, Poland promoted the country's defence as its priority and kept its commitments. The level of spending in 2011 was surpassed only in 2020. The long-term trend of non-fulfilment of the commitment naturally manifested itself in the deepening of the differences between the amount of military spending of the US and European countries. This trend led to the halting of the modernization and construction of the armed forces of the parasitic states and to their moral and technological retardation.

An example can be the situation in the underfunding of the modernization and development of the Army of the Czech Republic. The volume of the budget of the Ministry of Defence has been steadily decreasing since 2005 (2% of GDP) to the level of 0.96% to 0.97% of GDP in 2014 and 2016. Since 2017, there has been a gradual increase in resources. In 2023, the defence financing law was adopted, which is to guarantee the government's obligation to set aside at least 2% of the nominal gross domestic product for defence financing expenses every year in the draft law on the state budget. Approaching the threshold level of 2% of GDP should be achieved in 2024. The budget of the Ministry of Defence of the Slovak Republic in 2014 amounted to 0.98% of GDP, between 2015 and 2022 it ranged from 1.1% to 1.8% GDP.

An economic analysis of defence spending has shown that the governments of both countries have been parasitizing coalition defence for a long time. In this way, the governments of both countries inefficiently and purposefully allocated resources that should have been invested in their own and coalition defence from a macroeconomic point of view. The above research has confirmed the inefficiency and uneconomical allocation of defence spending. Macroeconomic analysis cannot provide information regarding the analysis of financing and management of funds intended for the defence of one's own country and the Alliance. Other methods of economic analysis are used to determine the so-called operational efficiency and economy of expenses. These include, for example, the analysis of budget expenditures, including the fulfilment of state budget indicators, or especially the budget chapters of the Department of Defence. It provides us with information about what funds were used for the acquisition of property (acquisition), works and services, personal expenses of professional soldiers and civilian and civil employees and for what purposes (goals), and what funds were not used for planned needs. These analyses are presented by the Ministry, for example, as part of the State Final Account and are publicly available. Among the most reliable analytical sources on the operational efficiency of defence spending are the records of audit conclusions from the audits of the Supreme Audit Office. Unfortunately, these conclusions analyse only selected spending areas of the Department of Defence. No other comprehensive assessment of defence spending activities is publicly available. Even from these partial analytical procedures, it follows that the reduced defence expenditures of the past years were not always used efficiently and economically.

The allocation inefficiency caused by freeriders i.e. states that did not comply with agreed obligations, also contributed to the operational inefficiency of the defence department. The lack of resources for the modernization of the armed forces has caused an internal debt during the last twenty years (inventories, restrictions on the repair, maintenance and functionality of military equipment, weapons systems, and training. Increasing defence spending increases the demand for military equipment and technology, weapons and weapon systems. This will be reflected in the lack of purchased items and the increase in their price. The trend of increasing defence spending does not mean that the internal debt and obligations to defence will be resolved within one or two years. It follows from the available analyses that the increase in defence spending is currently not proportionate increasing the defence capability of the state or the Alliance. The black passenger factor is a risk factor for the defence capability of the states and the Alliance, which was underestimated by the governments of the NATO countries. The policy of the long-term reduction of the military expenditures of the majority of the Alliance member countries and the parasitism of the collectively realized defence was a significant security threat for the individual states and the Alliance as a whole. The politicians of the parasitic states underestimated this situation.

4. Conclusion

The current overall unfavourable development in the global and regional security environment in order to ensure collective alliance and own individual defence requires a more effective and efficient redistribution of resources and an increase in defence spending. Mutual relations between defence and the economy are constantly developing, deepening, and today they are much closer and more interconnected than ever before.

The above graphs (see Fig. 1–3) confirm that the improvement or deterioration of the global and regional security environment and the security situation, together with the decrease or growth of military and non-military threats, has an indisputably significant impact on the allocation of defence expenditures from the state budgets of individual countries and the level of ensuring their defence. Based on the examination of several available relevant information, facts and characteristics, it can be concluded that the feeling of threat and a more intense perception of security threats leads to an increase in investments in the maintenance and modernization of existing defence capacities and capabilities, and at the same time in building new ones corresponding to new threats and challenges. This fact subsequently leads to an increase in the defence budgets of individual countries.

On the other hand, most of the European allies, from the point of view of economic theory, continue to take the position of free rider and still rely on the fact that their bill will be paid by other members of the Alliance, which has become a high-risk factor for ensuring the defence of the states and the Alliance. The Russian threat, as well as other non-military asymmetric security threats, did have an effect and caused several NATO member states to undergo changes in their security and defence policies and to changes in their strategies and doctrines. For example, after twenty years, the Czech Republic succeeded in enforcing the law on defence financing and at the same time fulfilling the above-mentioned commitment of 2% of GDP for defence in 2024. The Slovak Republic fulfilled this commitment in 2023. However, the increase in defence spending does not guarantee their allocation or operational efficiency and economy. It also does not guarantee that the long-term internal debt will be saturated in the short term.

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The Complexity of Military Force Readiness to Respond to Changes in the Electromagnetic Environment

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Abstract

This article examines changes in the electromagnetic environment and their implications for the operational environment and the military forces. The first part defines the context with operating environment and how electromagnetic energy shapes it. It then presents the research results in the form of consolidated text and visualizations using a futures wheel and images illustrating the approaches to military force capabilities proposed by the authors applicable in the future electromagnetic environment. Finally, it discusses the development of military capabilities applicable to future operations and generalized recommendations in response to the challenges for military forces in the electromagnetic environment.

KEY WORDS: *capabilities, electromagnetic energy, electromagnetic environment, electromagnetic spectrum, futures wheel, changes, military forces, operating environment.*

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1. Introduction

Sun Tzu said: *"Water shapes its course according to the nature of the ground over which it flows; the soldier works out his victory in relation to the foe whom he is facing. Therefore, just as water retains no constant shape, so in warfare there are no constant conditions. He who can modify his tactics in relation to his opponent and thereby succeed in winning, may be called a heaven-born captain."* [1].

Despite the changing nature of the operating environment (OE), this quote is still valid centuries later. Indeed, military approaches to warfare seek to reflect not only the physical terrain or the meteorological and oceanographic (METOC) aspects of these environments. They also continuously respond to the capabilities of adversaries and enemies, or their own capabilities, which are naturally developed in the context of trends affecting the nature of the OE. It is clear that the changing nature of the OE gives rise to not only predictable effects, but also stochastic side effects, which together create the potential for change in military art. Then, the accuracy of the OE prediction is to some extent a reflection of the ability to take a holistic approach, considering all the details that have the ability to shape this environment.

The OE is so comprehensive and complex that it can be examined from many perspectives. One of these perspectives is the electromagnetic environment (EME), which is an integral part of the OE. An interesting trend that may influence the shape and cause changes in the EME is for example the development of assets and technologies based on the use of electromagnetic (EM) energy. The importance of exploring the EME in terms of current and the future OE is due to the fact that the EME is pervasive and permeates all parts of the OE. It therefore has the potential to influence all operational domains. Since the North Atlantic Treaty Organization (NATO) defines an audience as *"an individual, group or entity whose interpretation of events and subsequent behaviour may affect the attainment of the end state"* [2, rec. 40605], and *"the audience may consist of publics, stakeholders and actors"* [2, rec. 40605], we can conclude that the EME has the potential to affect all audiences in the OE.

In line with the above, it is irrelevant what activities and in what operational area or environments of the OE military forces perform. The EME, as part of the OE, has the ability to significantly influence not only the nature of military campaigns and operations, but also to change the fighting power of individual actors in the OE. Consistent with military art theory, the deliberate application of military force in the electromagnetic spectrum (EMS) can be viewed as a game changer in combat. It follows the premise that EM energy can be an effective and *"a potent force multiplier"* [3, p. I-3] for any actor in a military operation. The term actor is to be understood, in accordance with NATO, as *"an individual, group or entity whose actions are affecting the attainment of the end state"* [2, rec. 40602].

It is no longer possible to conduct any military operation today without trying to maintain freedom of action in the EMS. The reason is that modern technology and techniques are, with few exceptions, dependent on EM energy, or are at least influenced by EM energy. Therefore, it is essential for the military forces to implement specific EMS activities to exploit EM energy in order to achieve desired effects on targeted users of the EMS. To sum up, the challenge is to determine what are the challenges that military forces must be prepared to deal with as the EME changes.

2. Methodology and limitations

Some of the results of the research presented in this article were prepared by one of the authors in 2022 as part of his final thesis for the General Staff course *"Conduct of electromagnetic operations from the perspective of the strategic level of command and control of the Czech Armed Forces"* [4]. Data and information to predict the nature of the OE were obtained through a systematic literature research, brainstorming and discussion with experts. One of the products developed was the futures wheel, which was used to identify and visualize the primary (first order) and secondary (second order) consequences of the trend *"development of assets and technologies based on the use of EM energy"* [4, p. 49]. The consequences of the futures wheel formulated in [4] were subsequently used by the authors of this article to draw implications and formulate proposed measures for military force development. These measures reflect the changing nature of the OE caused by the influence of EM energy.

However, only one generalized example will be given to illustrate possible approach of dealing with the consequences of the futures wheel. The reason is the sensitivity of the EME/EMS issue being addressed, more specifically the use of EM energy for military purposes. Since this topic is usually subject to protection and secrecy, the results presented need to be generalized. This generalization does not affect the validity of the presented results or their theoretical and practical contribution. The results elaborated by the authors can be used by military professionals as reference material in the context of solving operational requirements, or searching for specific capabilities of military forces that should be acquired for success in the future OE. Likewise, the results can be used for the development of military art in relation to the activities of military forces in all operational domains. The presented output can also be used as an additional background material for the subsequent development of a methodological approach to the development of military force capabilities, based on reflection of changes in the OE.

3. Electromagnetic energy as a factor shaping the operating environment

From a NATO perspective, the OE is defined as *"a composite of the conditions, circumstances and influences that affect the employment of capabilities and bear on the decisions of the commander"* [2, rec. 874]. It consists not only of audiences, but also of systems and combinations of many variables and environmental factors that do not originate solely from military activity, military technology, or the implementation of technology in military equipment and weaponry. These include the factors and effects of civilian aspects that influence the final form of the OE. [5, p. IV-8, IV-29], [6, p. 77–79] Thus, the modern concept of the OE is a mixture of variables, interdependencies, and potential synergies, making it a complex challenge for military planners and strategists. A visualization of the OE is depicted in Fig. 1.

Closely linked to the OE is operational readiness, defined by NATO as *"the preparedness of a unit, formation, weapon system or item of materiel to perform the missions, tasks or functions for which it is organized or designed"* [2, rec. 14960]. In the context of the above, this readiness needs to be developed by the military forces, with the aim of ensuring it in all operational domains (land, air, maritime, space and cyberspace) currently recognized by NATO. This is due to the unquestionable existence of the interdisciplinarity of the OE, which is related to the multi-domain approach to planning and conducting combat activities in military operations of the near future. A very important role here is then presented by EM energy, respectively the EME and specific EMS activities (electromagnetic warfare (EW), signals intelligence (SIGINT), navigation warfare (NAVWAR), intelligence, surveillance, target acquisition, reconnaissance (ISTAR), directed energy weapons (DEW), etc.).

The dependence of OE audiences on EM energy, its directed use, and military activities in the EMS have led the United States (US) armed forces to introduce the term electromagnetic operational environment (EMOE). This addresses only those sources of EM energy that can affect the activities of military forces in the conduct of military operations. The EMOE is described as physical, pervasive, constrained, congested, contested and dynamic. The characteristic aspects of the EMOE are related to extensive use of the EMS by a wide range of users. [3, p. I-2–I-3] The term EMOE is not yet officially introduced in NATO, but its content corresponds to the NATO term EME.

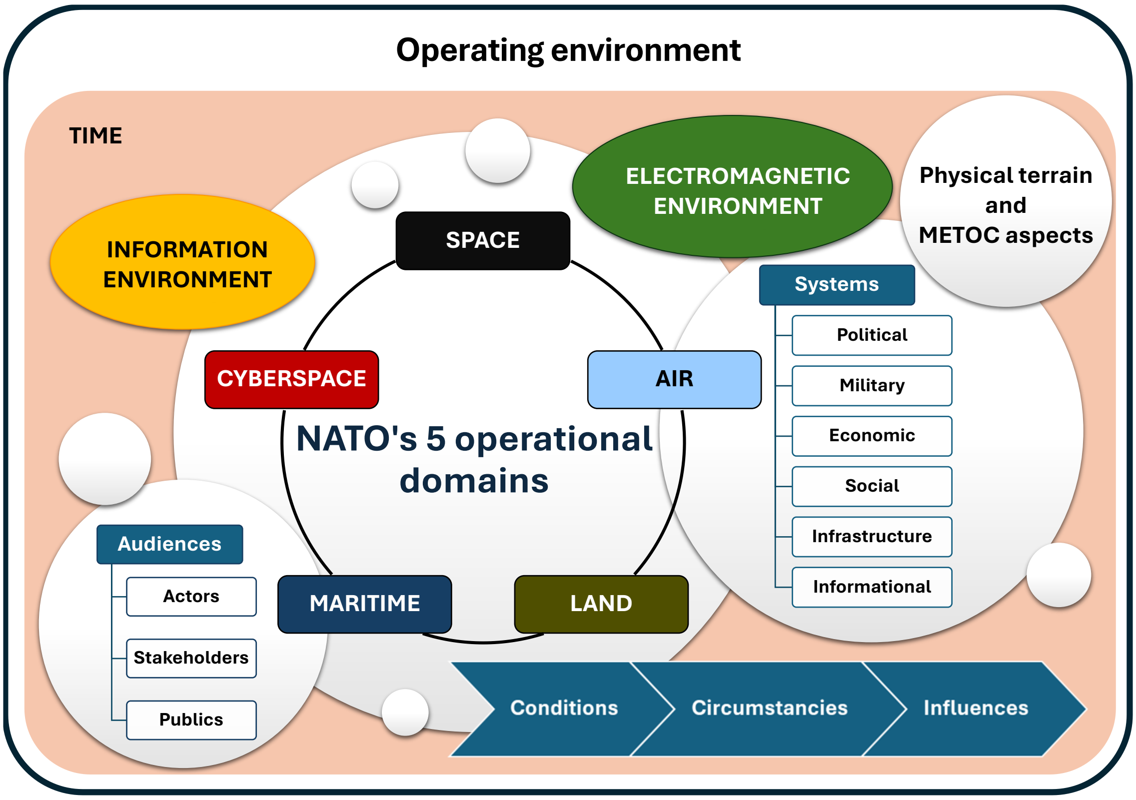

Fig. 1. Visualization of the OE (by the authors based on [5, p. IV-8], [6, p. 79])

The importance of the EMS and its use as a tool to achieve the end state of military operations have thus become not only commonplace, but also an indispensable foundation in a multi-domain approach to their conduct. This approach deals with the synchronization and orchestration of activities in different operational domains and environments of the OE. The goal is to expose adversaries and enemies to not only separate, but also complex dilemmas conducive to gaining battlespace superiority. In this relatively new concept of so-called multi-domain operations (MDO), introduced by the US Army, EM energy and related specific EMS activities of military forces play an irreplaceable role. However, the use of EM energy in military operations is not only a US prerogative. It is an issue that is currently being intensively considered also in NATO, and therefore in many NATO member states. Understanding the EME and its qualified prediction are therefore very important, if not essential, from the perspective of the future OE for the development of the military art and the effective operations of military forces in any operational domain. Indeed, EME intersects with both its physical and non-physical domains of the battlespace. [7, p. C1–C3]

4. Effects of electromagnetic energy on the nature of the operating environment

The issue of generating fighting power, which is closely linked to the capabilities of the military forces tied to its *“three interrelated components: the moral, conceptual and physical”* [2, rec. 40692]. Through their interaction, *“the ability of the armed forces to shape, contest, and fight”* [2, rec. 40692] is then achieved. In order to develop the capabilities of military forces in a broad and focused manner, it is necessary to be able to continuously conduct a predictive analysis of the future OE instead of simply describing the current state of the OE in order to achieve the maximum effect of the generated fighting power.

The view of the OE through EM energy, which has the potential to change the nature of the EME at a specific place and time, appears to be quite interesting and sometimes unfortunately neglected. Since the EME encompasses all operational domains and can theoretically be used to influence all audience in a military operation, it is inevitable to give it due consideration [8, p. 1–2]. Therefore, the question is not only what impact the development of assets and technologies based on the use of EM energy will have on the changing nature of the OE and with which problems will the military actors have to deal with in the near-future military conflicts. In addition to the above predictable problems associated with the EME, there is also a number of very dynamic issues. Military actors must be prepared to respond to those issues in an unplanned and ad-hoc manner. The readiness of military forces to respond to changes in the EME is a fairly complex issue that requires a balanced approach across all functional areas. These areas are known in military environment by the acronym DOTMLPFI (*“doctrine, organization, training, materiel, leadership development, personnel, facilities, and interoperability”* [2, rec. 36370]).

Given future military operations, it is very likely that the capabilities available to military forces today will not be sufficiently effective in future OE. In fact, with the challenges associated with the EME, it is almost certain that military actors' reliance on the EMS will have to be reduced or even eliminated at some point and time in the future military operations. Only such an approach, in parallel with the application of electromagnetic protection measures (EPMs) and specific EMS activities, can be effective and have the potential to reduce the likelihood of success for adversaries and enemies in achieving their EMS superiority.

5. Prediction of the nature of the operating environment

From a military perspective, understanding the OE is a key prerequisite for successfully achieving the end state of any military operation. However, the OE is so complex and variable that it must be addressed well in advance. It is therefore the task of many state and non-state entities to be able to predict the future nature of the OE as accurately as possible, so that the capabilities of the military forces operating in it can be adequately adapted to it. This prediction can be approached by using a wide range of scientific methods. The OE can be examined holistically or, alternatively, by analysing the impacts and influences of individual trends causing changes in its nature. Research on the OE is systematically addressed in the US. The outputs that are provided to the general public, for example, address the OE and implications of development to 2050, emphasising a holistic and heuristic approach to describing the future OE [9, p. 3]. The US Army Training and Doctrine Command (TRADOC) has identified 12 trends that fundamentally influence the nature of the future OE. As shown in Table 1, these trends were grouped into four categories – Emerging science & technology trends; Information, space, cyber & computing; Society, biomed & performance; and Strategic world. It is clear from the above content that a detailed analysis of 12 trends and a prediction of the OE based on this analysis is very time and resource consuming (human, financial, knowledge, etc.).

Table 1.

US Army TRADOC prediction of the nature of the OE [by the authors based on [9, p. 3]]

Trends	Categories
Power generation and storage	Emerging science & technology trends
Technology, engineering & manufacturing	
Robotics	
Big data	Information, space, cyber & computing
Cyber and space	
Artificial intelligence	
Human computer interaction	
Collective intelligence	Society, biomed & performance
Increased level of human performance	
Climate change and resource competition	Strategic world
Demographic and urbanization	
Economic rebalancing	

The research conducted by the authors of this article examined the consequences associated with changes in the EME, which is a fixed component of the OE. Its output was, among other things, a futures wheel [4, p. 49] that visualized the primary and secondary consequences of the examined trend on the nature of OE in the context of current knowledge. All of this was based on a foreign and domestic literature search, brainstorming and field research conducted through an interview method with military and civilian experts primarily in the fields of EW, EMS, and intelligence support. In order to make the futures wheel as usable as possible, the selected impacts were addressed not only from the perspective of military actors, but also from the rest of the audiences. Its visualisation is shown in Fig. 2. In the middle is the trend under study, i.e. “Development of assets and technologies based on the use of EM energy”. The primary consequences of this trend are shown on the blue ellipse, the secondary consequences on the green ellipse. Their causality is shown by different coloured lines and arrows.

Although there is not enough space in this article to explain the whole futures wheel in detail, an example of interpretation can be given as follows: the trend under examination, which is “Development of assets and technologies based on the use of EM energy” will primarily (among other things) result in “Easier availability of assets using the EMS by individual users” and “Expanding the portfolio of assets based on the use of the EMS designed to operate in one or more operational domains" (see Fig. 2, the trend is linked to the primary consequences by red arrows). The combination of these primary consequences then secondarily generates “The growing importance of the EMS management in the execution of MDO”, which is, however, also influenced by another secondary consequence, formulated as “Clash of generationally different military assets using the EMS” (see Fig. 2, linking these primary and secondary consequences by blue lines and arrow). The existence of this additional secondary consequence is linked to the already mentioned primary consequence “Expanding the portfolio of assets based on the use of the EMS designed to operate in one or more operational domains” and the not yet mentioned primary consequence “Development of modern systems based on modularity and open architecture” (see Fig. 2, linking these primary and secondary consequences by the yellow lines and arrow).

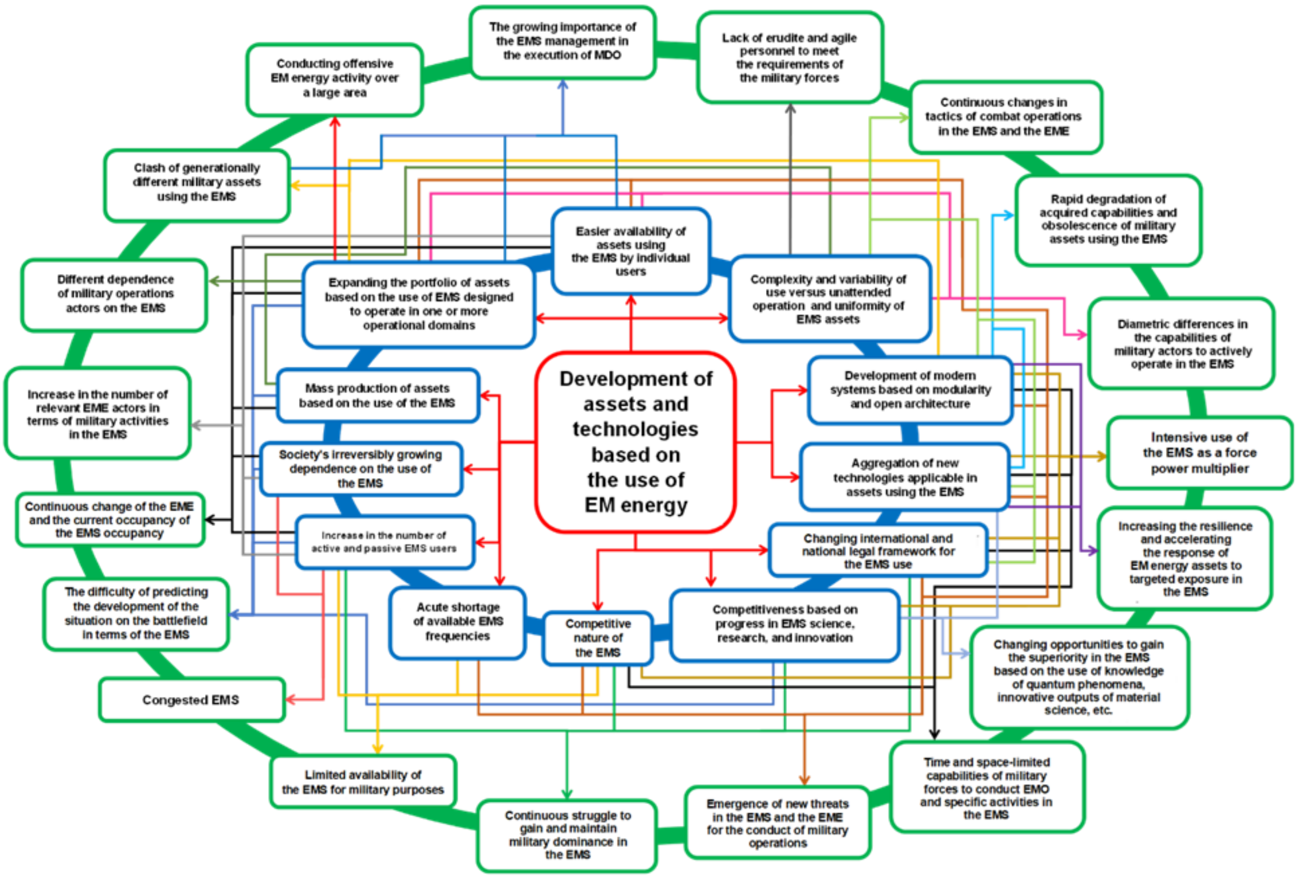

Fig. 2. Prediction of the future OE from the EMS perspective [4, p. 49]

From the above, it is clear that the futures wheel can be used to describe the interdependencies between the various primary and secondary consequences. As it is a representation of the prediction of the future OE from the EMS perspective, it can also be used to develop measures, methods and approaches of military forces to the EME and the EMS. The visualization of the expected changes in the nature of OE brought about by technical and technological advances has clearly shown that if military forces are to survive in future military operations, they must be prepared to conduct their own combat operations even in the complex EME. The EME must be viewed in terms of its existence, whereby the EME is pervasive and coexists independently of the will of anyone in the OE audience. This means that regardless of the operational area in which military forces are destined to conduct their own combat, they must simultaneously be able to operate effectively in the EME. Their EM activities (military forces' activities associated with EM energy-based equipment and technologies serving military units to support their own activities in their assigned operational domain), including specific EMS activities for some of them, must provide them with access to effective use of the EMS, i.e. freedom of action in the EMS.

Each military actor in the OE must be prepared to conduct its own combat activities in its assigned domain and simultaneously in the EME. This means that both existing and emerging military capabilities must be developed to be applicable in the future EME. Fig. 3 shows the development of military capabilities applicable in the future EME, regardless of whether it is a revision of existing capabilities, or the building of entirely new capabilities. It shows that the operational readiness of military forces for their effective use in the future EME is only possible when multiple factors of the future OE are simultaneously considered and defined. They may include, but are not limited to, implications based on direct and indirect consequences caused by trends changing the nature of the OE, opportunities and challenges associated with predicted changes in the nature of the OE, realistic ambitions that the military forces have in relation to the OE, constraints imposed by time and resources, or proposed recommendations that are shaped by the measures, methods, and approaches to the OE and the EME, respectively.

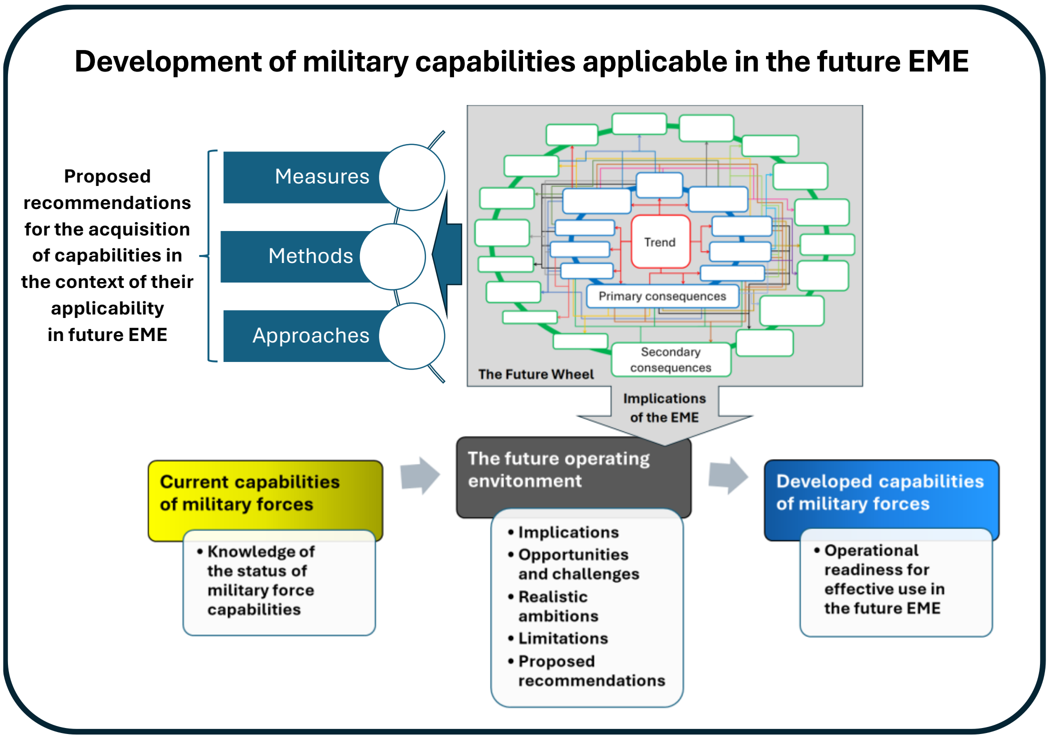

Fig. 3. Development of military capabilities applicable in the future EME [by the authors]

6. Military forces and their readiness to respond to changes in the electromagnetic environment

The details of tactics and approaches to the conduct of actual combat by military forces are themselves a very sensitive matter. Equally sensitive is the issue of their EM activities (including specific EMS activities), which is sometimes even subject to classified information protection. The following explanation of the use of the prediction of the future OE from the EME perspective will be made using a generalized example, without much detail. However, this does not diminish the quality of the presented results. In fact, the futures wheel is applicable to anyone dealing with the issue of adequate readiness of military forces and development of their capabilities for future operations, in accordance with the procedure described below.

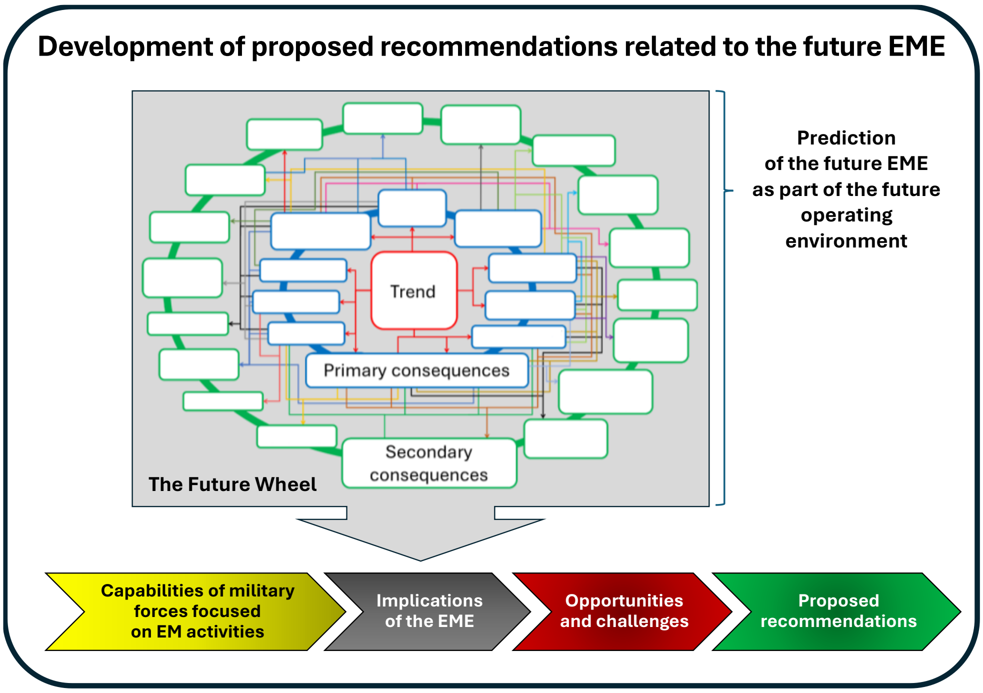

Fig. 4. Development of proposed recommendations for the future EME [by the authors]

Fig. 4 shows a simplified development of the proposed recommendations for the future EME. These recommendations are based on the clarification of capabilities of military forces focused on EM activities. The impact of the future EME on military forces is assessed through its predicted consequences caused by the explored trend. The degree of involvement of military forces in EM activities, which reflects their certain dependence on EM energy and indirectly their possible influenceability by specific EMS activities of enemies and adversaries, then expresses what opportunities and challenges military forces are facing. If the proposed recommendations are to be truly effective, they must reflect not only anticipated changes in the nature of the EME, but also the specific state of military forces, ambitions, limitations, etc.

Selected details that need to be addressed for the proposed recommendations leading to a revision of existing capabilities or the building of entirely new capabilities of military forces to operate in the future EME are shown in Fig. 5.

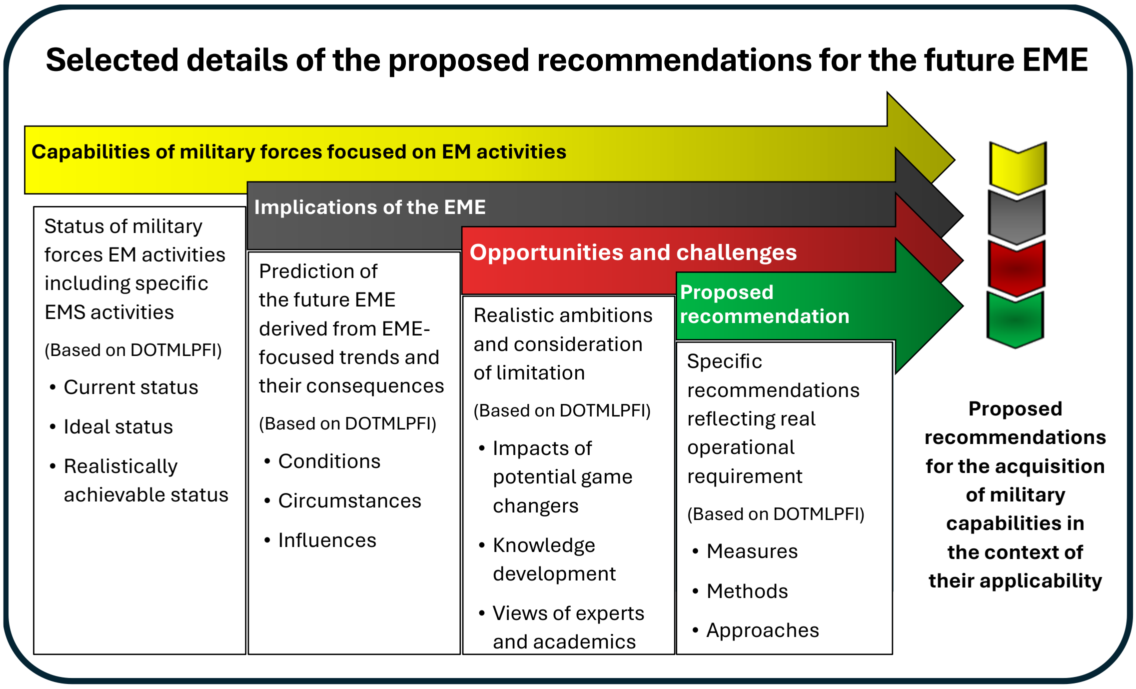

Fig. 5. Selected details of the proposed recommendations for the future EME [by the authors]

It is important to note that if the proposed recommendations are to be effective, it is appropriate to assess their impact in the different components that feed into them, considering the functional areas of the DOTMLPFI. This is the only way to ensure that none of the important areas to be addressed by the proposed recommendations are overlooked.

The research has shown which details of the different components involved in the development of the proposed recommendations should not be neglected. There is a total of four different components. The first relates to the capabilities of military forces focused on EM activities. To obtain the required information in this area, it is necessary to examine the status of military forces' EM activities, including specific EMS activities. Not only the current state and the so-called ideal state, i.e. the state we ideally want to achieve, should be assessed. Adequate recommendations should also be based on a realistically achievable state that substantially reflects the current reality of the capabilities of military forces in the context of what is achievable. The second component concerns the implications of the EME. It is based on predictions of future EME derived from EM-oriented trends and their consequences, which must include all related conditions, circumstances and impacts. The third part refers to opportunities and challenges. These are based on realistic ambitions and take into account limitations, reflecting the impact of potential game changers, knowledge development and the views of experts and academics. So-called potential game changers, whose actions will significantly influence the form of the proposed recommendation, are included, for example, in [8]. These include EM energy-related EW, DEW, cyber, space; internet of things, camouflage, cover, concealment, denial, deception, etc. The fourth component is related to the proposed recommendations. It is critical that proposed recommendations for revised or newly developed capabilities of military forces reflect the real operational requirements. The proposed recommendations must be a set of clear and focused measures, methods, and approaches that have the potential to achieve military force applicability in the future EME. In this context, the importance of EM energy as a potent force multiplier must not be overlooked. Even new sophisticated military technology with higher combat value may not automatically guarantee success and superiority over the enemy if the enemy is able to expose it to the effects of its own EMS activities.

7. Conclusions

It is logical that to achieve success in future military operations, it is important to know the OE in which these operations will take place. The complexity and variability of this environment are challenges that many military forces face today. Predication of the OE is a very complex and difficult matter. Outputs predicting the changing nature of the OE should ideally be reflected in the capabilities of military forces, as only then they will be able to adequately meet the future challenges associated with achieving the end state of military campaigns and operations. The ways in which the identified opportunities and challenges of the future OE can be addressed may vary. However, in all cases, proposed actions to develop individual military forces' capabilities should be considered across the full spectrum of DOTMLPFI functional areas. Only by following this approach the conditions for synergic development of the relevant military capabilities can be created.

EM energy is a factor that significantly influences the nature of the OE. The extent of this influence is based on the very physical nature of the propagation of EM energy. The fact that EM energy can be an effective multiplier of fighting power makes it an effective tool for future military operations as well. Although the EME is a fixed part of the OE, its importance is sometimes greatly underestimated. This is also proved by the current separation of operational domains, where NATO does not refer to the EME as a separate operational domain. This fact is sometimes the cause of a distorted perception of the potential impact of EM energy on the activities of military forces, both from the point of view of own forces as well as adversaries and enemies.

The futures wheel visualized in this article, the trend "Development of assets and technologies based on the use of EM energy", showed the magnitude and complexity of the interdependencies of first- and second-order consequences. The outlined process of the subsequent formulation of implications, the opportunities and challenges identified on their basis, and the proposed measures then completed the picture of the necessary and unavoidable complexity of military force readiness to respond to changes in the EME. The direct and indirect consequences of changes in the nature of the EME are then a real challenge for all military actors as they use EM energy in EM activities in support of the conduct of their own combat activities in their assigned operational domain. A special case is then the forces and assets of military forces destined to perform tasks related to specific EMS activities, whose task is to conduct combat activities in the EMS. Perhaps the greatest challenge associated with changes in the nature of the EME for future military operations is the very realization of the inherent dependence of military forces on EM energy and the vulnerability that this dependence presents. Equally important is the understanding of the personal and collective responsibility of all military actors to implement their own EPM, as well as a willingness to implement these measures by reducing dependence on the EMS use or eliminating it in a time and space constrained manner.

In any case, however, it will be necessary to monitor the influence of EM oriented trends on the nature of the EME and/or the OE. Research has shown that the development of assets and technologies based on the use of EM energy is, and will undoubtedly continue to be, a driver of change in the EME. These changes will certainly have a major impact on the ultimate nature of the OE. Thus, military forces in all operational domains will face many dilemmas as a result of dynamic changes in the OE. A good example of such challenges can be the effective integration of cyber and EW capabilities which is a key prerequisite for NATO ability to operate successfully in the future multi-domain environment [10, p. 518].

If military forces are unable to adequately address these dilemmas, their operational readiness may be significantly compromised by EM energy. It is therefore very important that all measures responding to the variability of the EME are addressed and implemented in all functional areas of DOTMLPFI. In addition to the assumption of continuous change in the EME, these measures must also reflect anticipated developments in the technical and technological fields, both on the part of the own forces and those of enemies and adversaries. It is an irrefutable truth that the importance of EM energy and the EME must neither be underestimated nor overestimated in the context of operational readiness and the conduct of future military operations. Both of these approaches create the potential to endanger not only military materiel but also human lives.

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Analysis of Traffic Accidents with the Deployment of the Fire Rescue Service in the Regions of the Czech Republic

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Abstract

Traffic accidents are an ongoing safety issue. The aim of this paper is to use a statistical apparatus to describe and model the random variable that is the daily number of accidents. The data on traffic accidents come from the database of the Fire Rescue Service of the Czech Republic from 2012–2021 and are described by time and location data. Analysis of variance for a random variable with a Poisson probability distribution was used in the modelling. The resulting analyses describe the evolution of the daily number of accidents with the deployment of firefighters in each region of the Czech Republic. The work that deals with the modelling of the number of traffic accidents, as a random variable with a Poisson probability distribution, using GLM methods is unique in the Czech Republic.

KEY WORDS: *Traffic accident, fire rescue service, generalised linear models, Poisson distribution.*

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1. Introduction

Traffic accidents are an ongoing safety issue. On the one hand, today's cars are equipped with all sorts of technology and manufactured with much more regard for safety than in the past, but on the other hand, cars are becoming more affordable, traffic is getting heavier and drivers are often encouraged to use high performance cars, which in turn has a negative effect on accident rates. The risk of a traffic accident is one of the most serious incidents investigated by the Integrated Rescue System. In traffic accidents such as those involving extrication [14], the need to deal with leaking fluids, the need to carry out fire-fighting measures on vehicles, or accidents in which it is necessary to restore traffic flow on the motorway, the intervention of fire brigades is required [9].

Many articles from our country and abroad are devoted to the topic of traffic accidents. The spatial representation to identify concentrations of motorcycle accident key hotspots is dealt with in [10]. They use the tool KDE+ (an extension of the kernel density estimation method), which allows to find the most dangerous sections of the Czech road network. Based on traffic accidents in the Czech Republic in 2016–2020, it can be said that traffic accidents are strongly seasonal in terms of time of day and year, and depend on population and traffic density, as well as weather and related conditions.

The road safety strategies for the Czech Republic for the period 2021–2030, presented in [8], are intended to reduce the negative impacts of traffic accidents. The aim of the convention, which is in line with the intentions of the European Union and the United Nations, is to reduce the number of deaths and injuries in road accidents by half. The strategy is a tool to achieve this objective. The key is to shift responsibility from national to local level, allowing concrete actions to be taken at the locations identified by the KDE+ method. Actions include activities in areas such as police surveillance of speed limits, traffic education, awareness of the impact of addictive substances on driving ability, mobile application for central reporting of defects on roads, research on the impact of new modes of transport and alternative vehicle propulsion and automation in relation to road safety, etc.

The topic of firefighting is currently being researched by experts at the University of Bourgogne Franche-Comté in France. The authors draw on data covering firefighting interventions from 2012-2017 in the Doubs department in France. They supplemented the data from the fire department database to 747 statistical features [6], such as meteorological data, astrological data, calendar data, and traffic events. In paper [2], the long short-term memory (LSTM) method from the field of artificial neural networks is mentioned. The work is developed in paper [3] and extended by comparing it with another method, extreme gradient boosting (XGBoost). The aim was to make predictions for each year based on data from other years. Predictions for years that were accompanied by natural disasters, and thus unexpected increased rescue activity, were less accurate. In terms of comparing the methods, the results proved almost comparable, with the XGBoost technique better at detecting extreme events during natural disasters. However, the authors also concluded that none of the neural network designs used were ideal due to the limitations of the number of neurons and hidden layers, and thus another approach should continue to be sought to create the best-fitting neural network to describe firefighter interventions.

A comparison of generalised linear model (GLM), i.e., the classical approach using statistics, and artificial neural network (ANN), i.e., the use of machine learning and intelligence, can also be found in [13]. The data of traffic accidents from 2005-2019 that occurred in the Province of Erzurum are considered. The paper describes the geographical characteristics of the study area, including the infrastructure, from which eight independent variables rise that affect the dependent variable: the number of traffic accidents. The calculations showed that ANN gives better results compared to GLM - high correlation coefficient and R-squared values as well as low MSE and RMSE of the tested network, thus confirming its superiority. The graphical representation showed that the ANN model is closer to real traffic accident data than GLM. The aim of this paper was to predict the risk factors and accident frequency. In conclusion, the proposed ANN model attained much better fitting and forecasting functionality compared to the GLM.

Two approaches to modelling the occurrence of traffic accidents are presented in [1]. First, the classical approach of generalised linear regression modelling was chosen for data with distributions such as Poisson, Negative Binomial (NB), Zero Inflated Poisson (ZIP), and Zero Inflated Negative Binomial (ZINB). The second approach, newly introduced, involves normalizing the data and using a linear regression model. This alternative approach was validated on crash data from 186 access roads in the state of Virginia, which was found to be negatively binomial distributed.

The use of a generalised Poisson linear model to evaluate fatal crashes that occurred in Romania between 2008 and 2012 is described in [12]. Factors characterising the crashes were date and time, infrastructure information, cause of crash, safety precautions, and visibility. The paper compares the Poisson and quasi-Poisson approaches of the distribution of the explained variable. As a result, it is concluded that the generalised Poisson linear model allows to select significant risk factors, which in this case turned out to be, among others, the side impact on curved roads.

Among the factors influencing the occurrence of a traffic accident is undoubtedly the influence of weather. The paper [7] analysing traffic accidents in the Chinese city of Shantou examines the influence of meteorological parameters on accident rates by time series methods, correlation analysis and multiple linear regression analysis. The models showed that road traffic injuries are positively correlated with temperature and sunshine duration, while negatively correlated with wind speed.

In the past ten years, a total of 198,773 accidents involving the deployment of fire rescue units occurred in 14 regions of the Czech Republic. The records of accidents in the years 2012-2021 were taken from the database of the Fire Rescue Service of the Czech Republic, where they are characterised by geographical position and time of occurrence. The aim of this work is to use statistical apparatus to describe a discrete random variable, which is the daily number of accidents, and to model it using a generalised linear model (GLM).

First, the probability distribution of the explained random variable was tested. Based on the results of these tests, the analysis of variance approach for statistical analysis with a count variable, following a Poisson distribution, was chosen for modelling. Multifactor analyses without and with interactions were used to describe the daily number of accidents. In this paper, we will consider the following factors: day of the week, month, and region. The results of the estimated models were compared with the statistical characteristics of the dataset. Additionally, it is important to include an interaction term in multifactor analyses.

2. The Mathematical Background

The number of traffic accidents has been successfully described by a random variable with a Poisson, Poisson-gamma, or zero-inflated probability distribution [11]. The Shapiro, Lilliefors, or Anderson-Darling tests can be used to verify the normal probability distribution of a random variable. To verify the Poisson probability distribution, the Cramer-von Mises or Anderson-Darling goodness-of-fit tests can be used. If the p-value of these tests is less than the chosen significance level α, we reject the null hypothesis of a Poisson distribution of the explained variable. Agreement with the assumed distribution can also be verified graphically, e.g., by plotting the relative frequencies of the observed variable or by comparing the empirical and theoretical distribution functions.

The main idea of this analysis is to decide on the dependence of the observed random variable on selected factors. The Y_i values of the explained random variable are sorted into groups according to the variations of the specified factor, and if the Y_i values are shown to differ between these groups, the dependence of the Y variable on the given factor is thereby demonstrated. In the case of a normal distribution of the random variable Y, the dependence on the factors is determined by analysis of variance (ANOVA). Furthermore, the use of multiple comparison tests makes it possible to decide which groups resulting from factor sorting are different. For data that do not follow a normal distribution, the non-parametric Kruskal-Wallis test is used [4]. If the p-values of the Kruskal-Wallis test come out smaller than the chosen significance level, it means that the explained random variable depends on the factor. For the purpose of multiple comparisons, for example, Nemenyi's all-pairs rank comparison test can be used.

For variables that do not meet the conditions for ANOVA, it is also possible to use generalised linear modelling GLM [5]. A random variable Y has a Poisson probability distribution if the probability function can be expressed in the form

$$p(y) = \frac{\lambda^y}{y!} e^{-\lambda}, \tag{1}$$

where parameter λ represents the average number of events per time unit and is both the mean and variance of Y. In this case, the natural logarithm is chosen as the link function of the generalised linear model. For the case of a two-factor analysis of variance with interactions, we can write for the means λ_{ij} $(i = 1,2, \dots, I,$ and $j = 1,2, \dots, J,)$

$$\log \lambda_{ij} = \mu + \alpha_i + \beta_j + \gamma_{ij}, \tag{2}$$

where α_i is the effect of the first factor, β_j is the effect for the second factor and γ_{ij} is the interaction effect. From the output of the computational process, it is possible to see how much each factor contributes to the estimate of the mean and how statistically significant their contribution is. The multivariate analysis can be performed in two forms, either without or with factor interactions. In the analysis with interactions, not only the effect of the individual factors on the explained variable is taken into account, but also the effect of the interaction between the different types of factors.

For both models, the percentage of explained variance can be determined by the expression

$$1 - \frac{D}{D_{null}}, \tag{3}$$

where null deviance D_{null} corresponds to a model containing only the intercept (the worst fit), and the residual deviation D is indicative of a model including the independent variables. The higher the D, the larger the difference between the estimated and observed values and thus the model is less able to describe the observed dependence. The percentage of explained deviance indicates how accurate the model is - it takes values from 0 to 1, the closer to 1, the better the model describes reality.

The calculations were performed in R, version 4.3.1.

3. Investigation Results

This article deals with the analysis of traffic accidents with the deployment of firefighters in the Czech Republic in the years 2012-2021. The initial dataset comes from the database of the Fire Rescue Service and includes records of 198,773 accidents that occurred in the Czech Republic from January 1st, 2012 to December 31th, 2021. The colour differentiation of the regions of the Czech Republic according to the number of such accidents can be seen in Fig. 1.

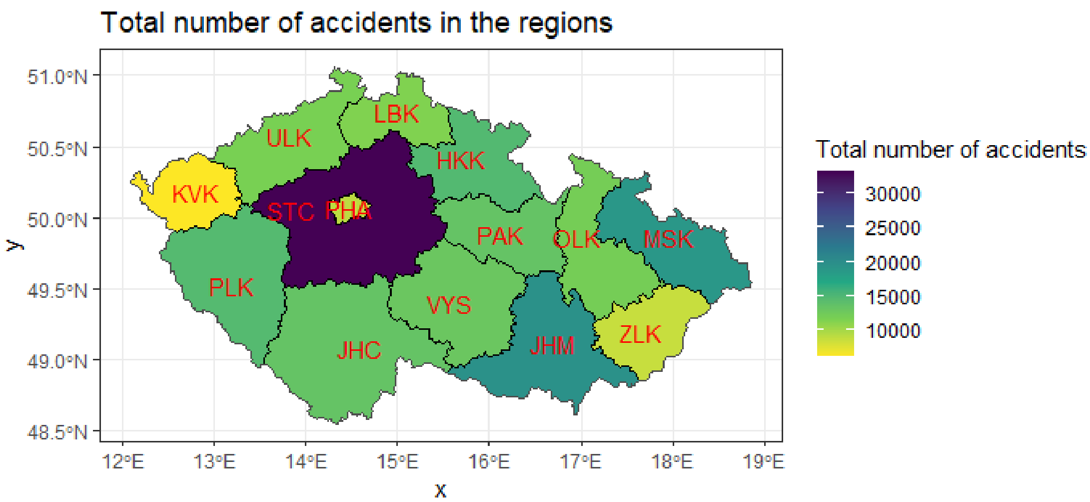

Fig. 1. Total number of accidents with the deployment of firefighters in the regions of the Czech Republic in the years 2012–2021.

Each accident in the database was described with time and location data. The explained coincidence variable is the daily number of traffic accidents with the deployment of firefighters. The observed factors are the *day* and *month* when the accident occurred and the *region* of the Czech Republic in which the accident occurred. The statistical characteristics of accidents in the individual regions of the Czech Republic for the period under study are presented in Table 1 and graphically represented by boxplots in Fig. 2. From Table 1 it can be seen that the region with the highest average daily number of traffic accidents involving deployment of firefighters is the Central Bohemia Region (STC). In contrast, the lowest average number of accidents per day occurred in the Karlovy Vary Region (KVK). In addition to the *mean* of daily number of accidents, the table shows the *minimum* and *maximum* number of accidents per day in a given region, the *median*, and the *standard deviation* of the region's average from the overall daily average. The number of all observations *n*, i.e., all days in the period of interest, is 3653, the same for all regions. The average comes out to 3.89 accidents per day per region.

Table 1.

Characteristics of the daily number of accidents for region.

Region	Mean	Median	Standard deviation	Min	Max
PHA	2.46	2	1.77	0	13
STC	9.08	9	4.61	0	43
JHC	3.65	3	2.33	0	19
PLK	3.98	4	2.56	0	22
KVK	1.66	1	1.48	0	12
ULK	3.19	3	2.08	0	16
LBK	3.10	3	2.24	0	20
HKK	4.02	4	2.56	0	26
PAK	3.65	3	2.82	0	64
VYS	3.53	3	2.62	0	48
JHM	5.34	3	3.28	0	40
OLK	3.28	3	2.28	0	36
MSK	5.15	5	3.00	0	42
ZLK	2.33	2	1.74	0	12

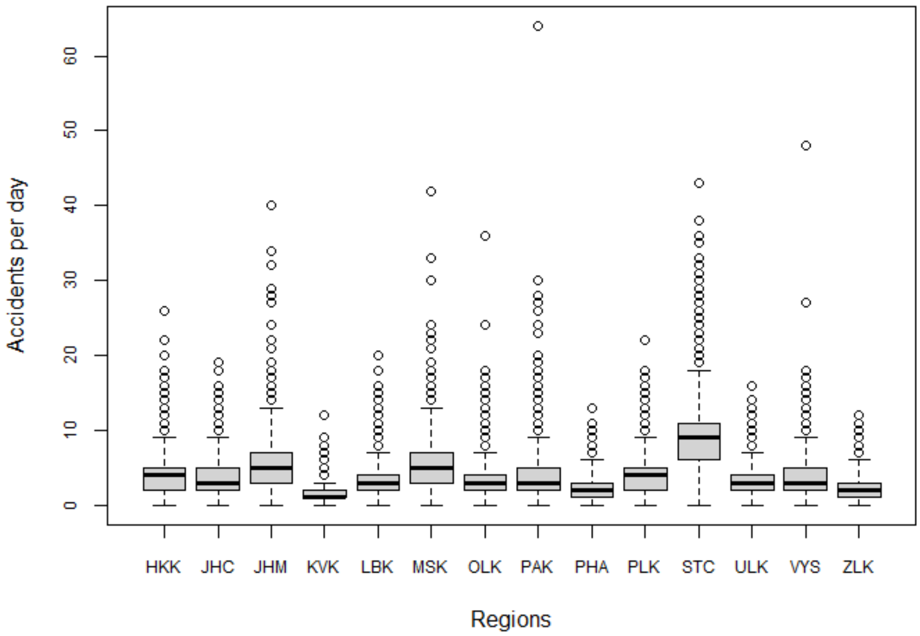

Fig. 2. Boxplots of the daily number of accidents in regions.

Outliers have not been removed from the data as they could be an important indicator of problem locations and periods when extreme numbers of accidents occur. The daily number of crashes in regions is an absolute frequency that has not been converted to region size or population. It is clear that many conditions have a significant effect on the accident rate in regions, e.g., region size, population density, length of the road network, presence of highway segments, etc., which may be the subject of further analysis.

During the initial stages of model development, tests were conducted to evaluate the normal distribution, but the results indicated that this probability distribution would not be appropriate. Therefore, goodness-of-fit tests were performed with the Poisson distribution, namely Cramer-von Mises or Anderson-Darling. Verification was also performed graphically using the values of the estimated likelihood function, or by plotting the relative frequencies for data sorted by region, month, and day of the week. As an example, the comparison plots for January Mondays in the Hradec Kralove region are presented in Fig. 3.

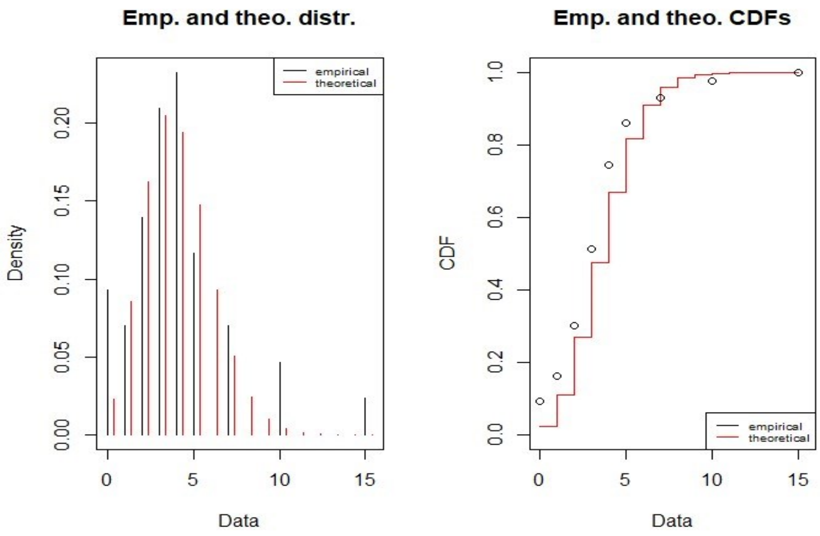

Fig. 3. Probability function and cumulative distribution function for the theoretical Poisson distribution function with estimated parameters and empirical data for accidents in the Hradec Kralove region that occurred on Mondays in January 2012–2021. The theoretical function is shown in red, the empirical function in black.

Since the normality assumptions for parametric analysis of variance are not met, one option is to use non-parametric methods, which is the Kruskal-Wallis test. The Kruskal-Wallis tests were demonstrated for all factors and showed that the p-value is much less than 0.05 for each of the *day* of week, *month* and *region* factors (p-value < 0.001), so that the null hypothesis of equality of means between groups of explanatory variables ordered by the *day* of week, *month* and *region* factors can be rejected. Furthermore, multiple comparison tests were demonstrated for regions, showing that all effects of the *region* factor are statistically significant.

Another option chosen was the generalised linear model approach for count data (Poisson distribution) [5]. This approach allows for both one-factor and multifactor analyses. The parameters estimated according to the one-factor model did not yield any surprising results, they just correspond to the statistical characteristics shown in Table 1.

Table 2.
Generalised linear model – parameter estimates of Model 1 (without interactions).

Factor	*Estimate*	*p-value*		*Factor*	*Estimate*	*p-value*	
Intercept	1.2653	<0.001	***	*HKK*	0.1142	<0.001	***
day1	0.0427	<0.001	***	*JHC*	0.0185	<0.001	***
day2	–0.0144	0.009	**	*JHM*	0.3990	0.027	*
day3	–0.0026	0.637		*KVK*	–0.7686	<0.001	***
day4	0.0253	<0.001	***	*LBK*	–0.1469	<0.001	***
day5	0.1562	<0.001	***	*MSK*	0.3617	<0.001	***
day6	–0.0248	<0.001	***	*OLK*	–0.0903	<0.001	***
day7	–0.1823	<0.001	***	*PAK*	0.0187	<0.001	***
month1	–0.0303	<0.001	***	*PHA*	–0.3777	0.026	*
month2	–0.1052	<0.001	***	*PLK*	0.1040	<0.001	***
month3	–0.2325	<0.001	***	*STC*	0.9297	<0.001	***
month4	–0.1733	<0.001	***	*ULK*	–0.1153	<0.001	***
month5	–0.0490	<0.001	***	*VYS*	–0.0159	<0.001	***
month6	0.1255	<0.001	***	*ZLK*	–0.4310	<0.001	***
month7	0.0713	<0.001	***				
month8	0.1076	<0.001	***				
month9	0.1223	<0.001	***				
month10	0.0872	<0.001	***				
month11	–0.0088	0.242					
month12	0.0853	<0.001	***				

The analysis is mainly focused on a multi-factor model. Parameter estimates were computed for the multivariate analysis of the model with *day*, *month* and *region* factors. Table 2 shows the values of the estimates for the model without interactions

$$\text{Model 1: } \log accidents_{ijk} = \beta_0 + region_i + month_j + day_k, \quad (4)$$

where $i = 1,\ldots,14$, $j = 1,\ldots,12$, $k = 1,\ldots,7$. Table 2 shows that the p-values for most of the factor variations indicate high statistical significance. The parameter estimates can be used to calculate an estimate of the average value of the daily number of traffic accidents in a particular *day*, *month* and *region*. For example, effect for Monday is exp(0.0427). Thus, the estimate of the daily number of accidents on a Monday in January in the Hradec Kralove region (HKK) is equal to exp(1.2653+0.0427–0.0303+0.1142) = 4.022.

The average daily numbers of accidents in each day and month were calculated for all regions. The tables with the calculated averages for the region with the lowest average daily number of accidents with fire brigade deployment, i.e. the Karlovy Vary Region (KVK) in Table 3, and for the region with the highest average daily number of accidents, i.e. the Central Bohemia Region (STC) in Table 4, are attached for your reference.

Table 3.

Predicted values of the daily number of accidents, Model 1 (without interactions) – KVK, the region with the lowest average daily number of accidents. The colour scale was chosen from green (= lowest value) to red (= highest value).

Month\Day	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
1	1.66	1.57	1.59	1.64	1.86	1.56	1.33
2	1.54	1.46	1.48	1.52	1.73	1.44	1.23
3	1.36	1.28	1.30	1.34	1.52	1.27	1.09
4	1.44	1.36	1.38	1.42	1.62	1.35	1.15
5	1.63	1.54	1.56	1.60	1.83	1.53	1.30
6	1.94	1.84	1.86	1.91	2.18	1.82	1.55
7	1.84	1.74	1.76	1.81	2.06	1.72	1.47
8	1.91	1.80	1.83	1.88	2.14	1.79	1.53
9	1.94	1.83	1.85	1.90	2.17	1.81	1.55
10	1.87	1.77	1.79	1.84	2.10	1.75	1.49
11	1.70	1.61	1.62	1.67	1.90	1.59	1.36
12	1.87	1.76	1.78	1.84	2.09	1.75	1.49

Table 4.

Predicted values of the daily number of accidents, Model 1 (without interactions) – STC, the region with the highest average daily number of accidents.

Month\Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	9.09	8.59	8.69	8.94	10.18	8.50	7.26
2	8.44	7.97	8.06	8.29	9.45	7.88	6.74
3	7.43	7.01	7.10	7.30	8.32	6.94	5.93
4	7.88	7.44	7.53	7.74	8.83	7.37	6.29
5	8.92	8.43	8.53	8.77	10.00	8.34	7.13
6	10.62	10.03	10.15	10.44	11.90	9.93	8.48
7	10.06	9.51	9.62	9.89	11.27	9.41	8.04
8	10.44	9.86	9.97	10.26	11.69	9.75	8.33
9	10.59	10.00	10.12	10.41	11.86	9.90	8.46
10	10.22	9.66	9.77	10.05	11.45	9.56	8.16
11	9.29	8.77	8.88	9.13	10.40	8.68	7.42
12	10.21	9.64	9.75	10.03	11.43	9.54	8.15

It can be seen that the factor *day* of the week showed that in terms of accidents, Mondays, Thursdays and Fridays are above average, while on Sundays the risk of a traffic accident involving the deployment of the fire rescue service was below average. The development of the risk of traffic accidents during the year, based on the collected data sample, shows that from November

to May, except December, the risk is below average, while from June to October and in December the risk is above average, for both displayed regions. Similar results emerge for the remaining regions of the Czech Republic.
The characteristics of the model without interactions resulting from the use of the GLM method are summarized in Table 5. To test the null hypothesis that the model describes the data well, the *deviance* statistic is used, which has an approximate χ^2 distribution with *Df* degrees of freedom. Here the model is compared to the saturated (maximum) model, which can be seen in the *Resid. Dev* value. The higher the deviance values, the worse the model. Thus, Table 5 shows that the percentage of explained deviance is 32.54%.

Table 5.
ANOVA – Model 1 (without interactions).

	Df	**Deviance**	**Resid. Df**	**Resid. Dev**	**Pr(>Chi)**
null			51141	117557	
region	13	34050	51128	83507	<0.001
day	6	1689	51111	79305	<0.001
month	11	2512	51117	80995	<0.001

Several possible interactions between factors have been studied, of which the *month* and *day* interaction seems to be the most meaningful. We apply the model

$$\text{Model 2: } \log accidents_{ijk} = \beta_0 + region_i + month_j + day_k + month \times day_{jk}, \quad (5)$$

where $i = 1,\dots,14$, $j = 1,\dots,12$, $k = 1,\dots,7$. This model with the interaction is shown in Table 6, a comprehensive table would contain 1176 values. The percentage of deviance explained by this model is 0.330. A comparison of the two models is made in Table 7, showing that the multi-factor model with interactions seems to be a suitable model for analysing the dependence of the daily number of accidents involving the deployment of the fire rescue service according to the *day* of the week, *month* and *region*, as evidenced by the very small p-value.

Table 6.
ANOVA – Model 2 (with interactions)

	Df	**Deviance**	**Resid. Df**	**Resid. Dev**	**Pr(>Chi)**
null			51141	117557	
region	13	34050	51128	83507	<0.001
day	6	1689	51111	79305	<0.001
month	11	2512	51117	80995	<0.001
month×day	66	539	51045	78766	<0.001

Table 7.
ANOVA – comparison of Model 1 and Model 2

	Df	**Deviance**	**Resid. Df**	**Resid. Dev**	**Pr(>Chi)**
1			51111	79305	
2	66	539.1	51045	78766	<0.001

For comparison, estimates of the daily means of traffic accidents were also calculated for the model with interactions, see Table 8 and 9. It can be seen that the model with interactions shows deeper differences between days, while the model without interactions shows more moderate values that are closer to the overall average.

Table 8.
Predicted values of the daily number of accidents, Model 2 (with interactions) – KVK,
the region with the lowest average daily number of accidents.

Month\Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	1.69	1.75	1.69	1.63	1.90	1.42	1.12
2	1.51	1.53	1.73	1.43	1.78	1.28	1.13
3	1.34	1.42	1.31	1.33	1.51	1.22	1.02
4	1.45	1.40	1.37	1.51	1.63	1.29	1.07
5	1.67	1.55	1.52	1.66	1.78	1.49	1.33
6	1.94	1.80	1.72	1.86	2.23	1.91	1.63

7	1.80	1.64	1.76	1.84	2.00	1.82	1.56
8	1.85	1.74	1.79	1.78	2.10	1.88	1.72
9	1.98	1.65	1.76	1.78	2.31	1.88	1.69
10	1.79	1.74	1.82	1.86	2.01	1.81	1.57
11	1.79	1.61	1.59	1.73	1.85	1.58	1.30
12	1.91	1.72	1.75	1.94	2.11	1.78	1.38

Table 9.

Predicted values of the daily number of accidents, Model 2 (with interactions) – STC, the region with the highest average daily number of accidents.

Month\Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	9.25	9.55	9.25	8.89	10.37	7.75	6.13
2	8.23	8.35	9.48	7.84	9.74	6.99	6.18
3	7.33	7.78	7.16	7.26	8.28	6.64	5.60
4	7.90	7.65	7.47	8.23	8.91	7.04	5.86
5	9.10	8.49	8.29	9.07	9.74	8.15	7.26
6	10.62	9.82	9.37	10.18	12.21	10.42	8.90
7	9.82	8.98	9.60	10.03	10.91	9.94	8.55
8	10.13	9.53	9.80	9.71	11.46	10.27	9.41
9	10.82	9.02	9.60	9.74	12.64	10.27	9.23
10	9.77	9.49	9.95	10.18	10.99	9.91	8.60
11	9.77	8.82	8.69	9.47	10.09	8.65	7.08
12	10.45	9.41	9.55	10.58	11.52	9.71	7.55

4. Conclusions

The aim of the study was to verify the dependence of the daily number of traffic accidents with the deployment of firefighters on the selected factors, which were the day of the week, month and region of the Czech Republic, using the methods of generalised linear modelling GLM for count variable with Poisson distribution. The results obtained were compared with the origin dataset and a conclusion was drawn based on this comparison.

The hypothesis of normality of the data was rejected after performing tests of normal distribution. Goodness-of-fit tests with Poisson distribution were performed for data sorted by region, month, day of the week and showed approximately good results. For the Kruskal-Wallis tests a p-value much smaller than 0.05 was obtained, based on these tests it can be concluded that the daily number of accidents depends on the observed factors. Further models showed that all factors examined were statistically significant. Multifactor analyses were performed, additive (without interactions between factors) and multiplicative (with interactions between day and month).

Both multifactor models, with and without interactions, were compared. Predicted values of daily number of accidents in the model without interactions are presented for the regions with the lowest and highest daily average number of accidents. In the case of multifactor models, the addition of an interaction term appears to be significant. The percentage of explained variance for the model without interactions is 32.54% and for the model with interactions is 33.00%, i.e., the model with interactions gives slightly better results for describing the observed variables.

The following conclusions emerged from the analyses. The day of the week factor showed that Mondays, Thursdays and Fridays were above average in terms of accident rates, while Sundays were below average in terms of the daily number of traffic accidents involving the deployment of the fire rescue service. Overall, the number of accidents is above average on weekdays compared to the weekend when accidents occur less frequently. The trend in the daily number of traffic accidents over the year based on the data sample collected shows that the daily number is below average in the winter and spring months, and from June to October the accident rate is above average relative to the overall annual average daily number of traffic accidents involving the deployment of the fire rescue service. December showed high values for the daily number of traffic accidents as well. These results reflect the busyness of traffic and how it changes during the week, throughout the year. Quieter days are days when people do not have to commute, for example for work. Summer is the time of year for travel, and high summer temperatures and long journeys have an adverse effect on drivers' attention spans. In the event of an accident, there is a greater need for fire-fighting measures in hot weather than in winter, for example. The dependence of the daily number of accidents on the region also proved statistical significance. The calculations show the lowest average of accidents per day in the Karlovy Vary Region and the highest in the Central Bohemia Region. The region factor was reflected in the accident rate mainly by the geographical conditions in the regions. Regions, where the winters are colder, show a higher accident rate, e.g. due to black ice.

Many factors play a role in traffic accidents. We have focused on the occurrence of traffic accidents in particular days, months and regions, however, other factors that certainly influence the number of traffic accidents with the deployment of firefighters are road infrastructure, region population, geographical characteristics of the region, but also the influence of weather and other meteorological phenomena, such as those mentioned in studies [6], [7], and impact of natural events, e.g. black ice, which are difficult to predict, because they vary from year to year and their influence on the prediction of the number of traffic accidents is rather unpredictable, see [2], [3].

It is hoped that, as a result of the above-mentioned studies, models of the development of the daily number of traffic accidents with the deployment of firefighters will be able to be useful in the field of traffic safety in the Czech Republic. The study provides a comprehensive view of the relationship between the number of accidents and days of the week, months of the year and regions of the Czech Republic. In the event of accidents, significant losses occur, not only financially, but also, and above all, in terms of damage to health and environmental damage. Reducing the need for deployment of firefighters would lead, among other things, to savings in terms of the equipment used and the costs of subsequent treatments and repairs [8]. Based on the knowledge of the development of the daily number of accidents, it is then possible to propose appropriate solutions to reduce the accident rate.

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Stress Coping Strategies of Young Soldiers in the Context of the Deteriorating Security Situation

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Abstract

The aim of the paper is to investigate how military students perceive and feel about the deteriorating security situation within the context of the Russia-Ukraine conflict. Additionally, it aims to identify their coping responses and strategies associated with the conflict. The quantitative research design was employed, specifically utilizing a standardized Brief COPE inventory. The data for this study was collected in 2024. The sample consists of 178 military students from the Faculty of Military Leadership of the University of Defence in the Czech Republic. The results indicate that young military students perceive the security situation as serious and believe it will affect their future careers. However, the security situation does not cause them significant stress, and they do not report significantly high levels of any of the coping strategies offered. To the highest extent, the students declare especially the application of the following strategies – Acceptance, Planning, and Humor.

KEY WORDS: *Stress-coping strategies; Military; Soldiers; Russia-Ukraine conflict; Brief COPE inventory.*

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1. Introduction

The military profession inherently carries a significant level of stress due to the diverse range of challenging situations that individuals encounter, even during times of peace. However, the stress intensifies during times of war and conflict. This affects not only soldiers directly engaged in combat but also those in active duty who are not directly involved in combat, as well as cadets (military students) preparing for their future roles.

In February 2022, the Russia-Ukraine conflict (RUC) erupted, plunging Europe into a war-torn state after many decades of peace. The security situation in NATO countries, particularly those in Eastern Europe, has significantly deteriorated due to this intervention.

Aside from the Ukrainian population directly impacted by the conflict, individuals living in other nations have also experienced its effects. For instance, in countries sharing geographical, historical, economic, and cultural ties with Russia and Ukraine, there is a natural development of deep emotions and concerns regarding potential involvement in the war. Moreover, individuals in countries lacking such connections with Russia and Ukraine have also observed the war's significance through media coverage. Consequently, insecurity among the entire population has heightened, resulting in increased stress levels. For instance, the findings of the study by Chudzicka-Czupała et al. [1] indicate that even residents not directly involved in the war experience higher levels of stress.

Lazarus [2] proposed that stress involves three distinct processes. The first process, known as *primary appraisal*, involves recognizing a perceived threat to oneself. *Secondary appraisal*, the second process, involves considering potential responses to the identified threat. *Coping*, the third process, refers to the execution of the chosen response. [3] *Coping strategies* have been demonstrated to serve as protective measures against the impacts of stress on both physical and psychological well-being, and the strategies used are often a reflection of the appraisal process. [4]

In recent decades, interest has increased significantly in the mechanisms individuals employ to cope with stress. Coping strategies can be categorized in various ways, including *adaptive* and *maladaptive* or *problem-focused*, *emotion-focused* and *avoidant* stress coping strategies. [5, 6]

In this paper, the authors focus on a specific target group directly impacted by the threat of RUC – soldiers, particularly first-year and second-year military students of the Czech Republic's sole military school – the University of

Defence, who in addition to the stress of war, must contend with the challenges of acclimating to military life. [7] The paper aims to identify and describe their coping responses and strategies connected with the RUC. Several tools are available for measuring and detecting stress-coping strategies. The authors employ the questionnaire method, utilizing the *Brief COPE inventory*.

However, to assess stress coping strategies, it is first necessary to determine how military students perceive and feel about the deteriorating situation. Therefore, the research questions are as follows:

- How do young military students perceive the deteriorating security situation and its potential impact on their future careers?
- What coping strategies do young military students utilize to navigate the security situation within the RUC?

2. Theoretical Background

A study conducted by Kurapov et al. [8] examined the psychological effects of RUC on Ukrainian university students and staff. 97.8% of participants experienced worsened mental and emotional states, marked by increased levels of depression, loneliness, nervousness, and anger. These findings align with those of Stadnik et al. [9], who observed similar trends among students and cadets of Ukrainian universities, indicating that proximity to the conflict zone intensified negative mental health outcomes, including somatic symptoms, anxiety, insomnia, social dysfunction, and severe depression. Additionally, Gilreath et al. [10] investigated stressors impacting the academic performance and well-being of youth in wartime, noting risks such as suicidal tendencies and substance abuse in both short and long terms.

Although the psychological impact of the conflict primarily affected individuals within the war zones, those ideologically aligned with the conflict in central Europe and beyond also experienced repercussions. Stressors and increased anxiety were observed globally. [11] For instance, Kimhi et al. [12] examined resilience and coping mechanisms among samples from Ukraine and neighboring countries during the conflict, highlighting differences in coping indicators such as hope, well-being, perceived threats, distress symptoms, and sense of danger. The Czech Republic exhibited the highest level of well-being but reported the lowest level of hope.

Stress arises as a natural physiological reaction to external perceived threats. Increased stress levels represent one of the psychological consequences of the ongoing Russian invasion of Ukraine. [13]

According to Carver [14], specific stress-coping strategies can be assigned to any of the following groups – self-distraction, active coping, denial, substance use, use of emotional or instrumental support, behavioral disengagement, venting, positive reframing, planning, humor, acceptance, religion, or self-blame.

The assessment of a coping strategy is fundamentally linked to whether it demonstrates an *adaptive* (beneficial) or *maladaptive* (detrimental) impact on an individual's well-being. Adaptive coping strategies encompass actions like physical activity, mindfulness practices, and seeking social support, while maladaptive behaviors include activities such as avoidance, overeating, and drug use. [15] The classification of coping strategies into adaptive and maladaptive behavior is a frequently utilized approach in coping strategy research. [16, 17]

Problem-focused coping involves managing the problem causing the stress, through actions like problem-solving and decision-making. *Emotion-focused* coping aims to manage the emotional response to the problem, often used when the stressor is seen as unchangeable, and includes strategies like seeking comfort and relaxation. *Avoidant* coping strategies involve consciously or subconsciously avoiding the stressor, which can lead to temporary relief but often exacerbates stress in the long run. These coping strategies can be adaptive or maladaptive, depending on the situation and how they are used. [5]

Studies show that effective coping skills correlate with enhanced life satisfaction and resilience, with problem-focused coping linked to higher resilience and emotion-focused coping associated with lower resilience. [18] Numerous studies indicate that individuals with a strong coping self-efficacy tend to employ more adaptive coping strategies. [19, 20]

Research suggests that the military system depends on, and reinforces, problem-focused behavior to a greater degree, which is why it favors a problem-focused coping strategy. [21] In a military context, Mikulincer and Florian [22] discovered that recruits who employed emotion-focused coping perceived basic training as threatening, while those who utilized problem-focused coping viewed it as a challenge. During basic training, West Point cadets demonstrated both efficient problem-solving and emotion-focused coping strategies, such as engaging in physical activity, humor, rationalization, and seeking strong social support, as identified by Gold and Friedman. [7] Among military personnel, Morgan et al. [23] found that the most common coping behaviors involved problem-solving, talking to friends, hobbies and physical activity. Similarly, Bray et al. [24] found that most of the US military employed problem-focused coping strategies, such as thinking of a plan to solve problems, seeking support from friends/family members, and exercising, rather than resorting to avoidant coping strategies like eating or drinking. Udeh et al. [25] also discovered in a study involving 261 Nigerian military personnel that the majority of them employ positive coping strategies for stress management, including thinking of plans to solve problems, engaging in physical exercise or sports, and reading. The Department of Defense Survey of Health Related Behaviors Among Active Duty Military Personnel indicated a preference for constructive active coping strategies over avoidance-oriented ones. These include seeking social support and engaging in physical activities or hobbies. This indicates an overall preference for adaptive coping strategies over maladaptive ones. However, a significant portion of military personnel reported maladaptive coping strategies like alcohol or tobacco use. [26]

In military settings, alcohol consumption is often seen as a way to relieve stress, offering a means to unwind after a challenging day [27] as several studies have noted an increase in drinking behavior during service. [28] Additionally, in a separate study, Dolan et al. [29] found that less experienced, lower-ranking junior-enlisted soldiers reported higher levels of maladaptive coping compared to noncommissioned officers and officers.

3. Methodology

Regarding the aim, the research was conducted within a quantitative paradigm. The basic component of the questionnaire survey is the standardized Brief COPE inventory [14], which allows the assessment of different ways in which people respond to stress. The authors utilized a brief form of a previously published measure called the COPE inventory [3], which is reliable and valid. The full COPE consists of 60 items distributed across 15 scales, with 4 items per scale. Within a given scale, there is considerable redundancy in item content. Therefore, the Brief COPE inventory, consisting of 14 scales, each containing two items, was developed. In total, it encompasses 28 items. [14] The 14 scales of the Brief COPE inventory focus on examining the extent to which the following strategies are used:

1. *Problem-Focused Coping* – Active coping, Use of Informational Support, Planning, Positive Reframing.
2. *Emotion-Focused Coping* – Venting, Use of Emotional Support, Humour, Acceptance, Self-Blame, Religion.
3. *Avoidant Coping* – Self Distraction, Denial, Substance Use, Behavioral Disengagement.

Data were collected at the beginning of 2024 through an online questionnaire. The target population consisted of first-year (89%) and second-year (11%) military students at the Faculty of Military Leadership of the University of Defence. The validity of the questionnaire was confirmed in a pre-survey conducted among selected military students. The purpose and aim of the research, including full assurance of anonymity, were explained to all participants before data collection.

A total of 178 respondents participated in the research, with 22% being women and 78% men. 98% of the respondents were between 19 and 24 years old, with the remaining 2% being older.

To address the first research question, four questions with responses on the Likert scale were created. Respondents were asked to indicate how they perceive the situation in Ukraine – whether they consider it serious, whether it makes them stressed/nervous, and whether they think it will affect their future careers. The response options included "I fully disagree," "I rather disagree," "I rather agree," and "I fully agree."

For the second research question, a Brief COPE inventory was employed. This 28-item closed-ended questionnaire explores stress-coping strategies. Respondents again used the aforementioned response scale. These 28 questions were then categorized based on their focus into 14 stress-coping strategies, following the procedure outlined by Carver. [14]

Quantitative data were analyzed statistically. The frequencies of responses, indicating the level of agreement with the presented statements regarding the perception of the security situation and the implemented stress-coping strategies, were determined. Mean values, standard deviations, and medians of the responses are also reported.

4. Results

Following the research questions, the authors initially examine how military students perceive the deteriorating security situation, particularly concerning the RUC. Subsequently, the results of the Brief COPE inventory are presented. In the paper, this instrument is used to identify the stress-coping strategies employed by the respondents (military students) to deal with the stress potentially induced by an uncertain future and deteriorating global security.

Firstly, it is important to understand how the respondents perceive the current emotionless situation. If they do not perceive it as too serious, it can be inferred that the current situation does not cause them significant stress or nervousness. Therefore, it may not be relevant to investigate their stress-coping strategies associated with increased safety risk. Conversely, if the respondents perceive the situation as serious, it can be expected (and is examined through the following closed questions) that the current situation is causing them some level of stress. In such cases, it is logical to explore the stress-coping strategies they employ.

The results pertaining to the first research question – how military students perceive the deteriorating security situation associated with the RUC – are presented in Table 1. (The possible response options are: 1 – I fully disagree; 2 – I rather disagree; 3 – I rather agree; 4 – I fully agree).

Table 1.

Perception of the security situation

Statement	*Average*	*STD*	*Median*
I perceive the situation as serious.	3.34	0.81	4
I am nervous about the situation.	2.26	0.87	2
The situation stresses me out.	1.84	0.79	2
The situation will likely impact my military career.	3.12	0.82	3

Table 1 indicates that military students perceive the situation as serious, with an average score of 3.34, placing it between "I rather agree" and "I fully agree". The median score is even higher at 4 ("I fully agree with the statement"). Additionally, they recognize that the current situation is likely to impact their military career. However, on average, this situation does not cause significant stress or unease for them. Students display a considerable level of consistency in their responses, with no significant differences noted (standard deviations are around 0.8). Further details of these results are visualized in Figure 1.

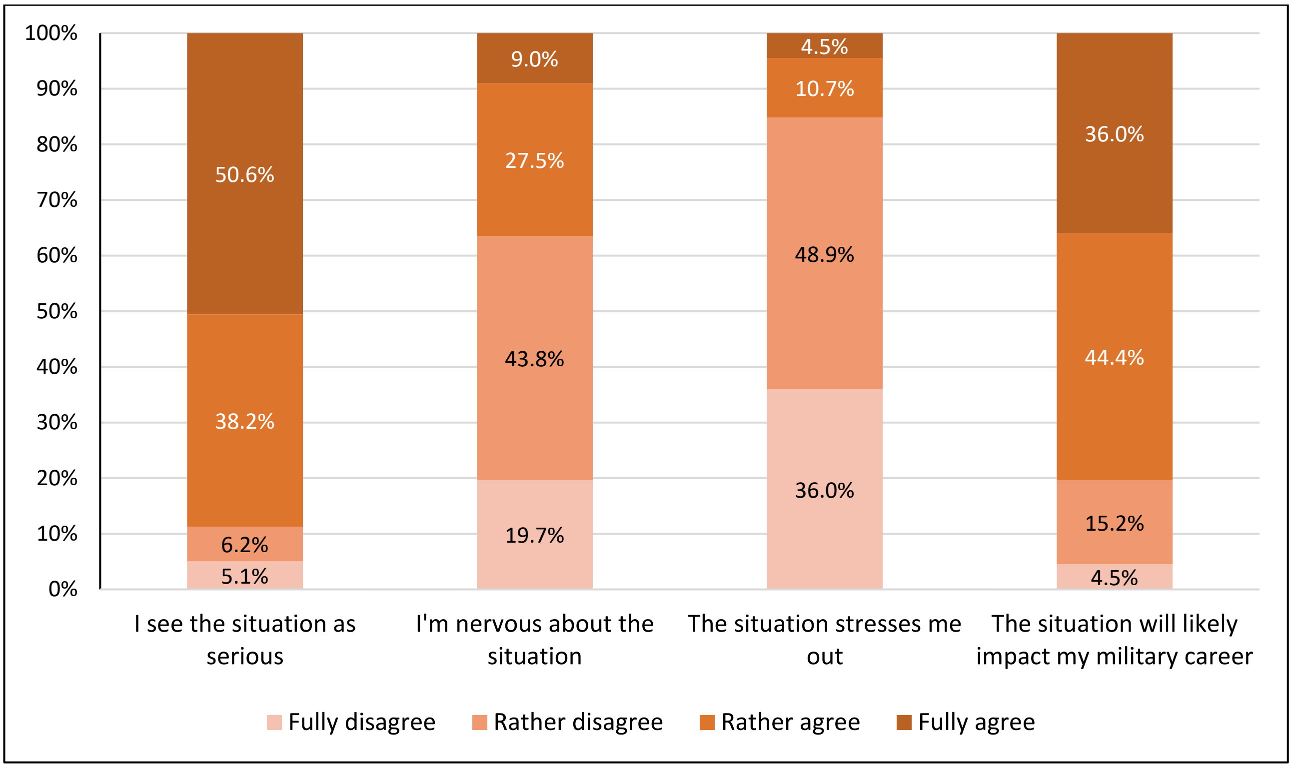

Fig. 1. Perception of the security situation

Figure 1 illustrates the strong perception among students regarding the seriousness of the security situation, with 89% of students overall agreeing with this statement. Among them, a significant proportion of 90 students – half of all respondents – strongly agree. Conversely, only 11% of students either strongly or somewhat disagree with this perception.

Table 2.

Stress-coping strategies of the military students

Statement	Average	STD	Median
SCS 1 (Self Distraction)	2.36	0.99	2
SCS 2 (Active coping)	2.35	1.01	2
SCS 3 (Denial)	1.75	0.9	1
SCS 4 (Substance Use)	1.46	0.77	1
SCS 5 (Emotional Support)	1.99	0.98	2
SCS 6 (Behavioral Disengagement)	2.00	1.02	2
SCS 7 (Venting)	2.00	0.91	2
SCS 8 (Use of Informational Support)	1.98	0.97	2
SCS 9 (Positive Reframing)	2.25	0.97	2
SCS 10 (Self-Blame)	1.58	0.84	1
SCS 11 (Planning)	2.46	1.04	3
SCS 12 (Humor)	2.60	1.05	3
SCS 13 (Acceptance)	2.93	0.94	3
SCS 14 (Religion)	1.60	0.94	1

Despite the perceived seriousness of the security situation resulting from the RUC, respondents do not report significant levels of stress or nervousness. A majority of 113 students (63%) did not confirm feeling nervous due to the situation. Furthermore, 85% express disagreement with the idea that the situation is stressing them out, with only 27 students (15%) admitting to feeling stressed by it.

Moreover, respondents indicate a high level of agreement with the statement suggesting that the RUC will likely impact their military career. Alongside a high mean score of 3.12, it is worth noting that 80% of respondents agree with this statement – 45% somewhat and 36% strongly. The remaining 19% express less conviction about the conflict's impact on their future career.

Based on the standard deviation, it can be inferred that respondents' opinions are quite consistent, with no significant differences in their answers. They are in relatively high agreement regarding their perception.

Next, the results pertaining to the second research question are presented. The assessment of the stress-coping strategies (SCS) employed by military students to manage the stress induced by the security situation, primarily related to the RUC, is detailed in Table 2.

Table 2 displays the basic statistical parameters of the declared stress-coping strategies related to coping with stress caused by a security situation, specifically RUC. The least applied strategies by respondents are substance use, self-blame, religion, denial, as well as emotional support, behavioral disengagement and venting. Positive reframing, self distraction, and active coping are then applied to a higher degree. On average, the most used strategies are planning, humour and acceptance, whose median value is 3 ("I rather agree").

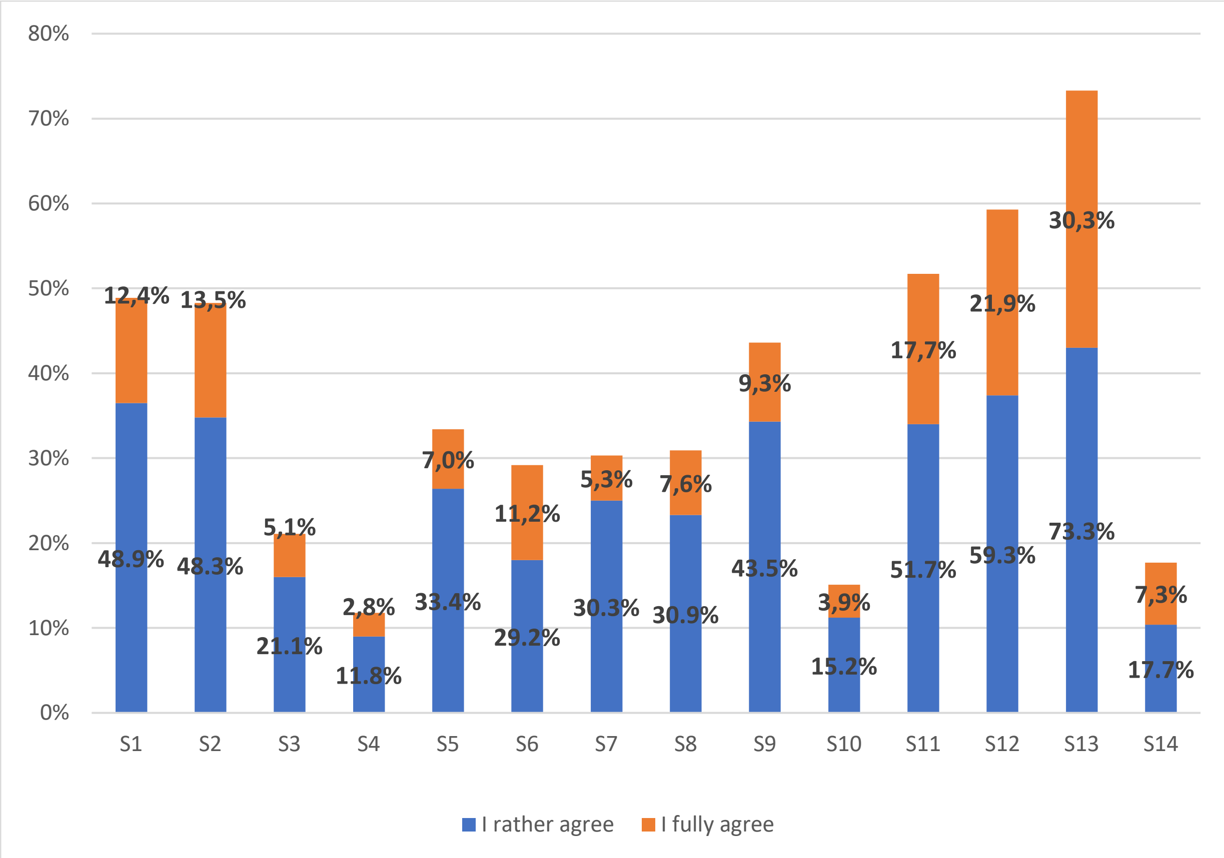

Fig. 2. Percentage of affirmative responses for the implementation of individual stress coping strategies.
Legend*: S1 – Self Distraction; S2 – Active Coping; S3 – Denial, S4 – Substance Use; S5 – Emotional Support; S6 - Behavioral Disengagement; S7 – Venting; S8 – Use of Informational Support; S9 – Positive Reframing; S10 – Self-Blame, S11 – Planning; S12 – Humor; S13 – Acceptance; S14 - Religion.*

The results for each stress-coping strategy are shown in more detail in Figure 2. It shows the level of agreement with the implementation of each stress-coping strategy. The values in the graph show the overall percentage of responses that confirm that the respondent uses the strategy. More than 50% of the respondents declare the application of the strategies planning (51.7%), humour (59.3%), and acceptance (73.3%). Of the values shown, always about one-third of the respondents even stated "I fully agree", i.e. they fully confirm that they use the strategy. The strategies self distraction and active coping (both confirmed by about 48% of the respondents) and positive reframing (43.5%) are also confirmed to a relatively high degree. About one-third of the respondents agree that they use the strategies of emotional support, behavioral disengagement, venting and use of informational support. The fewest students report using denial (21.1%), religion (17.7%), self-blame (15.2%) and substance use (11.8%) to reduce stress.

The above evidence suggests that students prioritize adaptive coping strategies over maladaptive ones. It is useful to further analyze which type of strategies predominates if we classify them into Problem-Focused, Emotion Focused and Avoidant strategies. The results are shown in Figure 3.

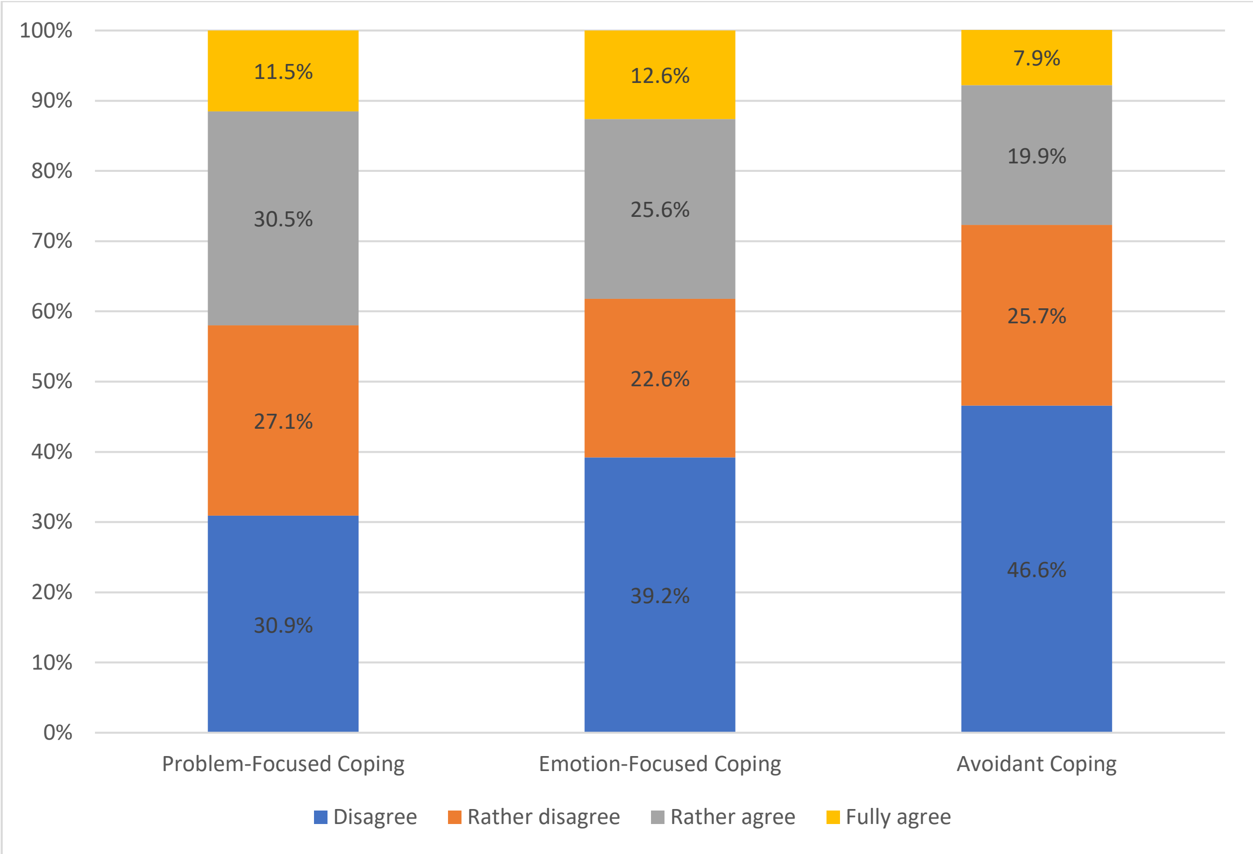

Fig. 3. Application of individual groups of stress-coping strategies

When stress-coping strategies are categorized according to their nature into Problem-Focused coping, Emotion-focused coping, and Avoidant coping (see Figure 3), then problem-focused and emotion-focused coping strategies are consistently reported by approximately 40% of the respondents. In contrast, Avoidant coping is reported by 27.8% of the respondents.

5. Discussion

The tendency of students toward *problem-focused* coping, followed by *emotion-focused* coping strategies, and with *avoidant coping* being the least used strategy, can be observed. In the study by Chudzicka-Czupała, the problem-focused coping strategy was also the most commonly used among the three groups of respondents (1,598 participants from Ukraine, Poland, and Taiwan), followed by emotion-focused and avoidance coping strategies. [1] This outcome is favorable because young soldiers who prefer avoidant coping are at greater risk of experiencing symptoms of mental health problems compared to those who utilize problem-focused and emotion-focused coping strategies. [21] Problem-focused coping strategies are generally used when people appraise the situation as changeable [30,31], which might be particularly in line with the finding that students don't feel significantly nervous or stressed about the security situation. This finding appears to be inconsistent with some of the previous research – e.g. [1]. The inclination toward *adaptive* strategies is evident, with humor and planning ranking among the top three coping strategies used, which is consistent with previous findings. [7, 24] On the contrary, the findings regarding *maladaptive* coping strategies [27, 28] have not been confirmed, as substance use was found to be the least utilized strategy among the 14 options provided by the questionnaire.

6. Conclusion

The aim of the paper was to investigate how young military students at the University of Defence in the Czech Republic perceive the deteriorating security situation, particularly focusing on the Russian-Ukrainian conflict. This formed the subject of the first research question because before identifying stress-coping strategies associated with this conflict, it was necessary to ascertain whether these young individuals perceived the situation as serious and potentially affecting their future careers.

The results revealed that young people who have chosen to join the Czech Armed Forces perceive the security situation as serious to a relatively high degree. A total of 89% of them agree with the statement that the situation is serious, with an average score of 3.34 on a scale ranging from 1 ("fully disagree") to 4 ("fully agree"). However, this awareness surprisingly does not correlate with high levels of stress and nervousness. More than 85% of respondents completely or somewhat disagree that the condition associated with the RUC significantly stresses them.

The combination of these students' statements reveals a certain bravery – they are aware of the seriousness of the situation, yet it does not cause them significant stress. Consistent with this finding, subsequent analyses examining specific stress coping strategies indicate that students do not report significantly high levels of any of the strategies offered. On average, students' responses range between 1.5 and 2.5 on the aforementioned scale. Only one of the strategies, Acceptance, has a higher value (2.93).

Consequently, the second and key research question focuses on identifying stress-coping strategies associated with dealing with a challenging security situation and an uncertain future. Students predominantly declare the application of the following strategies – acceptance, planning, and humor. Furthermore, positive reframing, self-distraction, and active coping are also implemented to some extent. The strategies least confirmed by respondents include substance use, self-blame, religion, denial, as well as emotional support, behavioral disengagement, and venting. *Problem-focused* coping and *adaptive* coping strategies are generally predominant.

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Design of Web GIS Application for Planning of Military River Crossing

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Abstract

Successful ground military operations necessitate thorough comprehension of the operational environment, particularly terrain and water features. This article advocates for the utilization of Geographic Information System (GIS) technology to develop a dynamic web application aimed at analyzing and planning watercourse crossings. By harnessing the capabilities of ArcGIS Pro and ArcGIS Online, the proposed application integrates hydrological and terrain data to provide comprehensive insights into the feasibility of crossing specific water obstacles under varying conditions. Key considerations include terrain characteristics, river channel profiles, and the tactical specifications of military vehicles. While the application is currently in the conceptual phase and awaits verification, its potential in enhancing operational planning for the Czech Armed Forces is underscored. This GIS-based approach promises to enhance decision-making processes by offering real-time, interactive support for evaluating and strategizing water obstacle crossings within military operations.

KEY WORDS: *river crossing, military planning, hydrologic modelling, Web GIS, ArcGIS Pro, ArcGIS Online, HEC RAS.*

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1. Introduction

The ground operations of rescue, security or military units necessitate thorough comprehension of the operational environment. For this purpose, terrain analysis involves a comprehensive assessment of the physical characteristics of the landscape to inform operational forces decision-making and their planning [1]. Terrain analysis involves assessing the natural features of an area to identify potential hazards and mitigate risks for military operations or other activities [1, 2]. There are various approaches to conducting terrain analysis and multiple purposes for which the resulting outputs can be utilized [2]. From a military perspective, terrain analysis focuses on topographic analysis, identification of key terrain, determination of avenues of approach, evaluation of natural and man-made obstacles and cover, assessment of visibility, determination of weather and environmental impacts, and identification of natural hazards [3].

Cross-country movement analysis involves assessing the feasibility and challenges of moving military forces, equipment, and vehicles across varied terrain types [4, 5]. It includes analyzing factors such as topography, soil conditions, vegetation, obstacles, waters and weather conditions to determine the most suitable routes for movement [4, 6]. Techniques used in cross-country movement analysis may include terrain modelling, route planning, and simulation to evaluate different scenarios and identify potential obstacles or hazards that could affect movement efficiency and effectiveness [3, 7, 8, 9]. The goal is to optimize mobility while minimizing risks and resource consumption [10]. A fundamental aspect of terrain passability analysis involves evaluating bodies of water primarily as obstacles to movement [11].

In military operations, the ability to overcome water obstacles swiftly and efficiently is crucial for achieving military objectives [12, 13]. Military forces employ a variety of specialized equipment for crossing water obstacles. This includes amphibious vehicles, pontoon bridges, assault boats, engineer reconnaissance vehicles, and vehicles adapted for fording [14, 15].

These assets are designed to facilitate the rapid movement of troops, vehicles, and supplies across bodies of water, enabling the continuation of operations without delay. In terms of the temporal sequence of situations, for decision-making and planning purposes regarding the overcoming of water obstacles, it is important not only to know the current hydrological situation but also to predict changes depending on the water regime and weather forecasts [1].

Outputs from hydrological modelling can serve as valuable informational resources for military commanders in both combat and non-combat scenarios [16]. For instance, in a combat situation, such outputs can provide insights into the feasibility of river crossings or the vulnerability of certain areas to flooding or erosion. Imagine a scenario where a military unit needs to traverse a river to execute a strategic maneuver. By utilizing hydrological data and predictions, commanders can assess the risk of crossing at different points along the river, considering factors like water depth, flow velocity, and potential changes due to weather conditions. This information enables them to make informed decisions to minimize risks to personnel and equipment.

Similarly, in non-combat situations such as disaster relief operations, hydrological modelling outputs can aid in assessing the impact of natural disasters like floods or landslides on infrastructure and civilian populations [17]. For instance, during a flood emergency, military units involved in relief efforts can use hydrological data to identify areas at high risk of inundation, prioritize evacuation routes, and allocate resources effectively. This proactive approach enhances the efficiency and effectiveness of disaster response operations, ultimately saving lives and minimizing property damage.

In summary, the integration of hydrological modelling outputs into military decision-making processes enhances situational awareness and enables commanders to make well-informed decisions in a variety of operational contexts, ranging from combat missions to humanitarian assistance and disaster relief operations. For this purpose, a GIS-based approach can provide a map-based interactive situational view to enhance decision-making processes.

2. Input assumptions

The topic is important for many different applications in scientific-technical and socio-environmental fields [17]. It is also addressed by components of rescue and safety systems worldwide, which collect precise data for evaluating the physical-geographical conditions of the area of interest. Cross-country movement and river crossing analyses typically involve complex calculations or simulations. The accuracy of these analyses relies heavily on the input assumptions, which shape the behavior of simulated agents or the physics of the environment [3, 5].

The research area of acquiring hydrological data for determining the profile characteristics of watercourses offers an abundance of new possibilities, technologies, and approaches for addressing this issue. One of the methods is multispectral classification of image data. A variation of the multispectral classification model, based on working with Sentinel-2 satellite data, was proposed by Mukhtar et al. (2023) [18], who present this method of data collection about a large watercourse and its surroundings as reliable, fast, and cost-effective. Their model distinguishes the watercourse, sedimentation barriers, vegetation areas, and, thanks to access to Sentinel-2 satellite images, also tracks their development over time. The method is suitable for various scientific applications, especially environmental ones, but does not provide information about the depth at specific locations of the watercourse.

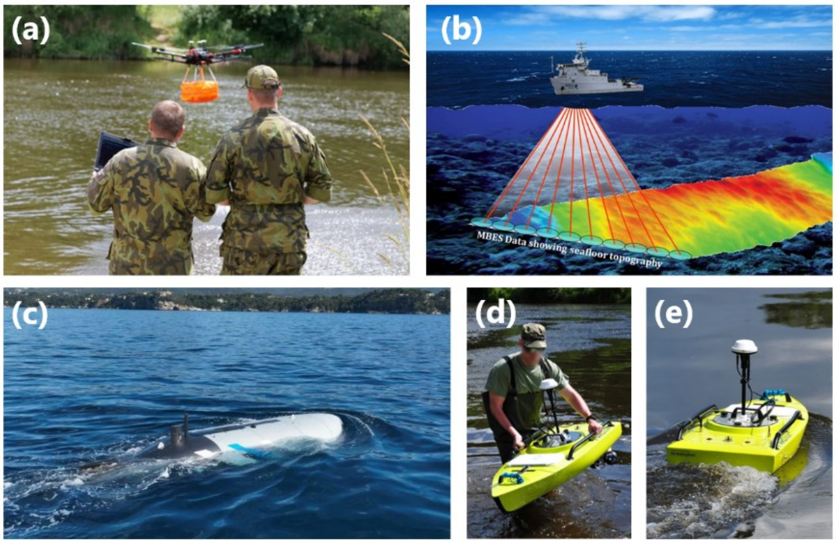

Fig. 1. Possible carriers of various detectors of electromagnetic radiation or sound providing bathymetric data: (a) UAV carrying GPR (Ground Penetrating Radar) [23], (b) ship as surface vehicle carrying SONAR [24], (c) UUV [25], (d) & (e) USV carrying SONAR [23].

To gather data on the relief of the riverbed, an alternative approach can be employed. This method, known as SDB (Spectrally Derived Bathymetry), relies on the absorption of light in the water column, which varies depending on the wavelength. The total radiation captured by the sensor comprises several components: backscatter from the atmosphere, water surface, water column, and riverbed (the primary source of light is the Sun). Assuming uniform surface and subsurface conditions, depth can be inferred from a single channel of a spectral image without requiring external reference data.

However, in practical applications, multiple radiometric bands of multispectral images are typically utilized. This is because the radiation reflected from the water surface is influenced by both water depth and the reflectivity of the riverbed, making these effects interdependent. To address and mitigate this limitation, Stumpf et al. (2003) [19] introduced a calculation method based on the ratio of two specific spectral bands. They observed that within a certain range of wavelengths, the reflectance value of the riverbed remains relatively constant. Consequently, it can be eliminated from the calculations without compromising the accuracy of the resulting depth estimates. The SDB method continues to be refined and enhanced, with advancements such as the integration of machine learning techniques [20].

Global trends in field measurement technology indicate a growing inclination towards gradually phasing out traditional in-situ geodetic methods for spatial data collection due to their time-consuming and costly nature. These conventional methods are now being replaced by modern geodetic measurements employing dGPS transect points [21]. Rather than relying on traditional methods, there is a shift towards contactless hydrological data collection through the transmission and subsequent detection of electromagnetic radiation or sound [22]. Various detectors utilize different carriers, including aircraft, unmanned aerial vehicles (UAVs), unmanned surface vehicles (USVs), and unmanned underwater vehicles (UUVs) – see figure 1. Additionally, there are throwaway sonars and sonars permanently affixed to bridge structures.

When precise bathymetric data of watercourses are needed and traditional in situ data collection methods are impractical, unmanned aerial vehicles (UAVs) present a suitable alternative. UAVs can navigate challenging terrains and deliver high-resolution data at relatively low costs. In 2023, Keanu Singh [26] authored a comprehensive technical report focusing on direct methods for bathymetric data collection, comparing various UAV approaches, including optical and acoustic measurements.

Green LiDAR (Light Detection and Ranging) represents a precise method for measuring riverbed depth and shape, with its primary advantage lying in its high accuracy. However, measurements can be influenced by factors such as water depth and clarity, bottom type, and flow. In a study conducted by Kastdalen and Heggenes [21], similar to Singh [26], several LiDAR sensors (mounted on different UAVs) were compared, and the results of individual measurements were further contrasted with the accuracy of traditional in situ data collection. While the study demonstrated the high accuracy of reflected green light from LiDAR emitters, it also revealed limitations such as signal loss with increasing depth, turbid water levels, and dark riverbeds.

Some LiDAR systems employ both green and infrared wavelengths to improve the accuracy of bathymetric measurements (Dual-Wavelength LiDAR) [26]. The green wavelength is utilized for water penetration and riverbed mapping, whereas the infrared wavelength is employed for topographic mapping of banks and surroundings. However, errors may still arise in determining the terrain of vegetated areas and due to false reflections caused by sediments in the water column. Mapping regions with river rapids and dam outlets has traditionally presented challenges.

SONAR (Sound Navigation and Ranging) systems are generally categorized into single-beam and multi-beam systems, with single-beam surveys being more cost-effective [26]. However, sonars face challenges when measuring very shallow depths due to surface clutter and multipath effects. Moreover, accuracy diminishes notably in vegetated rivers due to the high level of sound wave reflection from vegetation. Deploying Sonar on boats can be complex in remote regions and is restricted to navigable waters or, particularly for USVs, areas without dense floating aquatic vegetation.

Ground-penetrating radar (GPR) is commonly utilized in terrestrial environments for detecting subsurface features such as buried utilities, bedrock, or archaeological artifacts, but it can also serve bathymetric purposes [26]. It operates by emitting radio waves into the ground or water and measuring the time it takes for the waves to return. For instance, Bandini et al. (2018) [27] conducted field measurements using this method. In their study, the georadar, floating on the surface, was suspended under a UAV equipped with a radar altimeter, enabling the drone to maintain a constant height of 0.5 m above the water level. Georadar measurements were compared with sonar measurements, revealing that georadar significantly outperformed sonar in water bodies with medium or high aquatic vegetation density. Nonetheless, limitations arise in watercourse sections with depths less than 1 m, where georadar struggles to clearly identify underwater bed topography [26].

Digital photogrammetry and automated evaluation methods, such as Structure from Motion (SfM) and photogrammetric depth determination from stereo-images, are also garnering attention. SfM is a technique that identifies corresponding points between images and reconstructs a 3D model based on the geometric relationships between them. The result is a model that enables the determination of how individual 3D coordinates are projected onto camera images. When applied to bathymetry in river and reservoir systems, digital photogrammetry faces challenges due to light reflection and refraction on the water surface. This necessitates refraction correction, which is feasible if the water is clear and well-visible in the images. The approach provides high spatial resolution and performs better if the bottom is sufficiently structured to facilitate feature matching [26]. In summary, the use of photogrammetric methods is limited to water bodies with high water clarity.

The combination of the SfM method and chirp-modulated sonar was introduced by Tripathi and Murphy (2023) [28]. In their study, they utilized the underwater drone Hydronalix EMILY equipped with Humminbird sonar technology, which generates a point cloud of the waterbed surface. Using the Poisson reconstruction algorithm, a 3D model of the underwater relief is then generated, which remains amenable to further refinement (such as removing unnecessary structures caused by false reflections) in the Blender program. Additionally, the USV sonar is accompanied by a Teledyne FLIR camera. This camera produces a 3D model of the nearest relief above the water surface using the SfM method, calibrated to mitigate disruptions from false reflections of water and atmospheric particles. (In this case, the SfM method is modified for shooting in the opposite direction, i.e., from water to atmosphere.) The subsequent merging of the underwater and surface models is facilitated by the fact that both the sonar and the camera generate their models simultaneously from the same location, ensuring that these models are also georeferenced in a consistent manner. This allows for easy integration of the models within the Blender program.

The above-mentioned list of hydrological data collection methods, especially water depth in rivers, sediment deposit on riverbeds, flow velocity, and other parameters, can be utilized for the purpose of crossing watercourses during measurements, or potentially in the near future, assuming no alteration in water conditions due to extreme precipitation in the river basin or human regulation of water levels. Understanding these characteristics can aid in the decision-making process for operational decisions regarding units tasked with river crossing.

Given the planning of river crossing activities, the aforementioned data collection methods can be employed for simulating river flow regimes and numerically modelling the anticipated water state and other river characteristics. Key to this purpose is the knowledge of riverbed terrain morphology obtainable through the aforementioned data collection methods. Advantages lie in the possibilities of remote sensing and non-contact data collection methods rather than traditional terrestrial methods [29]. Currently, data collection methods are evolving through sensors placed on UGVs for object recognition in the vicinity and navigation in open space. It can be assumed that sensors mounted on these vehicles may have multiple applications. Not only do they collect data for spatial orientation and obstacle recognition, but they can also simultaneously gather data for further utilization, such as planning water obstacle crossings. This can play a significant role in operational-tactical preparation within the area of interest [30].

Data transmission and storage methods are not the subject of this article's research; however, it is important to mention this issue, especially concerning the article's topic on designing a web GIS application. GIS software operates with various geographic and hydrological data formats, which can be efficiently stored, for example, in databases. GIS systems represent an effective tool for data processing, analysis, and subsequent visualization. Dynamic and interactive GIS applications enable users to obtain the necessary informational support within the decision-making and planning process.

3. Data and Methodology

Modelling and simulating the overcoming of water obstacles, and respectively planning river crossings, can be extended to a broader global context, considering its potential for general universal utilization. However, due to data availability constraints and the need to simplify the studied phenomenon in order to design a web GIS application, a local modelling study was conducted. The area of interest became the lower course of the Dřevnice River, which flows through the regional city of Zlín in the Czech Republic – see figure 2.

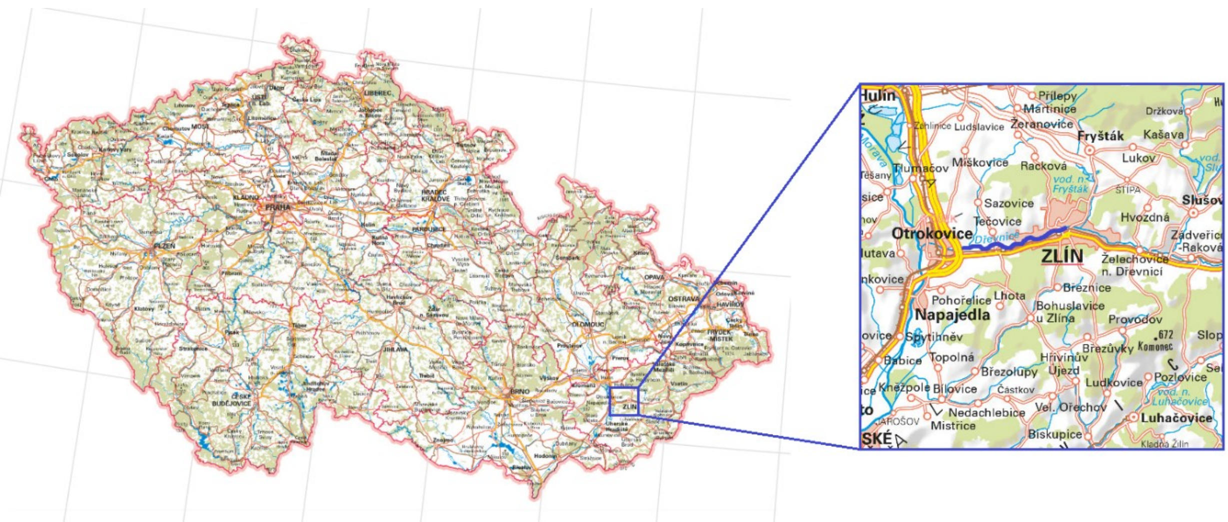

Fig. 2. An overview map and localization of the area of interest with marking of the section of the Dřevnice River [31].

For the development of the Web GIS Application, outputs from a numerical hydrological model were needed, which was carried out using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) software. HEC-RAS is a powerful software tool used for hydraulic modelling of riverine environments. The process consists of several steps: data preparation, data schematization and parameterization, and numerical simulation. The individual procedural steps are described in the following paragraphs.

3.1 Terrain morphology of the stream and floodplain

The terrain morphology was inputted into the hydraulic model as a digital terrain model (DTM) in raster TIF format with a pixel size of 0.3 m. The DTM was created based on data from Digital Terrain Model of the Czech Republic of the 5th generation (DMR5G) [31, 32] and the Dřevnice riverbed [33] – see figure 3. The hydraulic model also incorporated structures such as bridges and weirs on the Dřevnice River, as detailed in [33]. The height accuracy of the DMR5G is provided with a total mean height error of 0.18 m in open terrain and 0.3 m in forested terrain.

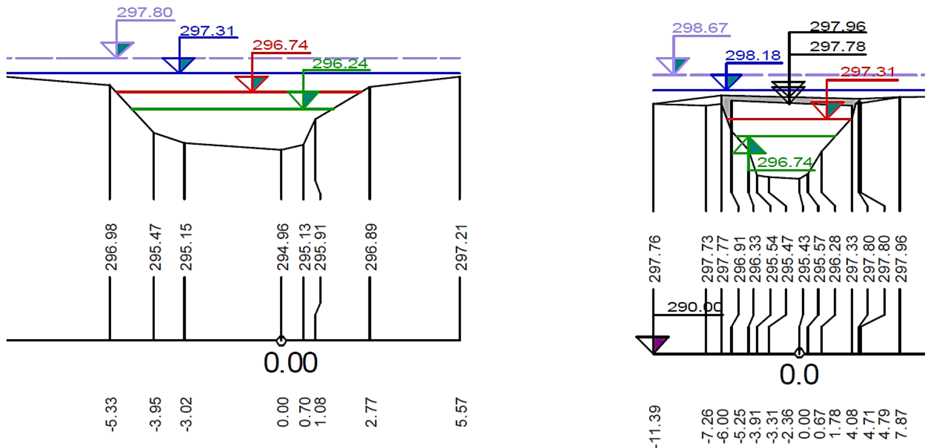

Fig. 3. The terrain morphology of the riverbed is depicted as a river cross-section (primary input dataset) on the left and with an object (bridge) on the right [33]. Colored lines represent heights indicating the modelled *N*-year water surface (output dataset).

3.2 Hydrological data

For hydraulic calculations, the hydrological data listed in table 1 were utilized for the Dřevnice – Zlín river profile, as documented [33]. The provided data were used as initial conditions for numerical hydrological modelling.

Table 1.

Values of *N*-year peak discharges for the Dřevnice River according to [33]

Profile	Qa	Q_1	Q_5	Q_{10}	Q_{20}	Q_{100}	Q_{500}
Dřevnice – Zlín profile on river km 13.200	1.88	48	115	153	196	320	488

**N* is annual peak discharges Q_N [m^3/s]; *a* is long-term average discharge.

3.3 Schematization of the area of interest

The area was schematized in 2D, with cells in the area having irregular shapes with 4 to 8 angles – see figure 4. The upper part of the area was located approximately at river km 12.500 (above the bridge on Gahurova Street), while the lower part was around river km 3.400 under the D55 road bridge. The lateral extent of the area was determined based on the extent of the Q_{500} flood area [33]. The cell size in the inundation varied from 8 to 15 meters, while in the river, it ranged from 2 to 3 meters. Breaklines were incorporated into the mesh at the riverbed axis, bank edges, and axes of dikes and roads. The total number of cells was approximately 130 thousand. Bridges and weirs were schematized using 1D objects, enabling hydraulic calculations using analytical equations.

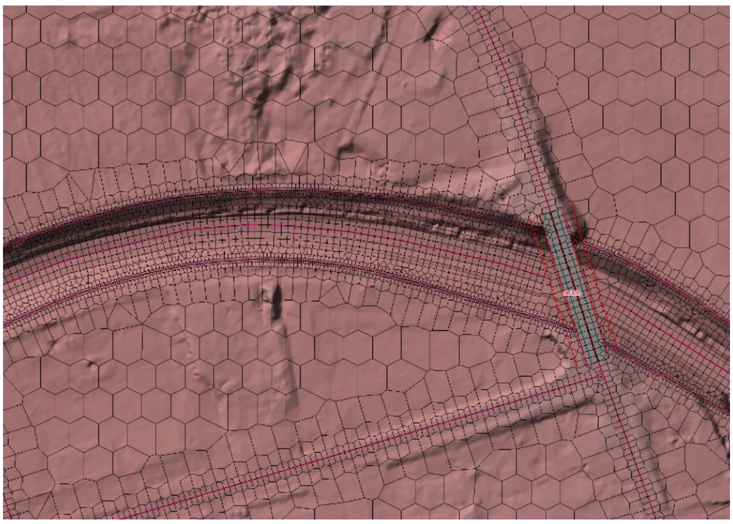

Fig. 4. Detail of the mesh.

3.4 Surface roughness of the river main channel and inundation area

Surface roughness data were incorporated into the model as Manning's roughness coefficients – see table 2. The roughness coefficients for different surface types were derived from The Fundamental Base of Geographic Data (ZABAGED) [34], which provides information on land use – see figure 5.

Table 2.

Values of roughness coefficients according to Manning

Type of surface	Values of roughness coefficient ***n*** according to Manning
The surface with dense vegetation	0.100–0.300
Other area in settlements	0.045
Buildings (non-flow-through structures)	0.500
Vegetation on the banks of streams	0.060
Forest	0.120
Garden	0.080
Acreage	0.035
Fenced gardens	0.150–0.300
Grassland	0.030
Paved roads	0.020–0.030
Watercourses	0.032–0.045
Fenced land (industrial areas)	0.150

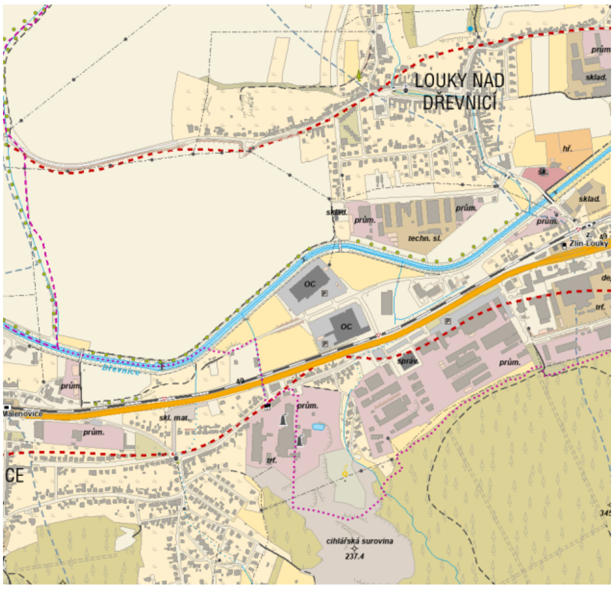

Fig. 5. Screenshot with cartography visualization of ZABAGED [34].

3.5 Boundary condition values

Boundary conditions (BC) for the steady-state calculation were defined at 2 open boundaries – see figure 6. These had the following BC values:

- Upper BC – Dřevnice, approximately river km 12.500 (above the bridge on Gahurova Street) – flow according to hydrological data for the Dřevnice – Zlín profile (see table 1) [33].
- Lower BC – Dřevnice, approximately river km 3.400 (above the road bridge of the D55 road) – energy slope $i = 0.001$ [33].

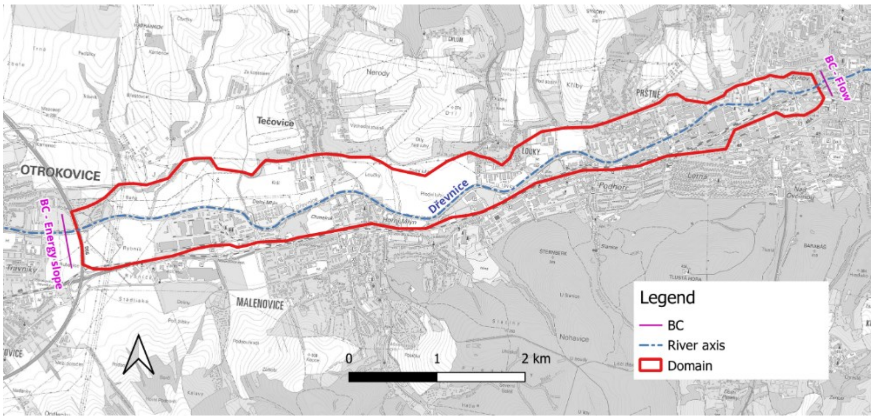

Fig. 6. Picture of the area of interest (Dřevnice River at approximately km 3.400–km 12.500) [32].

3.6 Numerical hydrological modelling and simulation

The HEC-RAS 6.5 numerical model software was utilized, enabling independent modelling of 1D, 2D, and composite 2D and 1D models. The numerical solution within the 2D model is based on solving the Shallow Water Flow equations using the finite volume method.

The simulation was run under steady flow conditions. While the HEC-RAS program can compute unsteady simulations, time-invariant boundary conditions were applied in this model. The simulation duration was 24 hours, with the time step ranging from 0.25 to 1 second based on the Courant number. Convergence criteria for the time step were set to 20 iterations or a level difference of 0.003 m between the last two calculation steps. Results were exported from the program for the final time step, at which water levels and velocities reached a steady flow. Depths and velocities were exported in raster format (TIFF) and represents important inputs for design of Web GIS Application.

4. Design of Web GIS Application

An objective of this contribution is to suggest what an application for planning of military river crossing could look like. In order to develop the design of the application based on real data, ArcGIS Pro Geographical Information System and ArcGIS Experience Builder online tool was used.

4.1. Application development process

As an objective of this contribution, it is set out to design an application for assessing the fordability of watercourses. The application should consider a wide range of variables, including the terrain's relief and micro-relief in the context of the tactical and technical characteristics of the given vehicle, the profile characteristics of the watercourse (especially depth and flow velocity), and other relevant factors. For subsequent analysis and modelling of the decision-making process the ArcGIS Pro software was chosen. The output should be in the form of a traffic light map showing the fordability of the watercourse. Due to the complexity of the problem, a diagram has been made to illustrate the individual criteria for assessing the watercourse's passability – see figure 7.

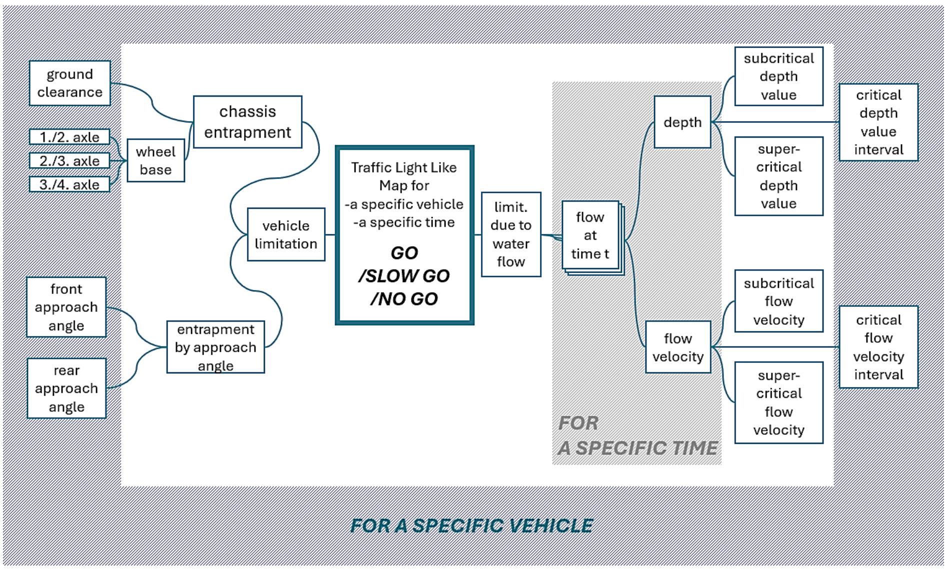

Fig. 7. Diagram of the criteria used to determine a passability of a water obstacle.

Among the most crucial tactical and technical data required to determine a vehicle's ability to traverse a water obstacle are wheelbase, ground clearance, approach and departure angles, wading depth, and limiting current velocity during fording. In a mathematical model, wheelbase and ground clearance determine whether the vehicle's undercarriage might get stuck on some microrelief feature [35]. Similarly, the approach and departure angles determine whether the vehicle will get stuck when entering or exiting the streambed. The limiting values of wading depth and current velocity during fording indicate whether it is even possible for the vehicle to cross a watercourse with these basic characteristics, such as stream depth and current velocity, regardless of relief and microrelief features – see figure 8.

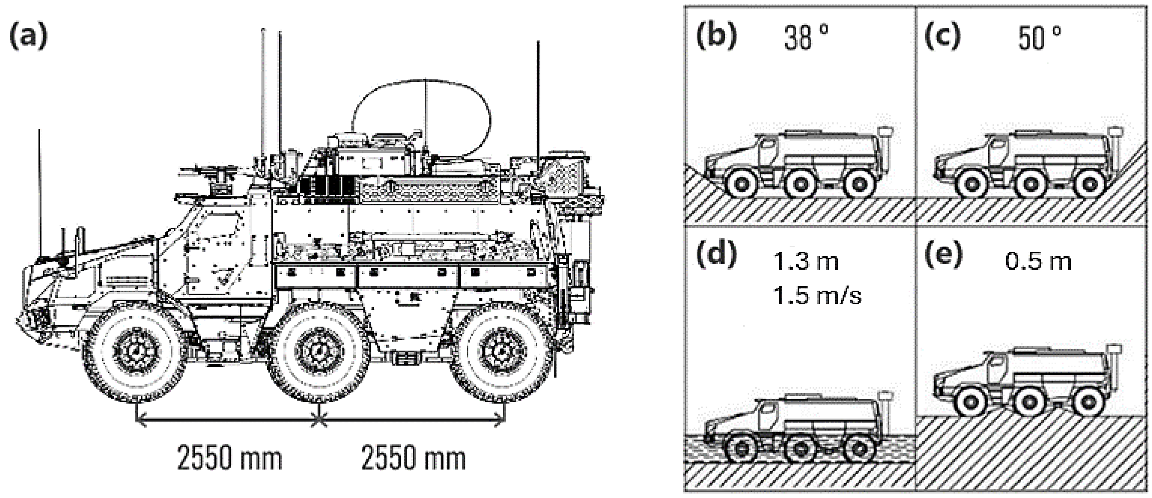

Fig. 8. Parameters of the military equipment necessary to know: (a) wheelbases, (b) front approach angle, (c) rear approach angle, (d) fording depth & limiting current speed during fording, (e) ground clearance [36]

The selection of military vehicles for the application's design is based on the inventory of the Czech Armed Forces. Given the objective of determining the fordability of water obstacles, the focus is narrowed to wheeled vehicles. The primary distinguishing characteristic among the selected vehicles is the number of axles. To ensure variability in the mathematical model's results when incorporating the input tactical and technical data of individual vehicles, vehicles with significant structural differences were chosen – see figure 9.

Fig. 9. Vehicles for which watercourse crossing has been modelled: (a) Toyota Hilux 4x4 [37], (b) Titus 6x6 [36],
(c) Pandur II 8x8 [38].

Given the objectives of this research, the streambed, banks, and surrounding area of the watercourse within a 50-meter radius of the channel were selected for the analysis of topographic and micro-topographic features. If the software identified potential vehicle undercarriage entrapment or stalling locations, these areas were designated as red zones and propagated to all subsequent layers as "NO GO" zones – see figure 10. Similarly, the software analyzed the depth and velocity of the watercourse for various temporal scenarios, considering the dynamic nature of stream profile characteristics over time (input from HEC-RAS modelling). The resulting traffic light-style passability map for a specific vehicle varies with different flow rates. As such, the specific time and associated watercourse characteristics become additional input parameters for the application.

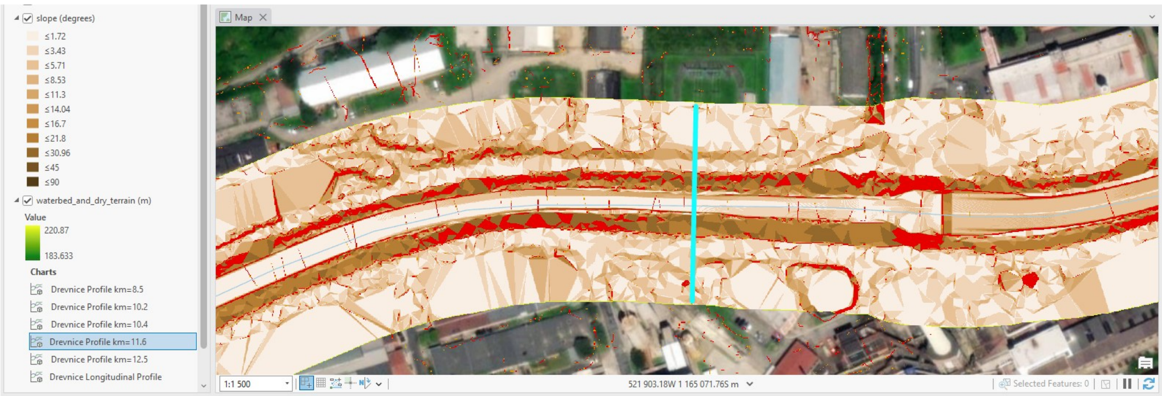

Fig. 10. Slope analysis of the riverbed, banks, and surrounding vicinity of the Dřevnice River.

4.2 Designing Web GIS Application

To create an application that presents the results of GIS modelling in a user-friendly way, ArcGIS Experience Builder is a useful tool. It combines map documents, data, widgets, and other elements into one interface. With that the application is capable of analyzing the possibilities of crossing a watercourse under various conditions by selecting the crossing location, initializing river conditions (forecast data), and choosing a specific military vehicle. The application provides information about the possibility of crossing a watercourse at a specific location; the variables determining the outcome include water level and flow velocity compared to the parameters of the military equipment used for crossing – see figure 11.

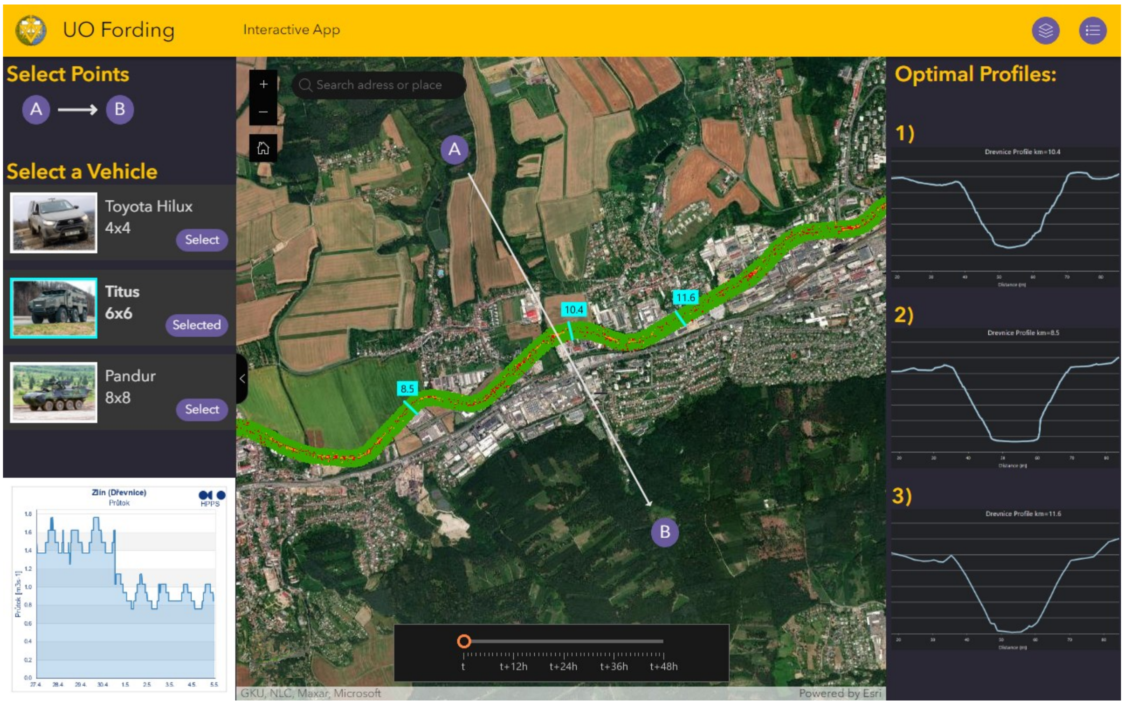

Fig. 11. User interface of the Web GIS application.

This system, designed to support users in combat and crisis situations, integrates various modelling outputs and provide an interactive interface for informed decision-making regarding watercourse access and overcoming strategies. The application is currently in the conceptual phase. Its potential in enhancing operational planning for the Czech Armed Forces is underscored. This GIS-based approach promises to enhance decision-making processes by offering real-time, interactive support for evaluating and strategizing water obstacle crossings within military operations.

5. Conclusion

With the development of new technologies, there are emerging, efficient possibilities for collecting geographical and hydrological data. Simultaneously, there is a growing demand for the quality and accuracy of such data, placing higher requirements on the quality of modelled outputs from numerical and predictive models of observed phenomena. The global trend in data collection is oriented towards non-contact methods utilizing UGVs, UAVs, or UUVs. Unmanned technologies can be effectively utilized in areas with increased security risks, thereby eliminating the danger of harm to human health. The acquired data can be utilized for further analytical purposes, aiding in decision-making and planning processes within the operational deployment of security and rescue forces.

Military engineers utilize HEC-RAS to simulate and analyze the flow of water in rivers and streams, allowing them to assess the feasibility of crossing locations and plan appropriate engineering solutions. HEC-RAS modelling plays a critical role in military operations by providing valuable insights into the hydraulic conditions of water obstacles. HEC-RAS can be used to predict water levels, flow velocities, and channel morphology, helping to identify suitable crossing sites and optimize the design of crossing structures.

Overcoming water obstacles is a complex task in military operations, requiring careful planning, specialized equipment, and advanced modelling techniques. GIS software serves as a valuable tool for obtaining comprehensive spatial information, with advanced analytical GIS tools playing a vital role in decision-making during river crossing planning. A comprehensive web (or desktop) application represents a potent tool for operational commanders, conveying a spatial understanding of the situation in broader contexts and, based on analytical insights, may become a decisive means to achieve operational-tactical objectives.

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The Impact of the Deteriorated Political and Security Situation on the Financial Stability of Arms Companies Operating in an Oligopolistic Market Environment

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Abstract

Economic measures, stability, efficiency, and effectiveness of arms expenditure are among the sources of national defense. The technological level of the industry, the ability of firms to carry out their development and innovation, together with the state's ability to specify and acquire requirements for new technologies promptly, in the short and long term, form the structure of factors that significantly determine success in a potential war conflict. This paper, conducted by a team of experienced researchers, aims to assess whether and to what extent the current deteriorated international and security situation impacts the employment and revenues of selected arms companies in the Czech Republic. The paper presents the results of the first research phase on 18 technological arms companies, commercial firms or manufacturers of technologically advanced products, which have been operating on the market of special military and security equipment for a long time. In the case study, we present a qualitative analysis of the impact of government demand and human and material capital on the level of potential products.

KEY WORDS: *capacity of the arms industry, comparative advantage, defense, development and innovation in the arms industry, oligopolistic market environment, research.*

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1. Introduction

The current state of the arms industry in the Czech Republic is a consequence of the transformation processes after 1989. Many state-owned companies are being broken up into private economic entities. The state-owned technical research institutes remain, but apart from research and development, they enter the market with their production and thus create competition for the private sector. On the demand side, there have been a series of successive reorganisations of the armed forces, accompanied by a sharp decline in the number of members of armed forces units and establishments. The international political situation is assessed as favourable to the peaceful coexistence of countries in Europe, irrespective of NATO or Warsaw Pact membership. The outbreak of a military conflict in Europe is not foreseen for a long time. The exceptions are the Balkan wars of 1991-1994 and the Kosovo War in 1999, culminating in the bombing of Yugoslavia. However, there is currently an escalation of the conflict between Ukraine and Russia, which two milestones can characterise, the occupation of Crimea in 2014 and Russia's armed entry into Ukrainian territory in 2022 [1,2,3].

The reduction of the armed forces affects the general demand for weapons systems. The overall situation since 1993 can be characterised as a disproportion between the development of the Czech Republic's national wealth and the trend in the acquisition of weapons systems for its defence (see Figure 1).

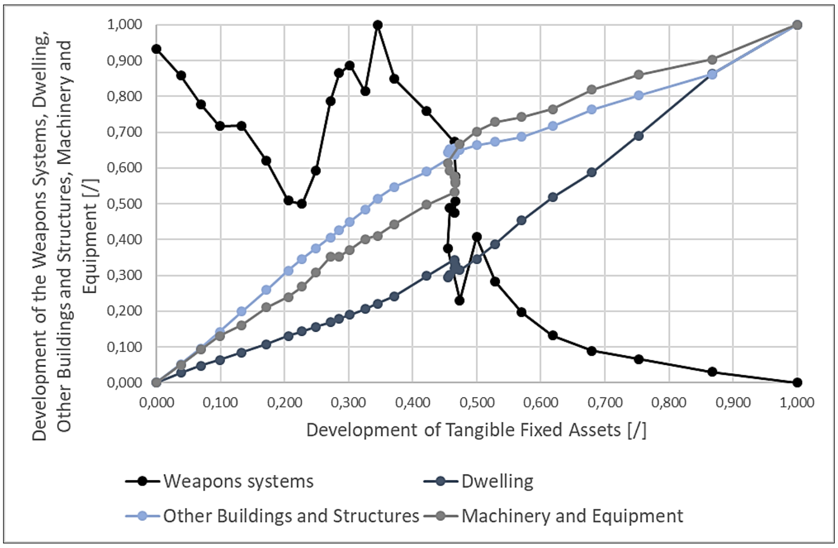

Fig. 1. Wealth development of the Czech Republic and acquisition of weapon systems until 2023. Data are normalised to the unit vector [7].

Given the above, especially with the emphasis on the deteriorating international security and political situation, it is important to address the capabilities of the domestic industry to provide such equipment with weapon systems and other segments of the arms product portfolio that correspond to the current situation, characterised by an increased likelihood of the outbreak of a so-called hot armed conflict. This is also the motivation for the research described below. [4,5,6]

2. Formulation of hypothesis

The basic idea of the article is that the negative change in the international and security situation in Europe impacts the economy of economic entities involved in arms production.

The hypothesis is formulated as follows: "*The worsened political and security situation has an impact on employment and revenue levels of arms companies in the Czech Republic, so that employment and revenues of arms companies are steadily increasing.*"

3. Literary research

The Ministry of the Interior of the Czech Republic (2024) defines the concept of defensibility as "The ability of a state to secure its sovereignty, territorial integrity and constitutional establishment against any military threat. It is achieved through international political, security, economic, protective, technical and other measures" [8]. In terms of the topic under study, the economic measures in the above quotation have particular relevance in terms of the specification of the state's demand for arms production. Defensiveness as a concept is mentioned alongside the concept of defence. Defensiveness is seen as a complex concept, including the measures discussed above, while defence, as a task of the armed forces, is one of the formulated capabilities. This capability is practically manifested mainly by security measures.

Oligopolistic market environments are often defined in the literature. Schiller (2004, p. 191) states, "Oligopoly, a market in which a few firms produce all or most of the market supply of a given good or service" [9]. Volejnikova (2017, p. 10) states, "An oligopoly is a form of market structure in which few firms operate in an industry, so that each firm has a significant market share" [10]. Similarly, Samuelson and Nordhaus (2013, p. 171) state, "The term oligopoly means "a few sellers" [11]. Several in this context can mean 2, 10, or 15. An important feature of an oligopoly is that each firm can influence the market price." In principle, these authors agree in their definitions. The subject of the article is the relationship between the state and arms firms with the expected increased demand for weapons systems on the state's part under a deteriorated security situation. Awareness of the existence of an oligopolistic market environment is essential. It has implications for the price demands of the state on the one hand and the pricing of supply on the part of firms. This situation is significantly different from an environment of perfect competition. In addition, there are natural barriers to entry into the arms industry in the form of secrecy requirements, increased risk of developing new technologies and reduced ability of firms to offer arms production to customers outside the security industry. This possibility is reflected in the level of revenue.

Potential output corresponds to the full use of available resources - factors of production. Dornbusch and Fischer (1994, p. 31) define potential output as "Output at full employment of resources" [12]. CNB (2024) lists several methods for determining potential output - a technique based on the Cobb-Douglas production function, the Kalman filter as "a multi-equation model estimated by a recursive algorithm", and the Hodrick-Prescott (HP) filter on time series GDP. The latter method includes a forecast of developments. As seen from the above source, each method gives completely different results [13]. Of particular interest in terms of the research addressed in this paper is the contribution of Cizek (2023), who notes the complications of empirical research on potential output caused by the fact that it is "an unobservable quantity that can only be estimated" [14]. She extends the current state of knowledge by forecasting the impact of the war in Ukraine using a simulation approach to determine confidence intervals for the level of potential output. The research results presented in this paper do not use potential products in the sense of the above definitions. The confidence intervals of the development of revenues, particularly its upper bound, are constructed as the maximum possible with the acceptance of the hypothesis that increasing government demand for weapons systems increases the demand for labour, and more workers contribute to higher revenues. Thus, growth in the economy is reflected in revenue growth and in the upper bound of the revenue forecast band.

The paper's subject is the analysis of the relationship between the demand for weapon systems, the derived demand for human capital with the subsequent impact on the level of revenue. In this area, the results of existing research are mixed. Korkmaz (2015) examines the causal relationship between defence spending, economic growth and unemployment. He conducted the analysis using a panel data method about Mediterranean countries between 2005 and 2012 and concluded that military spending hurts economic growth and increases unemployment [15]. Odehnal et al. (2023) analyse the evolution of indicators characterising military spending using NATO member countries from 1999 to 2020. Besides recommending further research, their conclusions could be more precise. They do not conclude on an apparent effect of arms spending on reducing unemployment. Still, they point to a possible relationship between military expenditure and unemployment using the examples of Poland, Bulgaria, Romania, and Albania [16]. Navarro and Cabello (2015) examine the relationship between military spending and unemployment in 15 selected European Union countries and conclude that it is minimal [17]. These sources generally point to a minimal relationship between demand for weapons systems and employment. However, apart from Odehnal, all the relevant sources cited focus on research from 2015, one year after the occupation of Crimea. The significance of the research results presented in this article lies in the analysis after 2014, a period expectedly affected by the deteriorating relationship between the Russian Federation and Ukraine in particular, which is graduated by the occupation of Crimea and the entry of Russia and its armed forces into the territory of Ukraine. In contrast, Krtalic and Major (2010) point to the need, in the long term, to increase defence spending and invest in the armed forces [18]. They base their view on the emergence of new threats, the development of technology and drastic changes in warfare, which significantly impact the structure and size of military spending.

An essential aspect of the subject analysis is the capability of the industry firms in terms of their production. Modern approaches to categorising firms in the arms industry emphasise the importance of product portfolio analysis, which allows for a better understanding of the economic aspects of doing business in this sector. According to Krtalic and Major (2010), it is crucial to identify how product diversity affects firms' financial performance and market position. Firms with a broader range of products can spread risks more effectively and exploit synergies between different segments. This approach is particularly relevant in the context of the arms industry, where innovation and adaptation to changing security requirements play a crucial role. Analysis from Krtalic and Major shows that firms that invest in developing a wide range of defence technologies tend to achieve higher revenues and are better prepared to face geopolitical uncertainties [18].

4. Characteristics of the arms industry in the Czech Republic

The Czech arms industry is characterised by a long history and specialist know-how, which predisposes it to an innovative approach to developing, producing and integrating defence systems and technologies. The sector is structured to respond effectively to customers' specific needs and requirements, which include state security and military forces and international markets. The sympathetic detonation can be used by units of combat forces in certain circumstances (e.g. demolition of objects of a minor nature, especially in built-up areas, demolition of enemy equipment, during mobility measures - passage in an obstacle, etc.). This activity, as well as the method of rapid demolition, is particularly useful in those places and tasks where the units are limited by time, the amount of ammunition and the establishment of a more demanding firing mechanism.

Companies in this sector develop and produce their own products, distribute products created abroad, and provide services for implementing new technologies into armaments. These activities are complemented by service and product lifecycle capabilities, enabling companies to maintain long-term relationships with customers and provide the necessary support throughout the systems' life.

Companies in this industry focus on domestic and international markets, with customers including NATO and other non-NATO countries. This focus allows Czech arms companies to adapt to changing international security trends and requirements, which requires flexibility in production processes and research and development of new technologies.

The Czech arms industry offers a wide range of products and capabilities, reflecting the diversity and specific focus of individual companies.

One crucial sector is developing and manufacturing optical and electronic systems, including night vision and targeting equipment, which are critical for modern military operations. Companies also specialise in distributing a wide range of sophisticated military and security equipment, including aircraft, radar systems, air defence systems and anti-drone systems. Another segment in which Czech companies excel is the development and production of munitions and explosives, where innovations in material and chemical technologies bring new opportunities for more efficient and safer use. In software solutions for military applications, companies focus on air traffic control systems and other specific applications requiring high precision and reliability. The production and maintenance of armoured vehicles also represent an essential part of the Czech arms industry, where companies offer comprehensive services from design to maintenance. Research and development in defence systems is another crucial pillar, with an emphasis on the integration of new radar and sensor technologies.

The arms industry in the Czech Republic has partial potential for integrating defence systems, which allows companies to combine domestic and foreign technologies effectively. This aspect is crucial for strengthening the Czech

Republic's ability to participate effectively in its armament development. Cooperation with international partners and suppliers plays a vital role in improving the quality and functionality of the systems supplied, which contributes to maintaining the competitiveness of Czech companies in the international market. This strategy enables the implementation of complex defence solutions and supports technological development and innovation throughout the sector. On the other hand, international cooperation is necessary for Czech companies to avoid significant challenges in maintaining competitiveness in the current competitive environment of the defence industry.

Although many Czech companies have historically acquired know-how and the ability to develop their products and systems, current end customers prefer proven, functional systems with references. This trend leads to the fact that the Czech defence industry often uses its capabilities more in reselling and distributing products developed by foreign partners or engages in industrial cooperation where it can introduce and adapt foreign technology. In the past, when end customers were willing to invest in products developed based on the demonstrated capabilities of domestic companies and adapted to their specific requirements, the situation was different. Today, however, the market prefers entities capable of rapid integration and adaptation to global technological standards and innovations.

5. Initial statistical data

The data source is the Public Register and the Collection of Deeds of the Ministry of Justice of the Czech Republic (2024) [19]. The Public Register and the Collection of Deeds contain information on companies registered in the Czech Republic, including annual accounts and reports. The basis for data processing and analysis is the data dictionary specified by the author and shown in Table 1.

Table 1.

Data dictionary [19]

Name	Literal title	Description
Year	Year of occurrence in the MS CR database (2024)	The period examined is from 2014 to 2022.
Company	Company, firm, registered company in the Czech Republic, economic entity	Individual company names. Only publicly available sources are used in this article. Nevertheless, due to the sensitivity of the conclusions, the individual companies are referred to as C_i for i ∈ ⟨1; 18⟩. The complete dataset for all companies is available from 2015 to 2021.
Revenue	Company Revenue	The company's revenue for the accounting period, generally from 1 January to 31 December, is under review from 2014 to 2022. Revenue ∈ ⟨0; 7 105 000 KCZK⟩; KCZK = 1 000 CZK.
NOE	Number of Employees	Expresses the average number of employees reported by the firm for the accounting period, usually from 1 January to 31 December of the year under review, from 2014 to 2022. N0E ∈ ⟨0; 2 375⟩

Chapter 3 examines the impact of the deteriorated political-security situation between 2014 and 2022 on the potential output of arms firms in the Czech Republic. It analyses 18 armaments companies, C1 to C18, members of the Association of the Defence Industry (AOBP), with different revenue levels and different numbers of employees.

Although the data source for the statistical investigation is information from publicly available portals, it is decided to anonymise the companies under investigation. This is because the marketing aspects of these firms are not the focus of this research paper and may influence perceptions in the public community. Therefore, the business names of the companies are replaced in this paper by the designations C1 to C18. These substitute names are listed in a random unordered order but correspond to the company names from the Czech Commercial Register, separated by a semicolon: Meopta – optics, s.r.o.; OMNIPOL a.s.; Forte a.s., DELINFO; spol. s.r.o.; Glomex MS, s.r.o.; Pramacom Group, s.r.o.; CS SOFT a.s.; Česká zbrojovka a.s.; EVPÚ Defence a.s.; LP Prague s.r.o.; Explosia a.s.; Military Technical institute, s.p.; RETIA, a.s.; ELDIS Pardubice, s.r.o.; URC Systems, s.r.o.; TATRA DEFENCE VEHICLE a.s.; ERA a.s.; Sellier & Bellot, a.s.

Figure 2 and Figure 3 provide a basic overview of the analysed firms concerning their revenues (T) and number of employees (NOE). The purpose of the figures 2 and 3 is to provide a basic overview. The clustering and how to construct the clusters are presented in the following section. Figure 2 provides information about the companies in 2015 and shows the two bare clusters on the Linkage Distance 2. One is formed by companies C2, C15, and C11, which are among the largest employers. The other companies create the second cluster. The tree diagram shows that the analysed sample of companies is composed of companies of different sizes, determined by revenues and number of employees. These clusters presented here play only an informative role and make it possible to draw a partial conclusion that the production of the Czech defence industry is based on companies of different sizes according to the number of employees. These private companies form an oligopolistic market structure in each product segment except for one single company.

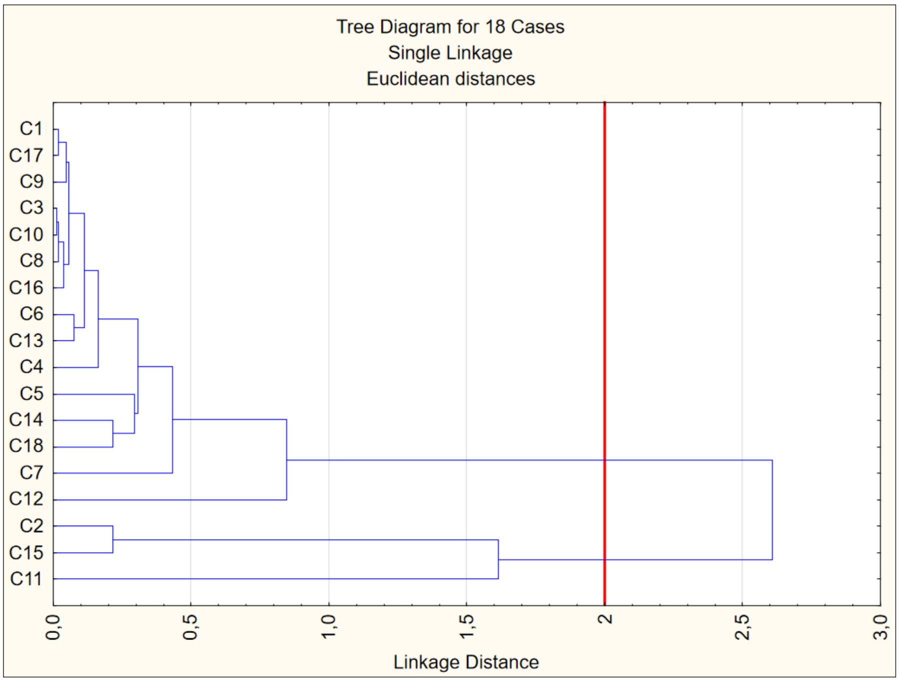

Fig. 2. Tree diagram of the position of the analysed defence industry companies in 2015

Figure 3 shows a similar situation in 2021. Comparing Figures 2 and 3, there is no significant change in the position of C2, C11, and C15. These companies are still among the most insignificant in the arms industry in the Czech Republic regarding the number of employees and revenues.

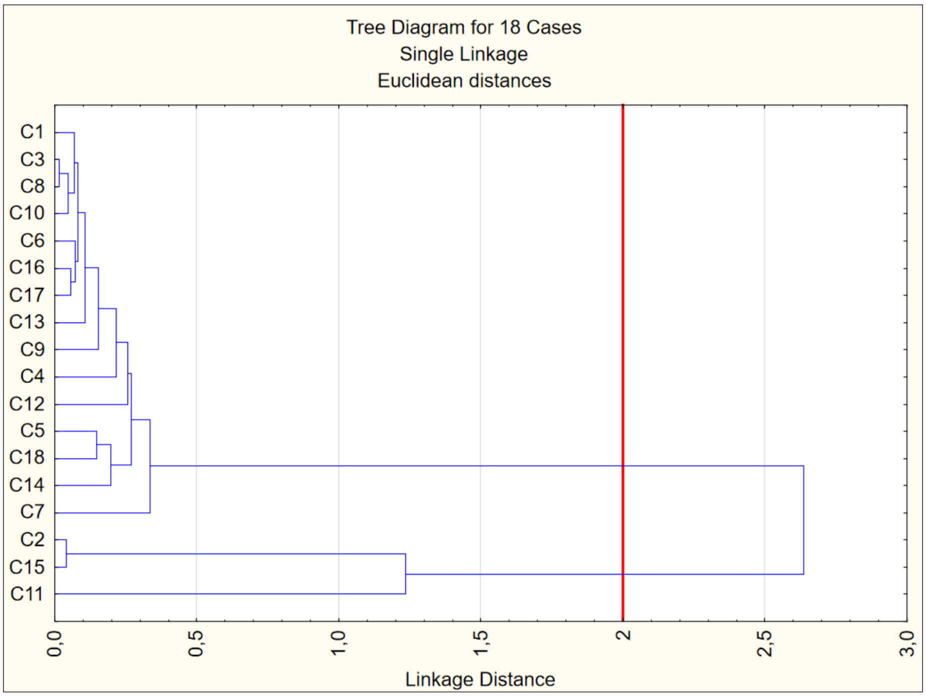

Fig. 3. Tree diagram of the position of the analysed defence industry companies in 2021

6. Partial conclusion

- Chapter 5 provides a basic view of the situation of selected arms companies in the Czech Republic.
- A cluster analysis of companies according to the amount of revenues and number of employees of the selected companies in 2015 and 2021 is performed.
- The Czech Republic's defence industry, represented in the article by a selection of 18 companies with a diverse range of product portfolios, is made up of private firms and a single state-owned firm, which form an oligopolistic market structure.

- The analysed companies are quite different in terms of number of employees.
- The analysed sample includes three companies that form a single cluster and exceed the other analysed companies regarding the number of employees and revenues.
- There are no significant changes in clustering over the period considered.
- No company in the sample is moving from a cluster of smaller companies to a cluster of larger companies.

7. Description of statistical processing of observations

The theoretical description of the statistical treatment of the observations consists of:

- The procedure for analysing the development of revenues from 2014 to 2022, depending on the number of employees.
- The description of the construction of clusters of companies based on the evolution of their revenues concerning the evolution of the number of employees.

In terms of the formulated hypothesis, this means:

The deteriorating political and security situation is affecting employment. This impact is reflected in an increase in the number of employees. The demand for employees is a derived demand. Its growth is a consequence of the demand to produce arms companies. One of the manifestations of increased government demand for the arms segments is the rising level of revenues. A situation where the revenues of arms firms are stagnant, or declining is a failure of the hypothesis. The increasing gap in the number of workers is reflected in the growing gap in the revenues achieved. The hypothesis is unconfirmed if increasing workers is not reflected in increasing revenues.

8. Development of revenue and number of employees

The situation is illustrated in Figure 4. The graph shows the timeline, the evolution of revenue, and the number of employees. The above observation evaluates the aggregated situation of all the analysed companies. The evolution of revenue over time and the evolution of the number of employees over time are monitored. The aggregate revenue growth was detected at 7.5 mld. CZK in 2014 to 28 mld. CZK in 2022, and the number of employees increased from 6 990 in 2014 to 7 327 in 2022. The observations are further elaborated and evaluated on a company-by-company basis in the following chapters.

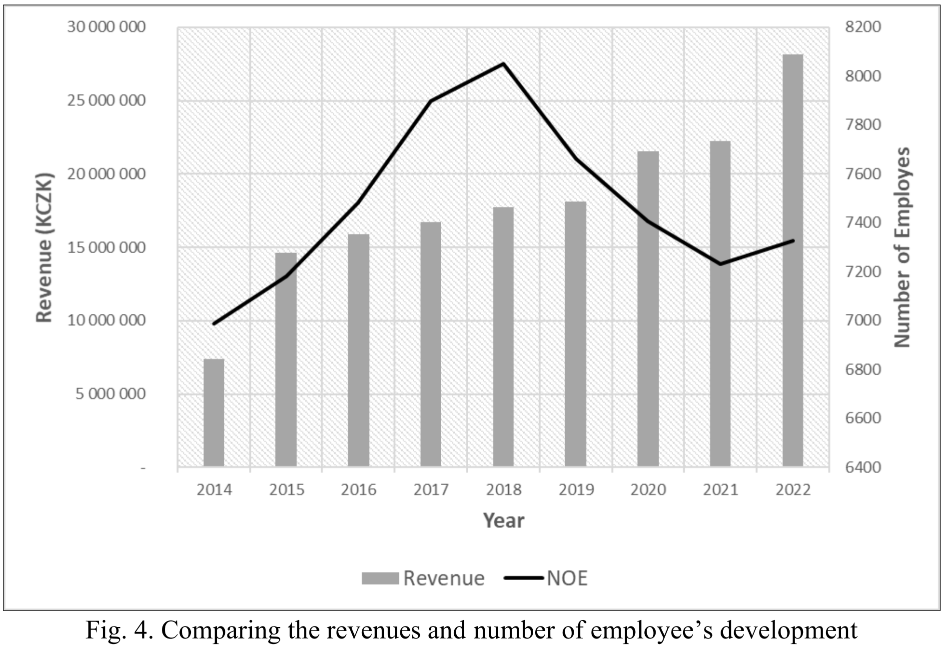

Fig. 4. Comparing the revenues and number of employee’s development

where: Revenue – the sum of revenues achieved by the analysed companies in [KCZK = 1 000 CZK]; NOE – number of employees of all analysed companies.

9. Clusters of companies based on the evolution of their revenues concerning the evolution of the number of employees

The previous chapter contains basic information on the total revenues of the analysed companies and the total number of employees at the beginning and end of the period under study. The following chapters provide an analysis of the development of revenues and employment. The subject of this chapter is:

- cluster analysis of companies based on the variables revenues (T) and number of employees (NOE) in 2015 (complete data for 2014 are not available for all companies).
- cluster analysis of companies based on the variables revenues (T) and number of employees (NOE) in 2021 (complete data for 2022 are not available for all companies).
- cluster analysis of companies based on the regression relationship of the effect of number of employees (NOE) on revenue (R) for the entire analysed period from 2014 to 2022.

The purpose of the chapter is to categorise the companies into classes and see whether the evolution between 2014 and 2022 affects the categorisation of the companies. That is, whether there is a company in the analysed portfolio that gains a more significant market share at the end of the period under study compared to 2014, with respect to the volume of revenues and the number of employees.

Procedure and conditions:

- The input data are the companies' T and NOE data.
- For cluster analysis, the input data are standardised.
- Linear regression is chosen to determine the dependence of R on NOE.

$$T = \propto + \beta . NOE \tag{1}$$

- α and β are the parameters of the regression line, which are the variables of cluster analysis of companies based on the dependence of T on NOE.

10. Input data

Table 2 summarises the input data for the cluster analysis.

Table 2.
Revenues (T) and number of employees (NOE) of the analysed companies in 2015 [19]

Company	Revenue (T, 2015)	NOE (2015)	Revenue (T, 2021)	NOE (2021)
C1	131 838	56	148 086	71
C2	3 391 385	1 574	5 839 905	1 542
C3	18 322	18	41 982	21
C4	152 817	161	388 202	240
C5	902 868	276	787 668	359
C6	255 813	51	346 952	80
C7	834 815	552	920 951	558
C8	9 882	29	13 688	24
C9	90 039	21	556 942	16
C10	30 269	15	50 682	48
C11	2 106 351	2 287	3 674 883	1 769
C12	1 772 394	91	945 785	95
C13	309 682	15	281 996	24
C14	604 894	205	872 366	250
C15	3 469 490	1 443	5 772 429	1 535
C16	2 407	54	234 576	108
C17	124 144	45	330 275	120
C18	412 398	288	1 049 585	373

The outliers are:

- Company C11 - most significant number of employees in 2015;
- Company C10 - smallest number of employees in 2015;
- Company C15 - highest revenues in 2015;
- Company C16 - lowest revenues in 2015;
- Company C11 - most significant number of employees in 2021;
- Company C9 - smallest number of employees in 2021;
- Company C2 - highest revenues in 2021;
- Company C8 - lowest revenues in 2021.

The results of the cluster analysis are presented in Table 3.

Table 3.
Company clusters by number of employees and revenue in 2015

The year 2015					Year 2021				
No. 1	**No. 2**				**No. 1**	**No. 2**			
C2	C12	C5	C1	C3	C2	C12	C5	C4	C1
C11		C7	C4	C8	C11	C9	C7	C6	C3
C15		C14	C6	C9	C15		C14	C16	C8
		C18	C13	C10			C18	C17	C10
			C17	C16				C4	C13

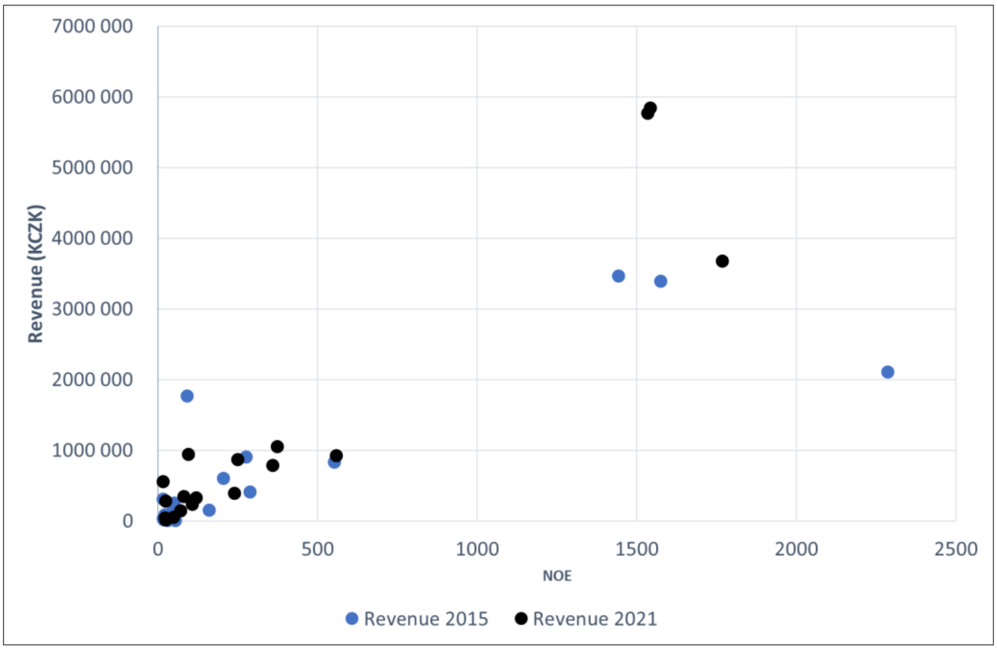

Fig. 5. Company revenues by NOE in 2015 and 2021

Figure 5 illustrates the clusters created. The graph shows NOE on the x-axis and T on the y-axis, and their relation reflects the situation in 2015 and 2021. The problem of the three companies analysed at the beginning and end of the period is quite different compared to the situation of the remaining companies. Figure 5, together with Table 3 and the clusters, as seen in Figures 2 and 3, clearly demonstrates the different situations of the analysed defence industry companies in the Czech Republic.

11. Partial conclusion

The companies are divided into two clusters. A comparison of the individual clusters shows:

- C2, C11, and C15 belong to the same cluster (No. 1) in both years (2015, 2021). The companies are among the largest in the sample despite the decrease in NOE for C11; at the same time, an increase in revenues is detected for all companies in the cluster;
- all the remaining companies form a cluster No. 2;
- the structure of the clusters of companies with the highest revenues remains unchanged, i.e. the deterioration of the security situation does not lead to a diametrically different market situation regarding the companies' revenues and number of employees.

12. Cluster analysis of companies based on the regression relationship

Cluster analysis based on the regression relationship between T and NOE forms clusters according to the functional dependence of T on each company's NOE development. The situation is illustrated in the following Table 4. It contains the values of the parameters of the regression function and the value of the coefficient of determination R^2. Data for the whole analysis period is processed, and linear regression is used. The coefficient of determination measures the model's accuracy and can take values from 0 to 1. The higher the value, the higher the accuracy of the model. Low values, usually below 0.5, indicate that other influences are related to the dependent variable. In the present analysis, this means that the movement in the number of employees is not a sufficient explanatory variable, and the conclusion of a close relationship between R and

NOE cannot be accepted. The regression relationship calculations are performed using Statistics software, and the chosen significance level is 0.05.

Table 4.

Regression function parameters and coefficients of determination

Company	α	β	R^2	Summary
C1	46 451	1 705.8	0.0594	Existence of unobserved independent variables.
C2	3 000 000	529.97	0.0009	
C3	-59 638	4 316.1	0.5394	54% accuracy of the model of the dependence of R on NOE.
C4	-211 670	3 561.5	0.2602	Existence of unobserved independent variables.
C5	-311 877	4 134.7	0.3632	
C6	73 489	2 477.1	0.3438	
C7	621 043	544.45	0.0064	
C8	4378.3	273.37	0.154	
C9	144 913	6 112.7	0.0462	
C10	-23 200	3 866.1	0.5536	55% accuracy of the model of the dependence of R on NOE.
C11	10 000 000	-3 472.5	0.8252	82% accuracy of the model of the dependence of R on NOE.
C12	5 000 000	-40 027	0.1006	Existence of unobserved independent variables.
C13	-7641.6	10 583	0.2011	
C14	23 755	1 944.4	0.0628	
C15	-10 000 000	11 796	0.4321	
C16	-306 136	8 827.8	0.2297	
C17	-25 727	2 179.5	0.5568	56% accuracy of the model of the dependence of R on NOE.
C18	-3 000 000	11 742	0.6168	62% accuracy of the model of the dependence of R on NOE.

Figures 5, 6, and 7 show the progression of the regression functions, cluster by cluster. The graphical representation provides a clear overview of the distribution of companies into clusters. Figure 5 shows the regression functions of the companies that always form a separate cluster. The waveforms are quite different.

Symptomatic for individual companies are:

- company C11 - decrease in NOE and increase in R, 82% accuracy of the model of the dependence of R on NOE, the development of the number of employees does not lead to an increase in revenue;
- company C12 - a slight increase in NOE and a decrease in R, due to R2 = 0.1006, the existence of other unobserved independent variables can be assumed;
- company C15 - increase in NOE and increase in R, 43% accuracy of the model of the dependence of R on NOE, the existence of other unobserved independent variables can be assumed;
- companies clustered in cluster 4 show a steep growth of the regression line (compared to the other clusters). For companies C18 and C16, the development of R and the growth of NOE are detected, but only for company C18, with a high precision of 62% (more than 50%, author's limit). For companies C13 and C16, the existence of other unobserved independent variables can be assumed;
- The other companies comprise cluster 5, except for C3, C10, C11 and C17, and other unobserved independent variables can be assumed.

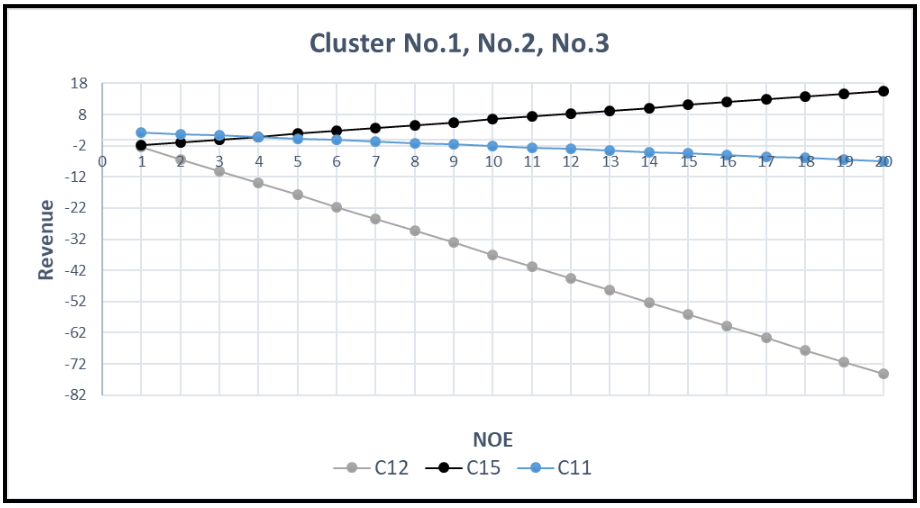

Fig. 6. Cluster analysis depending on regression function parameters – cluster No. 1, 2, 3

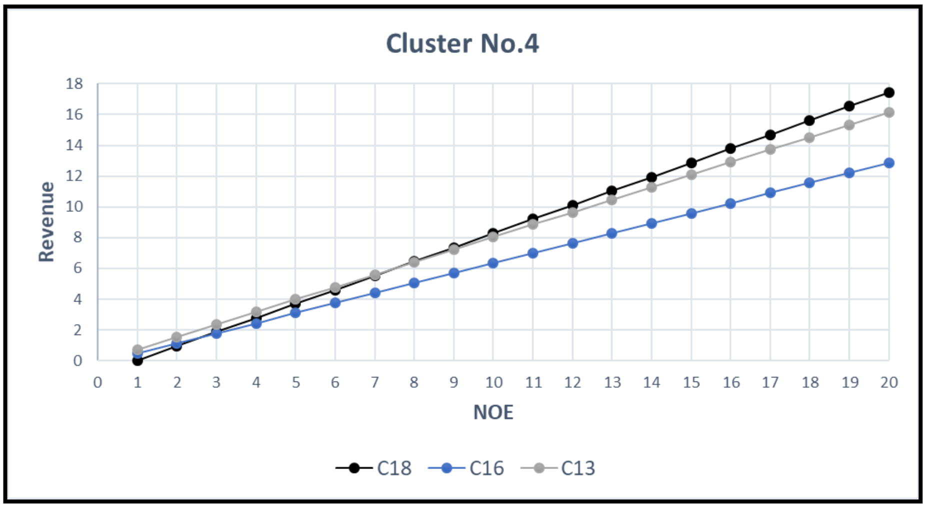

Fig. 7. Cluster analysis depending on regression function parameters - cluster No. 4

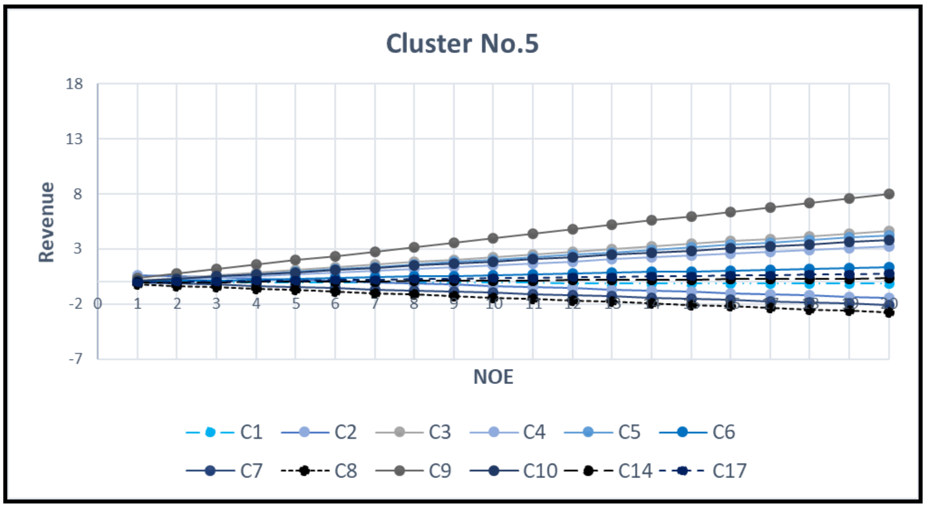

Fig. 8. Cluster analysis depending on regression function parameters - cluster No. 5

Partial summary of the cluster analysis:

- The overall worsened political and security situation is reflected in an increase in revenues and an overall increase in the number of employees.
- At the company level, the sample includes companies with a decline in revenues or a decline in the number of employees at the end of the period compared to the beginning of the period; in this sense, the hypothesis is rejected.
- The above chapter describes the situation in total and for individual companies. The situation for the analysed companies can be described as cyclical, with a rise and fall of R and NOE during the monitored period.
- With the exception of C3, C10, C11, C17, and C18, the effect of NOE on revenue development cannot be considered proven. The revenue of these companies is affected by other unobserved independent variables. The regression model proves this, and its accuracy is shown in Table 4. The high value of the R2 determination index of the regression function is not related to noise generation, with the exception of C11.
- Cluster analyses, depending on the individual variables R and NOE and the parameters of the regression function, yield different results.
- Different results indicate different company situations—the sample of arms companies varies from the smallest to the largest in terms of number of employees and revenues.
- There are no companies in the sample for which it is possible to detect a significantly different situation compared to other companies at the end of the period under review, as shown by the results of the cluster analyses, see Tables 4.

13. Conclusion

The article's subject is the results of the first stage of the research on changes in the revenue level in connection with the worsening international political situation due to the outbreak of the war conflict between the Russian Federation and Ukraine. The hypothesis is formulated: "*The worsened political and security situation has an impact on employment and revenue levels of arms companies in the Czech Republic, so that employment and revenues of arms companies are steadily increasing*."

The hypothesis must be rejected, both in the context of the above micro-view and because of the existence of companies whose revenues in 2022 are lower than in 2014.

Overall, the Czech arms industry is responding to the requirements of the dynamic international security environment, as evidenced by its technological level and ability to innovate. This capability is closely linked to the oligopolistic market structure, which shapes pricing strategies and encourages the development of new products, as shown by the economic analyses presented in the paper. Integrating systems and technologies form the basis for developing defence solutions and ensuring national defence capability in an unstable geopolitical climate.

Emphasis on research and development in the future is necessary for maintaining Czech companies' competitiveness and adaptability in the markets. Given the importance of these factors, future research should focus on strategies for state support of innovation in the arms industry to effectively counter current and future security threats [23, 24].

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Virtual War Medicine - A Key Element of Modern Warfare

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Abstract

The article deals with the impact of wars on the evolution of war medicine. The methodology includes an analysis of current approaches to the integration of new technologies, processes, and artificial intelligence in the treatment of wounded soldiers. In particular, the findings point to the lack of preparedness of medical information systems for intense conflict and highlight the need for rapid change in war medicine processes. Current studies point to the need for a multidisciplinary approach to its modernization, including its virtualization and legislative adaptation.

KEY WORDS: *new military technologies; Ukrainian war; patient; data protection; cyber security; soldier; virtual consilium; health law; cloud services*

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1. Introduction

In the period before the outbreak of the massive conflict in Ukraine (2022), the international concept of war medicine was primarily based on principles and methods that reflected the historical experience of past war conflicts. These approaches emphasized low-intensity combat operations and the dynamics of conflicts, separate isolated actions (see e.g. operations in Afghanistan, Syria, etc.), or the relative dominance of one of the warring parties. However, the current situation in Ukraine shows that these traditional approaches are no longer adequate in the face of new forms of warfare, which include, in particular, the extensive use of various booby traps, artillery, autonomous warfare, by-battle attacks, etc. The massive use of various types of drones and the ability to conduct long-range attacks is bringing new trends in the field of conflict management. The outlined specifics of the modern battlefield greatly complicate the traditional methods of evacuation of wounded soldiers, which forces a rapid rethinking and transformation of war medicine strategies.

In response to these new challenges, a greater focus on virtual warfare medicine and the implementation of related innovative technological solutions that can be effectively integrated into the new sub-processes of modern battlefield warfare medicine is required. The use of virtual consilia, the Internet of Things (IoT), generative machine learning (hereafter referred to as artificial intelligence - AI), and secure data transmission for real-time monitoring of soldiers' health status appears to be crucial for providing effective first aid and follow-up medical care. This implies the need to introduce new standards of healthcare delivery for medical personnel, both in individual military medicine roles and on the battlefield. The hybrid nature of the modern battlefield requires continuous evaluation and updating of strategies, which will allow for a better response to the needs of the wounded and increase the chances of survival.

In this context, an important element is the expansion of education and skills of medical staff not only in the professional sphere of medicine but also in the field of digital technologies and telemedicine. In addition to the necessary technological innovations, legislative and normative adaptation of modern war medicine also seems to be necessary. The security of medical data and its sharing between different levels of military command requires a careful revision of existing laws and rules, with an emphasis on the protection of the personal and medical data of soldiers [78]. All this is within the framework of individual NATO and EU armies, but also in the context of the interconnection of the two groups. This includes not only the adoption of new legal frameworks but also the creation of secure and efficient systems for the management and analysis of soldiers' health data and information in the context of military operations, virtually worldwide.

The paper aims to analyze the process of acquisition, transfer, storage, and evaluation of soldiers' health data in the context of limitations of their rights as patients in the context of virtual war medicine and the decision-making power of their superiors, including the proposal of specific measures and procedures for data transfer applicable in practice.

2. Ukraine - the experience of the first postmodern high-intensity conflict

More than two years after the official entry of Russian troops into Ukraine, the military conflict against the country continues. Since its beginning, the war has claimed many human lives, greatly depleted material resources, and caused a significant change not only in the European but also in the global security context. Before 24 February 2022, the perception of the possibility of war and its conduct was opposed to today's views. It should be noted that, despite possible interpretations, the Ukrainian conflict is a traditional, conventional war. Russia's aggression is a clear violation of it under international law [27]. The conventional conflict is evidenced by the fact that both countries have declared the mobilization of their citizens. According to the University of Upsalla, this conflict also fulfills the criteria for the designation of war, according to which war is "a conflict or rupture between two states that result in at least 1,000 combat-related deaths in a given calendar year" [60].

However, experience from the Ukrainian battlefield is now providing valuable information for strategic, tactical, and defensive planning for armies around the world that are not directly involved in the fighting. The publicly available or presented data on this conflict is also critical to modern war medicine for all armies, which draws valuable insights from it to adjust their procedures and standards. Although the war could be considered a local conflict carried out exclusively between two states, with fighting conducted by conventional means deliberately only on the territory of Ukraine (from the perspective of democratic states - Ukraine's allies), this conflict undoubtedly has a major international impact, as demonstrated, among other things, by the number of various foreign entities involved in direct or indirect financial assistance to Ukraine[35], but also, for example, through Russia's cyber attacks against Western institutions, both state and non-state. All these external activities carried out outside the conventional battlefield significantly increase the international significance of the conflict [77].

It is important to note that the current conflict is characterized by its enormous scale and extreme intensity, attributes not seen on the European battlefield since the end of the Second World War. The considerable consumption of resources is one of the main features of this war. If, for example, British forces had to maintain the operational tempo assumed by the Ukrainian armed forces in the first six months of the conflict, their ability to counter such a conflict would be exhausted in just a week [84]. In assessing the scope and intensity of this war, it is essential to consider both the military doctrine and force structure involved and the means employed. In particular, the volume of munitions consumed can serve as a key indicator for militaries around the world in relation to the challenges posed by contests between equals in the current era.

The above assertion regarding the scale and intensity is supported by the number of victims of the conflict on both sides. According to Milley's statement, Russia has already seen the loss of more than 100,000 of its troops in January 2023, with similarly serious losses on the Ukrainian side [69]. In March 2024, U.S. Secretary of Defense Lloyd J. Austin III detailed the enormous losses that Russian President Vladimir Putin has inflicted on his own country with his brutal war against Ukraine. In his words, Russia faces losses of at least 315,000 Russian soldiers (killed or wounded) [70]. Information from the New York Times in August points to more than half a million killed or wounded since the invasion began [9]. According to the General Staff of the Armed Forces of Ukraine, as of 1 March 2024, Russian combat losses amount to 414,680 soldiers. During a press conference on 25 February 2024, Ukrainian President Volodymyr Zelensky specified that a total of 180,000 Russians had been killed in Russia's full-scale war against Ukraine. With persons wounded or missing, the figure is as high as 500,000 soldiers [42].

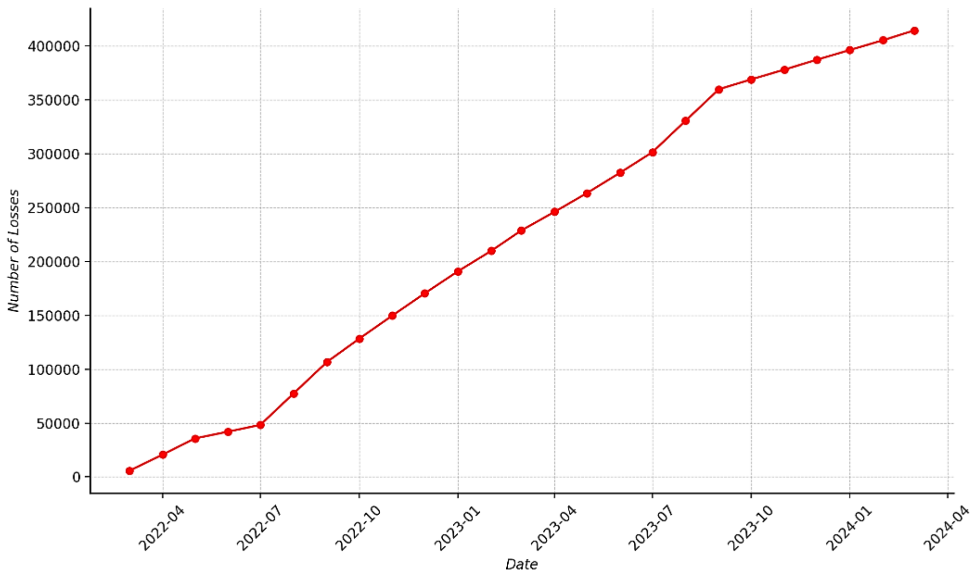

Fig. 1. Russian combat losses since February 24, 2022 [42]

In the early days of the confrontation, it was expected that Ukrainian resilience would not be enough against the superior Russian forces and that the country's defenses would collapse in a matter of days [6]. However, Ukraine has been surprised by its ability to adapt to the situation and confront challenging circumstances, undermining these predictions [2]. It is possible to observe not only Ukraine's tactical agility in the form of quick strikes and solid defense of key positions but also the ability to optimize its offensive maneuvers. The state of the conflict in 2023 embodied a mix of equal and different combat elements, with both sides engaging in a system of conventional and unconventional operations across different spheres of combat [23]. This situation prevails also in 2024, when, however, Ukraine's dependence on financial, material, and especially military assistance from external entities is more noticeable [11], without which it would be impossible to maintain an equal chance of waging conventional war in the style described and would necessarily lead to the abandonment of positions already gained and thus logically again to changes in the style of warfare.

The change like warfare is demonstrated by the inconsistency in the perception and use of military equipment, which is fundamentally reflected in the perception of the value and importance of tanks in this conflict. The initial view of tanks as obsolete instruments of warfare was reassessed in the early stages of the war, as their strategic use and lack of protection by other branches of the armed forces indicated an immediate need to revise their role [39]. With the arrival of spring 2023, there was a shift when Western countries began to supply Ukraine with tanks in particular, which many interpreted as a key moment that could strengthen the Ukrainian offensive [28]. This turn of events highlights that the dynamics of the current conflict are constantly influenced by the evolution of tactical and strategic approaches, with both sides of the conflict adapting their strategies and military structures to better respond to the challenges of the battlefield, as illustrated by the Russian military's significant shift in early 2023 to a divisional organization of their units [4, 16].

Another turning point in the tactics of warfare, which ultimately has significant implications for the principles of the logistics of war medicine, is the massive deployment of artillery and unmanned aerial vehicles on the modern battlefield. The conventional army operates towed artillery, which is transported to firing positions by army vehicles, and self-propelled artillery, which can maneuver itself into designated positions. However, experience from the Ukrainian battlefields declares that future artillery systems must be "constantly moving" without having to account for the time it takes its crew to move from an old to a new firing position [61]. In particular, experiments with extended-range cannon Artillery (ERCA) ammunition show a paradigm shift towards increasing the firing range of artillery, where tested rounds reached targets more than 110 km away [62]. These advanced tests, which included firing rounds from the Paladin howitzer that reportedly exceeded the range of all previous projectiles from this platform, are representative of the military's ambition to modernize and expand the operational capabilities of its artillery [61]. Russian military successes in rapidly targeting adversaries with drones and advanced surveillance technologies represent another significant change in artillery tactics [53]. Integrating drones into artillery operations allows Russian forces to engage targets with surprising speed, often within 180 seconds of detection. This efficiency contrasts with more traditional targeting methods, where the process from identification to engagement can take up to 30 minutes [61]. A significant surprise, then, was Russia's ability to effectively engage and destroy key Western weapons systems that had rarely been hit before, demonstrating the high level of sophistication and coordination within their artillery and intelligence operations [46]. Above all, it was the loss of important systems supplied by Western countries, such as Patriot anti-aircraft missile launchers, which until then had been considered an extremely effective defense system [5]. Similarly, Russia has managed to track down and destroy high-mobility artillery missile systems. All this highlights the challenges facing modern air defense and artillery strategies [76], which are also essential for the protection of rear and medical units, their equipment, facilities, and evacuation routes for the removal of the wounded.

The war in Ukraine reaffirms the old military truth that, even in the age of advanced technology and air power, ground combat is the basis of any conflict. Despite all modern methods of warfare, from precision strikes to the use of drones, the "boots on the ground" fight remains decisive [73]. This reality was also reflected in Ukraine, where neither extensive air and missile strikes at the beginning of the conflict nor advanced air operations during the conflict were able to fundamentally change the course of the fighting in favor of one side [7]. In contrast, efforts to maintain control of key positions through ground forces have shown that in the current conflict, victory depends primarily on the ability to seize and hold territory, which requires the effective deployment of ground forces [7].

Another aspect is adaptation to the ever-changing conditions of the modern battlefield, where traditional (conventional) air superiority no longer necessarily guarantees victory. Although air power plays a key role in reconnaissance, combat zone isolation, electronic warfare, and precision strikes, the ability to effectively employ ground forces to achieve strategic objectives remains essential [47]. It turns out that success lies not in achieving air superiority, but rather in the ability to limit the effects of enemy air power and maximize the potential of ground operations [48, 56]. In this context, the war in Ukraine appears to represent a shift from the traditional emphasis on air dominance to a more complex conception of conflict where the ability to combine different types of troops and tactics to achieve success on the battlefield is key, underscored by the massive casualties on both sides and the tactical innovations conducted in response to these challenges [47]. This evolution highlights that in modern conflicts, despite the growing importance of technology and innovation, ground combat and the strategic use of large numbers of ground forces remain critical success factors. However, such a mode of warfare inevitably brings with it enormous requirements for the provision of medical care to soldiers, with an emphasis on reducing casualties.

3. Modern warfare medicine - reasons for the path to virtualization

Already Napoleon Bonaparte was aware that when commanders move field hospitals to the front line of troops, they are declaring their intention to accept losses and also their intention to fight. In January 2022, the international community noted, largely in publicly available source material, that field hospitals were appearing along Ukraine's northern, eastern, and southeastern borders. There were, among other things, blood draws of university students, Russian military medical exercises, and tests of their medical evacuation chains back to St. Petersburg. These signals of Russian intentions already warned of impending war [51]. Unfortunately, it was only in the wartime environment of Ukraine that a significant shift in the concept and implementation of war medicine occurred, which was due to the exceptionally high number of wounded and the specific conditions of the battlefield, including the extensive deployment of artillery and the associated difficulties in evacuating the wounded. Deficiencies in the preparation and training of soldiers in the area of first aid, combined with the intensive use of artillery making it impossible to safely evacuate the wounded from the front line, resulted in significant casualties [81]. All of this has increased pressure on medical units, their equipment, and the implementation of new procedures, especially efforts to fully digitize the army's medical processes and the quality training of combat medics [85].

Changes in the conduct of war, as described in the previous section of this article, therefore require the adaptation of new war medicine strategies to effectively meet new challenges. In particular, the ability to respond to a broader spectrum of threats and the ability to provide rapid and effective care are key [65]. Rapid drone targeting and advanced technology mean that warfighting medicine must not only be mobile and flexible but also equipped to counter sophisticated attacks that can unexpectedly change the dynamics on the battlefield [7].

In July 2022, the Royal United Services Institute Journal published an article entitled "You are the weakest link: the limits of Britain's defense medical capabilities" [84]. This article stated that the war in Ukraine has highlighted the shortcomings and stagnation in the development of military medical capabilities for combat that have accrued during the 30-year peacetime period following the Cold War. Lessons learned from the war express the urgent need to restructure Allied wartime medical services [29], which is closely related to the implementation of operations to deter Russian aggression and prevent war [57]. With this knowledge, we have the space to address gaps in NATO's collective medical capabilities and can take appropriate corrective actions that would be shared directly with the NATO military medical community [19].

The need to revise the principles of war medicine is necessarily reinforced, among other things, by Russia's repeated violations of international humanitarian law and legal norms regulating armed conflicts. Traditionally, it was assumed that the adherence to the principles of the Geneva Conventions and the recognition of the Red Cross symbol protected field hospitals in international conflicts. However, recent conflicts, including those involving Russia, have shown that these assumptions may not always be met. Specifically, Amnesty International in 2016 highlighted the systematic and deliberate attacks by Russian and Syrian government forces on medical facilities in northern Aleppo as a strategy to facilitate the advance of ground forces [1]. As a result of these prolonged conflicts, medics have been forced to take refuge underground or in unmarked buildings to provide care to the wounded [45].

In Ukraine, it is now becoming clear that the international consensus and existing legal norms do not provide sufficient physical or virtual protection for medical units from an aggressor that recognizes neither the laws of armed conflict nor humanitarian principles [15]. In January 2023, Neil Bush, head of the UK delegation to the Organisation for Security and Co-operation in Europe, highlighted the growing evidence of war crimes against medical facilities committed by Russian forces in Ukraine, including attacks on areas under their control [24]. These continuous strikes on Ukrainian cities and civilian medical infrastructure have a lasting humanitarian impact not only on the population but also on wounded soldiers and their treatment options. Already in the first weeks of the invasion, many medical facilities were targeted, often with devastating consequences [65]. These findings, together with Ukraine's experience before the beginning of the conflict, when although the war was constantly mentioned in the media and communication with the public, Ukrainian hospitals were not prepared for the invasion on a systemic level [18], led to the extension of the application of the principles of war medicine also to civilian medical facilities, which in the event of a conflict will necessarily become part of the military medical infrastructure.

A possible sub-measure in such a context is a reassessment of operational procedures by the military health service, including the introduction of tactics of camouflage, deception, and distraction. This includes the use of underground structures, such as underground car parks or emergency hospital wards, to safely provide care to wounded soldiers [49]. In addition, it may be necessary to implement enhanced air and cyber defense measures for medical facilities located in critical areas to ensure their protection from hostile activities [49]. An example of this is the need to respond to hostile UAVs tracking marked medical vehicles to the extraction site (Role 2), often with artillery subsequently targeting the area to destroy or damage the area and the occupants [41].

It is not only about the physical security of military medical facilities in all roles but also about virtual security. In addition, the vulnerability of military medical facilities is their electromagnetic interference (EMI) signature [82], which extends beyond command-and-control locations to medical buildings, acting as a navigational beacon for enemy fire. According to Samuel L. Fricks, who served in Ukraine as a member of the U.S. Department of Defense's surveillance team, anything that is stable on the ground for more than seven minutes can be targeted by the enemy [41]. Thus, visual tracking is not needed for detection. The described situation is one of the basic causes of both high casualties and the need for mass evacuations and medical care for wounded soldiers in the field.

In response to these factors, war medicine must constantly adapt and transform to meet the demands of modern conflict. Simulations and analyses by some militaries suggest that in high-intensity conflicts such as the one in Ukraine, the role of war medicine becomes a key factor that can determine the outcome of the conflict [81]. The increasing use of artillery, air defense, and long-range strike capabilities limits the options for rapid medical evacuation, a challenge not encountered in previous lower-intensity conflicts [79].

These developments require innovative approaches, including the use of new technologies for on-scene diagnosis and treatment, improved rapid evacuation systems, and enhanced first-aid training for all soldiers [68]. Increasing the chances of survival of wounded soldiers on the modern battlefield will thus require not only traditional medical skills but also the ability to adapt quickly to the ever-changing conditions and challenges that modern conflicts bring. Integrating these elements into concepts of war medicine could mean the difference between life and death for many of those serving on the front lines [48]. The diversity of warfare brings a complex mosaic of tactics and strategies that reflects both the evolution of modern warfare and the continued importance of traditional combat methods [47], which goes hand in hand with the development of modern warfare medicine and its necessary virtualization.

4. Modern war medicine - front line

With conflict, the challenges of war medicine are transferred to the front lines, where wounded soldiers, due to the factors described above, are at risk of delayed evacuation due to intense and constant bombing. Traditional first aid and evacuation methods are tested to extremes, often forcing medical teams to adapt to difficult conditions on the ground. Although contemporary warfare contains elements of post-modern conflict, such as cryptographic communications and the use of private military companies that sometimes operate autonomously [32], conventional tactics such as persistent frontline warfare, massed artillery [83]. and extensive field fortifications must not be overlooked [23]. This complex course of war reflects not only technological advances but also the determination and ingenuity of both armies involved, which are constantly adapting and developing new methods to achieve strategic superiority [84]. In direct connection with this, emphasis is placed on changes in the concept of war medicine and especially first aid for the wounded on the battlefield, who cannot be evacuated "immediately".

The reaction of the allied armies watching the Ukrainian conflict consists, among other things, of the implementation of so-called war games, which allow simulation of the real possibilities of providing medical services to wounded soldiers and their further provision. In the context of the Ukrainian conflict, these simulations show dramatic casualties - up to 21,000 wounded soldiers during the first seven days of fighting [62]. These figures illustrate the demands of modern warfare and highlight the importance of effective and prompt medical care for wounded soldiers. Given the difficulty of evacuating the wounded during the so-called golden hour, a critical period when prompt and proper medical intervention can mean the difference between life and death, it appears that traditional approaches are no longer sufficient [62]. Failure to adequately move patients to higher levels of care affects the quality of care and mortality of trauma patients [25]. The transfer of wounded soldiers to a medical facility at the front during the golden hour is unlikely given the current constraints of the conflict. Evacuation times combined with overstretched and/or destroyed medical facilities significantly affect the mortality of trauma patients [25]. The use of aerial evacuation would significantly reduce the evacuation time but is currently not feasible due to the hazardous airspace in the combat zone [55]. Evidence from battlefield studies strongly suggests that many deaths and serious injuries are related to massive bleeding immediately after injury and that most preventable deaths can be achieved by controlling blood loss [34]. Intensive efforts to address the problems associated with massive blood loss are evidenced by the U.S. Army's Tactical Combat Casualty Care (TCCC) training and management programs for all members of the armed forces, which have been widely implemented or are reflected in similar programs in many other countries, including Ukraine [30]. Michael Talley also pointed out the need to review the organization and especially the training of military and medical personnel to prepare them for the challenges of high-intensity conflicts [62].

Another key factor revealed within the Russian military is that inadequate first-aid training has resulted in a high number of deaths and injuries. According to a report published by the Ria Novosti website, up to 50% of the deaths of Russian soldiers in Ukraine can be attributed to poor first aid due to inadequate training [52]. This problem is compounded by the fact that most Russian soldiers remain without adequate training, leading to high casualties. In contrast, Ukrainian forces, which have effectively trained their personnel in the area, show a significantly higher survival rate of their wounded, thanks in part to cooperation with Western instructors [8]. These data and revelations point to the critical importance of adequate training, first aid, and rapid medical intervention in modern warfare, particularly on the line of engagement. They also point to the need to rethink and innovate approaches to war medicine so that as much medical assistance as possible can be provided on the ground without the possibility of moving the injured person.

The U.S. military is responding to the challenges described above by developing new technologies and methods that expand the capabilities of medical care on the battlefield. Innovations include but are not limited to, synthetic blood, antigen therapy to improve compatibility in transfusions, the use of augmented reality, artificial intelligence, robotics, and 3D printing. These technologies aim to give military units' greater autonomy in caring for the wounded until evacuation is possible [80]. The combination of the described innovations and procedures necessarily requires, due to the impossibility of evacuation or the presence of qualified medical personnel directly on the battlefield, remote access to medicine and its useful extension from physical to virtual form.

5. Military health data transfer options

Military environments and crises such as wars and conflicts have historically acted as catalysts for the development of modern technologies. This trend is also evident in the case of the current conflict in Ukraine, where the military, given the aforementioned facts, is faced with an urgent need to innovate and adapt technologies in war medicine to effectively respond to the challenges of treating injuries in combat settings. History shows that militaries have long used telemedicine to overcome geographical and logistical barriers, enabling them to provide critical medical care in the most extreme conditions. The earliest use of radio telemedicine documented by the military has its roots in Australia at the Military and Veterans Health Centre in Brisbane, where in 1917, Perth physician J.J. Holland telegraphed a postmaster at Halls Creek, 2,900 kilometers away, how to treat a seriously injured stockman [36]. A significant step in the development of telemedicine in general was NASA's 1989 initiative to create the US-Soviet Space Bridge following the earthquake in Armenia, which caused extensive damage to medical infrastructure and loss of life [3]. This telebridge enabled the transmission of image documentation and the provision of consultative assistance to patients, which subsequently helped in the Russian city of Ufa after a tragic railway accident. The telemedicine link provided transmission of image documentation from the affected areas and subsequent consultation by U.S. military doctors [64]

In the military context, the possibility of data transmission is also related to the field of telepsychiatry and telerehabilitation, especially on bases, ships, and field hospitals, but also on the battlefield [80]. A significant benefit of telemedicine is its ability to provide rehabilitation support to wounded soldiers and civilians in war zones, as demonstrated in the United States, where telerehabilitation has developed primarily in military medicine [3]. This approach, in the context of today's times, illustrates the key role of telemedicine in the rapid and efficient delivery of medical care in extreme situations, and its use in the military and response to the war in Ukraine offers the promise of improved treatment outcomes and saving more lives.

The basis for the implementation of military telemedicine directly in Ukraine is the development of a coordinated national medical evacuation system and trauma registry, which would improve both evacuation time and especially clinical communication [37]. The development and use of such systems will enable critical improvements in the trauma system of Ukraine and will serve as the information backbone for process improvement of all systems within the entire system. A trauma registry is the foundation of a responsive and dynamic trauma system, which is lacking in Ukraine, that collects information related to trauma events, injuries, care, and outcomes across the continuum of trauma care. The data collected allows for systematic analysis leading to continuous quality improvement, resource allocation, and change in the practice of war medicine in general [54]. Ukraine is currently developing modified electronic systems and tools related to the complete computerization of its health care system concerning the ongoing armed conflict. It explores what approaches, policies, standards of care and guidelines are necessary to strengthen the trauma care system in addition to the trauma registry. Since the beginning of the war, the Ministry of Health has been concerned with setting up health care using global standards of disaster medicine, however, they decided to develop their trauma system to meet their needs and constraints [71, 72].

The Ukrainian experience with the development of electronic systems is an extremely valuable source of knowledge for the actual development of systems of other NATO armies enabling the transmission of data, not only on the health status of soldiers on the battlefield. It is imperative that NATO's Military Health Section, as well as those of the individual armies, begin to implement systems that enable the collection and analysis of physiological data directly from soldiers' bodies, for example, using IoT (i.e. biosensors and sensors) to monitor environmental parameters. This data should then be transmitted and stored in the databases of ambulatory or hospital information systems of military medical facilities through protocols that ideally use predefined interoperable standards.

The personalized evaluation of the health status of individual soldiers based on this data will not only enable more accurate and faster diagnosis of wounded soldiers but also prediction of the development of their health status and timely initiation of effective therapy, including subsequent rehabilitation. The implementation of such an integrated, adaptable system, which would also function in a decentralized manner and be accessible both at the individual soldier level and at the command level, represents a key step towards ensuring better care for the wounded in wartime conditions, including optimization of their evacuation.

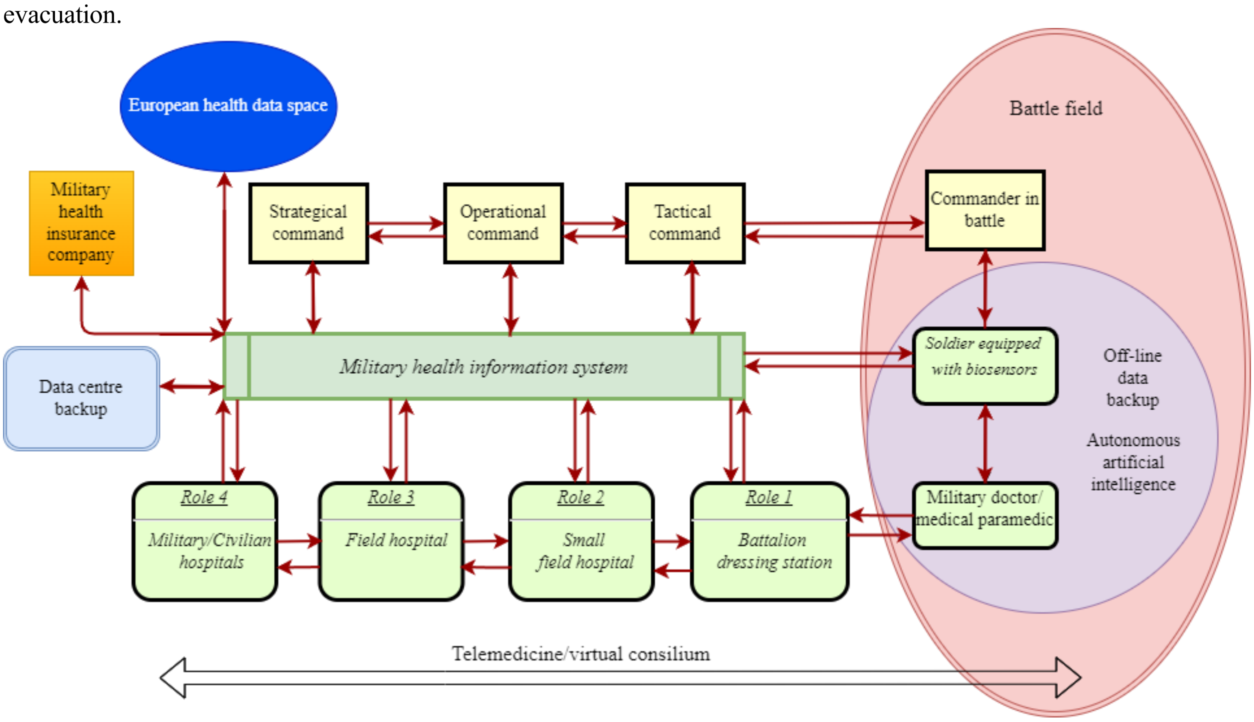

Fig. 2. The model for the transfer and use of military medical data.

This strategy, supported by digitalization and telemedicine, would not only be able to significantly expand the capabilities of war medicine but also increase the chances of soldiers' survival by enabling timely and targeted medical interventions based on real-time analysis of medical data without the need for immediate transport to a medical facility (field hospital). A possible solution is illustrated in the following diagram (see Fig. 2). The diagram in Fig. 2 depicts a sub-module, designed by the article's authors, that transfers and manages data (both content and metadata) about soldiers' health status from their deployment locations (e.g., battlefields, foreign missions) to various levels of the selected army's military medical service roles. This sub-module is integrated into a broader military health information system. This system will facilitate the collection, capture, analysis, and efficient transfer of vital health data for soldiers to medical officers and commanders at all levels within a critical time frame. The model also enables the creation of a secure virtual environment for the transmission of all types of required data, including the implementation of virtual consilia or the provision of health services through telemedicine.

At the individual command levels, the data obtained from the soldiers' sensors can be used for further evaluation and decision-making on their deployment or provision of medical assistance. The whole concept creates a holistic ecosystem, the central node of which is the military health information system, which collects, processes, and distributes soldiers' health data. This system communicates with various levels of command, military, and non-military health service providers, enabling the provision of rapid data access and real-time decision-making. However, should the military medical system experience an outage, it is still possible to store the data and transmit it to specific roles. The advantage of using a centralized system is the immediate distribution of data to authorized individuals and its independence from this central element.

The security protocols for data transmission must incorporate robust encryption standards and firewall protection to prevent unauthorized access or data breaches during both peacetime and armed conflicts. Such a solution must necessarily include security protocols for authorization, authentication, and identification of authorized persons and their authorization levels, ensuring that only authorized users or entities that can process and transmit data can have access and verification. From a cybersecurity perspective, the short-term operating horizon of the computer system is ideal, however, for more permanent use, it will be necessary, on the part of the Member States concerned, to build up an information technology infrastructure and establish appropriate legislation governing both the security and standards of its operation and the protection of personal data directly affected by the system.

A significant consideration is the potential use of existing non-military communication and encryption tools, such as civilian mobile applications [44]. The potential use of these tools has been confirmed by their use in Ukraine, where they have been used for pre-hospital care, remote patient monitoring, and also to improve standardized forms [37]. A fundamental prerequisite for the use of existing technologies and systems of the civilian sector for virtual military medicine is their use only if the digital signal used by them does not represent a potential target for attack [20, 74]. Another necessary measure for the implementation of these systems will be, for example, the suppression of the transfer of geolocation and contact data to other than authorized entities. This step has already been taken, for example, in Ukraine for all electronic health records [56]. Taking measures to remove the geographical and contact details of doctors, soldiers, and all other users of the system is essential to ensure optimal cyber security. An important lesson from the fighting in Ukraine is the implementation of the aforementioned telemedicine, which is used among civilians for primary care, but its role in trauma care has been severely limited due to language barriers, insufficient technological infrastructure, and, in particular, persistent concerns about ensuring cyber security [26, 38].

To ensure the transfer of data and information across different platforms and units, the alliance militaries need to establish and maintain interoperability standards. These standards will in the future, similar to the civilian sector, allow for the integration of systems from different vendors and ensure that data can be effectively shared and used by all relevant parties, both within the military sector and in the civilian health sector, if required.

The presented model assumes the use of a partially virtualized and cloud environment that can offer a high level of diversification and data availability. Such a solution appears to be suitable for military cloud platforms designed specifically for resilience against cyber threats and with the ability to operate in a variety of environments - from stable data centers to mobile and deployed operational units that require high levels of redundancy and rapid adaptability to changing conditions. However, as already mentioned, the transfer of data and information is not dependent on the cloud environment and allows for alternative ways of transferring data and information.

The diagram presented in Fig. 3 are also created by the authors, it illustrates the process of transferring medical data from the battlefield to the various levels of the military medical service. In the first step, the health data of the wounded soldier is collected by biosensors; it can be supplemented by first aid or autonomous first aid information using artificial intelligence. If online transmission is possible, the data is immediately sent to the military health information system, regardless of distance. If online transmission is not possible, the data is stored offline and transmitted over a short distance of up to 2 km to a military doctor who is on or near the battlefield where it can be evaluated and processed for further use. En route to the military doctor, the data can be further transmitted to the military medical service system, which is divided into several roles. Role 1 is the battalion dispensary, which can be located up to 10 km from the battlefield. Role 2 is a small field hospital that can be located up to 30 km from the battlefield. Role 3 is a full-field hospital that can be located up to 50 km away. Role 4 represents a military or civilian hospital where the data is finally integrated into the broader military health information system. In the military medical service system, data is coordinated and analyzed at the tactical, operational, and strategic command levels, allowing for informed decision-making regarding treatment and evacuation options for wounded soldiers. The medical information system serves as the basis for data collection, storage, and analysis, enabling telemedicine consultations and the provision of virtual medical care.

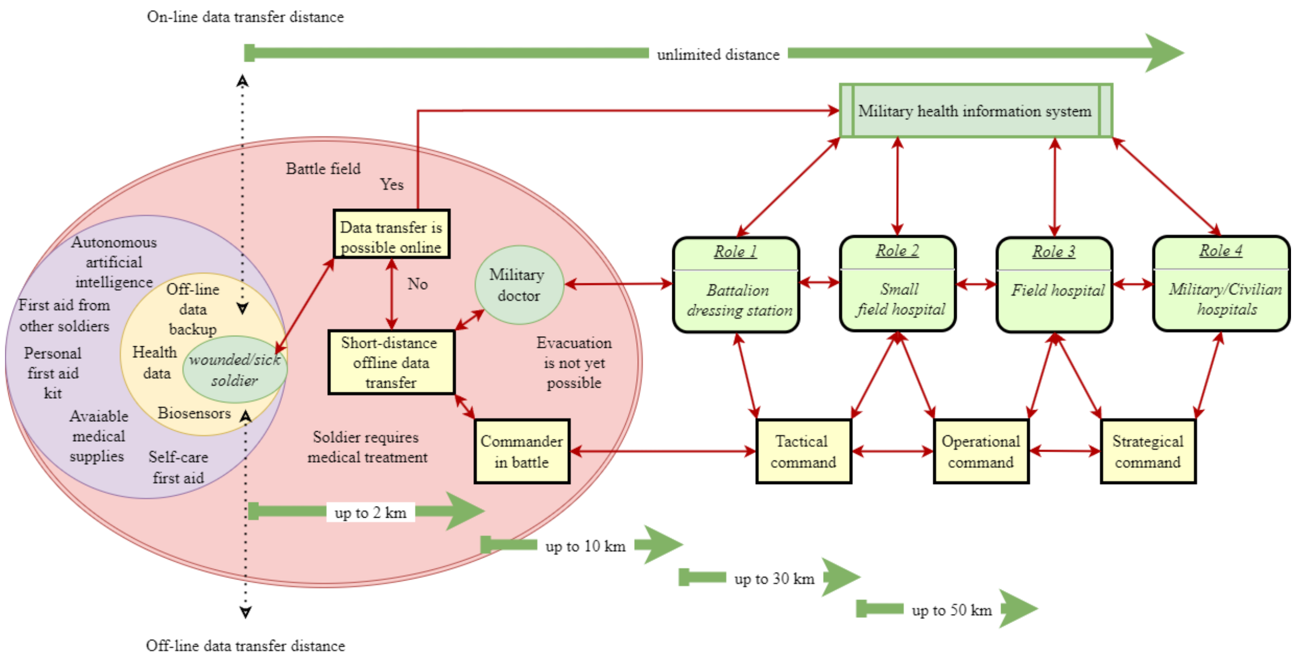

Fig. 3. The model (diagram) illustrating data transfer allowing for both cloud and semi-offline data.

From the experience of the Ukrainian battlefield, it can be assumed that it will not be possible to maintain this system relatively permanently online on the battlefield. It can be sad that Fig. 3 illustrates a sophisticated system for the transmission and use of military health data that is designed to withstand the challenges an army may face in combat conditions. It must be designed to remain functional under adverse conditions in high-intensity conflicts where immediate evacuation of the wounded is not possible. It includes an off-line/semi-off-line data collection and storage solution that will allow for continuous monitoring of soldiers' health status and that will provide backup and recovery of data when needed until it can be securely shared and connected to the Army network again. Related to the above is the possibility of linking artificial intelligence technologies that would be able to assist in providing medical services to a wounded soldier autonomously on the battlefield without network connectivity for some time [75]. The assumption is that artificial intelligence will be able to guide the soldiers performing the treatment through predefined steps, which will be variably evaluated based on the changing situation (see the use of generative AI data), to stabilize the injured person as much as possible, leading to a stable health state until possible transport. Generative AI could be used as a means to consult or assist military medics on the battlefield in their activities. According to the authors of the article, the combination of deepening unit medical training, AI, and telemedicine described earlier in the article can significantly increase the percentage chance of survival for wounded soldiers. The use of simulations, virtual consilia, and remotely controlled medical technology could make it possible to perform surgical procedures and provide necessary emergency medical care even in inaccessible or isolated battlefield environments.

The proposed system takes into account the requirements of both the civilian and military spheres - it maintains strict security standards while providing the flexibility and integration needed for civilian treatment facilities, facilitating the transition and continuation of care for military patients in the civilian health system, for example in the context of rehabilitation or when civilian medical facilities need to be used for military purposes.

6. Cloud as a possible interoperable platform

Significant developments in the acceptance of cloud-based solutions for the storage and transmission of medical data have already been made by some EU Member States. Here, in the context of the ever-evolving field of war medicine, the rapid and secure collection, processing, and distribution of data plays a key role. The study 'Cloud Intelligence for Decision Support and Analysis' (CLAUDIA), funded by the European Defence Agency (EDA), has revealed major benefits of cloud computing that can be applied to the described virtual military medicine model. Cloud technologies, which include computing capacity, data storage, and software tools hosted externally, offer both strategic and tactical advantages. The SWAN platform, developed by the CLAUDIA project, demonstrates the ability of clouds to support tactical and strategic military decision-making not only for military medicine, but especially for improved situational awareness and reduced response times in a variety of operational environments, through virtualization that enables the creation of virtual versions of servers, storage, and networks [10]. The EDA therefore plays a crucial role in the development of EU Member States' defence capabilities and the field of war medicine supports initiatives such as cloud computing that facilitate cross-border collaboration and the use of shared resources, which is invaluable in situations where it may not be possible to ensure the timely evacuation of the wounded. The use of telemedicine and virtual consilia in this setting is essential, enabling a high level of quality medical care regardless of physical distance from specialized medical facilities [58].

European Health Data Space (EHDS) [21]. also offers opportunities for the creation of a dedicated virtual space for the secure storage of sensitive data of EU Member States' militaries. This space, respecting the principles defined by Regulation

(EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation) and by Directive (EU) 2022/2555 of the European Parliament and of the Council of 14 December 2022 on measures for a high common level of cybersecurity across the Union, amending Regulation (EU) No 910/2014 and Directive (EU) 2018/1972, and repealing Directive (EU) 2016/1148 (NIS 2 Directive), represents an ecosystem specifically designed for the health domain, consisting of rules, common norms and infrastructures. Its primary goal is to empower individuals by giving them better control over their health data while ensuring a high level of data protection and privacy [22]. This structure could be specifically tailored to create an isolated and secure segment for military use, where only authorized individuals with military encryption keys have access, ensuring that operations in sensitive and dangerous environments remain protected.

The importance of EHDS to military health information systems is further enhanced by the integration of technologies that enable the secure exchange, reuse, and analysis of health data not only for healthcare delivery but also for research and innovation [22]. This approach supports the creation of a single market for electronic health records and related technologies, enabling effective cooperation and interoperability between military and civilian health systems of different Member States. The use of EHDS would also enable faster and more informed healthcare decision-making based on specific medical evidence, which is key to improving preparedness and crisis response. In addition, the creation of a dedicated military segment within the EHDS would ensure that even at the highest threat level, soldiers' health data is protected from cyber threats, which is in line with the cybersecurity requirements of the NIS 2 Directive.

7. Legal protection of soldiers' personal data

Apart from the physical and virtual security of the transmitted data and the ongoing processes, the issue of legal regulation of their processing also plays an important role, especially in the protection of soldiers' personal data, which includes sensitive personal data, such as information on the health status of soldiers and their biometric data. In light of current and future military operations conducted by both the EU and NATO, soldiers' personal data and their biometric information have become a key component of information superiority and operational effectiveness [40]. While there are strict rules for data protection in the EU civilian sector, a similarly strict framework is lacking for EU military missions. This represents a legal vacuum, especially about fundamental rights and data protection, which are protected in the EU by both primary and secondary law [33].

Biometric technologies are a usable element of the military health information system and are gradually becoming an essential tool in military intelligence and security, with the key benefit being the ability to strip enemies of the advantage of anonymity, which in turn can be a major weakness in the event of a data leak. This technology has already been implemented in NATO-led operations and, to a lesser extent, in EU missions [31]. Given the significant benefits of this technology in a military environment, efforts to make it more widely used in these missions can be expected. Another important aspect is the fact that, unlike NATO, the EU as an international organization has developed an extensive framework for data protection, including biometrics, which raises expectations regarding legal safeguards for the use of biometric systems in EU military missions, in particular as regards the sharing of biometric data [12]. This is particularly relevant for EU Member States that are also NATO members and may be bound by EU data protection law when participating in NATO operations [50]. This raises a very interesting legal question regarding the potential creation of a single NATO army and the sharing of soldiers' personal data between the different armies.

As regards the protection of personal data in the context of EU military missions, Article 39 of the Treaty on European Union (TEU) is the basis for specific rules on the protection of personal data in the framework of the Common Foreign and Security Policy (CFSP). Although the EU Council has not yet adopted a decision establishing a specific data protection regime for the CFSP, a certain level of protection can be achieved by applying existing EU data protection legislation. This is the GDPR, which is the most significant piece of data protection legislation and Directive (EU) 2016/680 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons about the processing of personal data by competent authorities for the prevention, investigation, detection or prosecution of criminal offenses or the execution of criminal penalties, and on the free movement of such data, and repealing Council Framework Decision 2008/977/JHA, which is lex specialis about the GDPR as regards the protection of natural persons in connection with the processing of personal data for law enforcement purposes. This EU legal framework also applies to the processing and sharing of biometric data in the context of CFSP-led missions. The use of biometric technology in EU military operations and missions is becoming increasingly important given its potential to reveal the identity of enemies and remove their advantage of anonymity. An example is the relatively recent EUNAVFOR MED IRINI operation, aimed at enforcing the UN arms embargo on Libya, which can collect and store personal data, including biometric data, to identify persons involved in the transport of prohibited items [13].

The EU's specific legal framework on data protection, covering health information and biometric data, raises the pressure to adopt high legal safeguards when processing and sharing data in the context of EU military missions. This also has implications for EU Member States that are also NATO members, as they may be bound by EU data protection law when participating in NATO operations [67]. The application of EU health data protection legislation to the sharing of biometric data in the context of EU military missions has an important role to play. The focus is on the impact of EU framework law on the processing and sharing of health data and biometric data, which includes cases where Member States implement EU legislation in their armed forces [14]. This approach will need to be brought into line with NATO requirements in the development of military health information systems and clear rules for sharing personal data between armies will need to be defined. The acceptance of the use of biometrics and the setting of rules for the protection of personal data within the national regulation of Member States shape the approval of their military use abroad. Moreover, how a Member State allows its military to process personal data shapes the processes by which technical interoperability is achieved between other militaries. For example, legal caveats for data retention - if applicable - must be part of the technical interoperability that accompanies exchanged health and biometric data throughout its lifecycle from cradle to grave [17]. Since the US can be considered a pioneer in the military use of biometrics and the specific processing of sensitive personal data, its legal safeguards and generally higher level of societal acceptance of the adoption and use of new technologies is strongly reflected in the current military-technical interoperability standards for the health information systems of the various NATO armies [14].

Another issue discussed is the impact of biometric systems on interoperability between different missions and the need to develop comprehensive data protection rules by Article 39 of the EU Treaty to effectively share personal data collected in the framework of CFSP missions with other elementary security regimes, such as NATO or the UN [50]. Within the EU, Article 39 TEU, in conjunction with Article 16 TEU, is key for the processing of personal data in the context of the Common Security and Defence Policy. Although primary EU law contains strong fundamental commitments to data protection, effective protection in practice depends on the details and implementation of secondary law that specifically addresses the unique circumstances of military missions and operations. Secondary legislation such as the GDPR, while not primarily designed for military missions, can serve as a primary guide and analogy for creating the missing framework [43]. It is therefore necessary for the EU member armies, which are also part of NATO, to use this approach as the basic legal framework for the development of military health information systems designed for the accuracy and processing of health data.

An essential element is the need for clearly defined and transparent processes for the sharing and processing of personal data, with the explicit consent of the persons concerned or based on other legitimate legal grounds. These measures must be underpinned by robust safeguards that protect against misuse and provide access to soldiers' personal data and data. Any transfer of personal data must be underpinned by adequate security standards, including in the case of data transfers between different international organizations or states. The issue of creating and adopting such standards will certainly be a very complicated one, but it is nevertheless necessary.

In light of the lack of a specific legal framework for the cyber protection of shared data in foreign military missions, the creation and adherence to detailed agreements that establish protocols for processing, sharing, and protecting data is essential. Such agreements could serve as a temporary substitute for the lack of legislation, although they are only a temporary solution, as unresolved legal issues can severely limit the effectiveness and interoperability of military operations. Advances in technology and lessons learned also play an important role in this area, where virtual medicine and the use of cloud technologies are pushing the boundaries of what is possible, yet always with an emphasis on security and individual soldier data protection.

8. Conclusions

The war in Ukraine and similar conflicts have exposed key shortcomings and the need to modernize war medicine. Developments show that current methods of healthcare may not be sufficient for a rapid and effective response in high-intensity conflicts. The urgent need for a fundamental transformation in the approach to war medicine lies in adapting to the rapidly changing nature of modern warfare. An essential element of this transformation is the integration of new technologies, such as artificial intelligence and advanced biomedical technologies, which can fundamentally improve diagnosis and treatment on the battlefield. The development of telemedicine services and virtual consilia will enable military doctors to provide fast and effective medical care, even in situations where the physical presence of a doctor is not possible or is only possible with hindsight. Importantly, such technologies enable faster and more secure processing and sharing of medical data, which is critical for real-time decision-making by commanders.

Another critical aspect is the need to develop and implement new educational programs and training modules that focus on the specifics of war medicine. Training of medical personnel must include scenarios that simulate realistic and intense conflict situations so that doctors and nurses are prepared to face the challenging conditions that modern conflicts present, with particular emphasis on first aid.

Last but not least, it is essential to stress the importance of the legal framework, which must be adapted to reflect the new opportunities and challenges associated with the use of modern technologies in war medicine. The protection of personal and particularly sensitive health data appears to be a priority to ensure that soldiers' health information is processed and shared by the highest standards of security and ethics, both within NATO and the EU.

The paper introduces a groundbreaking concept in military health data transfer that has the potential to transform the way armies address current war medicine challenges. The proposed model combines advanced technologies such as biosensors and artificial intelligence with a robust data system that ensures effective communication and coordination between all levels of the military health service. It demonstrates how continuity of care can be maintained in the face of disruption or complete network failure through off-line and semi-off-line capabilities and autonomous artificial intelligence. This integration has the potential to increase the chances of survival and the effectiveness of treatment for soldiers on the battlefield by enabling the immediate collection and analysis of real-time medical data, bringing significant improvements in the speed and accuracy of medical interventions. Our findings and proposals also provide new insights into the possibilities of information sharing within civilian and military medical systems, particularly in the context of the European Health Data Space. This interconnection provides a unique opportunity to significantly improve data transfer practices, enabling a faster and more effective response to the challenges of war. The proposed model can be seen as a basis for the development of systems that are resilient, adaptable, and capable of operating even in the most severe combat conditions. By using the described proposals and model it is possible to improve the care of the wounded not only on the battlefield but also in the process of their further treatment and rehabilitation. All this, together with the modernization of war medicine and its virtualization, contributes to a deeper understanding of the key role of telemedicine and innovative technologies in war conditions and their impact on saving lives, including improving the quality of care provided not only on the battlefield. This is the only way to ensure that military healthcare can respond effectively to the challenges of current and future warfare, increasing the likelihood of survival and minimizing the loss of life of members of the armed forces.

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Codes of Ethics and their Place in the New Security Environment as an Important Part of Human Resource Management

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Abstract

The research problem was determined whether the new socio-economic and security environment needs a code of ethics. The values of the code of ethics of a military professional were analyzed by students of the University of Defence of the Czech Republic and military professionals from practice in the Czech Republic, Poland and Germany. The research included quantitative and qualitative research. The results show that the existence of a code of ethics is becoming unprecedentedly important in the new security environment and furthermore that it should be specified according to the specific focus of the workplace, type of forces. The hypothesis confirmed that the importance of moral values is increasing in the military education system.

KEY WORDS: *code of ethics; military professional; human resource management.*

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1. Introduction

Ethics is an important part of human resource management for any employer organisation that wants to succeed in the 21st century labour market [1]. Ethics in an employer reveals two levels. Firstly, it is the attitude and behaviour towards people according to the norms of labour law but also decency and responsibility. Larger and multinational employers are aware of this fact and they seek to include in their policies the realization that: the strategic goals of the organization should include the rights and needs of employees, employees have the right to be treated as human beings, employees will be preserved their natural rights and will be treated fairly, honestly and respectfully [2]. Secondly, it is an approach more related to the profession the employee is in. In this second approach, it also takes into account the competencies of the profession especially the soft ones.

By claiming to be a profession, the military claims a special moral justification to carry out acts of extreme violence and destruction. Unlike most professionals, military personnel are allowed to kill, destroy the infrastructure of enemy states, and endanger the lives of military personnel under their command. If this is a profession, then the military deserves greater moral scrutiny through a code of ethics, and military personnel can be expected to meet high moral standards. The status of professional brings with it special moral authority, but it also imposes moral constraints: professionals must guide their actions by the regulatory ideal of their profession and must respect important broad-based moral norms. Professionals' special moral authority to violate ordinary moral norms or to weigh moral values differently within the profession is justified only if the profession genuinely serves an important human need, and only if such special authority is necessary to satisfy that need. Given that the military claims special moral authority of a very serious nature, we certainly want it to be a profession that is governed by high professional standards and professional responsibility. Without such a status, a code of ethics, the Army would be no better than a mercenary army.

2. Current status of the issue under study

Ethics is the basis of original law, but law contains a minimum of ethics. Ethics should be able to answer whether what we do as an individual or a company is good or bad. The answer is ambiguous due to individual and ethnic differences.

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Ethics is a normative science and defines the scope of ethical laws, which are called codes of ethics. Codes of ethics are only a morally binding standard, but they should not conflict with existing legislation. Ethics, according to Sokol [3], can be described as follows: “The science of morality is part of practical philosophy; it asks what is right and wrong and what should and should not be”. Ethics, according to Nytro [4], can be defined as what we can and cannot do, but it helps us to seek and expand at all times what is moral, what is immoral, and that we can act rightly or wrongly. Ethics is closely related to value theory. Since the “good” is considered ethically the highest human value, ethics teaches us to recognize what is good and what is not good. “A person acts morally if he acts consciously and voluntarily in accordance with his duties, otherwise we can speak of immoral conduct [5].” Morality determines socially desirable and undesirable actions and thus directs human behaviour in society. We assume here that humans are rational subjects and that free and rational choice is a necessary condition for moral responsibility. Ethics should be concerned with what is right and wrong, good and bad; it should examine the moral choices people make and the ways in which they seek to justify them. To the pair of morality and morality we add the concept of morality. As with morality, morality concerns conscience. Morality, first of all, depicts the moral sentiment where an individual can take upon himself the general concern in his conscience and translate it into his own convictions. In morality, the difference between actions is only in the dimension of what is morally good (in accordance with the conscience of a particular person) and what is morally bad (against the conscience of that person). Through morality, an opinion or statement related to morality should be communicated and also aims to instruct us [6,7].

Codes of ethics define norms of behavior in the workplace; their existence is evident in larger and multinational companies. Currently, companies are developing core ethical values and will be a key management and motivational tool [8]. Currently, the code of ethics can be one of the essential tools for the implementation of ethical principles into the conditions of the Army of the Czech Republic. The Code of Conduct should set certain desirable boundaries of behaviour. A code of ethics serves to define principles and rules of conduct and is usually based on a defined goal and values in a particular company. The situation arises for the military to determine its own code of ethics, how it will communicate and whether it will review the code periodically, and to what extent it will be binding on military professionals and whether violations will be addressed. Many professional fields have developed codes of ethics that are more or less binding on competent personnel. In some fields, e.g. advocacy, medicine, forensic science, there are codes of ethics with significant legal validity. Some authors place more emphasis on the value dimension than on ethical responsibility. Talking about ethics is not the same as doing ethics. Reaching consensus is not practicing ethics. An ethical solution does not necessarily satisfy the interests of all involved. Any decision a military professional makes related to what he or she does as a leader will have an ethical component because leadership involves the interaction of personalities – the basis and emergence of ethical concern. Many of the decisions to be made will involve a set of common ethical issues, although they will be set in a wide range of professional circumstances. The world's current social and economic development is going through a difficult period. A new quality of interrelationships between countries is taking shape, and value systems are changing in the context of fundamental changes in their social composition and domestic and international orientation. New values are finding their way into life with problems, as their implementation is accompanied by difficulties of both objective and subjective nature. Currently, the process of searching for and at the same time consolidating the values of the code of ethics of the military professional is underway.

The codes of ethics serve as a formalized basis for easier and more verifiable assessment of sudden action also in combat conditions and under conditions of maximum psychological stress. Codes of ethics have an unmistakable, moral educational and preventive significance. The North Atlantic Treaty Organization has developed a code of ethics that includes promoting the highest levels of trust in our integrity and impartiality, loyalty, accountability and professionalism. Therefore, these five basic principles exemplify them and form the basis of this Code, which guides the conduct of all NATO members, whether civilian or military personnel, in all areas of NATO activities and NATO organs [9].

Most countries have developed codes of ethics for military professionals. At present, the Ministry of Defence of the Czech Republic has an officially established code of ethics for the employees of the Ministry of Defence in RMO 6/2013 [10], which follows the Act No. 221/1999 Coll., on professional soldiers [11], Act No. 262/2006 Coll., Labour Code [12] and the Organisational Code of the Ministry of Defence [13]. The values of a military professional are displayed on the platform of the Virtual Recruitment Centre “doarmady.cz”. Those interested in a military profession or Active Reserve become familiar with the Military Ethics, the Military Oath and the Soldier's Code of Ethics, which summarises topics such as responsibility and sense of duty, dedication, courage, loyalty and honour [14, 15]. Therefore, the question arises whether the military profession needs its own code of ethics in the new security environment and also to manage human resources in the organisation. People with high emotional intelligence are able to feel many things, and thanks to this ability they can make the right decisions and take the right actions. They would not need a code of ethics. Other people do not have this talent and such a code could help them. Problem solving in the Army of the Czech Republic through emotional intelligence is limited by centralized command and control.

There are several basic steps or phases that a military professional in the new security environment should go through when making decisions of a moral nature:

- Identify the ethical issues associated with the situation and the decision to be made.
- Consider a range of possible alternatives.
- Consider the possible consequences for military professionals.
- Determine the potential social, material, and combat damage under each alternative.
- Loss of life:

– Avoidable damage/unavoidable damage.
– Residual damage/unavoidable damage.

- Determine the benefits to be gained from each alternative.

In many ways, however, the military profession differs from activities in other professions. In this context, we distinguish between the choice of a permanent profession and the temporary exercise of a profession [16]. Logically, we assume a higher value consciousness and a higher level of professional morality in military professionals [17]. The latter have voluntarily chosen to pursue a military profession on the basis of their awareness of their moral obligations. The current code of ethics of a military professional of the Army of the Czech Republic includes:

- Responsibility and sense of duty “be aware of your duties, show initiative and creative approach to service”.
- Sacrifice: “give everything, give more than you get, realize that the success of the whole is worth more than the success of the individual”.
- Courage: “do not be afraid to make decisions and take on new challenges, have the strength to overcome difficult, dangerous and risky situations”.
- Loyalty: “be loyal to your country and its army and loyal to your superiors, respect your co-workers”.
- Honour: “be direct and principled, always act in accordance with your conscience, your mission binds you”.

3. Data and Methods

The analysis was based on questionnaires. A written questionnaire was sent to 100 respondents of the military studies of the University of Defence, in each 1st to 5th year, that was 20 respondents. From the year group, the questionnaire was sent to every fifth military professional. The typical survey participant was an officer-in-waiting, a student between the ages of 20 and 25. In this paper, we are concerned with defining the code of ethics of the military professional and finding differences between beginning students and students in their final year of study in assessing the values of the military professional. The questionnaire contained closed-ended questions. The return rate of the questionnaire was 100%. In addition, the opinion of military professionals from practice in selected NATO countries on the place of the code of ethics in the activities of the armed forces was surveyed. The return rate of the questionnaires was 100%.

The main research question 1: Is it appropriate to examine the code of ethics of a military professional in the Czech Republic in relation to the new security environment?

The main research question 2: Is the current code of ethics for military professionals in the Czech Republic sufficient?

Hypothesis 1: In the military education system, the importance of moral values tends to increase.

4. Results and Discussion

The result of the research shows that the respondents' evaluation of the moral values of a military professional by the students of the University of Defence from the 1st to the 5th year has an increasing tendency. The same conclusions were reached by Krivanek in 2007 when examining moral values [17]. Up to 86 out of 100 respondents desire their own code of ethics. The results of the survey showed that 65 respondents believe that the Code meets their objective. Only 8 respondents do not reflect it. A positive finding is that military professionals recommend not to adopt only a branch, related ready-made code of ethics, but the Army of the Czech Republic should try to take into account the specifics and specific types of troops. When asked whether a code of ethics is “mandatory” for you, 64 respondents answered “yes”, 9 respondents answered “no”. Respondents were dissatisfied that the values of the Code of Ethics do not reflect military specialization. Up to 86 respondents called for legitimizing the code of ethics. On the other hand, only 8 respondents expressed negative views. The result gives us an answer to the question of whether there is any benefit to legitimizing the code of ethics. The majority of military professionals consider legalization necessary. Respondents state that if a code of ethics is adopted, it is more appropriate in judging the actions of military professionals and themselves in security and military situations, in fact, as some respondents state, it is an anchor of behavior. A code would eliminate the manifestation of excesses in combat situations and remove responsibility for the actions of the individual. Up to 75 respondents said that a code of ethics would lead to greater loyalty in the performance of duties and measurable behaviour. Only 10 responses stated that a code of ethics is only advisory and yet should be respected. The results show that respondents view a code of ethics as something that largely promotes the quality of military professionals, brings units together, and helps fulfill subordination. In only 13 cases did respondents indicate that a possible adopted code of ethics would have shortcomings. These deficiencies can be summarized as follows: the code of ethics does not represent and respect military specialization, does not fully address the relationship to commanders, peers, or the public.

Respondents' attitudes towards codes of ethics are very interesting. Up to 82 respondents were closest to saying that they considered codes of ethics very important. Although a significant number of respondents appreciate that they exist, they do not concern themselves with them as much; 23 respondents indicated this possibility. Respondents who are not very interested in codes of ethics were 8 and 7 respondents also indicated that they are unnecessary. The results show that codes of ethics do have their place, as two thirds of the respondents said that codes have some influence on them. The social responsibility of the military professional is closely related to ethics, even if ethical responsibility is not enacted. However, ethical conduct and trust suffer to a large extent in the current environment because of vested interests.

How does the relationship between competence and ethics manifest itself? When selecting military professionals, competence should be a primary consideration. Competence is defined as the ability of a military professional at any level to behave appropriately to the requirements of the military profession and thus contribute to the desired outcomes of the Army. Professional ethics plays an important role in the competence of a worker but does not make professionals more ethical, yet it develops sensitivity to value and moral issues and promotes clearer thinking that, based on general ethical principles, helps to understand the role and importance of professional positions in contemporary society.

The military profession is understood as a specific concept and appears in connection with a certain group of professions based on long-term theoretical training. Military competences are considered as the ability to successfully perform a military profession. Thus, they form the basic prerequisite for the performance not only of this but also of other military jobs. Competencies are skills that are widely applicable. Military competence constitutes the basic prerequisite for the performance of a military professional. It expresses the knowledge, skills, abilities, and attitudes military professionals should attain. Fig. 1 shows the perceived ethical values of the University of Defence military students towards the military profession. From Fig. 1, it can be seen that 5th year students perceive more ethical values to the military profession than 1st year students.

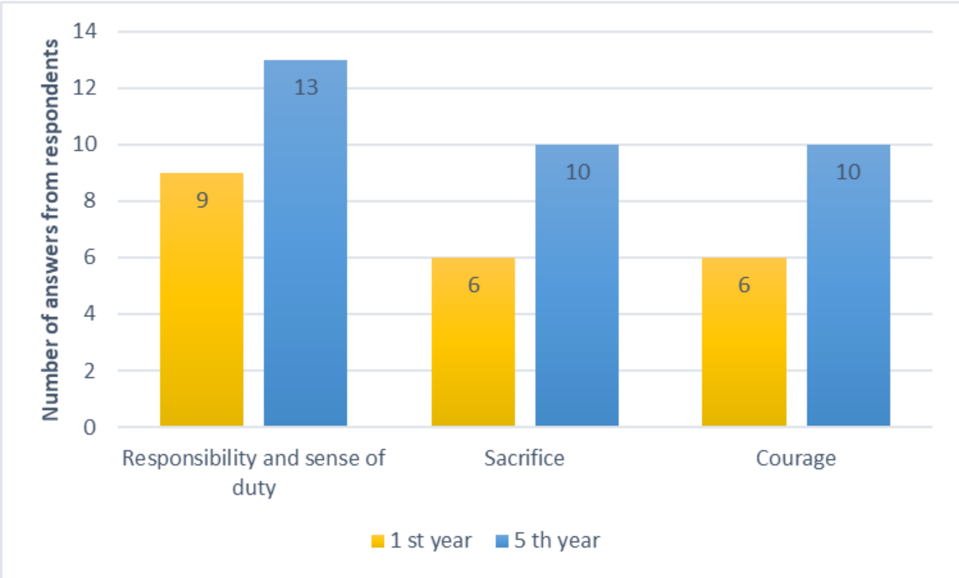

Fig. 1. Perceived ethical values of military students of the University of Defence towards the military profession.

The perception of ethical values of military professionals towards the military profession was also investigated among professionals in practice in the Czech Republic and in selected NATO member countries - see Table 1 [18, 19].

Table 1.

Perceived ethical values of military professionals towards the military profession

Military professionals	**Perceived ethical values**
Czech Republic (Army of the Czech Republic)	Honor, loyalty, responsibility, courage, sacrifice.
Republic of Poland (Polish Army)	Loyalty, courage, sacrifice, pride, integrity, duty, bravery, valor.
Federal Republic of Germany (Bundeswehr)	Honor, loyalty, courage, sacrifice, tenacity, fortitude, diligence, bravery, sincerity.

It is evident from the table and graph that military professionals in practice and students of the University of Defence perceive duty, sacrifice and courage in the same way. Similarly, it can be stated that military professionals of the selected countries perceive courage and sacrifice equally.

5. Conclusions

Answer to main research question 1. Is it appropriate to examine the code of ethics of a military professional in the Czech Republic in relation to the new security environment?

Yes, it can be stated that the existence of a code of ethics is of unprecedented importance in the new security environment. A code of ethics is lacking for military professionals who have to make decisions independently without interaction with the commander and the parent unit.

Answer to main research question 2. Is the current code of ethics for military professionals in the Czech Republic sufficient?

Partially sufficient, codes of ethics should be part of the internal directive or organisational regulations of the Army of the Czech Republic. As many as 86 respondents confirmed that the current code of ethics does not respect the differences and specifics of military specialties. The Code of Ethics should be specified according to the specific specialisation. The influence of the military environment, the system of military education is manifested in the fact that the importance of moral values for a military professional has an increasing tendency.

The behaviour of military professionals is governed by certain rules. Some assignments or guidelines may take the form of recommendations that are traditionally followed. Some need to be signed and affirmed. However, the legitimisation of a code of ethics does not enhance quality. On the contrary, the creation of a code of ethics specific to the troop types would influence the behaviour of military professionals. This fact was also observed in this research. It seems appropriate to maintain the basic points of the code of ethics, which should be fulfilled according to the specification, professional focus and other aspects of the specific type of troops. The importance of moral values is increasing in the military education system. The stated hypothesis H1 was confirmed by the questionnaire investigation. The values listed in the Code of Ethics of the Professional of the Army of the Czech Republic have the highest rating among students of the last year of study. This confirms the importance of military education in the preparation of a military professional. Similarly, military professionals in the practice of the selected NATO countries perceive the same ethical values as courage and sacrifice.

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Risk Analysis of Strategic Commodities in Customs Procedures in Relation to Global Security Threats

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Abstract
The paper analyses the impact of technological innovation on the risks associated with strategic commodities, means of control of the international trade with strategic commoditites and the need to adapt security measures to current needs. The paper analyses the risks of strategic commodities in customs management in the context of global security threats as a key element of the security and protection of national borders and the Union space in the context of national economic interests. The first step is to identify commodities that are key to the functioning of the national economy and the security of the country. The paper identifies and assesses potential threats and risks associated with strategic commodities, analyses the activities and activities of key suppliers of strategic commodities to the Czech Republic and their vulnerabilities. The paper identifies the geographical areas where these commodities are exported and the imbalance of exports due to political changes. The paper substantively identifies vulnerabilities in customs management and puts forward feasible measures to improve the situation in this area and looks at strategic commodities from two an economic and a security perspective. The second step, is interpretation of the results of export of the strategic commodities within third countries. The results shows that changes in the regulatory environment and legislative requirements have a significant impact on trade in strategic commodities. The last step - risk analysis presented in this area includes an assessment of the potential impact of changes in security and trade regulations and policies.

KEY WORDS: *Dual-use items, military material, safety, security, simplified customs procedure, strategic commodities.*

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1. Introduction

The commodities trade is as old as mankind itself. The classification of commodities as strategic has changed over the centuries due to changing needs and the identification of the importance of the commodities in question. Generally speaking, a strategic commodity is any good or technology whose production, possession or trade gives those who possess it an advantage over those who do not possess, produce or trade it. Strategic commodities can be viewed from two perspectives. From an economic point of view, they are valuable items that are easily monetised. From a security perspective, they are means of protecting the population, natural resources and nature itself. From a safety and security point of view, these will be dual-use goods and military material, which are currently more attractive

Security has been, given the location of the Czech Republic, a very important part of state policy. In the past, a considerable amount of financial and human capital has always been spent on it. The primary reason for this was both the location and the changes in the political situation during the 20th century. Due to the presence of the Iron Curtain and stable natural conditions, the focus on industry and mining was an absolutely logical direction to set the orientation of the Republic. The paper analyses the risks of strategic commodities in customs management in relation to global security threats as a key element of security and protection of national borders and the EU area, in the context of national economic interests. The first step is the identification of commodities that are key to the operation of the national economy and the security of the country. The paper includes raw materials, energy resources, foodstuffs, pharmaceuticals and others essential for the functioning of society and industry. As a second step through exports of strategic commodities for 2022 and 2023 to third countries, it analyzes possible threats in the area of safety and security. Last step proposes possible countermeasures - more accurate electronic risk analysis in combination with maximum cooperation of all security forces and state authorities.

The paper identifies and assesses the potential threats and risks associated with strategic commodities that may be important to national security, the economy and public health. The paper analyses the activities and operations of key suppliers of strategic commodities to the Czech Republic and their vulnerabilities also the geographic areas where these commodities are produced and highlights their unreliability and associated vulnerability to supply disruptions, particularly as a result of global negative events such as conflicts, natural disasters or pandemics.

The paper targets security threats and risks. Primarily, terrorism, cyber-attacks, organised crime, but also the proliferation of weapons of mass destruction. The paper substantively identifies the vulnerabilities in customs management and puts forward feasible measures to improve the situation in this area. The paper looks at strategic commodities from two perspectives. From an economic and a security perspective. The aim of the paper is to analyze and evaluate the structure of exports of selected strategic commodities to selected third countries. These countries were chosen as high-risk due to the increase in the volume of exports of dual-use goods from the point of view of safety and security. The documents were obtained through a request to the General directoriate of the customs and are official data that are provided for the processing of the European Commission's annual report. Based on the analysis and evaluation of this data, development trends related to the security situation not only in Europe, but also worldwide can be seen.

2. Basic legal instruments for trade in strategic commodities

While foreign trade in military material is regulated directly by law in the Czech Republic [1], the basic instrument for trade in strategic commodities is the Act implementing the European Community regime for the control of exports of dual-use goods and technology [2]. "The Act directly regulates the Council Regulation and defines the control of exports of dual-use goods, including software and technology (hereinafter referred to as "dual-use goods"), the provision of brokering services related to dual-use goods and transit in compliance with international regimes, international treaties and arrangements, the Czech Republic has undertaken to fulfil, as well as certain rights and obligations of intermediaries of exporters of dual-use goods and other persons involved in the export, rights and obligations of persons transporting dual-use goods from the territory of the Czech Republic to the territory of another EU Member State. These international treaties and arrangements are also binding on all EU Member States. The Act also regulates the control of the provision of technical assistance relating to certain military end-uses, the rights and obligations of persons importing dual-use goods into the Czech Republic." [2].

The main partner for the trader of such goods is primarily the Ministry of Industry and Trade, which implements the measures entrusted by the EU to the Member State. These are mainly licensing procedures for the export and transport of dual-use goods, communicating to the subject whether a licence will be required for the export or brokering of trade. It is also responsible for deciding on transit bans, cooperating with the competent authorities of the Czech Republic (in particular the Customs Administration of the Czech Republic) and cooperating with the competent EU Community authorities. It is also authorised to provide and request information within the scope of the law, in particular from the Customs Administration of the Czech Republic, the Office for Foreign Relations and Information, the Security Information Service, the Ministry of the Interior or the State Office for Nuclear Safety. The authorization procedure shall take place if all the requirements laid down are met. The basic requirement is a certain determination that the goods are dual use and are in the Council Regulation. If it is directly stated or so designated by the Department, the form of the permit must be specified. This is for reasons of public safety or protection of human rights and applies not only to exports but also to the transport of goods.

Another equally important document is the Council Regulation (EC) establishing a Community regime for the control of exports, transfer, brokering and transit of dual-use items [3]. "The subject of this Council Regulation is dual-use goods, which are goods, including software and technology, that can be used for both civilian and military purposes and includes all goods that can be used for both non-explosive purposes and for any form of support for the production of nuclear weapons or other nuclear explosive devices." [3]. This Regulation applies from 2021 and is binding on all EU Member States. The list of goods forming an integral part of this Regulation is regularly updated in the framework of meetings of the International Control Regimes Groups. Due to the breadth of the subject, for the purposes of this article, aggregated data will be used.

3. Customs Management of Trade in Strategic Commodities

3.1. The customs procedure initiation

The customs procedure is initiated by lodging a customs declaration, which may be written or electronic, but the law does not exclude the oral form. For the purposes of the customs procedure in trade, the person lodging the customs declaration, hereinafter referred to as the declarant, shall use the single administrative document. This document is the basic document accompanying the customs procedure and contains all the essential elements for the customs procedure. It includes information on the consignor, the consignee, the end user, the goods in question and their weight, value and customs classification. Additional documents, licenses, delivery and transport notes are also an integral part of the customs procedure. The declarant may be a natural or legal person established in the EU and may act for himself or on his own behalf. The representation may be direct or indirect. Representation is advantageous for the declarant if he is not technically, professionally or financially equipped to deal with customs or government authorities. Customs procedures are therefore a comparison of the declared information in the documents with the actual situation. The customs authorities may proceed to a documentary check or compare the condition physically as part of a random or full inspection of the goods. [4] Very specific in the customs procedure is possibility to become Authorize economic operator (AEO). This is big benefit for companies, but it is very dangerous for safety and security area. It is very simple to be AEO. The registration into this program is very easy and fulfilling the conditions is also simple. Every company who is paying taxes and doing foreign trade can be AEO.

Big advantage of this simple custom procedure is for example easier admittance to customs simplifications or fewer physical and document-based controls [5]. It will be described below.

The customs authority uses the Common Customs Tariff to determine the amount of duty and tariff classification. The Customs Tariff 4 (TARIC application) is the basic instrument of the EU's common customs policy. This tariff is continuously updated, promulgated irregularly in the form of a Council Regulation according to the current needs and interests of the EU. The Customs Tariff is a complex system of combining the numerical designation of goods and their classification into groups. The groups are indicated by Roman numerals and are not part of the nomenclature of goods. Within each class, goods are further subdivided by a four-digit code for the designated chapters and subchapters and a six-digit code for the groups. The resultant code is the final code on the basis of which the goods are accurately identified and the calculation of customs or excise duties and VAT takes place. From a security perspective, TARIC is important for the accurate allocation of the resultant code (HS code), which helps to identify whether the goods are subject to documentary or physical control [6].

3.2. International control regimes

Today, more than ever, the illicit handling of dual-use goods and technologies is being addressed not only by the relevant state authorities, but also by the public. Dual-use goods and technologies can be used in peaceful, i.e. civilian, applications in the energy sector, in engineering, but also in the chemical industry or in the IT sector. However, the danger lies in the ease with which they can be misused for military or terrorist purposes. There is also a risk that their transport to selected targets could be misused or that certain technologies could be made available.

International control regimes set conditions for the legal import, export, transit and other handling of these selected commodities. Technological developments, availability and the speed of logistics operations result in the constant updating of the listing of these commodities and the regulation and monitoring of trade. This applies not only to the producers and transporters of these commodities, but also to trade intermediaries. The cost and time complexity of trade in strategic commodities forces end-users of dual-use goods and technologies to use specialised agencies that provide turnkey delivery of the required goods - i.e. ordering, financing, delivery and training of operators. This trend was particularly evident in Russian companies, which were often linked to Czech producers. According to the Ministry of Foreign Affairs of the Czech Republic (2020), the international control regimes include the following groups and committees:

The Australia Group (AG) - focusing on the control of exports of biological and chemical agents, as well as facilities misused for the production or development of chemical and biological weapons [7].

The Nuclear Suppliers Group (NSG) - provides international control of nuclear items (components intended for civil nuclear purposes) [8].

The Wassenaar Arrangement (WA) is aimed at controlling a wide range of conventional weapons and dual-use goods and technologies, mainly located in the industrial sector. It has the widest scope of action as it covers both military technology and dual-use goods (The Wassenaar Arrangement, 2020) [9].

The Missile Technology Control Regime (MTCR) is a set of export measures implemented to prevent the proliferation of missile technology and related equipment and substances that are necessary for the development and production of missile systems [10].

The Zangger Committee focusing not to export directly or indirectly nuclear material and equipment to non nuclear weapon states unless the export is subject to International Atomic Energy Agency safeguards [11].

4. Method of Investigation

4.1. Quantitative analyses of the data

Quantitative analyses of the data provided by the General Directorate of Customs for the period 2013-2023 shows that for the total period, more than EUR 6 billion worth of military material was directly exported from the Czech Republic to third countries, and more than EUR 7 billion worth of dual use. Thus, these are goods worth more than EUR 13.25 billion, which are a security risk. The volume of data that has been provided for the purpose of writing this article is too extensive in its volume, and can be categorized by HS codes. However, the limitation of this data is due to its generality - at the moment it is not possible to disambiguate specific data and identify a specific recipient from it, as the law does not allow us to do so. However, it is possible to disambiguate the specific item that was exported to the state, which gives us the ability to see what items are most heavily traded and why this is the case. Even so, this data is valuable and provides relevant information on trade trends and possible trends. The table and the following chart compare trade trends for 2022 and 2023 for countries of interest in particular, or alternatively analyses the excesses, which are mainly unexpected changes in the volume of exports of military equipment and dual-use goods. The reason for the refinement of this analysis is mainly due to changes in the security situation in Europe, the Middle East and the Ukrainian conflict. Second method of investigation if synthesis of the hard data combined with changing of the security situation in world. Third method is risk analysis based on the outputs analysis and synthesis.

4.2. Risk Analysis

In the context of customs management, the main task of risk analysis is to prevent illegal export of strategic commodities to risky third countries in the area of safety and security. This is the most important task to which the Czech Republic is committed through Article 46 of the EU Customs Code (Regulation (EU) No 952/2013 of the European Parliament and of the Council). Here, the requirements for the collective implementation of EU risk analysis are set by common risk criteria. A secondary task, which is no less important from a methodological point of view, is the monitoring and gathering of information that leads to innovative solutions to the risk analysis, its refinement, and ultimately reflects trade trends.

Risk analysis can be carried out manually or electronically. Both methods have their advantages and disadvantages. Manual risk analysis in a customs environment is heavily dependent on the availability of skilled customs officers who are able to process a limited amount of data in a set amount of time. However, their results will be based on in-depth research and the extraction of information from open sources and internal registers. This analysis is carried out by customs officers in real time, which means that enormous pressure is placed on them to process quickly and accurately. However, it will not be possible to process large amounts of data given the number of export permits.

In contrast, the electronic analysis will act as a rapid tool, but will rely on perfect interconnection with the electronic customs management tools. Its principle is based primarily on the selection of risky commercial transactions on the basis of predefined risk profiles. These profiles are stored, modified and maintained according to predefined criteria and draw on data stored in the data warehouse. Such data include export and import declarations, licences and permits, offence and criminal proceedings. The e-analysis risk profiles are set by the customs officer according to the customs classification of the goods, as well as the name of the exporter, the destination of the goods, the price, the name of the consignee and, of course, the previous behaviour of the client. By setting up such a profile, it is possible to achieve that out of hundreds of thousands of customs declarations, the e-analysis will evaluate as risky even one tenth of the trade transactions [12].

However, even here there is, of course, a way around the system. If the declarant (exporter) intentionally or unintentionally enters an incorrect customs classification code or hides the name of the consignee, the analysis will obviously not be accurate. If the declarant suspects or knows that Customs is checking the shipments or operations of a foreign consignee, he can always try to export the goods through another Member State where the chances of success may be higher. Reason for improving current rules and conditions and setting new rules and conditions is very simple. Russia was in past one of the biggest business partner in area of strategic commodities. Russia focused for selected electronic equipment and items, which are very important for producing new technologies dedicated for Russian Armed Forces. Now, they have reached a comparative high level of the digitalization of equipment and interconnetivity among own participants [13].

5. Investigation Results

The biggest jump compared to other years in the volume of military equipment was in exports to Ukraine, where military equipment worth more than EUR 1.6 billion was exported in the period 2022 - 2023. Also of interest is the significant increase in exports of military equipment to other countries, which this article will look at in more detail. Historically, the Czech Republic has always cooperated in the arms industry with countries of the former socialist bloc or countries that cooperated with the Soviet Union. These ties remained even after the fall of the Iron Curtain and the Warsaw Pact. It is logical, therefore, that companies involved in the production and sale of military equipment and strategic commodities would have focused on these markets. The situation in Ukraine, the armed conflicts in the Caucasus or Israel, and the re-imposition of sanctions against states, companies or individuals have changed the nature of trade transactions and the availability of the items of greatest interest. Apart from Ukraine, NATO countries - i.e. the US and Turkey - have long been the largest buyers of military material. What has changed a great deal, however, has been the increase in exports to countries where there is very free access to trade and where there has been a noticeable increase in volume, especially after the conflict in Ukraine - Indonesia, Malaysia, Vietnam or the United Arab Emirates. There has also been an increase in trade in military equipment in African countries (Uganda, Ethiopia).

In the dual use category, the situation is similar. Although it does not currently reach the same numbers as the trade in military material, there have been changes in this category as well. Again, trade was based on historical ties. Historically, the largest trading partners in the dual-use category were China and Russia, which mainly took machine tools, chemicals or spent nuclear fuel from the Czech Republic. As a result of international sanctions, trade with China has been reduced and trade with Russia has defacto ceased, but interestingly the volume of trade in these products with Russia's trading partners has increased. A specific role here is played by the increase in trade with Serbia, which in 2023 took goods worth more than 63 million Euros, although in 2021 it took goods worth only 673 thousand Euros. The purpose was to purchase converters that can be used in the military industry, as well as chips and cellular networks [14].

Analysis of the available data clearly shows an increase in the volume of customs declarations in trade in strategic commodities. It can be assumed that the current upward trend in the volume of customs declarations will continue due to technological progress and the security situation in the world. The dynamic development of the world, international trade and the process of information sharing, technological advances, requires the customs authority or other governmental institution to expedite and facilitate trade. Efforts to maximize the speed of customs procedures entail the risk of increased errors in control activities and insufficient communication across institutions. This daunting task can only be managed if there is good cooperation in providing complete, correct data in the required format so that even the data warehouse managers can accurately prepare the data for the selected analysts. Only data prepared in this way and collaboration working in this way can be the basis for effective risk analysis.

Table 1.
Volume of the exports of the military material and dual-use items within 3rd countries in ths. Eur

Country	Military material		Dual-use items		Total Export	
	2022	2023	2022	2023	2022	2023
Albania	0 €	666 €	183 €	73 €	**183 €**	**739 €**
Armenia	1 €	1 538 €	371 €	3 073 €	**372 €**	**4 610 €**
Azerbaijan	51 €	4 106 €	502 €	1 608 €	**553 €**	**5 714 €**
Bangladesh	3 333 €	1 683 €	30 €	6 945 €	**3 363 €**	**8 628 €**
Bosnia and Herzegovina	632 €	3 223 €	247 €	179 €	**879 €**	**3 402 €**
Ethiopia	1 032 €	4 696 €	0 €	0 €	**1 032 €**	**4 696 €**
Georgia	1 694 €	1 013 €	140 €	1 288 €	**1 835 €**	**2 301 €**
Guinea	0 €	0 €	19 €	4 842 €	**19 €**	**4 842 €**
China	7 615 €	2 038 €	136 636 €	92 169 €	**144 250 €**	**94 207 €**
Indonesia	2 641 €	48 956 €	841 €	238 €	**3 481 €**	**49 194 €**
Iran	0 €	0 €	909 €	1 192 €	**909 €**	**1 192 €**
Israel	26 790 €	33 855 €	8 424 €	16 920 €	**35 214 €**	**50 775 €**
Japan	0 €	0 €	57 830 €	53 085 €	**57 830 €**	**53 085 €**
Kazakhstan	15 137 €	12 202 €	4 423 €	5 477 €	**19 560 €**	**17 679 €**
Kosova	1 357 €	1 469 €	67 €	107 €	**1 424 €**	**1 576 €**
Kyrgyzstan	1 €	0 €	1 €	1 699 €	**1 €**	**1 699 €**
Lebanon	1 155 €	2 725 €	0 €	0 €	**1 155 €**	**2 725 €**
Malaysia	1 485 €	2 973 €	212 €	869 €	**1 697 €**	**3 842 €**
Montenegro	5 571 €	14 657 €	98 €	265 €	**5 669 €**	**14 923 €**
Morocco	26 883 €	2 827 €	1 840 €	3 607 €	**28 723 €**	**6 434 €**
Nigeria	21 660 €	5 988 €	1 109 €	3 892 €	**22 769 €**	**9 880 €**
Pakistan	6 108 €	1 022 €	1 783 €	597 €	**7 891 €**	**1 619 €**
Peru	1 036 €	259 €	34 €	89 €	**1 070 €**	**349 €**
Qatar	3 037 €	57 €	2 621 €	2 132 €	**5 659 €**	**2 189 €**
Russia	0 €	0 €	2 854 €	545 €	**2 854 €**	**545 €**
Serbia	1 378 €	2 397 €	38 982 €	63 283 €	**40 360 €**	**65 680 €**
Singapore	0 €	0 €	78 707 €	144 155 €	**78 707 €**	**144 155 €**
South Africa	239 €	2 123 €	7 943 €	8 100 €	**8 182 €**	**10 223 €**
Switzerland	11 047 €	23 138 €	47 003 €	55 900 €	**58 050 €**	**79 038 €**
Tanzania	263 €	154 €	169 €	1 172 €	**432 €**	**1 326 €**
Thailand	4 427 €	3 513 €	869 €	699 €	**5 296 €**	**4 212 €**
Turkey	27 115 €	23 024 €	23 486 €	23 064 €	**50 601 €**	**46 087 €**
Uganda	2 523 €	30 203 €	1 093 €	196 €	**3 616 €**	**30 399 €**
Ukraine	620 623 €	998 319 €	23 973 €	17 399 €	**644 596 €**	**1 015 718 €**
United Arab Emirates	6 755 €	23 348 €	4 964 €	12 857 €	**11 719 €**	**36 205 €**
USA	34 297 €	40 005 €	371 291 €	305 921 €	**405 589 €**	**345 926 €**
Uzbekistan	33 €	35 €	44 €	923 €	**77 €**	**958 €**
Vietnam	29 883 €	84 228 €	1 740 €	125 €	**31 622 €**	**84 353 €**
Zimbabwe	0 €	0 €	329 €	897 €	**329 €**	**897 €**

Source: General Directoriate of the Customs

Equally important is the correct implementation of the acquired knowledge, the use of such knowledge in joint cooperation meetings of state institutions and the setting of uniform rules so that the exporter cannot get a double interpretation of the law, implementing regulations or European Commission regulations. It must not be forgotten, however, that even the best prepared data, the most sophisticated electronic risk analysis cannot replace the human factor, its suspiciousness, its ability to empathise with the perpetrator, its experience of previous cases, its sensitivity and anticipation.The harmonious use of both combinations of the risk analysis, quality training, system updates and more accurate open source work make risk analysis telling and applicable to patrols and field operations. This paper highlights historical facts, analyzing relationships between regions, without which a quality analyst cannot work; it is not the goal to cover every commodity in detail (see Table 1).

6. Discussions and Conclusions

Technological advances and developments are constantly moving forward. There is also enormous pressure on state organisations and security forces involved in inspections, particularly to speed up and automate the inspection process. The European Commission is exerting systematic pressure to electronic documentary checks and minimize the number of physical checks. The customs administrations of the countries of the European Community are creating electronic risk analysis systems, which they are of course trying to improve, but the problem remains that even the best electronic tool cannot replace the work of an experienced customs officer and cannot incorporate current knowledge so that he or she can work fully. These tools can only act as a complementary tool, as a sieve to facilitate the customs officer's control activities by sending the riskiest cases to automatic control. At present, the very imperfection of the above mentioned legal norms is evident; although they are being amended and Member States exchange their experience in control activities and interceptions at regular meetings, the speed of development of technologies and their availability to users of the timely axis makes this work more difficult. The political situation, the risks of terrorist attacks and the arms race and technological developments put pressure on the continuous and above all systematic training of security forces, their synergy in combating illegal activities and the creation of common policies, working places and workshops in which they can share common information. Technological advances are often linked to the affordability of older technologies, but these are just as much of a threat as they were before. Just as dual-use technologies are evolving, particularly in the area of drones, so too is the availability of information that can be obtained from open sources on the Internet. Technologies that were previously not in the dual-use category are being improved and are now represented there. 3D printers are a phenomenon in the same way that drones were in their early days. Any 3D printer that can use metal powder for its operation belongs to the dual-use category, as it can also produce a specialised component that can be used in a military programme. Working with open sources is much easier than it used to be, the amount of information about technologies, AEO subjects or companies involved in development, production and sales is growing every year. It is clear that in the future there will be a greater proportion of trade in these commodities that is conducted outside traditional shops, especially in the area of auction portals where the anonymity of both buyer and seller is guaranteed. The darknet environment should not be underestimated, where the absence of traditional financial means, the anonymity of the environment and the difficulty of monitoring all contribute to illegal trade. The conditions of state institutions, i.e. the method of issuing export permits to third countries and the method of control by customs authorities, as well as sanctions and pressure from lobbyists on the export of goods to third countries, will also depend heavily on the trend of trade in strategic commodities. The trend of accelerating trade and transport will lead to a relaxation of controls and a pro-client approach will facilitate this trade. The demand for computerisation, automation and accessibility of customs systems has presented customs authorities with a new challenge of linking their systems to one that will serve as a place to share messages, alert on risks and threats, archive and build a pan-European data warehouse that will be available 24/7 to registered users. The data in it will be in dedicated mode. This system, which will be primarily built for supervisory departments, should have business intelligence status. That is, it will manage and design surveillance activities based on set objectives and priorities, retrieve detailed information on surveillance subjects, and become an aid to field patrols. From the author's point of view, the basic rule is to set priorities - i.e., focus on controlling and monitoring trade or promoting trade in every possible way in order to promote employment and the receipt of money for the state budget. It is also necessary to remember that the Czech Republic, as an EU member state, is bound by international treaties and is a member of international organisations.

The current problem is primarily pressure on the speed of customs operations. This pressure is being exerted by foreign companies on the customs administration and the EU, which is trying to order customs administrations to behave in a pro-client manner by taking completely nonsensical steps. Customs is a security force whose job should be to support and protect the market, the country and its people. It cannot operate on the principle of trust in an individual or an organisation. This principle has already backfired, for example, in the migration crisis. Therefore, given the investment in electronic customs systems across the EU, a more acceptable option would be to use intelligent systems that can model crisis scenarios with design measures based on previous modus operandi. However, the condition would be full ownership and management of the system by the Customs Administration of the Czech Republic, so that the system could not be abused by the development company and, of course, the system would have to be fully compatible with other similar systems operating in other EU Member States so that simplified information exchange could be carried out.

The next step should be to tighten up the penalties for companies and individuals for breaches of customs regulations so that, although the fine is enforceable, it faithfully replicates the seriousness of the breach and takes into account the economic situation of the offender.

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Analysis of the Possibilities of Developing the Resilience of Employees and Members of the Integrated Rescue System in the Czech Republic as Part of Lifelong Education

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Abstract

As part of their professional activities, members and employees of the individual components of the integrated rescue system are involved in solving a wide range of very mentally and physically demanding tasks related not only to saving human lives, but also property. During long-term activities related to dealing with the consequences of emergencies and crisis situations, they are exposed to extreme physical and psychological strain, the long-term influence of which may affect the psychosomatic state and well-being of the intervening personnel. The article deals with some aspects of traumatization, psychological first aid, post-traumatic care, crisis communication, crisis intervention and aspects that are directly related to it. A research investigation was conducted to determine the current state of implementation of intervention activities, the findings of which are the main part of this scientific communication. The article also includes a comprehensive overview of the use of post-traumatic care, crisis intervention and psychosocial assistance to affected persons by individual components of the integrated rescue system over the last ten years. Through the implementation of an anonymous non-standardized research survey, where the respondents were members and employees of individual components of the integrated rescue system, information regarding the provision of post-traumatic care to affected persons, as well as to the intervening professionals, was collected. Including the identification of motivational factors serving as salutoprotective factors. The findings of the investigation will be incorporated into the undergraduate and continuing education system.

KEY WORDS: *traumatization, rumination, resilience, self-efficacy, posttraumatic growth, education*

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1. Introduction

During the performance of their profession, officers and members of the basic components of the Integrated Rescue System (hereinafter referred to as IRS) get into a number of traumatic situations in which the effects of dealing with emergencies and crisis situations can have a negative impact on their psyche. Particularly in the context of such emergencies and crisis situations, which are associated with higher levels of aggression and aggressiveness; a greater number of injured and dead persons; increased media interest or in which they feel the time pressure factor to issue a quick decision, etc. It is important to note that poor decision making in the exercise of the profession (especially in the case of the basic components of the IRS) can sometimes have fatal consequences. Time pressure combined with a lack of all relevant information can negatively affect the course of care provided. Especially if the assistance is provided by telephone (emergency call). This is a largely uncertain, ambiguous and emotionally volatile environment (e.g. on the part of the caller, the presence of fear, uncertainty, acute stress reactions, etc.), but where quick and accurate decision-making on the part of the intervener is required. Emergency operators are obliged to cooperate with people in crisis, gather essential information about them, determine the type and extent of the emergency, assess the forces and resources needed to cope with the emergency and, last but not least, give instructions to callers [2]. One of the possible sources of work stress, therefore, may be the burden of time-pressured decision-making. The following two phenomena can also be considered as another stressful factor negatively affecting the emotional tuning and the course of providing assistance to the affected persons: unethical behaviour at the scene

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of the emergency (in the sense of photographing or filming videos of human suffering with subsequent posting on social networks) and the bystander effect [3].

From the analysis of professional literature related to the issue under study, it can be stated that the need to implement crisis communication and interaction with the affected person at the scene of the emergency and crisis situation; notification of bad news; coping with the consequences of an acute stress reaction, the need to provide first psychological aid, etc. can also be considered as a stressful factor in the performance of the profession by individual IRS units. In accordance with the legislation in force, every officer or member of the IRS at the scene of an emergency or crisis situation is obliged to provide first psychological aid. Psychological first aid is a set of simple procedures aimed at stabilising the psychological state so that the situation for the affected person does not deteriorate any further, ensuring basic human needs, including the promotion of a sense of security and transfer to further care. Everly and Lating [4] view psychological first aid as an effective way of being a supportive and compassionate presence that aids the process of stabilizing the psychosomatic state of the affected person and easing the course of the acute stress reaction. It also contributes to facilitate the access of intervening professionals to the affected persons.

It depends on the individual's level of resilience and their ability to cope effectively with the traumatic event. Resilience can be understood as the general ability of an individual to develop within the limits of normal or healthy development, despite the presence of traumatic circumstances. The central goal of resilience, according to an analysis of the literature, can be considered to be the active ability of an individual to cope effectively with stress and solve problems [5]. A traumatic event is one that is so powerful or frightening to the individual that he or she is unable to process it on his or her own. A traumatic event provokes deep upset. Psychological trauma is caused by a single extremely stressful experience or a prolonged stressful situation that has the following characteristics: the cause is external, extremely frightening and induces the experience of a threat to life, physical or mental integrity and induces feelings of helplessness [6]. These can be, for example, experiences of threats to one's own life or physical integrity, terrorist attacks, natural disasters, mass disabilities, etc. As a result of the traumatisation, the affected person may develop rumination. This is a condition in which the affected person repeatedly dwells on the traumatic event experienced. As part of this process, he or she may repeatedly reflect on and retrospectively evaluate his or her decisions, the process of dealing with the situation, etc. In general, rumination has a negative (sometimes almost paralysing) effect on the person affected. Rumination can be considered the opposite of resilience [7].

In our opinion, it is important for officers and members of the emergency services to understand that it is possible to find meaning in what has happened to an individual and to take positives from this traumatic event in the future. These can then be used effectively in the process of post-traumatic growth. Posttraumatic growth can be described as a positive psychological change that some individuals experience after experiencing a life crisis or traumatic event. Posttraumatic growth does not deny deep suffering, but rather assumes that adversity can inadvertently cause positive changes in understanding of self, others, and the world around us. [8].

2. Analysis of the Possibility of Using Post-Traumatic Assistance in the Basic Components of the Integrated Rescue System

Considering the above-mentioned facts, a system of providing post-traumatic care, crisis intervention and psychosocial intervention services was created in the individual IRS units. It is the provision of this professional care that is the subject of the present paper. The authors' intention in this section was to describe the existing system and to analyse annual reports over the last 10 years on the provision of this specialist assistance to people affected by the consequences of emergencies and crisis situations.

2.1 Fire Rescue Service of the Czech Republic

Post-traumatic care at the Fire and Rescue Service (FRS) of the Czech Republic (CR) was established based on the recognition that the profession of firefighting is one of the most hazardous professions, with extreme physical and psychological stress. In 2002, the concept of the psychological service of the FRS of the CR was approved. To ensure the provision of post-traumatic intervention care, a Post-Traumatic Care Team was established in each region. The coordinator of the team is a psychologist of the Fire Brigade of the given region and the members of the post-traumatic care team are trained firefighters with personal aptitude and motivation to help others. Post-traumatic care is provided to victims of emergencies and crisis situations, to members and employees of the FRS of the CR, as well as to their families. The Concept of the Psychological Service of the Fire Brigade of the CR for 2017-2025 is currently in force.

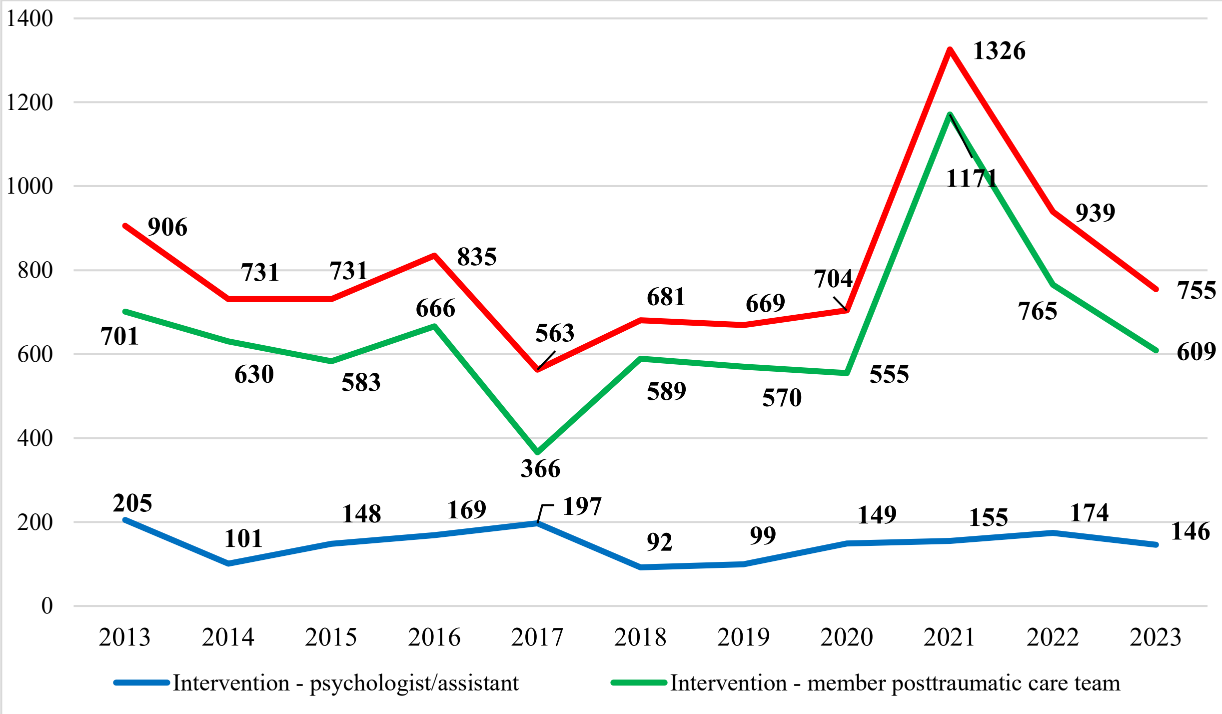

Fig. 1 Number of implemented interventions within post-traumatic intervention care at the FRS of the CR in the period 2013-2023 (source: data provided by the leading psychologist Col. Mgr. M. Wolf Čapková from the psychological workplace of the Ministry of Internal Affairs - General directorate of FRS of the CR)

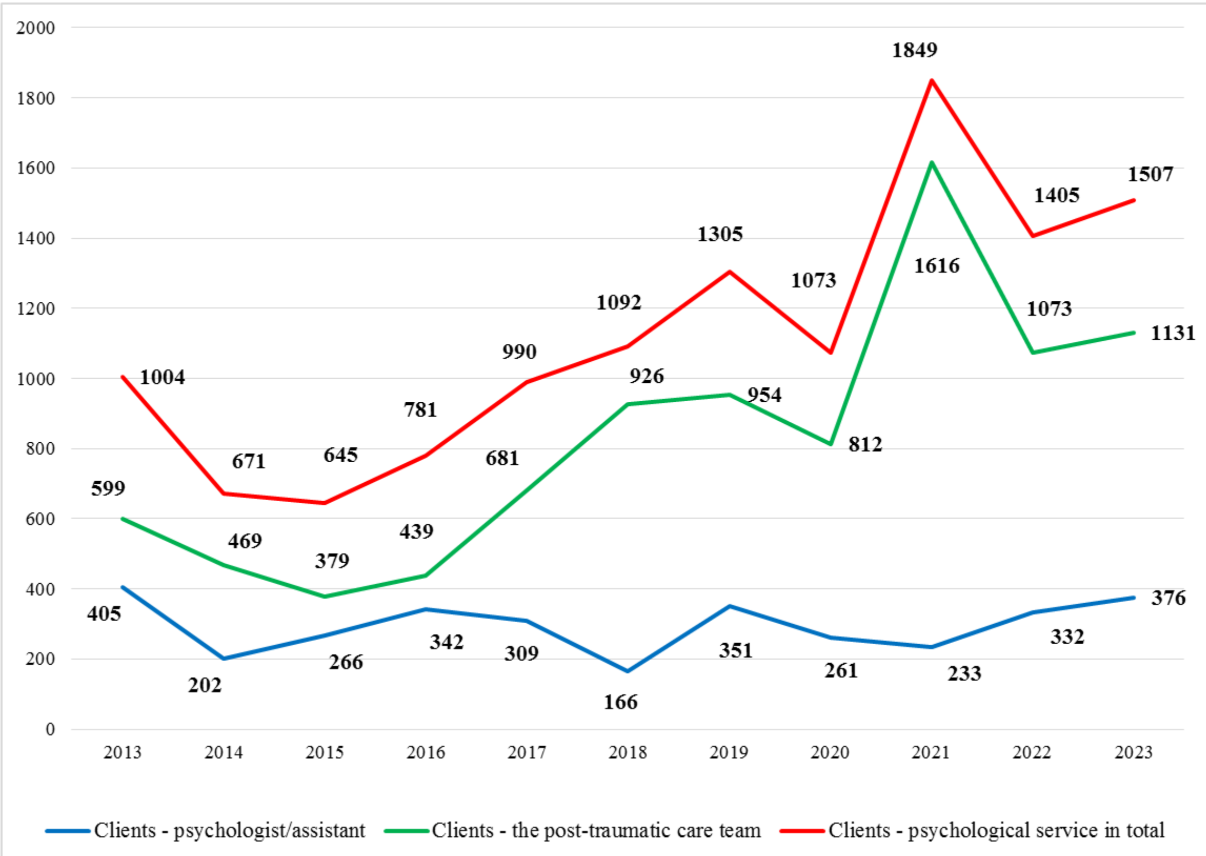

Fig. 2. Graph 2 Number of clients in post-traumatic intervention care at the FRS of the CR in the period 2013-2023 (source: data provided by the leading psychologist Col. Mgr. M. Wolf Čapková from the psychological workplace of the Ministry of Internal Affairs - General directorate of FRS of the CR)

2.2 Emergency Medical Services

Since 2012, the Psychosocial Intervention Service System has been gradually built in the Czech Medical Emergency Service (EMS). This professional assistance is oriented towards supporting health professionals, especially those who have been and are most exposed to acute stressful and post-traumatic influences. These are workers in the ambulance service (pre-hospital emergency care), emergency admissions (hospital care), but also other disciplines. However, the service can be used by healthcare workers regardless of the department where they work.

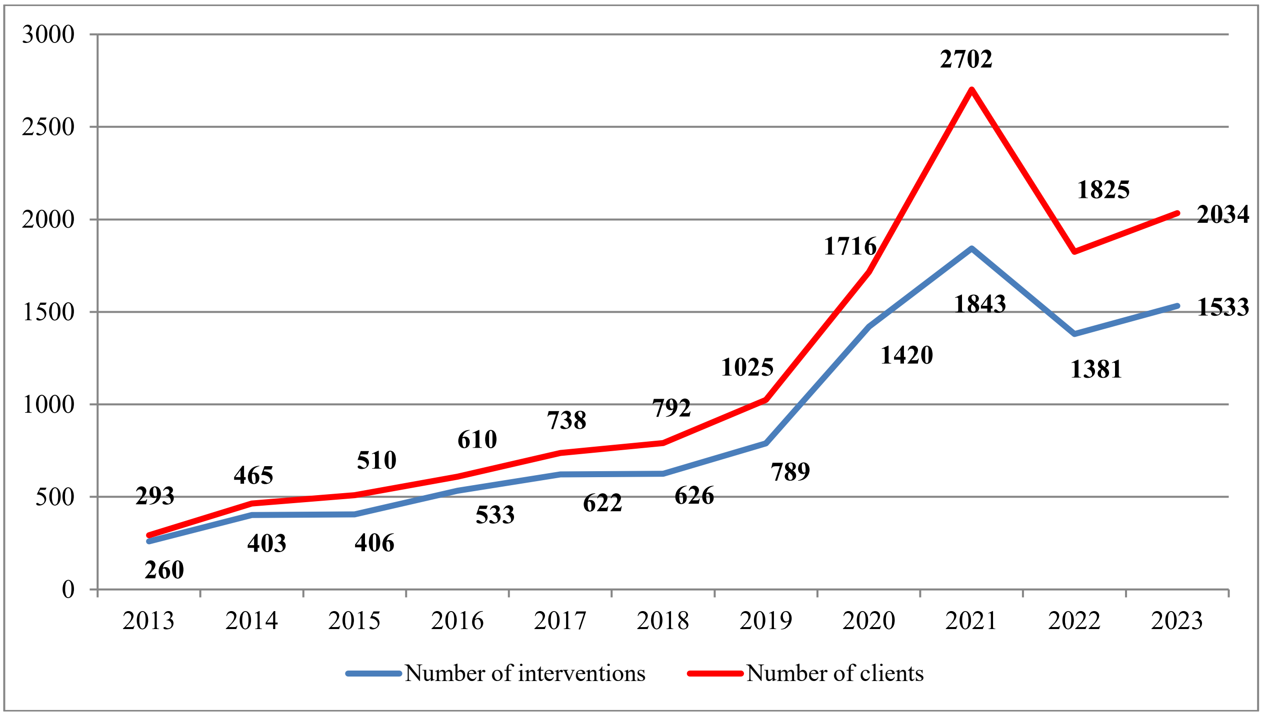

Fig. 3 Overview of PEER support provided within the Psychosocial Intervention Service System in the period 2013 – 2023 (source: data provided by system guarantor PhDr. Lukáš Humpl)

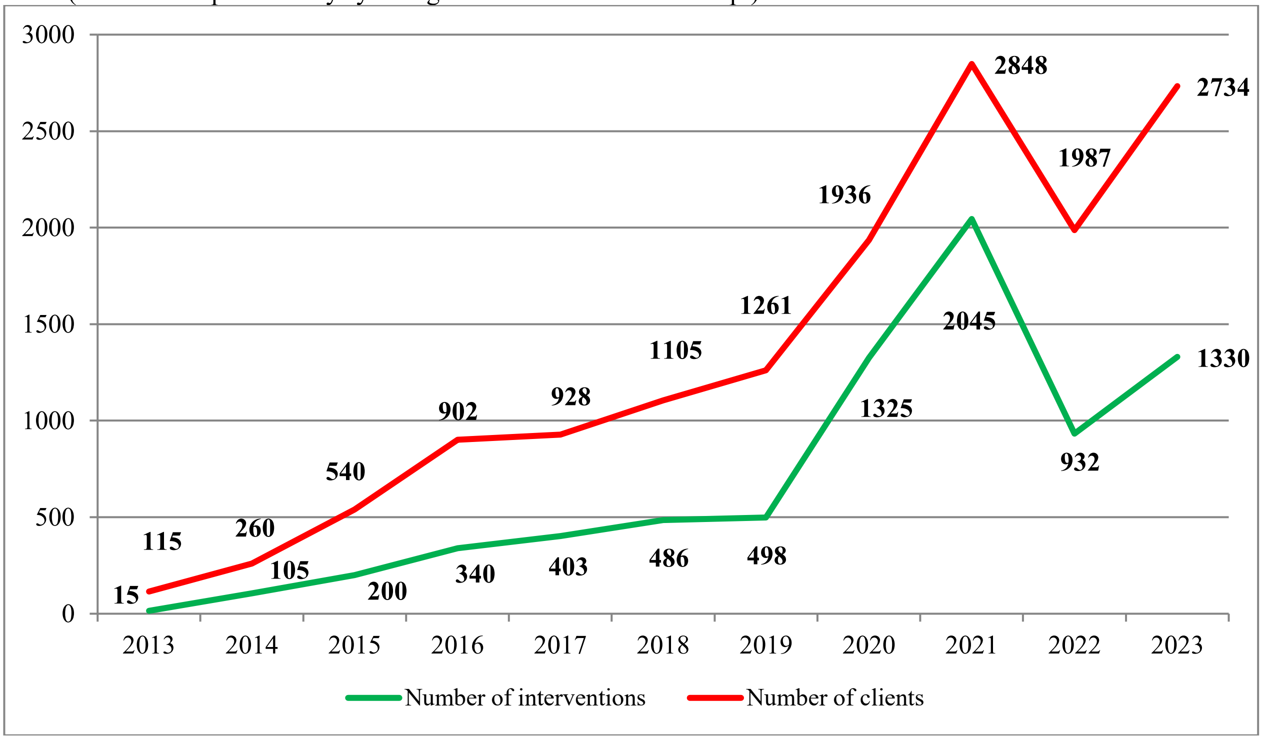

Fig. 4 Graph4 Overview of first psychological help provided to loved ones and survivors within the Psychosocial Intervention Service System in the period 2013 – 2023 (source: data provided by system guarantor PhDr. Lukáš Humpl)

Within the activities of this professional service, attention is paid to the training of its individual members. These are the interveners who provide PEER support to their colleagues within the organisation. As well as health interveners who provide psychosocial intervention care to those affected at the scene of an emergency or crisis. The National Centre for Nursing and Non-Medical Health Professions in Brno is involved in the training of these professionals [7].

2.3. Police of the Czech Republic

Within the Police of the CR there are psychological workplaces where police psychologists are assigned. These psychologists provide a range of activities such as assessing the personality of applicants for admission to the Police of the CR, assessing the suitability of officers for the performance of leadership and other special functions, as well as providing psychological care to police officers and police employees (e.g. The provision of psychological assistance to police officers and police staff in the performance of police activities (e.g. communicationally demanding situations with members of the public, carrying out acts within the framework of preparatory proceedings under the Criminal Procedure Code).

In 2023, police psychologists provided psychological care to a total of 4,910 contacts.4,724 clients received individual care and 186 clients received group care [10]. Since 2010, police psychologists have also provided psychological assistance to victims of crime and emergencies.

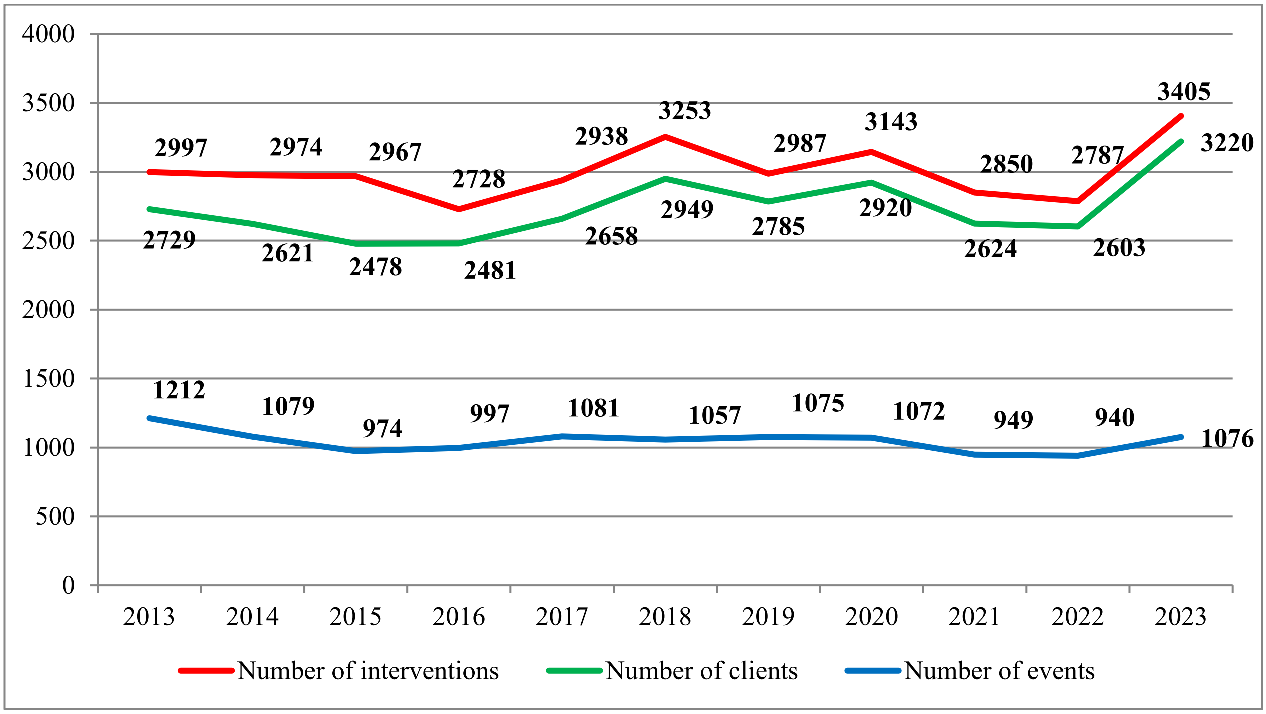

Fig. 5 Overview of crisis intervention provided within the Police of the Czech Republic in the period 2013-2023 [10]

With the issuance of the Police President's Instruction No. 231/2016 on psychological services, a system of collegial support was established to expand the provision of psychological support to police officers and employees to prevent the development of psychological difficulties. This system is often referred to as peer support and the peer is the provider of the peer support. Peer support consists of offering to talk to a colleague, sharing feelings and problems, offering specific help or information, and referring to professional help where appropriate. Peers will often reduce a colleague's fear of receiving professional help by their actions. There are currently 382 peers and 43 trainers/psychologists in the system [10].

Another option for professional help is the anonymous Crisis Helpline (telephone number +420 974 834 688). This is a round-the-clock service that provides expert psychological help and support to members and employees of individual components of the IRS. Professional assistance is also provided to their relatives and loved ones. The staff of this hotline provides continuous post-traumatic care in connection with the performance of service or work tasks, telephone assistance in acute and long-term states of mental distress, psychological support and prevention of harmful and damaging actions directed towards oneself or the environment as a result of difficult psychological situations [9].

The following graph shows the use of the anonymous Crisis Helpline in the period 2013-2023.

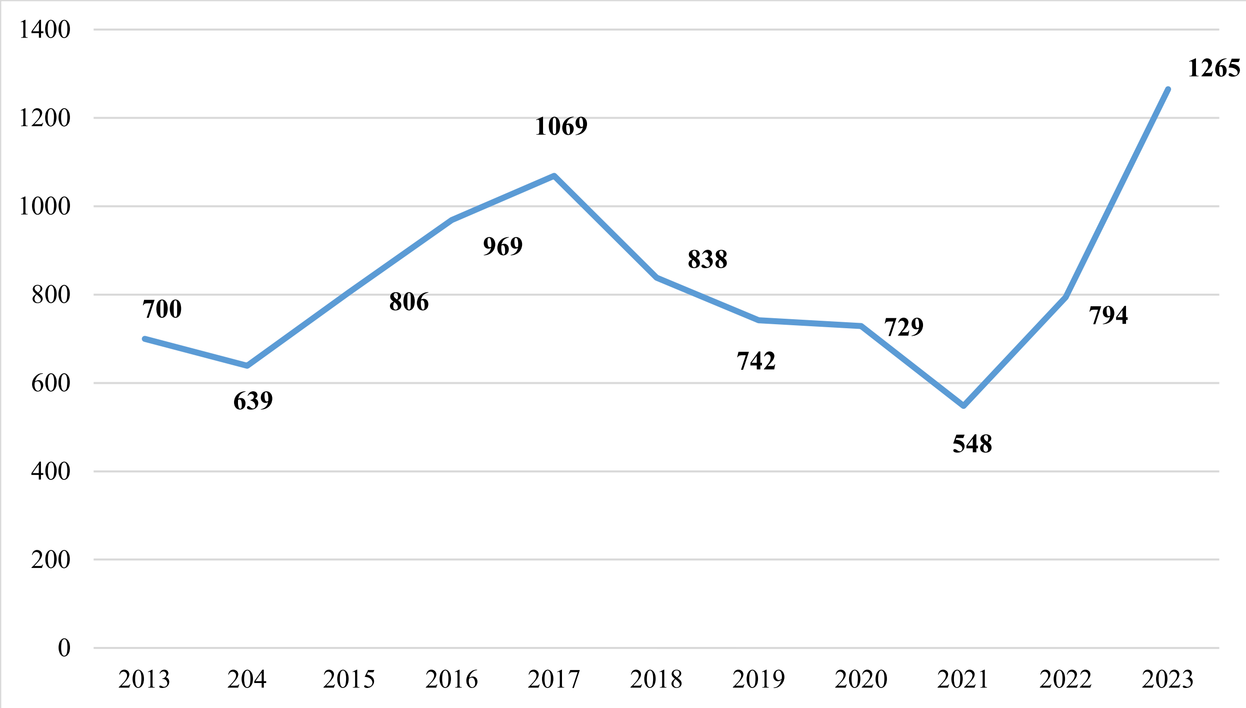

Fig. 6 Number of crisis calls made to the anonymous Crisis Helpline in the period 2013-2023 [10]

In 2023, Crisis Helpline staff received a total of 1,955 contacts. Of these, 1,265 were crisis phone calls. Within crisis calls and emails, clients contacted helpline staff most often with personal problems. Problems with oneself occurred in 46.4% of calls, feelings related to loneliness accounted for 17.3% of calls, and suicidal ideation was the third most common problem at 11.2% of calls [10].

3. Method of investigation

The criteria for the selection of the respondents were the performance of the profession in the basic components of the integrated rescue system and active participation in solving extraordinary events and crisis situations. A total of 819 members and employees of the integrated rescue system filled out an anonymous, non-standardized questionnaire.

For the purpose of finding and analyzing data within the research, a non-standardized questionnaire was used, which, in addition to demographic data, also investigated: the frequency of respondents' encounters with traumatic events; the impact of traumatic events on the psychological state of respondents; motivational factors related to the performance of the respondents' profession; the ability to strengthen resilience; the use of offered post-traumatic care and crisis intervention by respondents and competencies in the field of providing first psychological assistance, etc. The questionnaire included open and closed questions.

A Likert rating scale (measuring respondents' attitudes) was used, with a rating scale of 1 = not important - very important = 5.

For the selected items, the median was calculated, that is, the value that is exactly in the middle of the group of ranked values. Data obtained through some selected questions are evaluated through numerical or percentage values.

4. Investigation results

The research involved 819 employees and members of the basic components of the IRS. Specifically, Police of the Czech Republic: 197 respondents, FRS of the CZ: 305 respondents and EMS: 317 respondents. The analysis of demographic data shows that: the average age of respondents was: 42 years and the average length of employment or service was: 19 years.

Regarding the frequency with which respondents encounter an incident or crisis situation that they rate as traumatic, it was found that more than 47% of respondents encounter such an incident or situation once a month. This was followed by responses of once a week for 11% of respondents and once a year for 23% of respondents. 19% never encountered such an event or situation.

The subjects were also investigated on the extent of the negative impact of factors related to their occupation. For each item, respondents completed a rating on a scale of 1 to 5, where each digit had an ascending value (level of traumatic impact). The median was then calculated.

Table 1 Degree of impact of the traumatic event

Traumatic event	Police of the CR - median	FRS of the CR - median	EMS - median
High level of responsibility	5	4	4
Decision-making under the influence of time constraints	3	3	4
Excessive administration Overload	4	3	3
Overload	4	3	4
Workplace conflicts	3	2	4
Lack of information at the scene of the intervention	3	3	4
Endangering your own health	4	3	3
Injury	4	4	4
Injuring a colleague	3	4	3
Intervention in a person under the influence of an addictive substance	3	2	4
Intervention associated with brachial aggression	4	3	4
Intervention with a person threatening to use a weapon (stabbing, cutting, firearm)	4	4	4
Intervention to demonstrate intent to commit suicide	3	3	3
Response to an emergency with a large number of injured persons	4	3	4
Adult death	3	3	3
Death of a child	4	4	5
Crisis communication with the victim of an emergency or crisis situation	3	3	4
The influence of occupation on personal life	4	3	4
The necessity of involvement in the lifelong learning process	2	1	2

* Scale: 1 = not traumatic – very traumatic = 5

The survey also included a subjective evaluation, where respondents gave a subjective evaluation of the following statement:

- I usually feel in good mental condition.
- I usually feel in good physical condition.
- I have a high level of resilience.
- I use individual coping strategies to cope with traumatic events.
- I am experiencing Post-Traumatic Growth.
- I am prone to depression and anxiety.
- I tend to revisit the traumatic event in my memories.
- I am experiencing symptoms of Post-Traumatic Stress Disorder.
- I am experiencing symptoms of Burnout Syndrome.
- I am provided with sufficient information within my employment regarding Critical Incident Stress Management techniques which can be used to reduce the impact of traumatic events on the psyche of the person affected.
- As part of my employment, I am provided with sufficient information regarding the provision of post-traumatic care.
- I use the post-traumatic care offered to manage traumatic events and situations: psychological help, crisis intervention, post-traumatic intervention care or PEER support.
- I am competent in providing psychological first aid to affected persons.
- At the intervention site, I am frequently encountered providing post-traumatic intervention care, crisis intervention or psychosocial intervention services to affected persons.

- I consider the provision of post-traumatic care to affected persons to be an important part of the overall assistance provided.

The evaluation was again carried out using a Likert scale ranging from 1 - strongly disagree, to strongly agree - 5.

Table 2 Average subjective assessment respondents

Average subjective assessment	**Police of the CR - median**	**FRS of the CR - median**	**EMS - median**
Mental condition	3	4	4
Physical condition	4	4	4
Resilience	4	4	4
Use of individual coping strategies	5	5	5
Post-Traumatic Growth	4	5	4
Tendencies to depression and anxiety	2	1	2
Occurrence of memories of a traumatic event	2	1	3
Incidence of symptoms of Post-traumatic stress disorders	1	1	2
Incidence of symptoms of Burnout Syndrome	3	2	3
Providing information on Critical Incident stress management methods	3	4	4
Providing information on the provision of post-traumatic care	4	4	5
Use of post-trauma care by respondents	1	2	2
Competence in providing first psychological aid to affected persons	3	4	4
Meeting at the intervention site to provide post-traumatic care to affected persons	2	3	4
The importance of providing post-traumatic care to affected persons	4	5	5

* Scale: 1 = strongly disagree - strongly agree = 5

The reasons why respondents do not take advantage of the post-traumatic care offered by their employer were also investigated. The most common reasons for not using the post-traumatic care and crisis intervention offered include: lack of trust in the anonymity of the help provided (38% of respondents) and fear that the use of professional help could be used to their disadvantage (49% of respondents). A large majority, 72% of respondents, said that they had not yet used professional help.

With regard to the possibility of using motivational factors support in the process of undergraduate or lifelong education of these professionals, we were interested in what motivational factors our respondents consider important for the performance of their profession in individual components of the IRS. Respondents assigned scores to each predefined factor using a rating scale. The results are shown in the table below.

Table 3 Factors motivating to perform the profession

Average subjective assessment	**Police of the CR - median**	**FRS of the CR - median**	**EMS - median**
Wanting to help people	3	4	5

Exciting career	4	4	4
Attending emergencies	4	5	4
Saving lives	4	4	5
Giving back to the community	4	5	4
An admired and trusted profession	3	5	5
Wearing a uniform	4	5	5
Employment prospects	4	5	5
Pay rate	4	4	4
Job security	3	4	3
Shift work	2	3	3
Working environment	3	4	4
Recognition/appreciation by superiors	3	3	4

* Scale: 1 = not important – very important = 5

5. Result discussion

In view of the above, we believe it is important to offer intervening professionals professional assistance (psychological help, post-traumatic intervention care, crisis intervention, peer support or psychosocial intervention services). This is in view of the prevalence of risk and traumatic factors that occur in connection with the exercise of their profession. Particularly when dealing with crisis situations and emergencies, including their consequences. Also with regard to the concept of vicarious traumatisation, introduced into the literature by McCann and Pearlman. With the help of their theory, they tried to explain the cause of traumatic symptoms appearing in emergency professionals who did not experience primary traumatization themselves, but by virtue of their profession worked with victims of emergencies and crisis situations. As a consequence of secondary traumatization, these individuals experience long-term changes in cognitive schemas, but also intrusive memories (flashbacks) of traumatic events, which are typical of posttraumatic stress disorder [11]. The analysis of the data shows that the respondents reported the occurrence of memories of a traumatic event (FRS of the CR median 2, Police of the Czech Republic median 1 and EMS median 3). The affected person may also develop Post Traumatic Stress Disorder. The term post-traumatic stress disorder refers to a set of various behavioural and experiential disturbances, including somatic reactions (sleep disturbances, sweating, tremors, nausea, etc.) that arise as a result of an extreme stress experience beyond the normal human experience. The tricky thing about post-traumatic stress disorder is that the varied symptoms may not erupt until a prolonged period of time has elapsed since the crisis [12]. One can agree with the authors Shiromani, Ledoux, Keane that members and employees of the emergency services are a more vulnerable group at risk of developing PTSD. This is because, by the nature of their employment, they encounter more cases that can seriously shake the human psyche [13]. Traumatisation also leads to different reactions to severe stress and maladjustment. Reactions include a tendency to anxiety and depression. As a result, depressive and anxiety disorders can begin to develop. Depressive symptoms can severely limit trauma victims in their daily lives. They often affect functions such as sleep, food intake, self-esteem, and suicidal thoughts may occur. As a result, withdrawal occurs, the affected person feels shame and finds it difficult to confide in another person [14]. During the implementation of the research, it was found that the respondents did not have symptoms of PTSD (FRS of the CR median 1, Police of the Czech Republic median 1 and EMS median 2) and did not have a significant tendency to depression and anxiety (FRS of the CR median 2, Police of the Czech CR median 1 and EMS median 2).

Repetitive and intrusive thoughts can be handled by using Critical Incident Stress Management methods such as: demobilization, defusing and debriefing. Critical Incident Stress Management can be defined as a comprehensive, integrated, multi-component, systematic crisis intervention program. It aims to provide education, support, assessment, and intervention for emergency responders who are frequently exposed to and affected by critical incidents [15]. On the positive side, we consider that responders are provided with information regarding this issue by their employer. We also consider it important to build the resilience of these professionals. As can be seen from the results of our research, subjectively respondents rated their resilience capacity positively (median 4), as well as their Posttraumatic Growth capacity (median 4/5). Our statement collides with the opinion of the authors Lepore, Rovenson, who point out the following forms of resilience to traumatic events: Healing (after the negative impact of the trauma is over, the individual is able to eliminate and completely remove the negative consequences of the experienced event), Resistance (the individual processes the negative impact of the traumatic event in a specific way, in which the impact of the event on the individual's behaviour cannot be observed) or Reconfiguration (as a result of the negative impact of the traumatic event, the personality of the affected individual is altered, either in a positive direction: on the basis of the traumatic event experienced and its subsequent processing, he/she will be prepared to cope successfully with other traumatic events in the future, or in a negative direction, when a temporary or permanent undesirable personality change occurs). Attention needs to be paid to preventing and monitoring symptoms of adverse personality change, which may subsequently take the form of feelings of hopelessness, a sense of threat and alienation [16].

We agree with author Berger's assertion that post-trauma care is not a one-session affair. If a person develops PTSD, it takes a very long time for the affected person's defense mechanisms to be properly reactivated. It is important, if post-traumatic care is already being provided, that the person affected knows that there are options that can help them. That he or she does not have to worry about coping on his or her own, but that it is necessary to seek out a specialist in the field. This care already requires someone who has some experience in providing it, because the affected person needs to be approached with great caution so that his or her symptoms do not get worse [8].

It follows from the above that considerable attention needs to be paid to preventing the development of undesirable negative consequences of the impact of emergencies and crisis situations. In particular, to focus on building psychological resilience and the ability to use coping strategies and individual methods of Critical Incident Stress Management. We also consider it important to develop the competences of intervention professionals in the field of psychological first aid and post-traumatic care. A positive finding was that respondents positively assessed their competencies in providing first psychological aid to affected persons. Similarly, respondents consider the provision of post-traumatic care to affected persons to be very important (FRS if the CR median 5, Police of the CR median 4 and EMS median 5).

Our findings on the most important motivating factors: job prospects, belonging to a community that wears the uniform, and wanting to help people conflict with the results of research by Ross and van Huizen. They investigated students' motivation to pursue a career as a paramedic. They cited the following as the most important motivating factors: wanting to help people, saving lives, an exciting career, belonging to a community that wears the uniform, perspective and job security. The findings suggest that, like other medical students, those studying paramedicine do so for intrinsic motives such as wanting to help people, saving lives and an exciting career" [17].

We are actively involved in the process of undergraduate and lifelong education of members and employees of individual IRS units. Therefore, we were interested in the level of psychological resilience of our respondents (ability to use coping strategies, resilience skills, tendencies to anxiety and depression, occurrence of symptoms of burnout syndrome, etc.). All these findings, including data on motivational factors, will be incorporated into the training content [18].

6. Conclusions

On the basis of the analysis of professional literature dealing with the issue at hand, as well as practical experience, we conclude that the provision of post-traumatic care, crisis intervention and psychosocial assistance at the scene of an emergency or crisis situation to the affected persons, as well as to the interveners, is of considerable importance. It helps to cushion the impact of the negative effects of the experienced event and at the same time has a preventive character. Firstly, it prevents the onset of an acute stress reaction and, if it has already developed, it moderates its course. It also has an indispensable place in preventing the onset of rumination, the development of depression, anxiety, PTSD and other undesirable consequences of unprocessed traumatization. As can be seen from the analysis of the annual reports, the number of interventions provided has been on an upward trend over the last 10 years, and the number of calls to the anonymous Crisis Helpline has also been increasing. On the one hand, intervention professionals are actively offering this professional help to the affected persons and, on the other hand, they are also using it themselves. It is noticeable (and positive) that the stigma attached to the use of this professional help is disappearing.

Since we are actively involved in the process of undergraduate and lifelong education of members and employees of individual units of the IRS, the information obtained through the implementation of research will be incorporated into the content of education. Problems of psychological resilience, resilience, coping strategies, anxiety, depression, burnout syndrome to the content of the course psychology of crisis and psychology of disasters. The information found regarding motivational factors will be used in the subjects of public protection, management and crisis management. We believe that the issues and data will inspire other researchers working on traumatization and the provision of post-traumatic care. But also researchers dealing with the issue of preparation of future professionals in the process of undergraduate education as well as in the context of lifelong learning.

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Specific Activities in the Electromagnetic Spectrum and their Relevance in Future Military Operations

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Abstract

This article examines specific activities in the electromagnetic spectrum that are discussed in the context of electromagnetic operations of which these activities may be a part. The subject of discussion is the impact of the operational environment on ongoing military operations conducted in accordance with the North Atlantic Treaty Organization principles, with emphasis on the importance of the electromagnetic environment. The operational environment is presented in terms of physical and non-physical battlespaces. It formulates and explains what the categories of military forces in terms of their utilization of the electromagnetic spectrum and their dependence on its use are.

KEY WORDS: *battlespace, electromagnetic energy, electromagnetic environment, electromagnetic spectrum, intelligence preparation of the operating environment, joint intelligence preparation of the operating environment, military forces, military operations, operating environment, specific activities in the electromagnetic spectrum.*

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1. Introduction

The 21st century is characterised by considerable dynamism. It manifests itself in all areas of human activity and raises myriad dilemmas facing humanity. These are caused not only by opportunities but also by challenges that can come from virtually anything and anyone. These dilemmas, which also concern security and defence, are then, in the light of the real experience of the wars of recent decades, the source of revisionist attempts to change the art of war. In direct relation to the activities of military forces, it is thus a response to the possibilities and challenges associated with the operating environment (OE) and its changing, multidisciplinary and interdisciplinary nature. However, it is questionable whether these revisionist efforts are desirable at all times and in all circumstances.

The nature of the OE, which the North Atlantic Treaty Organization (NATO) defines as *"a composite of the conditions, circumstances and influences that affect the employment of capabilities and bear on the decisions of the commander"* [1, rec. 874], is constantly influenced by the interaction of countless variables. This does not mean, however, that efforts to analyse, describe, estimate, and predict the OE can be ignored, neglected, or in any way suppressed. Understanding the OE is critical to current and future military operations (MILOPs) and/or campaigns. The analysis and description of the current state of the OE serve as the foundation for both its estimation and prediction. The term "estimation" is used to describe the process of assessing the near-future appearance of the OE. In contrast, the term "prediction" is employed to describe the assessment of the OE's appearance over the medium to long term. The prediction of the OE therefore takes into account mainly trends and megatrends, while the estimation reflects primarily the influence of current factors shaping or having the potential to shape the OE. Indeed, the conduct of operations, which is defined as *"the art of directing, coordinating, controlling and adjusting the actions of forces to achieve specific objectives"* [1, rec. 14799], must not only reflect this OE but also respect the principles of operational art, i.e. *"the employment of forces to achieve strategic and/or operational objectives through the design, organization, integration and conduct of strategies, campaigns, major operations and battles"* [1, rec. 15720].

Although much has been written about operational art, it is not an easy subject to navigate. A multitude of sources of information, including military doctrines, publications, and manuals, some of which are accessible to the general public, frequently address operational art issues without providing detailed interrelationships.

This often results in information gaps where it is challenging to comprehend the interrelationships without further clarification. Paradoxically, when it comes to the OE estimate and MILOPs and/or campaigns, the details seem less difficult to understand than the interrelationships and overall functionality of the mechanism of external and internal interconnectedness. This may be due to the fact that the discussion of the OE focuses on individual phenomena, opportunities and challenges in relative isolation, with the relationship to the various levels of command and control (C2) and the products they produce being addressed horizontally rather than vertically. This is not helped by the occasional tendency to sometimes glorify the activities of military forces at the tactical level and/or downplay the importance of the operational level of C2. In practice, there is a risk of encountering misconceptions that could have serious consequences. These misconceptions include the idea that the OE is solely a matter for operational level C2, and that it need not be addressed at all for tactical level forces. To eliminate or at least reduce these negative consequences, it is necessary to define the missing dependencies and at least modify the unclear ones. Therefore, understanding the interdependencies between the activities of military forces at the operational and tactical levels, including their attitudes toward the OE estimates, is critical to the effective engagement of military forces in MILOPs and campaign.

The OE is inherently complex and continuously changing. It also includes the electromagnetic environment (EME), which is sometimes not given enough attention, although it can even have a fatal impact on MILOPs and campaigns. Since this environment is defined as *"the totality of electromagnetic phenomena existing at a given location"* [1, rec. 18831], its final form is determined by the interaction of electromagnetic (EM) energy at a given place and time. The sources of EM energy that shape the final form of the EME can then be both natural and artificial, with unintentional or intentional emission. Progressive scientific and technological development is contributing to the introduction of new equipment and advanced technologies in all areas of human activity, including the military sector. The military forces are equipped with a wide range of military equipment, such as radio-electronic and electro-optical devices, which are mainly based on the use of EM energy. Military personnel using this equipment within their duties automatically become users of the electromagnetic spectrum (EMS). To some extent, the freedom of action of military personnel is affected by their dependence on the availability of the EMS. If this availability is reduced or eliminated, these military EMS users cannot adequately perform their combat tasks. The situation is further complicated by the fact that even when the EMS is available, military forces can be targeted with EM energy.

It is a fact that in terms of MILOPs, EM energy can be used as a *"potent force multiplier"* [2, p. I-3]. By concentrating military forces in the EMS, EM energy can then be used to deliver non-lethal effects caused by specific EMS activities. These can then be used to affect the audience of the OE. This can be done either separately or as an integral part of electromagnetic operations (EMO). Accordingly, the current question is whether all NATO Allies should begin to consider EMO as a necessary capability for their own forces, and whether such operations must inevitably become a national aspiration. Similarly, how specific EMS activities will be viewed in the implementation of EMO, and whether there should be internal changes that alter their nature as a result of some integration into EMO, need to be answered. These issues should be discussed not only in the context of the OE and the operational level, but also the tactical level of C2. Particular attention must then be paid to the EME and understanding what EM activities are and why it is appropriate to categorize so-called specific EMS activities.

2. Methodology and limitations

The first part of the article deals with MILOPs in the context of operational and tactical levels of C2. The term "MILOPs" should not be understood as a substitute for a campaign, as a campaign is defined as *"set of MILOPs planned and conducted to achieve a strategic objective"* [1, rec. 5536]. Only non-classified information concerning the current NATO approach to the conduct of MILOPs is presented. It is focused on the planning framework, designated areas and selected products of the operational and tactical levels of C2, generated by individual headquarters (HQ) and units in relation to the OE. Reflecting on the OE, it explains and visualises the differences in the selected products in terms of the detail and quantity of information contained in them, clarifying the way in which these products should be disseminated. It also discusses some of the less clearly defined approaches of operational and tactical C2 levels to the OE, placing the formulations in the context of publicly available NATO documents. It is also based on the authors' 2021 research on "*The role of joint intelligence preparation of the operational environment in support of future military operations"* presented at the NATO Science and Technology Organization (STO) conference [3].

The second part of the article partly reflects research results in the field of specific EMS activities, in particular electromagnetic warfare (EW), conducted by one of the authors in the period 2017–2020. It is a doctoral thesis entitled *"The development of EW in the Czech Armed Forces providing combat support in the EME during operations in the near future"* [4]. This thesis was developed using a combination of qualitative and quantitative methodological approaches. The methods used were literature research, field research through individual informal interviews, identification of key issues, causal analysis, risk assessment and brainstorming. This part of the article also generalizes some results of the author's final thesis from the General Staff Course, prepared in 2022, on the topic *"Conduct of EMO from the perspective of the strategic level of C2 of the Czech Armed Forces"* [5]. This result was created by applying a qualitative methodological approach using a systematic literature search, a prognostic method – the futures wheel, brainstorming, questionnaires, interviews with experts and field research using the method of semi-structured interviews.

Selected findings from the above two theses were placed in the context of current and publicly available information on the issue of specific EMS activities of the military forces in the area of MILOPs. Findings on the current opportunities and challenges that the military may face in relation to the issues raised were also taken into account. Although in this article it is not possible due to its sensitivity to discuss all the details of the findings, the presented results are a relevant basis for the subsequent professional debate on the issue of the EMS and the operational art from the perspective of the activities of military forces in the EME. The results of the authors' research are presented in the form of a consolidated text, which is complemented by its own visualization through images accompanied by explanatory text.

3. The operating environment in the context of current military operations

Much has been written about the OE, its changes and the resulting opportunities and challenges. Because *"commanders make decisions based on their understanding of the OE"* [6, p. 3-6], the ability to not only analyse and describe but also estimate the OE is critical to planning, executing, and sustaining current and near-future MILOPs and campaigns. In order to gain as much insight as possible into the above quote, it should be emphasised that the OE is not just a matter for the operational level commander and staff. Therefore, there must be a process to continuously describe, analyse, and validly estimate the nature and changes in the OE. A clear understanding of the OE is essential to assess and estimate the impact of this environment on all military activities and to create the conditions for achieving the desired end states of MILOPs and campaigns.

It is a fact that a comprehensive analysis, description, and estimation of the current and near-future of the OE is carried out at the operational level. In light of the aforementioned considerations, NATO has implemented the term "comprehensive preparation of the operating environment" (CPOE) with the goal of *"comprehensive understanding of the operating environment (CUOE)"* [7, p. 96]. The CUOE represents the primary and continuous process through which the joint task force (JTF) staff oversees the analysis and development of products designed to assist the commander and key staff in understanding the OE. [7, p. 96] It is also stated, that *"the CPOE may also take into account the assessments of non-military and non-governmental organizations, the joint intelligence preparation of the operating environment (JIPOE) and the joint intelligence estimate support."* [8, p. 3-2]. Consequently, commanders and staff, particularly those at the operational level of C2, or those who have undergone extensive training for JTF HQ, must be able to produce and work with both the CPOE and JIPOE. To prepare the CPOE, the staff can use the PMESII (political, military, economic, social, information, and infrastructure) analytical framework to identify relationships and interdependencies relevant to a particular MILOP or campaign [9, p. 55, 145]. When relevant OE facts are identified, they are used at the same level for JIPOE, *"the analytical process used to produce intelligence estimates and other intelligence products in support of the commanders' decision-making and operations planning"* [1, rec. 12313]. JIPOE is also generated product which must be designed to provide the commander and staff with a comprehensive view of the crisis background, root causes and specific dynamics, and to holistically describe the main characteristics of the OE in which MILOPs will be conducted. While JIPOE product is intended primarily for the operational level commander, it is also shared with tactical level C2. Similarly, the CPOE can be shared with the tactical level, but information critical to the MILOPs should be included in JIPOE. Although JIPOE is focused on the conduct of a specific MILOP, as opposed to the broader CPOE, the PMESII analytical framework is also employed. [8, p. 3-2] The above-mentioned facts are visualised in Fig. 1.

Fig. 1 also illustrates a JTF HQ, as an operational level command, generating the CPOE and JIPOE. The CPOE may contain information about the OE related to the entire theatre of operations (TOO), i.e. *"a designated area, which may include one or more joint operations areas"* [1, rec. 25356]. JIPOE is focused on the OE within joint operations area (JOA), which is defined as *"a temporary area within a theatre of operations defined by the Supreme Allied Commander Europe, in which a designated joint force commander plans and executes a specific mission at the operational level"* [1, rec. 6762]. Both of these products support the operations planning process (OPP) at the operational C2 level. Additionally, primarily JIPOE, but alternatively the CPOE is shared with the component commands (CC) to facilitate their military decision-making process (MDMP). At the tactical level, information on the OE related to their area of operations (AOO) is processed at the HQ of CC, divisions (Div), brigades (Bde) or regiments (Regt), with the resulting product being the intelligence preparation of the operating environment (IPOE). As shown in the figure, IPOE of a superior HQ is provided to a subordinate HQ. In the case of battalion, due to the smaller HQ intelligence staff, IPOE is usually no longer processed, and the intelligence preparation of the battlespace (IPB) is generated. The IPB is subsequently used to specify the mission variables, i.e. the information on mission, enemy, troops, terrain - time and civilians (METT-TC). These are used in troop leading procedures (TLP) to properly prepare activities of companies (Coy), platoons (Plt) and squads.

The left part of Fig. 1 shows not only the products generated by each HQ, but also the level of detail and quantity of information contained in each product. It is evident that IPB or IPOE contains more detailed information about the OE, but in terms of quantity it is much less than in JIPOE. This is because tactical level units need more detailed information to conduct *"activities, deployments, and engagements that are planned and executed to achieve the military objectives assigned to tactical formations and units"* [1, rec. 16309] contrary to JTF HQ, which must plan, conduct, and sustain campaigns and major operations *"to accomplish strategic objectives within theatres or areas of operations"* [1, rec. 16311]. By comparing the content of the rectangles of the individual products (CPOE – light red coloured, JIPOE – yellow coloured, IPOE of CC HQ – blue coloured, etc.) to the volume of the rectangle of the OE (grey coloured) and to each other, it is possible to get a proportional idea of the amount of information from the OE that the individual products work with.

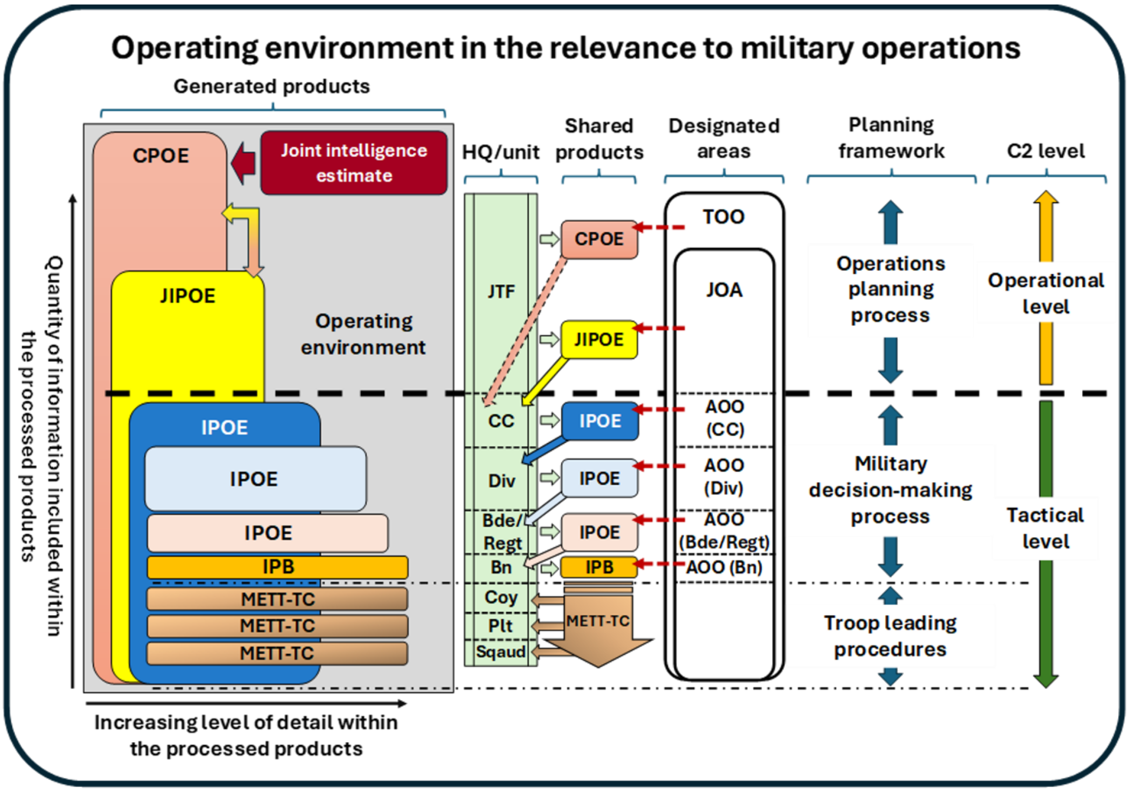

Fig. 1. Visualization of the OE in the relevance to MILOPs [by the authors based on [3], [6], [10]]

4. Perception of the operating environment estimation based on physical and non-physical battlespace

Continuous development of understanding of the OE, in which MILOPs are then carried out, represents an application of a holistic approach to all relevant conditions, circumstances and influences that affect or may affect the environment. As shown in Fig. 2, NATO currently recognises a total of five operational domains (land, air, maritime, space and cyberspace) that reflect MILOPs and the activities of military forces. The capabilities and activities of the forces within the operational domains create physical, virtual, and cognitive effects in the engagement space. The engagement space is synonymous with the "battlespace", defined as *"the portion of the OE where actions and activities are planned and executed"* [1, rec. 15752]. A clear understanding of the interactions producing effects enables commanders to coordinate and organize available capabilities to achieve desired MILOP's and campaign's end states through flexible, agile, and integrated actions while maintaining resilience to disruptive or hostile actions. Beyond all of the above, NATO has explicitly stated that information is not a separate operational domain, which is identical to the approach to the acoustic spectrum and the EMS. However, this statement does not exclude the acoustic spectrum, the EMS or information from the OE assessment, as all these variables directly or indirectly affect all five operational domains. [7, p. 2, 97–98] In addition to the above, contemporary operational art also emphasizes the importance of not overlooking the OE in the context of the audience. *"The audience may consist of publics, stakeholders and actors"* [1, rec. 40605], and is defined as *"an individual, group or entity whose interpretation of events and subsequent behaviour may affect the attainment of the end state"* [1, rec. 40605]. It is therefore very important to include the attitudes and behaviour of all relevant actors, stakeholders, and the public in the estimation of the OE. It is also required to take into account the relevant relationships and interdependencies that have been identified through the PMESII analytical framework, or the meteorological and oceanographic (METOC) aspects of the OE. [10, p. IV-8]

Fig. 2 illustrates the perception of OE estimation when OE is accessed through battlespace, more specifically physical and non-physical battlespaces. The physical is defined as maritime, land, air, and space, while the non-physical as cyberspace, the EME, information, and time. The separate components of a physical or non-physical battlespace can sometimes be called domains or environments, i.e., physical or non-physical domains or environments. The ambiguity of the terminology employed in the context of battlespaces is frequently problematic in practice. This is primarily due to the lack of clarity surrounding the term "domain" in military practice, which has resulted in a lack of consensus on its definition. It is proposed that it is not possible to consider a single physical or non-physical battlespace in isolation, as the actions carried out in one separate component of the battlespace can have implications for others. This is demonstrated by the components of the non-physical battlespace that permeate the entire physical battlespace and have the potential to influence the activities of all audiences in the land, air, maritime, space and cyberspace. [6, p. C-1–C-7] It is evident that the requisite conditions for the planning, implementation, and maintenance of MILOPs cannot be created without prior awareness of the battlespace division. Closely related to this, however, is the ability to manage, synchronize, and orchestrate the activities of military forces, which must be understood not only in the context of the overarching MILOPs, but in the details provided by the conditions, circumstances, and influences of the OE, including the details of the physical and non-physical battlespace.

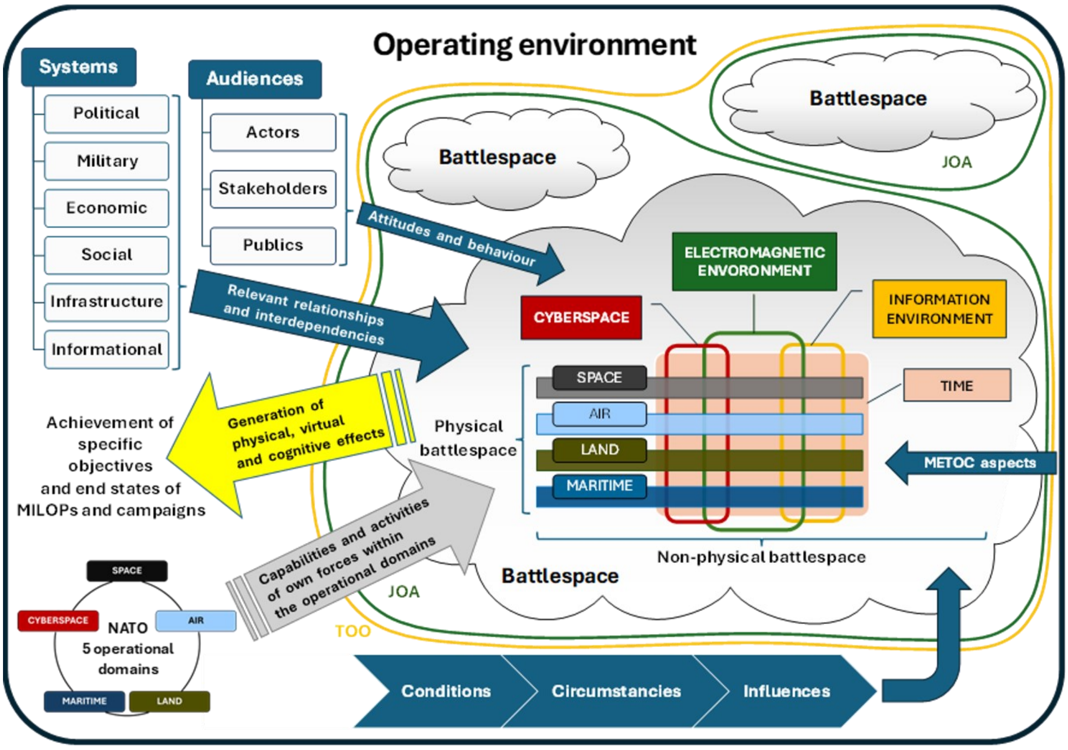

Fig. 2. Perception of the OE estimation [by the authors based on [6, p. C-1–C-7]], [7, p. 79]], [10, p. IV-8]]

Fig. 2 also shows that one TOO can contain multiple JOAs and one JOA can include multiple battlespaces. Although the distribution of the AOO of a given unit, as outlined in Chapter 3, is not shown in relation to the battlespace, it is understood that it will in fact replicate the unit's allocated space. The assigned AOOs, in which military forces will conduct their own combat and other activities, will then dimensionally divide the physical battlespace, while the non-physical battlespace will influence the activities of military forces within them. Although NATO has defined an approach to OE estimation, it is evident that the implementation of these provisions will vary in practice. The manner of OE estimation will depend on several variables, including the product being processed, the time and number of personnel devoted to analysis, description and estimation, the type and conditions of MILOPs planned and executed, desired end state, and so forth.

The issues outlined in this chapter have the potential to affect both the JIPOE and the CPOE. It is therefore critical not to underestimate, but also not to overestimate, any conditions, circumstances or influences that affect or may affect the resulting character of the OE and, ultimately, the conduct MILOPs or campaigns. *"It is assessed that the current way, in which JIPOE is conducted, provides a solid foundation but it needs to be improved to better accomplish requirements and effectively support of future operations. In order to make JIPOE more relevant and adequate for future MILOPs, it will be necessary to consider all of the physical and non-physical domains, including the EME, as a combination of tools for achievement of future operational objectives."* [3, p. 3-6] This quotation is based on extensive research by authors who have dealt with military forces' specific EMS activities and who have often emphasised the importance of EM energy and the impact of the EME on military forces' activities, as this has not always been fully acknowledged and understood. Although the EME is not the only non-physical domain of the battlespace, a brief discussion of this specific issue will be conducted in the following chapter.

5. The electromagnetic environment and specific activities of military forces in the electromagnetic spectrum

The EME and the activities of military forces in the EMS play a very significant role in influencing, affecting and shaping the nature of the OE. The ever-increasing capability of NATO adversaries and competitors to win without fighting relies, among other things, on the use of EM energy [11, p. 8]. One of the key challenges currently facing military strategists and practitioners is how to mitigate the effects of EM energy on their own forces, as well as how to establish superiority in EMS, which is an integral part of the modern approach to operational art. Therefore, experts are discussing many areas related to EM energy, such as management of the EMS and electromagnetic warfare (EW), development of navigation warfare (NAVWAR), adaptation of commercial technologies based on EMS exploitation, disruptive EMS capabilities, specialised intelligence to achieve EMS superiority, overall EMS force readiness, the form and manner of EMO planning and execution, etc. [12]. Despite differing views and approaches to individual solutions, military theorists agree that gaining and maintaining superiority in the EMS and achieving freedom of action within the EMS is vital for MILOPs. This makes highly developed assets and technologies based on EM energy a so-called *"potential game changer"* [13, p. 11–14], [14, p. 1–2].

As shown in Fig. 3, it is inevitable that current and future MILOPs, regardless of whether they are combat or crisis response operations, will require the use of EM energy. Military forces are composed of personnel and assets that, in terms of their utilisation in the EMS and their dependence on its use, can be divided into three interconnected categories [5, p. 26–28]:

- Category 1 – personnel and assets dedicated to the implementation of specific EMS activities: Their primary role is to plan and conduct special activities in the EMS that are directly related to their predetermination. These include EW (including electromagnetic attack (EA) realized through electromagnetic countermeasures (ECM), electromagnetic surveillance (ES) realized through electromagnetic support measures (ESM), and electromagnetic defence (ED) realized through electromagnetic protective measures (EPM)), NAVWAR, signal intelligence (SIGINT), EMS management or intelligence, surveillance, target acquisition, and reconnaissance (ISTAR), suppression of enemy air defences (SEAD), protection against radio-controlled improvised explosive device (RCIED), directed energy weapon (DEW), etc. These personnel and assets are also dependent on the EMS in compliance with Category 2 and Category 3;
- Category 2 – personnel and assets directly dependent on the use of EMS: These use EM energy to provide support of their own predetermination. These include radars, positioning, navigation and timing (PNT) signals, electrooptical (EO) / infrared (IR) sensors, satellite communication (SATCOM), radio frequency (RF) sensors, amplitude modulation (AM) / frequency modulation (FM) / television (TV) broadcast, identification friend or foe (IFF) signals, etc. These personnel and assets are also affected by specific EMS activities as Category 3 but are not predetermined to implement special EMS activities as Category 1;
- Category 3 – personnel and assets affected by specific EMS activities: They do not use EM energy for their activities. Personnel and assets that are neither Category 1 nor Category 2, whether or not they use electronic components. Nevertheless, their activities related to their predetermination can be affected by specific EMS activities.

The above categorised dependency of military forces on EM energy clearly shows that all military personnel and assets can be affected by specific EMS activities. Consequently, EW, at least in the context of ED and EPM, is a matter for all military actors in the battlespace. However, the affectability by specific ESM activities is not only on military actors, but on all audiences of the OE (see Fig. 3). It is therefore clear that those, who are able to achieve freedom of action within the EMS and to gain and maintain superiority in the EMS, will be in a position to create the appropriate conditions for achieving the desired end states of MILOPs and campaigns.

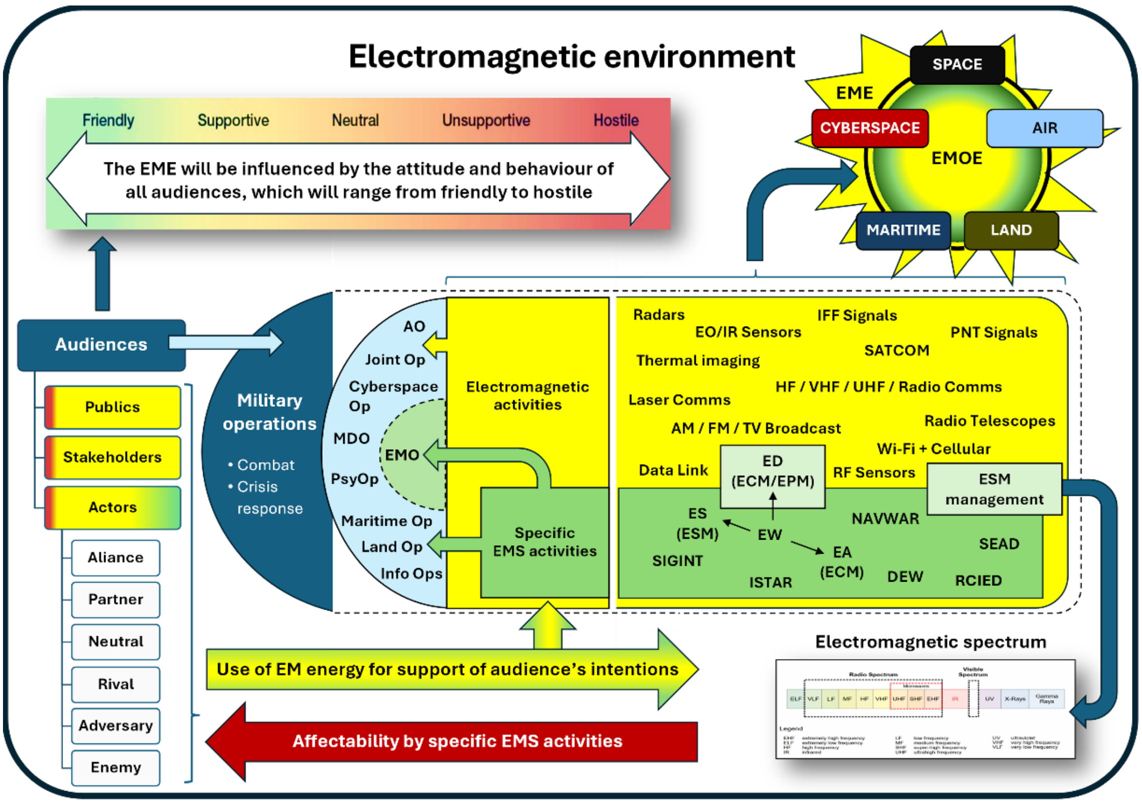

Fig. 3. The EME and EM activities of military forces in the modern battlespace [by the authors]

As visualised in Fig. 3, this article treats the specific EMS activities of military forces as a subset of EM activities. Implementing these specific EMS activities allows one to reinforce one's own EM hardiness in the EMS and to affect any actor in MILOPs. Because the EME permeates all physical and non-physical battlespaces, it is possible via the EMS to affect the audience in any operational domain where that audience is predetermined to act. Separate specific EMS activities can be conducted independently or in a coordinated manner with one another. An alternative approach would be to manage them as an integral part of EMO, which NATO define as "*all operations that shape or exploit the EME or use it for attack or defence including the use of the EME to support operations in all other operating environments"* [1, rec. 26254]. In accordance with NATO, *"EMO include, but are not limited to, EW; SIGINT; ISTAR; NAVWAR and battlespace spectrum management"* [1, rec. 26254].

The NATO approach to EMO, for instance, differs from the United States (US) approach to so-called electromagnetic spectrum operations (EMSO), which are described as *"military actions to exploit, attack, protect, and manage the electromagnetic operational environment"* [15, p. 4]. The electromagnetic operational environment (EMOE) is then *"a composite of the actual and potential EM radiation, conditions, circumstances, and influences that affect the employment of capabilities and the decisions of the commander. It includes the existing background radiation (i.e., EME) as well as the friendly, neutral, adversary, and enemy EM systems able to radiate within the EM area of influence. This includes systems currently radiating or receiving, or those that may radiate, that can potentially affect joint operations."* [2, p. I-2] Another difference is that the US only includes two coordinated efforts in EMSO, namely EW and EMS management [16, p. 8].

Despite the fact that both EMO and EMSO are operations in the EMS, it is clear from the above quotations that there are differences in the understanding of both their content and subsequent implementation leading to the fulfilment of the vision – freedom of action in the EMS. As stated in the US EMS Strategy *"freedom of action in the EMS, at the time, place, and parameters of our choosing, is a required precursor to the successful conduct of operations in all domains. Forces in 2030 and beyond will be ready to fight and win through the deliberate, institutional pursuit of EMS superiority"* [12, p. 2]. Unfortunately, with regard to NATO and EMO, or specific EMS activities, there is no publicly available information on when NATO will be ready to fight and win through the deliberate, institutional pursuit of EMS superiority. The absence of this proclamation gives the false impression to NATO personnel not familiar with EMO issues, specific EMS activities, EMS management, etc., that these areas do not need to be addressed. A lack of attention to the EM activities of military forces, and in particular to specific EMS activities, may lead to an undesirable degradation or even elimination of those capabilities predetermined to conduct deliberate activities within the EMS if any of the functional areas of *"doctrine, organization, training, materiel, leadership development, personnel, facilities, and interoperability (DOTMLPFI)"* [1, rec. 36370] will be underestimated.

Answering the questions posed in Chapter 1 of this article is challenging due to the complex and evolving nature of the OE, changes in operational art, the necessity for military forces to acquire the capability to conduct MDO, and other factors and variables. In order to respond to these questions, it is first necessary to present the authors' findings regarding the specific EMS activities that may or may not be part of EMO. From the authors' perspective, it is important to note that if military forces are able to conduct these specific EMS activities, or any part of them, this does not necessarily mean that they have acquired the capability to conduct EMO. The capacity to conduct EMO is not only about the ability to conduct individual specific EMS activities and to be able to coordinate them. EMO are also about the ability to organize specific EMS activities in which military forces are able to expose adversaries and enemies to dilemmas in any of the currently recognized operational domains and gain and maintain freedom of action in the EMS, by creating synergistic effects on the adversaries and enemies through the EMS. All of these activities must equally be inextricably linked to the ability to manage the entire EMS, not just a select portion of it. Furthermore, the military force itself must be able to refrain from using the portion of the EMS at a given time and space. The research also shows that all NATO allies should start thinking rationally about EMO, i.e.:

- EMO is one of NATO's capabilities under construction. When NATO conducts EMO as part of MILOPs, individual Allies and all their forces and assets participating in those MILOPs will always be part of NATO EMO. This is true whether the forces are using EM energy (i.e. conducting specific EM activities, even separately or as part of EMO – see Category 1, or just conducting EM activities – see Category 2) or not using EM energy at all, but possibly being affected by specific EMS activities of enemies or adversaries – see Category 3);
- The ability to conduct EMO must also be seen through the prism of a capability that our enemies or adversaries may possess. This creates real threats and risks to all forces in the Alliance, to which we must be prepared to respond appropriately in all operational domains, both through ED/EPM and effective management of the overall EMS, as well as through the conduct of our own specific EMS even separately or as part of EMO;
- Not all Allies necessarily have national C2 EMO ambitions, although they must have the capability to participate in NATO EMO when they are conducted. On the other hand, all Allies should at least have the ambition to develop specific EMO activities, including coordination among them.

It follows that if individual NATO nations decide to develop their own C2 capability for own EMO, they must respond by being prepared to integrate all own specific EMS activities into EMO. If there is no such ambition and alliance member states will only participate in NATO EMO, it will be necessary to implement this readiness only with personnel and assets that are assigned for NATO operations. However, the EMO must be understood consistently across the Alliance at all levels of C2, regardless of the ambitions of individual Allies. All functional areas of the DOTMLPFI must be adapted to this and can only be developed in parallel and symbiosis with each other. Similar coherence must exist between all specific EMS activities and other MILOPs in which these specific EMS activities can be implemented separately or as part of an EMO (see Fig. 3).

6. Conclusions

The continuous use of EM energy will be closely linked to the availability of modern technical equipment and the introduction of emerging disruptive technologies, as well as to the rising standard of living, which will further lead to a greater dependence of the population on the EMS. The availability of the EMS will be subject to competition, which will limit its availability not only to the private and public sectors, but also to the military. Therefore, the availability of EMS for security and defence purposes is already the subject of expert discussions. These discussions need to be continued with national EMS regulators, because even in peacetime we see hostile specific EMS activities on a daily basis that affect not only the security and defence of Alliance nations, but also their populations, public services, and so on [17]. The congested and contested nature of the EMS and the resulting implications for shaping the EME will have a lasting impact on the changing nature of the OE at any given place and time.

As previously mentioned, EM energy has the potential to fundamentally affect the fighting power of any military force in any operational domain. Appropriate use of EM energy, achievable through specific EMS activities at particular places and times, can contribute significantly to the end states of MILOPs as well as to the reduction of friendly combat losses. The development of EM activities, especially specific EMS activities, brings with it a number of opportunities but also challenges. In order to use EM energy properly, it is necessary to continuously assess the capability of military forces in relation to the use of the EMS and their affectability through it. However, the assessment must always be realistic, both for friendly forces and for adversaries and enemies. It is crucial to highlight that underestimating the capability to exploit or be affected by EMS activities can have as many negative implications as overestimating them. It is of the utmost importance that military forces are able to conduct their own ED and provide their own EM hardening through EPM to defend against the non-lethal effects of adversaries' and enemies' specific EMS activities. The execution of specific EMS activities must then be built in accordance with operational art by seamlessly integrating them into the real MILOPs.

The nature of the current OE and the trends that will shape it in the near future underscore the need for military forces to have realistic capabilities to gain and maintain superiority in the EMS. To achieve this goal in major operations or campaigns, however, having only the capability to conduct specific EMS activities will not be sufficient in the future. The development of the concept of MDO makes it clear that military capabilities will need to be addressed in all operational domains in the future. This means that the operational level of command will necessarily have to deal with both planning and conducting EMO, despite the fact that the task of conducting specific EMS activities that will be incorporated into EMO will remain at the tactical level. EMO will therefore have to be an indispensable capability for those military forces or political-military formations whose ambition will be to conduct military operations independently, not just to participate in them. However, it should certainly be the ambition of all NATO member states to understand the concept of EMO, as their military forces can participate in NATO EMO. Similarly, the issue of EMO should not go unnoticed for reasons of defence necessity, as the ability to plan and conduct EMO can hypothetically be acquired by adversaries or enemies.

In order to prevent this from happening, it is necessary to realistically appreciate the importance of the EMS to MILOPs, as evidenced by an unambiguous assertion of Air Chief Marshal the Lord Stuart PEACH KG GBE KCB DL, former Chairman of the NATO Military Committee and former UK Chief of Defence Staff, that *"We need to spend time understanding warfare, including EMS activities."* [17]. His clear statement was made at a conference organized by the Association of Old Crows in Oslo, Norway, on 14–15 May 2024. The objective of this conference was to present the most recent findings and to engage in discourse regarding the matters of EW and other activities related to the EMS, including EMS management and EMO, among other topics. The expert community, comprising representatives from the military, industry, and academia, discussed upon the genuine threats that we are already confronted with in the EMS on a daily basis. It is necessary to be able to explain to the population and the political representation that the EME, due to its permeability to other operational domains, is an extremely effective tool not only for the acquisition of situational awareness, but also for the projection of offensive effects against NATO and its member states. This affects not only the military and security forces, but also the public sector and the population. The necessity of readiness to face the action of adversaries by deterrence and defence was particularly emphasized. In this context, it is important to be able to implement the capabilities of our own activities in EMS. Furthermore, the necessity for addressing significant challenges was highlighted, including the necessity for broad-spectrum education of soldiers in the field of electromagnetic activities, encompassing special EMS activities. It was noted that the effects of EME are not limited to a single domain, but rather operate across the entire matrix of domains, including land, air, space, and cyberspace, where MILOPs and campaigns are conducted. The necessity for the specification of real operational tasks and closer interaction between military, industry and academia has also been acknowledged. Dissemination of needs, knowledge and experience is the only possible way to ensure that the EMS is prepared to face current and future threats. It is notable that neither the necessity for the development of interoperability, which is one of the functional areas of DOTMLPFI, as outlined in this article, has been addressed. [17]

It is evident that the EMS, EM activities and specific EMS activities will continue to play a pivotal role in the current and future warfighting environment. While they may not become the last resort solution in the immediate future, their significance in modern warfare must not be overlooked!

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Conceptual Mapping in the System of Population Protection Education

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Abstract

Mind and concept mapping represents a progressive approach to the implementation of education. Within the framework of the general approach to the creation of concept maps, it is possible to start from the fact that concept mapping represents a comprehensive system of working with information based on data and enabling the strengthening of a personal and systematic approach to the implementation of educational activities regarding modern technologies in the educational process. The individual elements of the system, thus concepts, represent sub-problems that in their interrelations and contexts represent the potential of systems thinking in dealing with complex problems in the field of education. Mind and concept mapping achieved high utility especially during the COVID-19 pandemic. At that time, teachers at all educational levels were faced with new challenges that were often not easy to overcome. Applications based on mind mapping and concept mapping became very important aids and tools for distance and subsequently face-to-face teaching. They are very effective in transforming linear text, which is often accompanied by supporting explanatory information and often ballast and relatively unnecessary information, into concepts, ideas and relationships between them. The aim of this article is to present the possibilities of using mind and concept mapping in educational practice focused on the issue of population protection. Furthermore, the main advantages and disadvantages of concept mapping are discussed. Several examples are used to show the possibilities of converting linear text into conceptual maps. The paper discusses some of the software products, tools and applications, with the focus on the application of ContextMinds and its use in teaching and learning in population protection. Several examples are used to show the practical possibilities of its use in practice.

KEY WORDS: *ContextMinds; concept map; mind map; educational strategies; relationship; population protection, teaching system*

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7. Introduction

Concept mapping is a complex system that integrates various types of information, including visual elements, textual descriptions, and logical relationships, to create a comprehensible and coherent overview of a given topic or concept. Experience so far shows that concept mapping can be a very useful tool in the educational process, not only from the perspective of the teacher but also from the perspective of the pupil or student. During the preparation and de facto decision making process for a sub-topic, both the student and the teacher can create a concept map that includes individual concepts representing the issues that will need to be considered in the preparation process. Based on this initial analysis, the decision-making process can then decide whether the difficulty, interest and relevance of the topic are adequate in terms of the abilities of the target audience. Based on an assessment of the initial linear text and against the background of a running decision-making process that helps to interrelate the concepts into a logically organized concept map, it can be decided whether concept mapping will be beneficial for a given learning unit or whether another form of processing or presenting the information would be more appropriate.

For the purpose of this paper, a concept map is understood as a visually processed (hierarchical) structure of concepts (abstract, technical, exemplary) and relationships (horizontal, vertical, intersecting) among them. It serves mainly to structure knowledge of a predominantly declarative character of one person (usually a teacher) and a group (students).

Working with concept and mind maps, or also concept or mind mapping, is a technique used to illustrate the connections among different concepts. This technique was developed in the early 1970s. The basic principle is that concepts and ideas are connected by described links, forming a branching structure [1]. The relationship between concepts is expressed by a link label, for example, “comes from”, “causes”, and so on (Fig. 1).

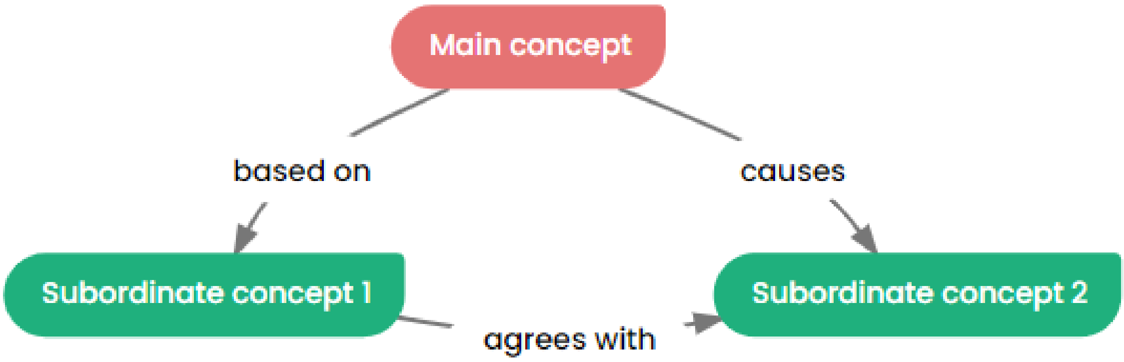

Fig. 1. A model example of the basic approach of creating a concept map (own elaboration).

From the above model case, a concept map is essentially a diagram that represents a summary of the selected topic in such a way that it selects only the most important keywords (concepts). Like a mind map, it can be in colour. The same groups of concepts are highlighted in one colour to distinguish them from other concepts listed in other parts of the map. Remembering the marked words is easier with this approach, especially because it also better engages visual memory [2].

The created graphic structure, thus a conceptual or mind map, can then be interpreted as a linear text or modified by other verbal expressions depending on the abilities and skills of its author, usually the teacher.

8. Brief History and Development of Concept Mapping and Selected Tools

a. History of conceptual mapping

The concept mapping technique was created by American educator Joseph Donald Novak and his development team at Cornell University in the 1970s as a means of facilitating the acquisition of scientific knowledge by students [3]. Since then, they have been gradually applied in American schools and, over time, their popularity has spread abroad. Research has focused on the psychology of children's learning. At that time, it sought to find out how changes in science learning take place in students. He was inspired by Ausubel's theory of meaningful learning, where learning takes place by matching new information to that already stored in memory. The final product of the whole research was the creation of concept or mind maps. These consist of the smallest semantic units (concepts) and the relationships between them. Since then, it has become apparent that concept maps have found use to increase the effectiveness of meaningful learning, even though they have not been worked with very intensively. Concept maps are also used to represent the expertise of individuals and teams in education and related activities. Experience from applied pedagogical practice shows that learning by this method proves to be more effective, especially for pupils (students) with a variety of learning disabilities. In fact, it has been shown that the use of concept maps makes it easier to remember the necessary information and at the same time to gain a deeper understanding of the context [3].

In the Czech Republic (CR), concept maps are only very slowly becoming known to the public. They are often confused with the better-known mind maps, which have been used for many years in education and have also received detailed analyses in several publications [4-7]. In 2005, Professor Tomáš Janík published a handbook focusing on the pedagogical knowledge of teachers [8]. In the section on methods of diagnosing knowledge, the author of the book analyses mind maps together with their use and examples (Fig. 2). However, the mind map does not contain information on the interrelationships among concepts. Reading such a mind map may cause problems not only for its author but also for pupils (students) who would work with it, for example, in the context of independent study or e-learning. This is because they do not contain relationships among concepts, which, when translated into a linear spoken text, can cause problems not only for the teacher but also for the pupil in his/her process of independent learning and consolidation of the material [9,10].

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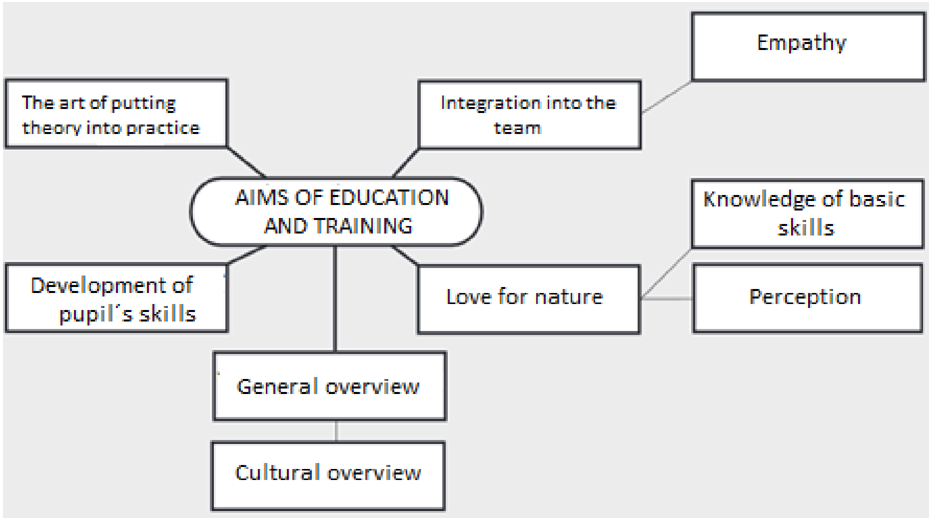

Fig. 2. Sample mind map from the book “Knowledge as a key category of teacher education” (adapted from [8]).

The historical aspects of the conceptual mapping are graphically presented in Fig. 3, which is available for more detailed study on the website https://app.contextminds.com/?m=QJZPd. This figure also summarizes the basic principles of meaningful learning. Fig. 3 is in better resolution also attached as a supplementary file.

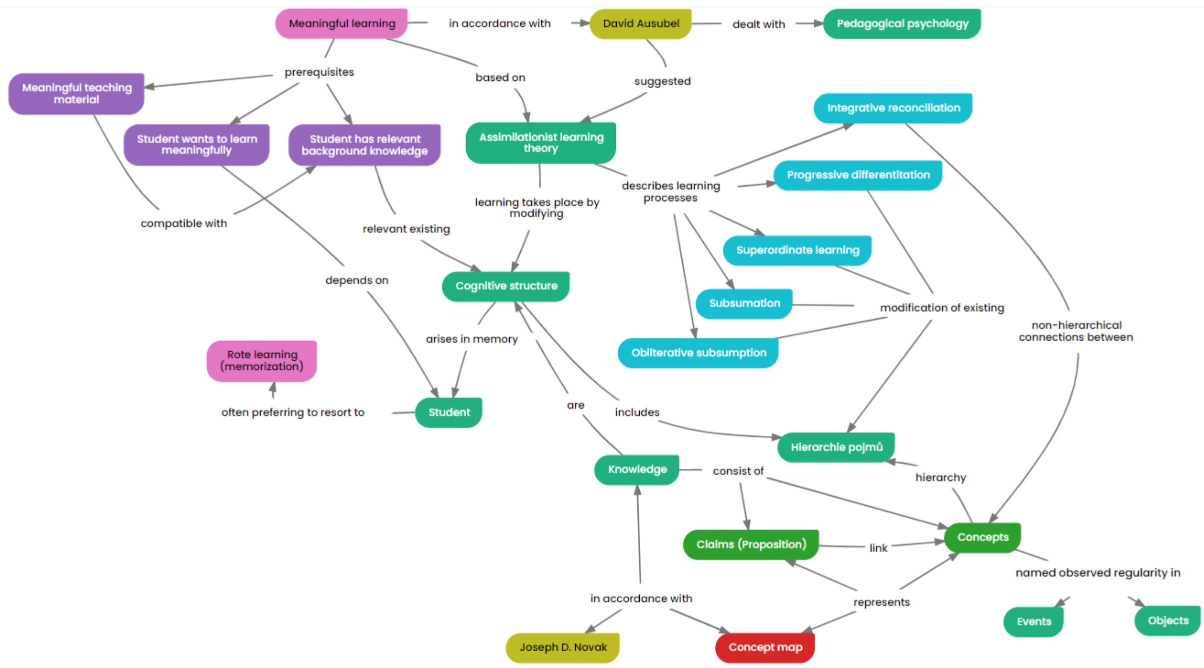

Fig. 3. Basic principles of meaningful learning (own elaboration for detail available https://app.contextminds.com/?m=QJZPd).

The conceptual (mind) map in Fig. 3 shows that the theory of meaningful learning has been implemented in accordance with David Ausubel's approaches. This American psychologist, who contributed significantly to the development of areas related to educational and cognitive psychology and to the development of science education, was also very much involved in the problems of conceptual or mind mapping. The main idea of his theory is that learning takes place by adding new concepts and propositions to those already stored in the interconnected structures of our memory. This facilitates the process of remembering. He posited that meaningful learning works with the basic attributes of well-crafted learning material, a pupil (student) who wants to learn meaningfully, and a pupil (student) who has relevant background knowledge. Thus, meaningful learning using very well-developed materials is interconnected with background knowledge. Meaningful learning is further based on the assimilation theory of learning, which is divided into several basic aspects according to the processes through which learning takes place. On the one hand, learning takes place through the method of so-called cognitive reconciliation, and currently the term integration or inclusion, or inclusive education, is often used in the CR and abroad. At its essence, it is about having to work with a very different quality of target group of pupils (students) and a different approach to the system and the way they work in terms of inclusion amongst "ordinary" pupils (students). In the implementation phase, it is about creating as similar conditions as possible for pupils (students) to be able to learn and attend common schools with some support. It is important to note that these individuals are still seen as a specific group of pupils (students) with different (specific) educational needs.

The map in Fig. 3 further shows that it is also possible to talk about learning processes in terms of progressive differentiation, which aims to promote pupils' activity in the learning process and thus contribute to its effectiveness. Intrinsic differentiation means that within a lesson the content of the material and the methods and forms of work of the teacher are adapted to the different levels of the pupils. When implementing differentiated instruction, the teacher asks himself the question of what goal to set for the pupil (student). The teacher also works with the problem of what learning processes will achieve the set goals with the maximum degree of effectiveness. It also deals with the description of ways of appropriately sequencing learning. In practice, this means that the teacher addresses the problem of the appropriate way to combine new data with already learned information. Thus, it is necessary to think of the problem what is related to what, what is superior and what is inferior in terms of information, what the hierarchy of interrelationships is, and with the idea of how these can then be visually represented. Mind maps and concept maps undoubtedly contribute to this process. It turns out that a mind map full of colours and pictures is one of the very effective forms of conveying learning and recording it in the written notes of the pupils (students). Instructional material prepared in this way is very likely to contribute to the best retention of the information presented. Subsumption in the context of meaningful learning means that the correct concept is assigned to its specific meaning. Furthermore, the notion of obliterative subsumption is worked with. This term in the context of concept mapping means that it is a technique used to illustrate the links between different concepts by invoking (showing) the relationships between them, whereby the concepts are linked together in different relationships and there is a summation of knowledge that a given teacher can present to a target audience. It is based on the idea that meaningfully learned material cannot be recalled in the exact form in which it was originally presented. It is further worked with the fact that no one must be forced to learn the material presented mechanically. The basic purpose is therefore to create cognitive material with a clearly defined structure, which in practice means contributing to the creation of positive knowledge about new interrelationships that arise in the memory of the pupil or student. Another possible goal is that the individual concepts form a fixed place in the pupil's (student's) memory in a given hierarchical structure, and that the concept or concepts and the relationships between them support the meaning of the new statements and represent the given concept map, with the understanding that the named and observed regularity will contribute to the formation of the relationships, events and objects that are represented on the map [11,12].

The opposite of meaningful learning, according to David Ausubel, is rote learning or memorization. It is characterized by the repetition of unrelated concepts. Memorization is thus only short lived and yields only shallow knowledge without the ability to grasp connections. It has already been stated that meaningful learning works with a precisely elaborated structure of the communicated information. Meaningful learning is superior to memorization because it already requires working with information stored in our memory. In most situations, it proves to be more effective, as pupils (students) can recall the material more easily and, above all, to learn to understand it in context. This style of learning can be suitably applied in all types of schools and in staff training. In both cases, the recipients of the information need to have a good understanding of the topic and be able to apply it correctly in practice. The fact that nowadays pupils (students) tend to memorize, or so-called rote learning is widely known and has been rightly criticized for a very long time. It must be admitted that in the context of contemporary education and the education system, this is quite often a required fact. Concept maps, by reducing the amount of text to be transmitted, do not contribute to the memorization process. Rather, it is evident that they contribute to the creation of a positive relationship between pictorial thinking and the formation of explanatory concepts and the relatively flexible possibilities of linking their meanings [13].

It should be noted that the use of, and therefore education in, concept mapping is not new. For example, at the Faculty of Education of Charles University in 2008/2009 a course on Authority in Education was opened, where one of the teaching methods used was conceptual mapping. Thanks to this, it was possible to better structure the selected curriculum. According to the study that was subsequently written up, the participants had problems with the first maps. In addition to incorrect wording, they lacked marking the orientation line. These are important for concept maps because they determine the link between concepts and the direction of reading. However, after further time, there was an improvement. Thus, the study shows that concept maps need to be practiced gradually to achieve good results.

b. Methods – Selected software tools and applications for creating conceptual maps

With the development of computer technology and its mass spread among ordinary users, several application and software tools (software) designed to create conceptual maps have been developed. It is undeniable that the creation of conceptual maps is facilitated by a multitude of modern computer programs, allowing their creation, and sharing among teachers, pupils (students) and other users. Computer programs are usually designed as relatively simple and intuitive tools that allow for quick creation, customization and sharing of the conceptual maps created. For example, the ContextMinds project is the first Czech online program for creating conceptual and mind maps. The program does not need to be downloaded and works completely free of charge. You can try working with it by launching the ContextMinds application after typing its name, for example, into the Google search engine. A very important advantage of ContextMinds is that the concept maps are stored on the server (cloud) and it is not necessary to download them to the user's computer when working with them. This approach allows working directly in the browser environment, which significantly reduces the data flow requirements when communicating with the concept map storage.

There are quite a lot of computer programs and tools available for creating mind and concept maps. It has already been mentioned that their use is relatively intuitive and user friendly. The differences among them are mainly due to the amount of conceptual (idea) maps that can be created without having to pay any money. Even though the cost of using the applications listed below is not high, the user usually looks for applications that are completely free. An overview of selected simple programs designed for processing conceptual (idea) maps is given in [14-16].

9. Results – Identified Advantages and Disadvantages of Concept Mapping

a. Advantages of Concept Mapping

Concept mapping can be considered a very progressive and beneficial approach to mastering the curriculum. They can provide a very effective and quick systematic overview of a given topic. Well-chosen linking words in the link descriptions very appropriately highlight the relationships between concepts. The use of this approach can be beneficial in perceiving what is more and less important in the description of a given problem developed in the form of a concept map, or what falls into the category of a more detailed understanding of the problem being addressed. Artificial intelligence, which is very often processed into the essence of the applications themselves, can also help in the choice of concepts and relationships between them. Their quality can therefore to some extent be automatically assessed by the software tools used and it is up to the map maker to accept or reject them. It turned out to be a very suitable "helper" for the operational creation of ad-hoc concept maps directly during the teaching lesson, which can be used to discover facts and relationships other than those learned so far. From what has already been stated, it follows that concept mapping is very well applicable in methods and forms of teaching that involve a higher form of cooperation between teacher and pupils (students) or pupils (students) than in those methods and forms that are conducted in the form of monotonous interpretation using a linear text. Concept maps are also very effective in involving pupils (students) actively in the process of completing a pre-prepared map, or in a map where the links between the main and subordinate concepts have been deliberately hidden. In these practices, visual memory is engaged and contributes more effectively to consolidation and retention of the material.

Another very important aspect of the use of concept maps is that they can be a very good basis for starting and conducting discussions. In educational establishments and institutions, concept maps can be of practical use in developing (for example, in brainstorming), defending, and sharing proposals for educational programs, curricula and documents of a similar nature. We believe that clear and structured planning information, which integrates elements of the actual long term and short-term implementation, is better presented in the form of interrelated ideas (concepts) than in the form of a linear and often long text. We further argue that, based on critical thinking, the subsequent correction of conceptual maps and incorporation of ideas in the course of collective work becomes a more efficient and easier way of proofreading text documents. In a reasonable way, though very similar in principle, concept mapping can be used to prepare a balance sheet for the preparation and actual organization of a particular course. In this case, it is up to the skills of the teacher to determine the level of detail in which he or she develops the concept maps, what information is referenced, and how the lesson is ultimately taught. However, it is important to point out here that the concept map is also a background material for the pupils (students) and that less is not always more and vice versa. Their main purpose, besides preparing the teacher for a specific subject (lesson), is also to help encourage students in the direction of thinking creatively about the topic, in context and with the possibility of developing prior knowledge within the new topic [17].

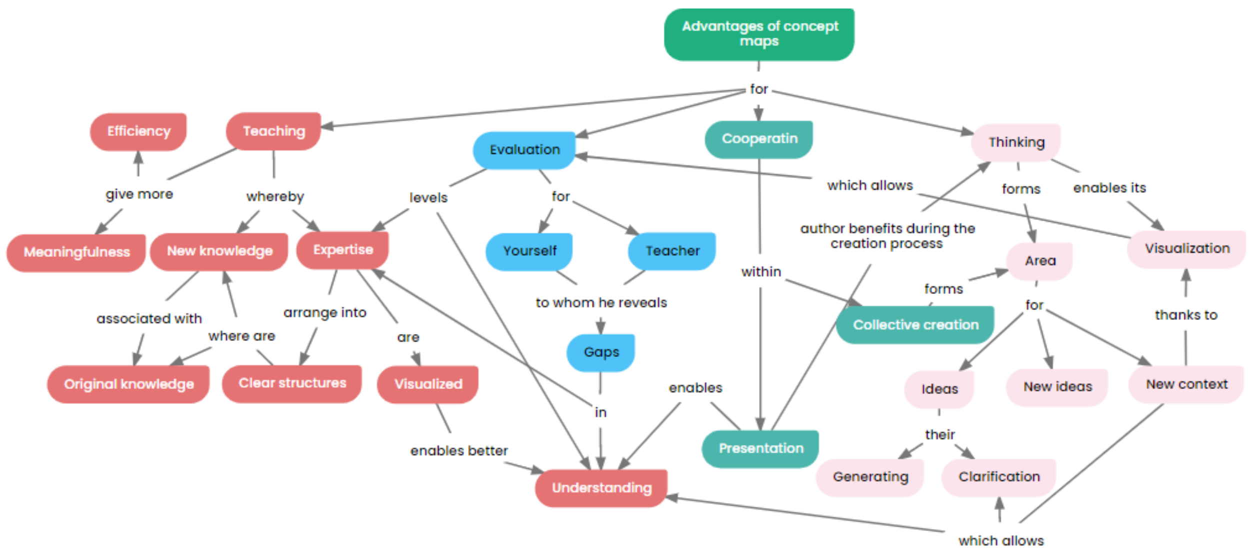

Fig. 4. Advantages of concept maps (own elaboration for detail available https://app.contextminds.com/?m=6EnyN).

Experience also shows that concept mapping helps pupils (students) with ADHD, who usually find it difficult to present unstructured ideas in the form of linear text. In this case, the principle that less is more in terms of the effectiveness of the educational process very often applies [18-21]. In this case, the diagram and structure of the material should be more in line with the situation where it also corresponds to the way the material is written [22,23]. The text presented in this chapter can be converted from linear form to the form of Fig. 4. This figure is available for more detailed study at the website https://app.contextminds.com/?m=6EnyN. This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

b. Disadvantages of Concept Mapping

Conceptual mapping is not exclusively associated with benefits. When working with applications and software, it is necessary to consider that a significant majority of them are in a language other than the teacher's mother tongue and are usually bound by licensing agreements. It follows from the principle and nature of concept maps that they are usually used for declarative knowledge. However, this deficiency can be partially overcome through a sequential or cyclic concept map. Concept maps are not universally applicable. However, even this disadvantage is only relative. It is easy to copy the concept map and adapt it for the purpose of a specific lesson with significant help of pupils (students). The fact that concept maps do not benefit learners who have not mastered prior knowledge perfectly can be considered as a relatively major disadvantage. Furthermore, they are very difficult to use for pupils (students) who do not prefer visual learning or for pupils (students) who prefer linear text and for whom structured, and partly creative thinking is problematic. Since some languages (typically Czech) are quite complex languages in terms of their grammar, it should be noted that concept maps do not support declension and conjugation for these types of languages. The text presented in this section can be converted from linear form to the form of Fig. 5. This figure is available for more detailed study at the website https://app.contextminds.com/?m=wvLx8 [17].

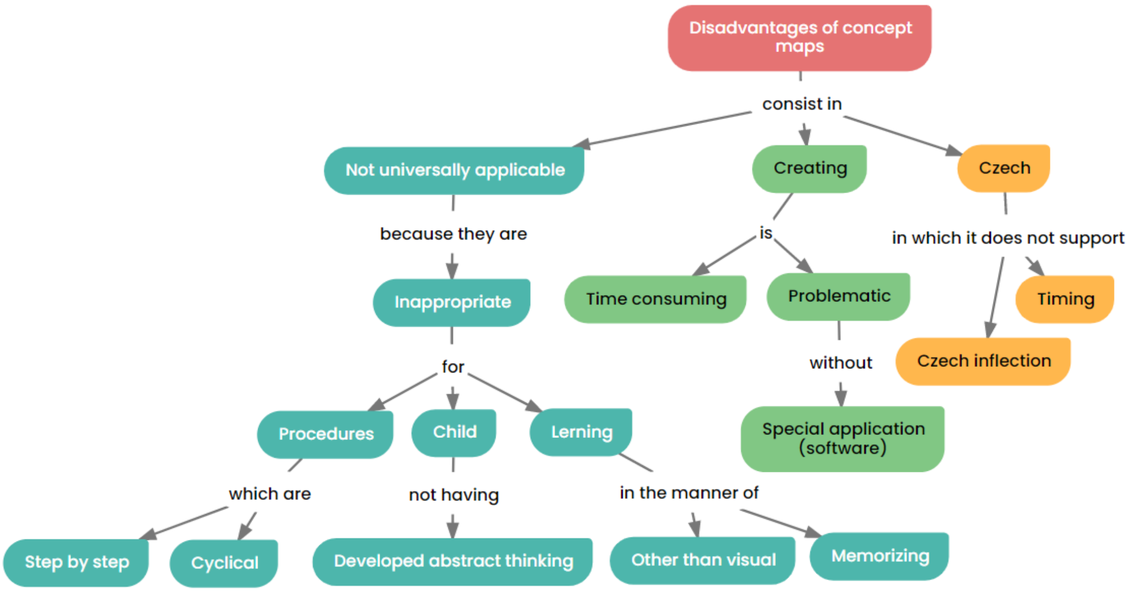

Fig. 5. Disadvantages of concept maps and concept mapping (own elaboration for detail available https://app.contextminds.com/?m=wvLx8).

10. Applications – Use of Conceptual Mapping in Population Protection

The branch of population protection integrates a wide range of knowledge based on a considerable amount of theoretical and practical knowledge. Achieving a level of knowledge in this field that can then be applied meaningfully in practice requires mastering, understanding, and interconnecting a considerable amount of information. We will mention at random that this information is based on knowledge of the rules of nature (chemistry, biology, radiation chemistry and others), earth sciences (geography, topography, hydrology, etc.), as well as knowledge of the laws and decrees in force within the integrated rescue system and many others. To achieve the highest level of effectiveness, it is necessary to prepare appropriate materials for so called meaningful learning. It turns out that a suitable solution for making learning more meaningful is to integrate concept maps directly into teaching. In contrast to mind maps, concept maps make it possible to represent all the important relationships between concepts in a single diagram. Thus, well-designed concept maps make it easier for pupils (students) to understand how concepts are related and to relate them to their prior knowledge [4].

To achieve high efficiency of meaningful learning, it is necessary to adapt the learning material to the level of the learners' (students') initial knowledge. It is therefore necessary to prepare differently designed concept maps for primary school students than for students of subject oriented universities. For this reason, it is necessary to keep in mind the pupils' (students') prior knowledge of the material being discussed and to select the ap-propriate topic accordingly, together with the materials used to create the concept map.

Another important assumption is because the pupil (student) wants to learn in a meaningful way and is sufficiently motivated for this form of knowledge acquisition. The teacher can influence this part mainly by explaining the new material and by managing the motivation of the pupils (students) to be interested in learning more about the topic. Consequently, it is also important how the level of knowledge achieved is tested and verified. If the teacher chooses a test method based on simple short answers only, he/she is leading the pupils (students) towards mere memorization. It is therefore important that the teacher tries to create questions during the test that lead the pupils (students) to think more deeply about the topic.

a. Example of using concept mapping

In terms of using the principles of meaningful learning and applying them to concept mapping, we present the following example. Act 239/2000 Coll. states that the protection of the population means the performance of civil protection tasks pursuant to Article 61 of the Additional Protocol to the Geneva Conventions of 12 August 1949 relative to the Protection of Victims of International Armed Conflicts, in particular in the field of warning, evacuation, shelter and emergency survival of the population and other measures to ensure the protection of their life, health and property. This relatively inexpressive definition, written in the form of a linear text, can be translated in a simplified form, for example for primary and secondary schools, into the form of the concept map shown in Fig. 6. A more complex form, which would meet the requirements of subject specific university students, could be as shown in Fig. 7 and Fig. 8. Fig. 8 is in better resolution also attached as a supplementary file.

Even in these cases, the maps can be studied in more detail on the websites https://app.contextminds.com/?m=may8Y, https://app.contextminds.com/?m=a2xEN and finally https://app.contextminds.com/?m=z6XN0 [14].

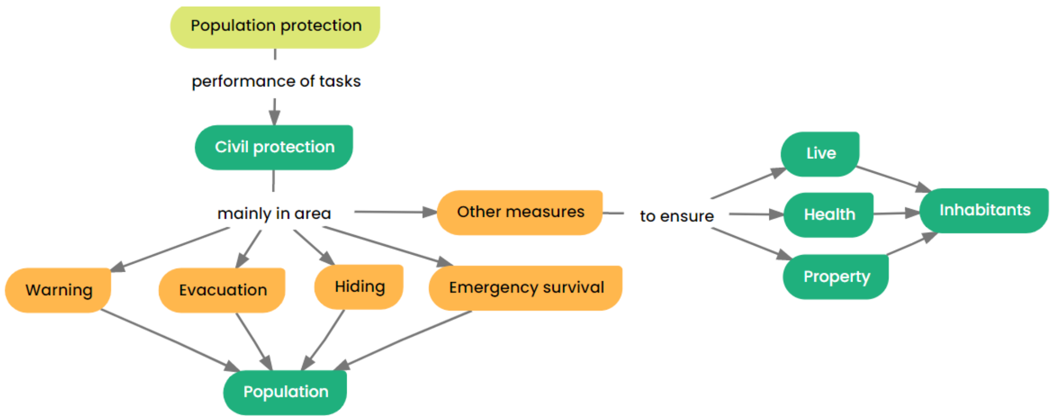

Fig. 6. Public protection for primary school pupils without information containing details of Article 61 of the Additional Protocol (own elaboration for detail available https://app.contextminds.com/?m=may8Y).

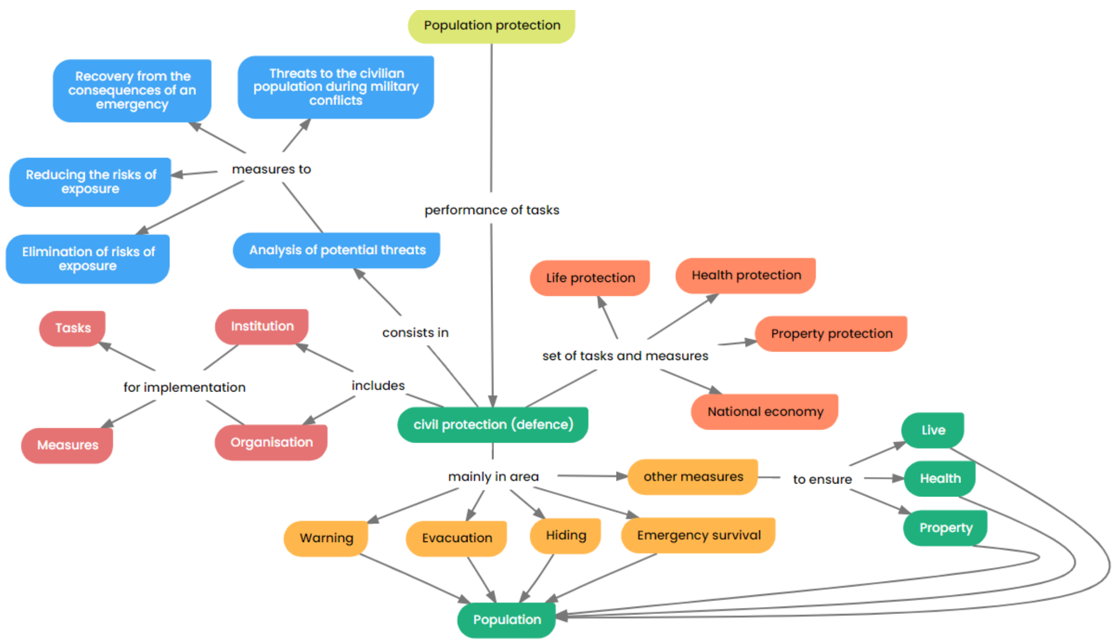

Fig. 7. Protection of the population for students of specialized universities without information containing details of Article 61 of the Additional Protocol (own elaboration for detail available https://app.contextminds.com/?m=a2xEN).

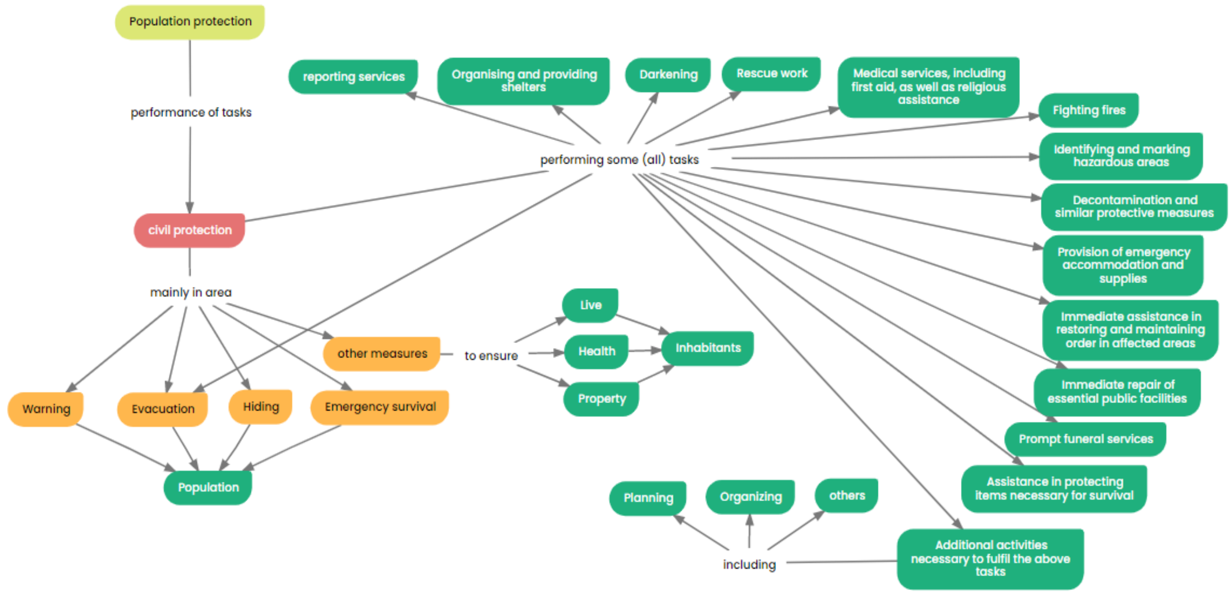

Fig. 8. Protection of the public for students of specialized universities with information containing details of Article 61 of the Additional Protocol (own elaboration for detail available https://app.contextminds.com/?m=z6XN0).

Conclusion

Concept mapping is currently a relatively progressive approach to managing large amounts of information. It allows teachers and pupils (students) to work with information by converting long linear text into structured concept maps. Although there are a number of software and application tools on the market that can be used to create concept maps for free or for a relatively low fee, it should be noted that only a small number of them are programmed and fully usable in multiple languages. Despite the considerable user intuitiveness when using application tools for creating concept maps, it is still preferable to work with applications that are created in the teacher's native language.

In this paper, attention was further focused on specifying the advantages and disadvantages of concept mapping. Furthermore, one specific example was given of how concept maps can be used in a particular field. This illustrative example shows that concept maps can be adapted not only to the level of pupils and their knowledge, but also to the level of individual schools. For this reason, we believe that concept mapping should be used as one of the very advantageous methods and forms of presenting the curriculum to pupils and students.

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Mathematical Modelling of Segmentation Synthetic Aperture Radar Data for Military Purposes

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Abstract

Digital image processing is the use of algorithms and mathematical models to process and analyze digital images. The goal of digital image processing is to enhance the quality of images, extract meaningful information from images, and automate image-based tasks. In this contribution we discuss and use mathematical modelling for segmentation of image data. We focus on Synthetic Aperture Radar (SAR) data, which plays an important role in military area. Our own approach brings our own software for segmentation of SAR images. We use discrete mathematical models, graph cut, grab cut and random walker. Our own approach is in implementation of these algorithms and their implementation in programming languages as C, C++, and Python. We provide segmentation of noise images, and we focus on segmentation of paths, roads, objects, rivers etc. We provide segmentation of SAR images. We do preprocess and post processing of data based on requirements of authors. The advantage of our methods is in the better and clearer segmentations with better boundaries. Our solution can also proceed noise data, what is the big problem by SAR data analyses. We deal with SAR data, and we try to segment objects. There are some limitations for processing real image data. We cannot deal with data which has too many lines, or too big distances in shadow colors. Another limitation brings scaling of images and too big and too noisy data.

KEY WORDS: *Image Processing, SAR segmentation, Graph Cut, Grab Cut, Random Walker*

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1. Introduction

Digital image processing is a field of computer science and engineering that focuses on using algorithms and mathematical models to analyze, manipulate, and enhance digital images. The primary goal of digital image processing is to improve the visual quality of images and to extract meaningful information, enabling automation in various image-based tasks. As imaging technology becomes increasingly sophisticated, digital image processing has become crucial in numerous sectors, including defense, healthcare, industry, and environmental monitoring. In this context, the application of image processing extends far beyond basic image enhancement, encompassing a comprehensive range of steps that serve to optimize the interpretation and utility of digital data. The typical steps of digital image processing include:

1. **Image Acquisition.** The initial step involves capturing an image through sensors, such as cameras, satellites, or other imaging devices, which convert physical phenomena into a digital form.
2. **Image Enhancement**. This phase aims to improve image quality by refining visual elements such as contrast, sharpness, and brightness to make important features more distinguishable.
3. **Image Restoration**. The process of restoring a degraded image, often due to noise, motion blur, or other distortions, to recover its original form or enhance its quality.
4. **Color Image Processing**. Techniques applied to manipulate and analyze images in the color space, helping with tasks such as object recognition and classification.
5. **Wavelets and Multiresolution Processing**. This method involves breaking down an image into different scales or resolutions to analyze features at varying levels of detail.
6. **Image Compression**. A process to reduce the storage size of an image without significant loss of quality, critical for efficient storage and transmission.

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7. **Morphological Processing**. A technique focused on the structure and shape of objects within an image, often used for object detection and segmentation.
8. **Image Segmentation**. The partitioning of an image into distinct regions or objects for further analysis, critical for applications such as object tracking and recognition.

By using computer vision, the military can securely derive critical information and data, make smart decisions, and act more agility to protect national security. Because technology is always changing, it's important to know what's new in computer vision and how it can be used in the defense business. The role of image and video processing in army and military stuff: Helicopters and other military vehicles use vision systems enabled by rugged embedded hardware to operate in degraded visual environments. Currently, the military and technology industry collaborate to provide frontline warfighters with the latest intelligence. Electro-optics, along with advanced embedded computing image and video processors, collaborate to condense the overwhelming amount of information into useful intelligence due to the rapid processing speed of modern systems. However, we condemn with moral outrage and disapproval individuals who are deceived and corrupted by the temporary allure of pleasure, so consumed by desire that they cannot anticipate the inevitable suffering and difficulties that will follow; and the same amount of fault lies with those who neglect their responsibilities due to their lack of strength.

This can also be expressed as avoiding hard work and suffering. Identifying autonomous targets in drones and missiles is straightforward, as is using satellites to identify hostile targets on land, in the air, or at sea. Combat pilots benefit from integrated head-up displays for targeting and situational awareness, while infantry use head-mounted vision systems for situational awareness. All these limitations belong for the general processing of digital images, of Sar data and other visual objects. They can be considered as general problems and limitations by the processing of digital image processing.

In the field of aerospace, vision-based navigation or star tracking, spectral sensing for mapping Earth and lunar terrain, and AI-based navigation removing satellites from orbit are key technologies. In relation to avionics, examples include the use of vision-based technology in cockpit simulators and the installation of closed-circuit cameras within the aircraft for pilot monitoring. Electro-optical sensors contribute a wealth of information to the situational awareness system. Curtiss-Wright's Garnett explains that improvements in electro-optics enhance the quantity and quality of information accessible, while high performance embedded computing can handle the vast amount of real-time data and deliver it in a user-friendly format using modern rugged displays. The potential of both computation and software lies in their ability to process data in new ways to reduce operator task overload, while also introducing novel ways of analysis and presentation in real-time, for optimal mission results. If you're unable to quantify or spot the danger, you won't be able to control or react to it. Instantaneous image analysis is essential for automated target identification, tracking of friendly and enemy forces, reducing instances of friendly fire, accelerating the OODA loop, among other things. We mention some applications of computer vision and image processing in the security sector. We present some examples of computer vision contributing to enhancing the precision and overall efficiency of defense equipment: [1, 5, 8, 9].

Official studies show that facial recognition technology is increasingly being used in different sectors, such as defense, to improve security and identification processes. Computer vision allows for the use of face recognition, an essential element in defense that boosts security and streamlines precise identification. This technology offers a more efficient and streamlined method for reaching these goals. Face recognition systems make it easier to identify people by utilizing computer vision technology. They study facial characteristics like the eyes, nose, and mouth to generate an individualized facial blueprint. This pattern is then matched with a database of familiar faces, allowing military personnel to easily find individuals that could be dangerous. By utilizing computer vision and facial recognition technology, defense forces can improve security measures, speed up identification procedures, and quickly react to possible risks or dangers. This technology enables them to effectively protect the well-being of people and uphold a safe atmosphere. Facial recognition technology can be utilized in defense facilities and for counter-terrorism purposes.

Research has revealed an increase in the use of object recognition technologies in a range of industries, including defense. The Defense Advanced Research Projects Agency has also been actively dedicating resources to the research and development of object recognition. This technology depends on the visual characteristics of objects to accurately identify them. They assist the military in evaluating potential threats, monitoring resources, and enhancing the security of defense locations through threat assessment, inventory management, and safety improvement.

Surveillance and monitoring, which are made possible by computer vision, are very important for defense because they can detect intrusions, surveil borders, and secure defense sites. It emphasizes the increasing adoption and investment in surveillance technologies to safeguard military installations, border areas, and critical infrastructure. Computer vision programs installed on military bases can assess the constant feed of visual data immediately to instantly.

In a study by the Federation of American Scientists [8], self-driving vehicles with computer vision successfully navigated challenging terrains and conducted logistics tasks with less human oversight. These vehicles displayed increased operational efficiency, decreased risks to personnel, and improved mission success rates. In this regard, we can discuss enhanced maneuverability and increased realism. Incorporating computer vision technology enhances the precision and dependability of self-driving vehicles during critical scenarios. These vehicles are capable of carrying out significant duties with minimal manual intervention or input. This reduces the potential danger to military personnel and makes operations more efficient.

A study published in the Journal of DTIC [8] revealed that using AR technology in military training can improve soldier performance. This improvement is attributed to the ability of AR to provide real-time information, enhance decision-making, and simulate realistic combat situations. According to a report by Zion Market Research, the global augmented reality in the defense market is expected to reach a value of $128 Billion by 2028, growing at a CAGR of around 29% from 2021 to 2028. This showcases the increasing adoption of AR technology in defense training applications. This can be applied in improvement of training and defense resource optimization through computer vision and augmented reality.

Research has demonstrated that the user-friendly design of the pilot's interface in the cockpit, along with their engagement with the image control on the display, decreases the burden on the pilot and boosts their reaction speeds, thereby augmenting the success of the mission. The use of computer vision technology aids in understanding human movements, leading to a smoother and more natural interaction between people and machines in the defense industry. This improves teamwork in the intricate setting of defense activities.

Biometric recognition, underpinned by computer vision technology, plays a pivotal role in upholding security standards. It ensures that access to sensitive domains within the defense sector is exclusively granted to individuals devoid of any criminal affiliations, thereby maintaining the integrity of security operations. Defense systems can use biometric recognition to ensure only authorized personnel have access to restricted areas or classified information. This ensures the safety of sensitive information and assets. These include protected access and efficient security operations.

Studies in medical and scientific publications have demonstrated that technology designed for visual recognition can reliably identify severe injuries, including gunshot wounds, broken bones, and bleeding inside the body, achieving a success rate higher than 90%. This enhanced accuracy enables faster evaluations and targeted medical interventions, which can be crucial in life-threatening scenarios. The expansion of medical applications is driven by the increasing demand for advanced medical devices that can enhance the success and speed of medical support in war zones. Prompt treatment and remote medical support are key elements in delivering healthcare.

Certain government agencies and armed forces have incorporated computer vision algorithms into their analysis of satellite imagery. This app allows for the recognition and monitoring of important items, surveillance of border actions, and identification of security risks, thus boosting the strategic scope of defense maneuvers. We highlight the increased precision of immediate data and quicker identification of patterns.

In the defense sector, it is essential to conduct thorough damage assessment to determine the effects of attacks, natural disasters, or accidents on vital infrastructure. Computer vision has a significant impact in this process as it utilizes advanced algorithms and image analysis techniques to evaluate structural damage and pinpoint possible vulnerabilities. Below are the main components of applying computer vision for damage evaluation in the military field. This is related to improved visual inspection, identifying vulnerabilities with computer vision, quick response, and decision-making, monitoring the environment, and detecting hazards. One-way computer vision can be applied is detecting and tracking wildfires, monitoring terrain or vegetation changes, and identifying hazardous materials or chemical leaks. Through constant analysis of visual data, military, and defense personnel can identify potential environmental dangers in advance and implement necessary actions to minimize their effects.

Computer vision utilization in the defense industry has the capability to cause significant disruption and enhance the effectiveness of current systems. Computer vision can enhance processes by increasing efficiency, accuracy, and optimization, making it simpler to surveil the enemy, pinpoint targets, and detect hostiles. The main point is that computer vision provides the military with advanced tools to update their performance, including better surveillance, increased lethality, and enhanced military operations. With the use of computer vision, the military can obtain important information and data securely, as well as make informed decisions and act quickly to safeguard national security. Due to constant technological advancements, keeping up with the latest in computer vision is crucial for leveraging its applications in the defense industry.

In our contribution we focus on the image processing of the digital images concretely SAR images and SAR data. In our research we study and provide segmentation process of SAR data. We present special methods, graph cut method and random walker method. We provide our own implementation in the programming language C++ and Python. With these software applications we segment SAR data and provide image analyses. The strong point of our approach is that our method can process as well blurry data as well as data with noise. At the end we bring the results obtained by grab cut algorithm, where we can get the whole segmented object. Our methods bring in general better segmentation results in the sense of better edges boundaries. Both techniques can work and proceed the natural noise on image data.

2. **Synthetic Aperture Radar Data**

Synthetic Aperture Radar (SAR) is a type of active data collection where a sensor produces its own energy and then records the amount of that energy reflected after interacting with the Earth. SAR technology provides terrain structural information to geologists for mineral exploration, oil spill boundaries on water to environmentalists, sea state and ice hazard maps to navigators, and reconnaissance and targeting information to military and intelligence operations. Resolution of ERS SAR is the following: The ERS SAR has a bandwidth of 15.6 MHz, an antenna length of 10 m and a look angle of 23˚. The ground range resolution is about 25 m and the maximum azimuth resolution is 5 m. The main disadvantage of the SAR and satellite images is that the data extracted from these sensors are not always available for a specific region since they are orbiting and recording data at different frequencies.

Differences between multi-looking processing produces enhanced radiometric resolution is in higher sensitivity to brightness changes and less noise. The single look image on the left has significant speckle noise but the multi -look version on the right had much improved image clarity and target detectability. Synthetic Aperture Radar (SAR) represents a type of active remote sensing technology that uses microwave electromagnetic radiation to produce and send data to the surface of a target location. SAR imaging is frequently used in national security applications since it is unaffected by weather, geographical location, or time. In this system, many approaches are examined, to improve automation for segmentation and classification. The utilization of Deep Neural Networks (DNNs) to classify SAR images has gotten a lot of attention, and it usually requires several layers of deep models for feature learning. With insufficient training data, however, the DNN will get affected by the overfitting issue. The major purpose of this work is to make a development on introducing a new framework for SAR image segmentation and categorization using deep learning. Owing to the coherent nature of the backscattering signal, SARs create speckle noise in their images. If the image has noisy material, classification becomes more challenging. Hence, the pre-processing of the images is employed by linear spatial filtering to remove the noise. [15]

3. Image segmentation

It is the process of dividing an image into multiple segments or regions, where each segment represents a homogeneous part of the image with similar characteristics. The goal of image segmentation is to simplify or reduce the representation of an image and allow easier analysis or processing of the image at the segment level. Also, for example, in medicine, image processing by computational algorithms is used because of to automate the process of analyzing larger amounts of data. Image segmentation can be performed in a variety of ways, including methods based on color, intensity, texture, edges, and other image properties. It is often used in various fields such as image processing, computer vision, medical diagnosis, robotics, and many others. Segmentation allows different parts of an image to be analyzed and identified.

1. **Medical images**: In medical diagnostics, image segmentation is used for dentification and localization structures in medical images such as CT scans, MRIs or X-rays. It helps in diagnosing diseases and planning surgical procedures.
2. **Automotive**: In the development of autonomous vehicles, image segmentation is critical for identifying objects around the vehicle. This technique enables the vehicle to recognize roads, vehicles, pedestrians, and other objects on the road.
3. **Safety systems**: In surveillance and monitoring systems, image segmentation is used to identify and track the movement of people or objects based on their shape and movement.
4. **Computer vision and object recognition:** Image segmentation is used in the field of computer vision to recognize objects and their boundaries in real time. This is important for a variety of applications, including interacting with devices using cameras.
5. **Industry**: In industrial applications, image segmentation is used for quality control products, monitor processes and identify irregularities or defects.
6. **Agriculture**: In agriculture, image segmentation can be used to identify crops, plant growth monitoring or disease detection. [8]

In this contribution we focus mainly on SAR data.

4. The Mathematical Background

For image segmentation there are several mathematical algorithms and methods. They come from different parts of mathematics and include also different kinds of mathematical tools, even their combinations. We can mention classical methods (threshold methods), gradient methods (region growing methods), clustering methods, graph methods (graph cuts, grab cut methods, intelligent scissors), mixed methods with combination of probability (random walker), mixed methods with mixed Gaussian models. At least but not last, we mention neural networks, machine learning methods, deep learning methods, aggregation methods, fuzzy methods and others [1, 2, 3, 4, 8].

We explain in detail just three algorithms, which bring our own implementations and own new software for processing of image data.

4.1. Random walker algorithm and segmentation via Random walker

The term random walk, translated as random walk, was first published by mathematician Karl Pearson in 1905, [6]. The definition of this term is about assumptions and probabilities. Assume that at each step the user starts from some base point. He moves a fixed length with a randomly chosen angle. What is the distribution of the walker, over multiple steps? This is exactly the random walk problem. In the same year Albert Einstein published his paper, he modeled Brownian motion as a random walk. This paper had a huge impact on the whole algorithm, because it started to provide proofs of discrete particles in time. So, most scientists began to believe that the matter had a continuum character. And this is something continuous, e.g. in mathematics it can be a set of real numbers (so also a number axis), or any interval of that set. Image segmentation using random walk was first applied in 1979, where random walk was first used in computer science for texture discrimination, and more researchers started to pay attention to this. The Random Walker algorithm received attention only later, as it was first published by Grady in 2006 under the name Random Walker. Algorithm definition: A random walker is a walker moving on an edge between vertices with a probability that is proportional to the capacity on the edge. A weighted graph $G(V, E, W)$ is constructed to represent the relationships between nodes, where V is the set of vertices, E is the set of edges, and W is the weights added to each edge to denote the similarities between them. The goal of clustering is to divide the data nodes into several groups, so that nodes in the same group are similar and those in different groups are dissimilar. The solution to the clustering problem occurs here in finding the region of a given graph. Moreover, in addition, edges within the same group have high weight and in different groups have low weight in turn. It ensures that the points are distinct from each other and within the same, cluster are like each other. When segmenting an image or data, the output of the algorithm will be the segmentation of K objects that correspond to K groups of source pixels and have different labels. The algorithm will label the most likely label to assign to the non-source pixels. For each such pixel, the probability of a pedestrian starting from that pixel reaching the source pixel labeled s first will be computed. Thus, for each pixel there will be K probabilities [6, 11, 12].

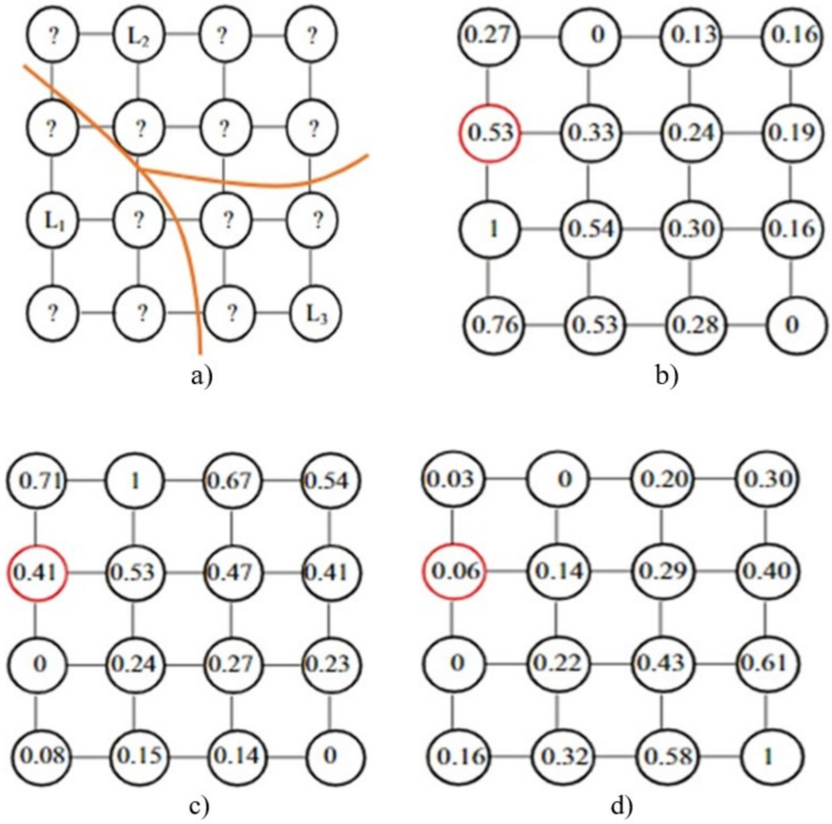


Fig.1. For each pixel there will be K probabilities: a) Beginning of the algorithm; b) The red point from which we calculate what is the probability of the walker getting to points L1; c) The red point from which we calculate what is the probability of the walker getting to points L2; d) The red point from which we calculate what is the probability of the walker getting to points L3.

We can illustrate the random walker model in the figures above. We have a 4x4 graph with three starting points, L1, L2, L3 and a subsequent segmentation. Fig. 1(a) shows these points and in the next figures Fig. 1 (b), (c), (d) we can see the red point from which we calculate what is the probability of the walker getting to points L1, L2 and L3, see Fig. 1. The probabilities are 0.53, 0.41 and 0.06, which gives us a total of exactly 1, i.e., a 100% fraction. Since the highest probability reaches 0.53 at point L1, the marked starting point of our walker belongs to the same cluster as point L1.

The basic algorithm is simple, and we can formulate it equivalently to the combinatorial Dirichlet problem defined on the graph. Given data nodes in a connected graph $G(V, E, W)$ with n vertices $V = \{v1, v2, . . . , vn\}$ and m edges $E = \{e1, e2, . . . , en\}$ we can construct a graph. To be able to partition vertices into clusters, the algorithm needs K labeled vertices. From this we can make a so-called combinatorial Laplacian matrix. We will not discuss this in depth, but the basic steps of this algorithm are:

1. Convert pixel intensities to edge weights in the graph.
2. Selecting and labeling K sets of source vertices (pixels).
3. Solving a system of equations, yielding K probabilities for each node.
4. Determine a label for each pixel based on the maximum probability value.

A problem can arise if we select a few source pixels, because the output of the algorithm is a slice that separates the source pixels from the rest of the image [6, 13, 14].

Description of the random walk algorithm

#0. Creating the graph.

#1. Initializing the graph.

An empty graph representing the image is created. Each pixel of the image becomes a vertex. of the graph. Each vertex is given a *vxy* numbering, where $0 < x \leq$ image width, $0 < y \leq$ image height

#2. Adding edges.

Add edges between vertices that represent adjacent pixels in the image. Per vertex neighbors with coordinates *(x, y)* are vertices: *(x-1, y), (x+1, y), (x, y-1), (x, y+1)*. Each edge is assigned a weight equal to the intensity difference of neighboring pixels in the image. Let us denote it as *wij*, where *i* and *j* are the respective row and column in the graph incidence matrix.

#3. Vertex initialization.

Each vertex is assigned a truth probability *(n, pxy)* for each segment *n, pxy=0*, where *n* and *m* is the visible number of segments. This value will represent the probability that a vertex *v* with coordinates *(x, y)* belongs to segment *n*. Also, each vertex will store information about the intensity of the corresponding pixel $0 \leq$ Ixy ≤ 255th of the associated pixel.

#4. Creating semantic tags.

A semantic tag in the context of the random walk algorithm means the rules according to which the algorithm processes the apparent segments. For example, we need to process the following image. Let the black parts be segment number *1*, the white parts be segment number *2*. The black parts can obviously be defined as those where the intensity satisfies the following condition *Ixy < 20.* The white vertices should satisfy the condition *200 < Ixy*. Thus, we have processed a larger part of the image. We are left with only those pixels that do not satisfy any rules. In other words, the grey pixels, which represent a fuzzy gradient on the segment boundary. Just such fuzzy pixels will be solved using the random walk algorithm.

#5. Random walk.

Movement with respect to the similarity of the Neighbor's properties will be selected with respect to similarity of pixels in the selected property. For example, we take intensity. We will always select the neighbor with the smallest difference in intensity. Thus, we will only move on similar vertices, which will give us a higher probability that the peak we are studying and the peak-marker we encounter will be from the same segment [6, 9, 11, 14].

Random walker. Image segmentation has often been defined as the problem of localizing regions of an image relative to content (e.g., image homogeneity). However, recent image segmentation approaches have provided interactive methods that implicitly define the segmentation problem relative to a particular task of content localization. The random walker algorithm determines the segmentation of an image from a set of markers labeling several phases (2 or more). An anisotropic diffusion equation is solved with tracers initiated at the markers' position. The local diffusivity coefficient is greater if neighboring pixels have similar values, so diffusion is difficult across high gradients. The label of each unknown pixel is attributed to the label of the known marker that has the highest probability to be reached first during this diffusion process. In this example, two phases are clearly visible, but the data are too noisy to perform the segmentation from the histogram only. We determine markers of the two phases from the extreme tails of the histogram of gray values and use the random walker for the segmentation [6, 9, 11, 12, 13, 14].

Random Walks for image segmentation. First random walks are introduced in the order of *1D* (without barriers and with barriers), 2D (without barriers and with barriers). Then Markov property is explained. The Markov property is proved for the *1D* simple case and a complicated *2D* case with both absorbing and reflecting barriers. Image segmentation problem is introduced from an application point of view and converted into a mathematical formulation. Random walker algorithm for image segmentation is introduced and it is proven to be a Markov process. The study is concluded by implementing the Random Walker algorithm and testing it by segmenting a set of images.

Another approach:

Generating a random walker for image segmentation involves defining a graph where each pixel in the image is represented by a node, and the edges between nodes represent the similarity between the corresponding pixels. The random walker algorithm then uses this graph to segment the image by assigning labels to each pixel based on the connectivity of the graph. There are several open-source tools available for implementing the random walker algorithm for image segmentation, including [6, 9, 11, 12, 13, 14]:

1. scikit-image: A Python library for image processing that includes an implementation of the random walker algorithm.
2. ITK-SNAP: A software application for medical image segmentation that includes a random walker algorithm.
3. Fiji: An open-source image processing package that includes a plugin for the random walker algorithm.

To use these tools for simulating real-world scenarios, you would need to provide appropriate input data in the form of images or other types of data that can be processed by the algorithm. You may also need to modify the algorithm parameters to achieve the desired results for your specific application.

We implemented the algorithm and created our own software providing image segmentation. We present original SAR data [15] from open Gallery and provide results of segmentation via Random Walker in the Fig. 2., 3., 4. and 5.

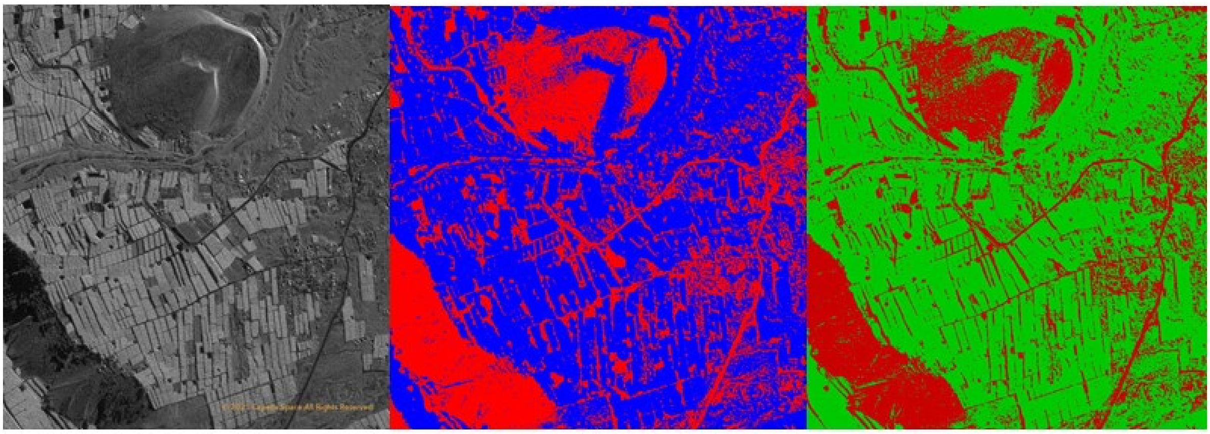
5. Results

In this study, we analyzed Synthetic Aperture Radar (SAR) data obtained from an open-source, freely licensed repository, as referenced in source [15]. Open-source SAR datasets provide a valuable resource for research and experimentation, allowing for the testing and validation of new algorithms without the constraints of proprietary data.

To process and analyze this data, we developed our own custom software, implementing state-of-the-art segmentation algorithms tailored for SAR image processing. The use of in-house software enabled flexibility in optimizing the algorithms for specific tasks, such as object detection and boundary delineation, which are critical for accurate interpretation of SAR imagery. By employing custom-built tools, we were able to fine-tune parameters and enhance the performance of segmentation algorithms like the Random Walker and Graph Cut techniques, ensuring that the SAR data was processed in a manner suited to its unique characteristics, such as speckle noise and resolution variances.

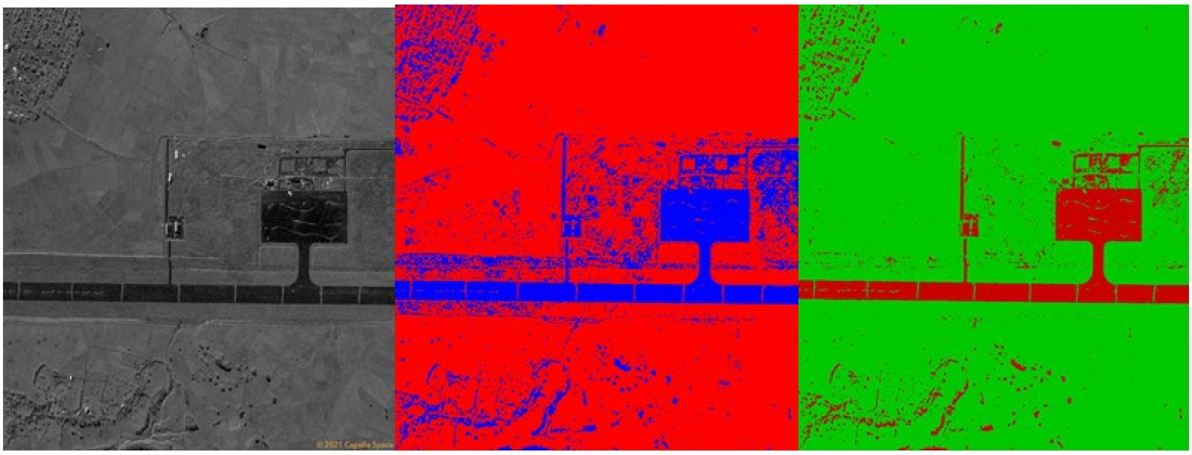
The use of open-source SAR data facilitated the reproducibility of our results, as this data is accessible to the wider scientific community. This allows for further experimentation and comparison across different research groups, contributing to advancements in SAR image analysis. The custom software also provides a platform for future improvements and the integration of additional image processing techniques, enabling continuous development in the field of SAR data analysis for defense and surveillance applications.

5.1. Segmentation via Random walker method [12, 13, 14]



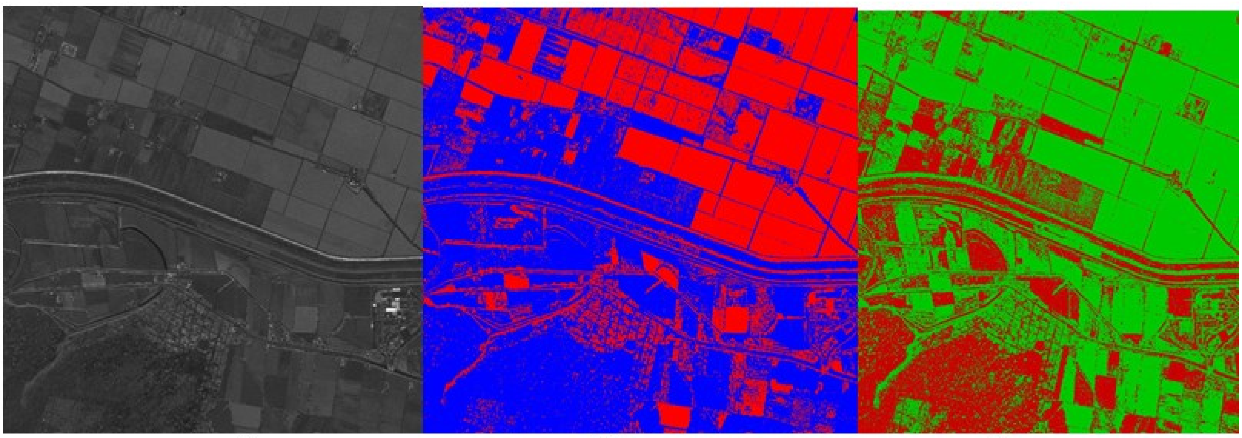
a) b) c)

Fig.2. Data source explanation: a) Original data, source: [15], b) Segmented data, c) Segmented data



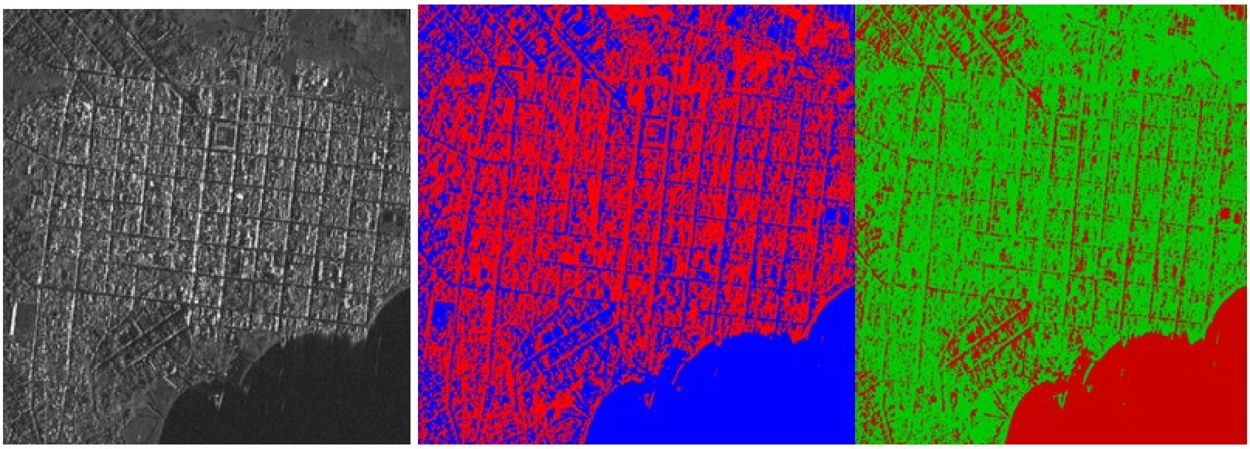
a) b) c)

Fig.3. Data source explanation: a) Original data, source: [15], b) Segmented data, c) Segmented data



a) b) c)

Fig.4. Data source explanation: a) Original data, source: [15, 16], b) Segmented data, c) Segmented data



a) b) c)

Fig.5. Data source explanation: a) Original data, source: [15], b) Segmented data, c) Segmented data

5.2. Segmentation via Graph Cuts method: Segmentation using maximum flow and minimum cut, [1, 2, 3, 5]

a) b)

Fig. 6. a) Original Image: The 3x3 image, we choose the input data, object O and background B. b)Segmented Results

The two algorithms, the Ford-Fulkerson and Edmonds- Karp algorithms, see [1, 2, 3], we can use one of them to find the maximum flow and the minimum cut, see Fig. 6. We will now show how a simple 2D segmentation works on a 3x3 image, based on the figures and a brief description, see Fig.6, Fig.7, and Fig. 8.

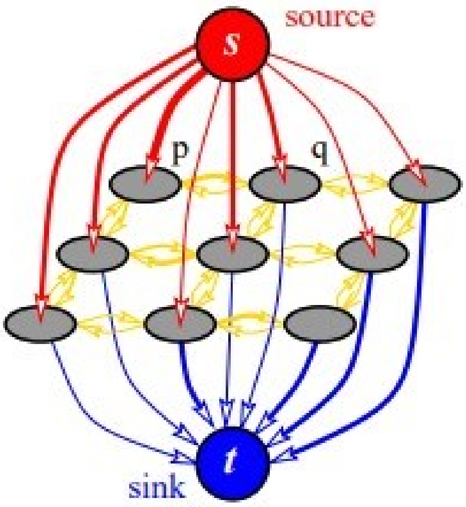


Fig. 7. Oriented Network

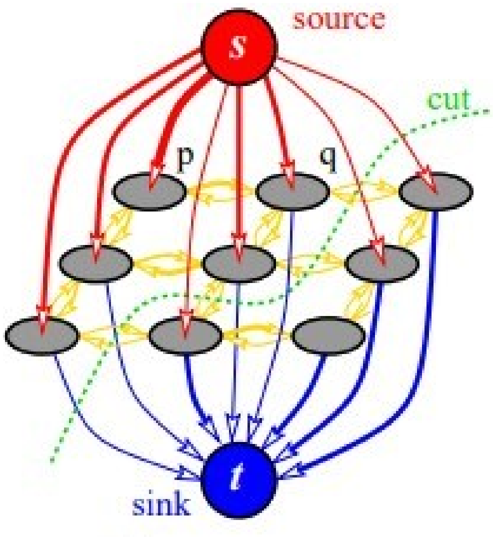


Fig. 8. Minimal Cut

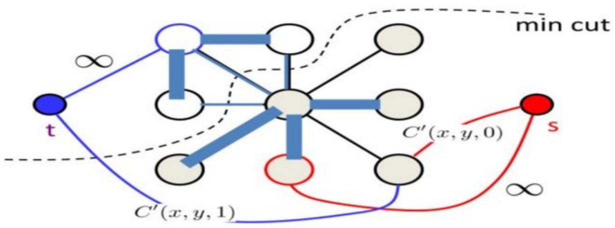
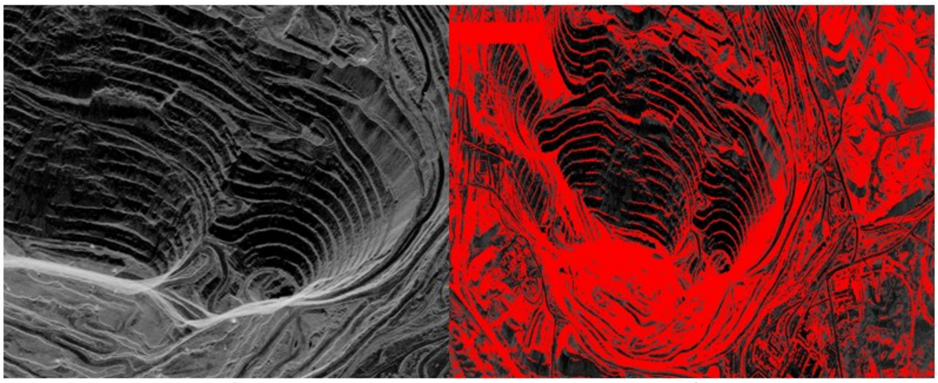


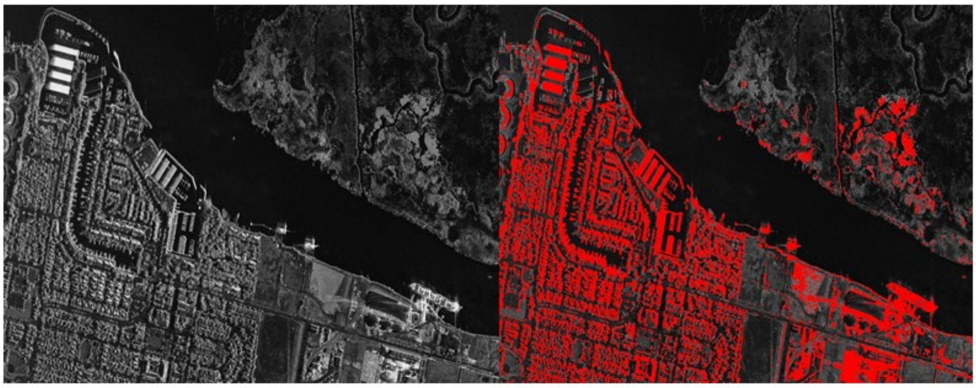
Fig. 9. Minimal Cut

The image is made into a graph, where two disjunctive sets are formed. One is connected to the source *s*, so the set of objects. And the other is associated with the mouth *t*, where the background seeds are. We obtained a minimal cut that splits the set into two sets based on the similarity of the pixels and the connection to the source *s* and the mouth *t*, see Fig. 9. This is then segmented, and the output is shown in the last figure [1, 2, 3, 5]. Here we can see that from the base image after segmentation using these methods, we have two sets that are correctly segmented. For segmentation we used for segmentation data from Open Gallery [1]. Segmented results obtained via Graph Cut method are visible on Fig. 12, 13, 14.



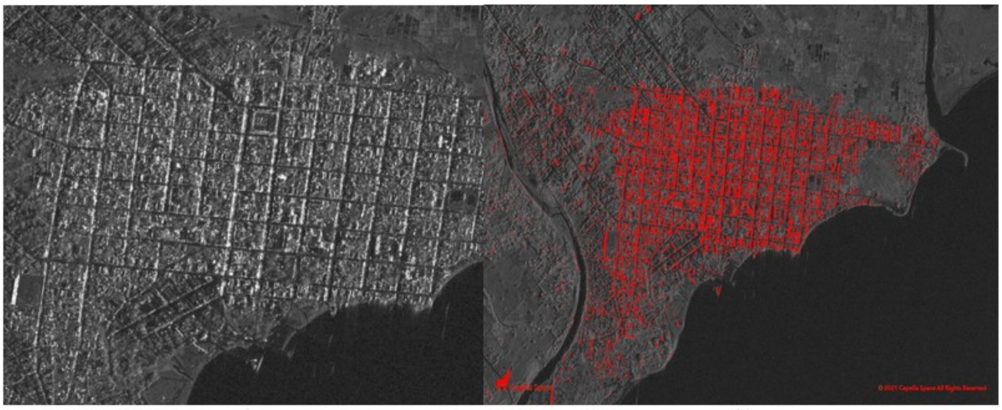
a) b

Fig.10. Data source explanation: a) Original data source: [15], b) Segmented data



a) b)

Fig 11. Data source explanation: a) Original data, source: [15], b) Segmented data



a) b)

Fig.12. Data source explanation: a) Original data source: [15], b) Segmented data

Moreover, if we want to segment the whole concrete object, we can use Grab cut technique, which is focused on the boundary of the object. See the result bellow. First we detect the object and consequently we get the solo segmented object, Fig. 13, Fig.14.

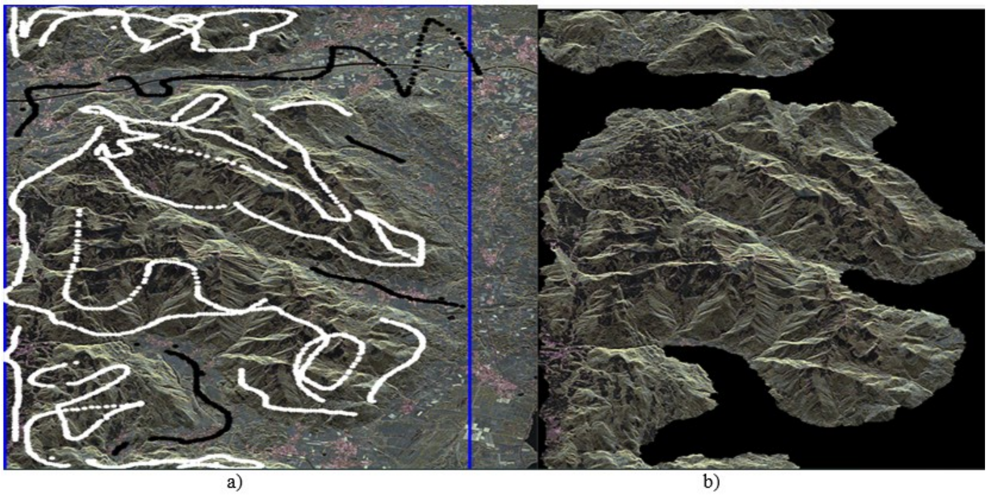


Fig.13. Data source explanation: a) Original data source: [15], with marks of object and background b) Segmented object

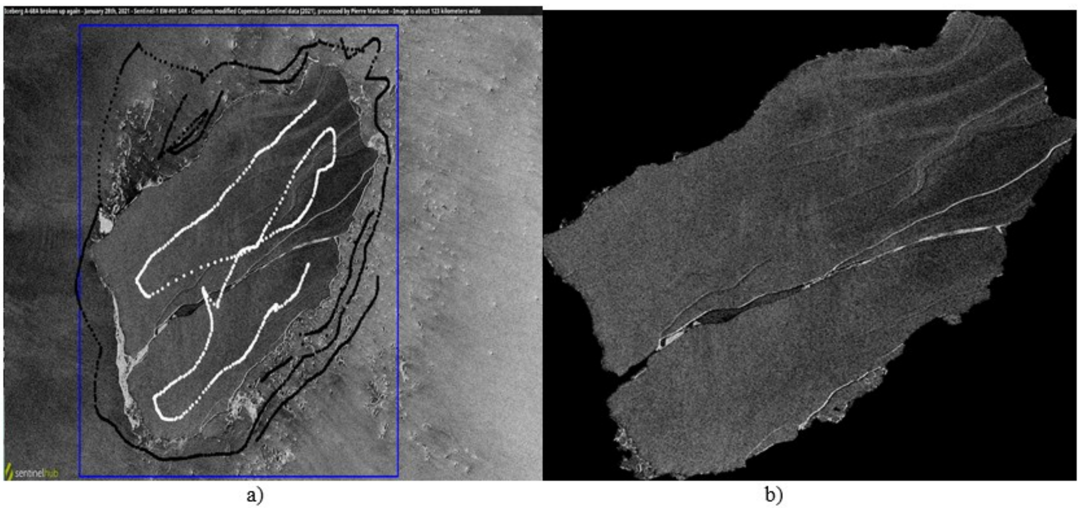


Fig.14. Data source explanation: a) Original data source: [15], with marks background, b) Segmented object

6. Conclusions

In summary, this study highlights the crucial role that image processing and computer vision play in the defense and military sectors, particularly in the analysis of Synthetic Aperture Radar (SAR) data. The use of advanced image processing techniques is vital for enhancing the visualization and analysis of SAR data, which can be instrumental in applications such as object detection, target identification, and surveillance.

This contribution focused on the segmentation of SAR data to improve visual clarity and enable more precise image analysis. Specifically, two segmentation algorithms—Random Walker and Graph Cut—were implemented and optimized using C++ and Python. These methods allowed for the segmentation of SAR data into object and background regions, facilitating improved understanding of the imagery. Both techniques demonstrated good performance in handling SAR data and produced satisfactory segmentations under certain conditions.

However, both methods presented limitations. The segmentation process using Graph Cut and Random Walker is intensity-based, meaning the algorithms rely on pixel intensities to distinguish between object and background. In scenarios where SAR data contain noise, ambiguities at object boundaries, or small irrelevant artifacts, these methods can misclassify pixels, leading to segmentation errors. For instance, the edges of objects might not be accurately segmented, or small regions might be mistakenly classified as part of the object.

To address these limitations, the GrabCut algorithm was suggested as a more refined approach, especially when boundary accuracy is critical. GrabCut offers more precise control over object boundaries by iteratively refining the segmentation process, making it well-suited for applications where clear object delineation is essential.

In conclusion, while the Random Walker and Graph Cut algorithms offer robust solutions for general SAR data segmentation, their limitations in edge accuracy and intensity-based segmentation indicate that more sophisticated methods like GrabCut could provide improved results. Continued research and optimization of these techniques are necessary to overcome the challenges of SAR data segmentation, enabling more reliable image analysis in military applications. The implementation of these algorithms in custom-built software provides a flexible framework for future enhancements and integration of additional segmentation techniques.

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Reliability Analysis of the GEOSL2000 Soil Passability Prediction Model and its Implications for Military Use

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Abstract

The objective of this study was to validate a geoprocess model devised to predict soil passability based on in-situ measurements of soil bearing capacity. The bearing capacity of the soils was gauged using a conical penetrometer, and the measured values were juxtaposed with the Vehicle Coin Index (VCI) value for typical vehicles deployed in the Czech Armed Forces. Field measurements were conducted across nine distinct locations over a span of several years. The measured values were compared with the modelled passability, which was in line with the actual meteorological conditions on the individual days of measurement. The results clearly indicate that the model, created for the needs of the Army of the Czech Republic, exhibits significant inaccuracies. In most instances, it considerably overestimates the real situation. The primary recommendation of the research is the implementation of major modifications or the development of a new geoprocess model.

KEY WORDS: *soils, passability, modeling, CCM, VCI, GIS, reliability*

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1. Introduction

Soils have a major impact in the evaluation of terrain passability by military equipment [1]. For this reason, the issue of soil passability assessment is given a lot of attention across different armies. Within the evaluation of soil passability, attention is focused mainly on the grain size composition of soils and on soil properties reflecting the way individual soil types are formed [2, 3] and on the actual method of measuring passability. Penetrometric measurement is currently used as the key method for determining soil passability [4, 5, 6]. Determination of soil passability using penetrometric measurements is usually based on procedures established and used by the U.S. Army [7, 8].

The measuring principle is based on the measurement of soil penetration resistance against the penetration of the metal tip of the penetrometer by gradual pushing into the soil. The amount of soil resistance is directly proportional to the degree of soil compaction, soil composition and soil moisture. On the scale, the resistance values in the critical layers (depths) of 0, 6, 12 and 18 inches (approx. 0, 15, 30 and 45 cm) are read. From the measurements taken at one location, the arithmetic mean is used to calculate the value of penetration resistance for individual depths and the value of the cone index (CI) for individual depths of the critical layer. The use of the critical layer value depends on the type of vehicle chassis, its weight, the type of soil and the monitored number of passes. The second step is to determine the RI (remolding index) for fine-grained soils that are subject to deformation under load and the resulting changes in volume and consistency. To determine the formation index, a soil sample is taken from the critical layer for the vehicle using a piston sampler. To calculate the actual passability depending on the type of vehicle and its weight, it is necessary to calculate the RCI (rating cone index). The actual determination of the passability of the monitored locality is based on the comparison of the values of the RCI index with the cone index of the vehicle VCI (vehicle cone index). The calculated VCI values are permanently valid for the vehicle unless there is a change in the tactical and technical parameters affecting the calculation. Although this procedure for determining soil passability is time-consuming both in the measurement and data processing phases, it is more reliable than other methods due to the fact that soil passability assessment is assessed for specific vehicles.

This was also proven by independent measurements carried out by the Department of Engineering Technologies of the University of Defence [9, 10]. This procedure for determining soil passability is also commonly used in a number of foreign scientific papers dealing with soil passability [11, 12, 13]. Due to its reliability and its widespread use in other research work, it was used to determine reference values of patency within this work.

Contemporary methodologies, primarily aimed at predicting soil passability, leverage digital geographic soil data, remote sensing imagery, meteorological data (with particular emphasis on soil moisture and precipitation), and the application of Geographic Information System (GIS) tools [14, 15, 16, 17]. The genesis of these methodologies coincides with the advent of GIS technology and its application in the geographical security of military forces.

One such methodology is a model developed by the Geographical Service of the Army of the Czech Republic towards the end of the 20th century, known as GOESL2000. This model utilizes the Special-Purpose Soil Database (SPSD), created in the late 1990s, as a data source for assessing the impact of soil passability. The database is a digital adaptation of the Soil Map of the Czech Republic, scaled at 1:200,000. It encompasses information on the dominant component of the soil type and soil-forming substrate, along with associated characteristics of the grain size composition for individual soil areas. However, the database's scope is confined to the territory of the Czech Republic.

For the evaluation of soil passability, it is feasible to categorize soil areas into four groups based on expert opinion [18]:

- passable soils (GO);
- soils with limited pasability under difficult meteorological conditions (SLOW GO);
- soils impassable under difficult meteorological conditions (SLOW/NO GO);
- impassable soils throughout the year (NO GO).

Difficul meteorological conditions are delineated based on the season and the cumulative precipitation over a span of three consecutive days within the observed period. During the summer months (May through September), these conditions are characterized by precipitation totals exceeding 60 mm (70 mm in certain contexts). However, the specific circumstances under which the 70 mm threshold applies remain unclear due to the lack of available documentation. Consequently, a threshold of 60 mm was adopted for summer conditions.

In contrast, the winter period (October through April) designates challenging meteorological conditions as those with total precipitation surpassing 40 mm [19].

The primary objective of the research was to validate the outcomes of soil passability modeling derived from the GEOSL2000 process. Furthermore, it aimed to ascertain the reliability of soil passability predictions for the principal soil groups, utilizing field measurements procured through a penetrometer.

2. Selection of localities, implementation of control measurements and preparation of meteorological data

A total of nine localities within Moravia, each characterized by distinct soil classifications, were selected for the measurements. The selection process was conducted in collaboration with pedologists, and was informed by extensive practical experience accumulated through the analysis of soil probes and field testing of equipment feasibility.

The selection was strategically designed to enable the completion of measurements across all localities within a single day. Simultaneously, the chosen localities represented a diverse range of soil areas, encompassing various soil types found within the Czech Republic (Figure 1). The classification of soil at the measurement sites, as per the SPSD, along with the control sample procured during the initial measurement, is presented in Table 1.

Table 1.

Classification of soils at the measurement site according to database and soil control probe

	SPSD		Soil probe	
Locality	Soil type	Grain	Soil type	Grain
Záhlinice A	Phaeozems	Clay loam	Fluvisols	Sandy loam
Záhlinice B	Phaeozems	Clay loam	Gleysols	Loamy
Chropyně	Fluvisols	Clay loam	Fluvisols	Clay loam
Troubky	Fluvisols	Clay loam	Fluvisols	Loamy
Tovačov	Phaeozems	Loamy clay	Phaeozems	Loamy
Štětovice	Peat	N/A	Histosols	Loamy
Olšany	Phaeozems	Loamy	Phaeozems	Clay loam
Křtiny	Cambisols	Loamy	Gleysols	Clay loam
Ochoz	Cambisols	Sandy loam	Stagnosols	Loamy

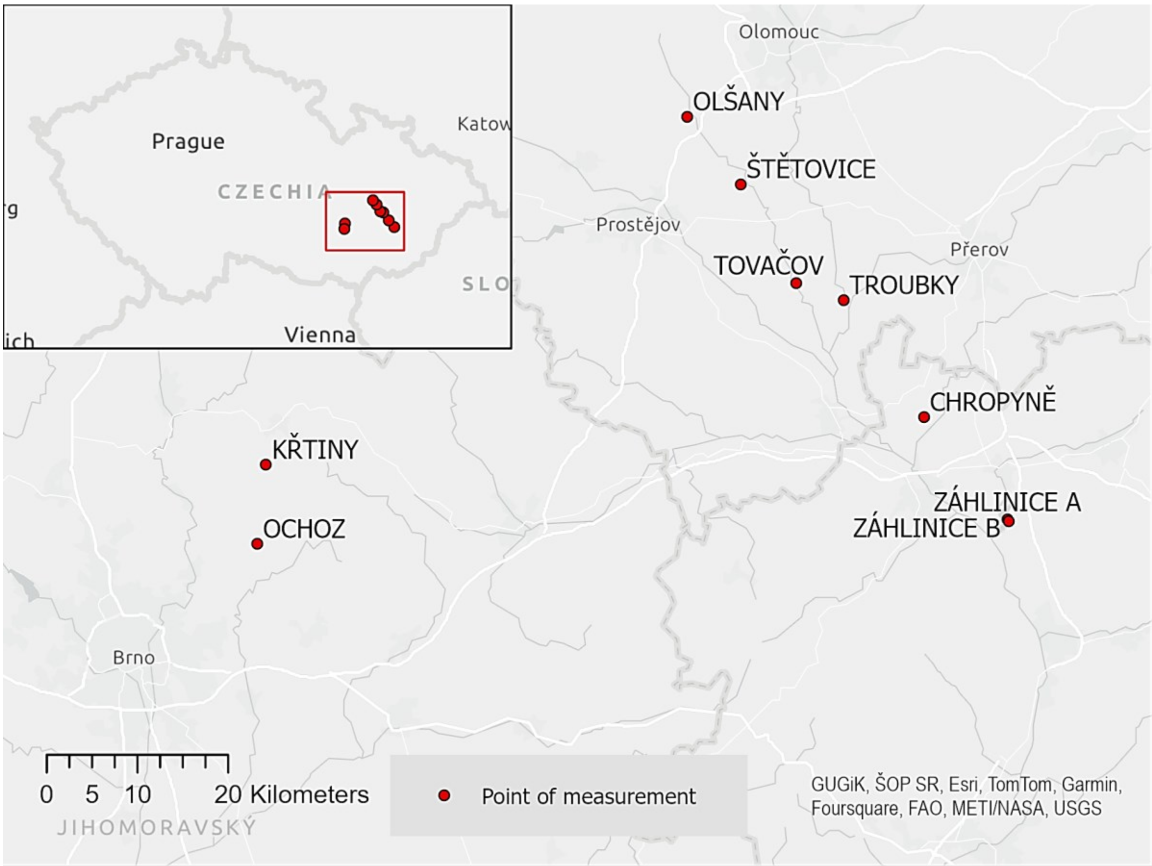

Fig. 1. Localization of measurement points in Moravia.

Systematic, repeated measurements of soil bearing capacity were conducted across various locations utilizing the E-960 soil passability measurement apparatus. The measurement process spanned from December 2014 to September 2016. A total of fourteen measurements were executed at disparate intervals, predominantly during the more humid part of the year. Of these fourteen measurements, three were conducted during the summer season (May through September), while the remaining eleven measurements were carried out during the winter period (October through April). The classification of the periods into summer or winter was determined based on the methodology delineated in the documentation for the GEOSL2000 model [19].

The relatively fewer measurements during the summer can be attributed to the prevailing weather conditions, which rendered the soils dry, firm, and passable. Owing to the overall shift in the weather pattern in the Czech Republic [20], the climatic conditions in the area of interest deviated from the average climatic values during the measurement period. Predominantly, it was a drier period characterized by below-average precipitation, above-average temperatures, and a longer sunshine duration than is typical for an average year. This anomaly also influenced the measured values of load capacity.

This atypical weather pattern can be substantiated by comparing long-term and current (as of the date of measurement) average temperatures and precipitation totals. Data from the meteorological station of the Czech Hydrometeorological Institute (CHMI) Brno-Turany, situated in proximity to some of the locations, were utilized for this demonstration.

Figures 2-4 provide a comparative analysis of the 2015 data against the 30-year average spanning from 1981 to 2010. During the summer months of 2015, the average monthly air temperatures were observed to be higher, deviating from the long-term averages by up to 5 °C (Figure 2). The most significant temperature extremes were recorded in August, which, in conjunction with the precipitation deficit, influenced the passability of soils. The majority of the soils were notably dry and highly passable throughout the autumn season. In terms of precipitation totals in 2015, they were predominantly below average in most months, often amounting to half of the long-term average (Figure 3). In instances where precipitation reached or even surpassed normal values (notably in the month of August), it typically occurred over fewer days. The majority of the precipitation during these periods was in the form of torrential rains, which resulted in surface runoff. A smaller number of days with precipitation of at least one millimetre can be as restrictive as the total amount of precipitation. The final significant meteorological phenomenon impacting soil moisture, and consequently the bearing capacity of soils, is the duration of sunshine. A comparison of the number of clear days and the duration of sunshine in 2015 with the long-term average (Figure 4) reveals an increase in values. This increase, coupled with higher temperatures and lower precipitation, results in the overall drying of soils, thereby enhancing the bearing capacity of soils.

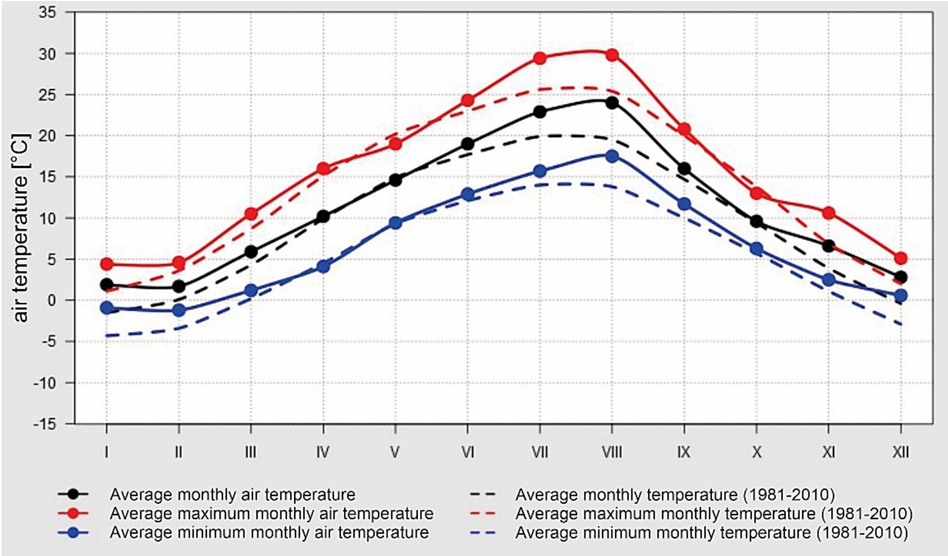

Fig. 2. Course of average monthly, average monthly maximum and minimum air temperature in 2015 compared to the long-term average 1981-2010 [21].

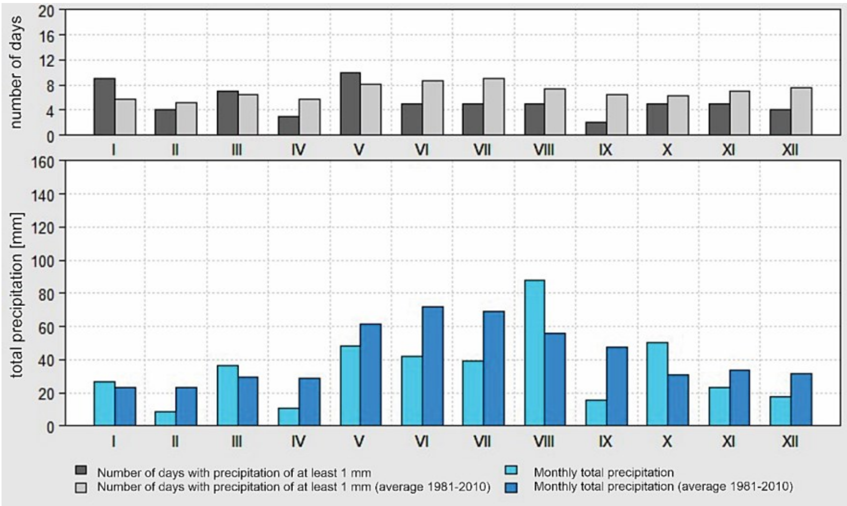

Fig. 3. Course of monthly precipitation and monthly number of days with precipitation of at least 1 mm in 2015 compared to the long-term average 1981-2010 [21].

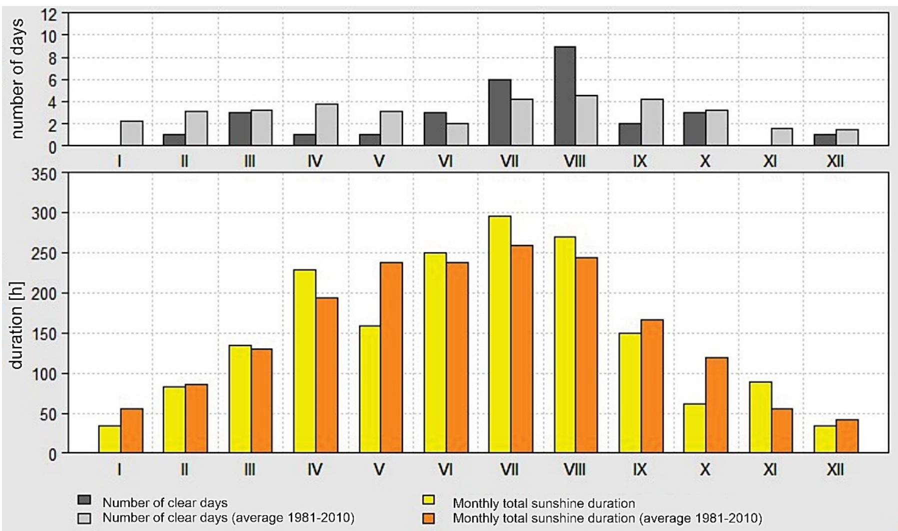

Fig. 4. Course of monthly totals of solar irradiance and monthly number of clear days in 2015 compared to the long-term average 1981-2010 [21].

The observed meteorological phenomena in 2016 did not exhibit significant alterations. The sole distinction was the higher precipitation recorded in some months of the first half of the year. Both temperatures and sunshine duration throughout the year surpassed long-term averages. Graphs representing these trends for 2016 can be accessed on the CHMI website [21].
Subsequent to the measurements, the bearing capacity of soils was calculated using the Rating Cone Index (RCI), which was then compared with the Vehicle Cone Index (VCI) value. The latter was determined for the basic types of vehicles deployed in the Czech Armed Forces. The measured passability was simplified to three fundamental categories: GO, SLOW GO, and NO GO. This categorization facilitated a comparison with the results derived from the GEOSL2000 continuity model. The actual passability, thus obtained at individual locations, was juxtaposed with the outputs of the analytical model GEOSL2000. The model incorporated real precipitation totals for individual locations and measurement dates in its calculations. This comparative analysis served to validate the reliability and accuracy of the GEOSL2000 model in predicting soil passability.
To facilitate a comparison between the soil passability model, as per the GEOSL2000 methodology, and the actual measured values, it is imperative to ascertain the passability of soils at the measurement sites. The analysis reveals that the majority of the sites are situated in areas with soils that pose difficulties for passability under deteriorated meteorological conditions. Two of the sites are located in areas where soils are passable without any restrictions, while one site is in an area where soils are impassable, irrespective of weather conditions (Table 2). It is important to note that the results of the soil passability analysis, as per this methodology, do not take into account the type of vehicle.
In three instances, the measurement sites are in close proximity (80 to 250 m) to the interface with passable soil areas (Olšany, Štětovice, Tovačov). Consequently, if the course of the interface is inaccurately drawn, it could lead to an erroneous classification of passability. For the purpose of this comparison, it is assumed that the course of the interface is accurately drawn.

Table 2.
Throughput of sites according to SPSD under favourable and unfavourable conditions according to the GEOSL2000

Locality / METEO conditions	Záhlinice A	Záhlinice B	Chropyně	Troubky	Tovačov	Štětovice	Olšany	Křtiny	Ochoz
Favourable	GO	GO	GO	GO	GO	NO	GO	GO	GO
Difficult	SLOW	SLOW	SLOW	SLOW	SLOW	NO	SLOW	GO	GO

To compare the passability measurements at individual locations with the values derived from the analysis according to the GEOSL2000 methodology, it is essential to ascertain whether the meteorological conditions were favourable or difficult at the respective measurement dates. This involves determining the amount of precipitation for the three days preceding the day of measurement and discerning whether it is a summer or winter season. Given that the average distance between the penetrometric measurement sites and the nearest rain gauge is approximately 5.7 km [14], it is not suitable to determine the precipitation total based on values obtained from the nearest rain gauge stations. Consequently, combined precipitation estimates were employed. These estimates amalgamate information from meteorological radars, calibrated in accordance with the precise values obtained at the locations of individual rain gauge stations. In the Czech Republic, such data have been generated by the Czech Hydrometeorological Institute since 2003. The resultant data, currently calculated for a 1 × 1 km network at five-minute intervals, can be regarded as the most accurate information on precipitation total in the Czech Republic, notwithstanding the potential error rate of the calculation [22].

3. Verify the reliability of the GEOSL2000 model

Based on the derived area estimates of precipitation, the cumulative precipitation for the three days preceding the day of measurement was computed for each date and location, in accordance with the GEOSL2000 methodology for evaluating soil passability. The computations reveal that the maximum three-day precipitation totals were recorded during the measurements conducted in February, March, and September 2016. However, in all instances, the values did not exceed the thresholds established for the categorization of difficult conditions. The peak values of three-day totals during these periods ranged between 10 and 15 mm at certain locations, while in all other cases, they were less than 10 mm. Consequently, it can be asserted that the meteorological conditions can be classified as favourable on all measurement dates. In terms of the impact of soils, all sites should be navigable without any issues, with the exception of the Štětovice site, which is predicted to be impassable under any meteorological conditions (Table 2 – first row).
Utilizing the recorded values of penetrometric resistance of soils, the CI and the RI were computed for each location and measurement date, following the methodology delineated in the referenced literature [7, 8]. Subsequently, the rating cone indexes (RCI_1 and RCI_{50}) were derived. The computed values of the rating cone indexes were juxtaposed with the vehicle cone indixes (VCI_1 and VCI_{50}). This approach facilitates a comprehensive understanding of the soil onditions and their implications on vehicle passability in all localities.

$$if\ RCI_i > VCI_i \quad \rightarrow \quad GO, \tag{1}$$

$$if\ RCI_i < VCI_i \quad \rightarrow \quad \text{NO}\ GO, \qquad (2)$$

where: $i = 1$ or $i = 50$.
As per Equation 1, if the computed RCI value at a specific location surpasses the VCI value of the observed vehicle, the location is deemed passable. Conversely, as dictated by Equation 2, the site is assessed as impassable. As an integral component of the problem resolution, the passability was ascertained for all fundamental categories of vehicles utilized in the Czech Armed Forces across all fourteen measurement dates. In the context of trucks, the scenario of a fully loaded vehicle was consistently considered for comparison. This systematic approach provides a comprehensive evaluation of vehicle passability in all localities under varying conditions.
The results obtained indicate the anticipated unreliability of the soil passability model GEOSL2000. Based on the collected data, it is evident that despite favourable meteorological conditions, certain locations, specifically Záhlinice A, Záhlinice B, and Křtiny, are often impassable or extremely challenging to traverse. In some instances, the localities of Štětovice, Olšany, and Tovačov also become difficult to navigate. All other sites were navigable for all types of monitored equipment, with a few exceptions of poor passability for certain trucks (notably the Tatra T815 4×4).
In addition to the actual soil conditions, the reduced passability at these locations was partially attributed to agricultural activities. The results also clearly indicate that a universal assessment of soil passability, as implemented by the GEOSL2000 procedure, is not suitable. In locations with passability issues, it is imperative to evaluate individual vehicles, or at the very least, groups of vehicles. The obtained results reveal similar calculated passability outcomes for the following groups of vehicles:

- off-road passenger car (OPC);
- off-road truck (OT);
- wheeled combat vehicles (WCV);
- tracked combat vehicles (TCV).

Differences can also be discerned among individual groups of vehicles, primarily dependent on the total weight of the vehicles and the configuration of the chassis. However, with a degree of generalization, this basic categorization could be utilized to modify the existing model or to devise a new method for assessing soil passability.

Table 3.
Evaluation of the passability of selected locations at certain measurement dates for defined groups of vehicles

Locality	**Group of vehicles**	**Selected measurement dates**										
		9. 12. 2014	26. 3. 2015	13. 8. 2015	14. 10. 2015	19. 11. 2015	10. 12. 2015	19. 1. 2016	17. 2. 2016	14. 4. 2016	16. 6. 2016	6. 9. 2016
Záhlinice A	OPC	N	N	S	G	S	S	G	N	N	S	S
	OT	N	N	N	N	N	N	S	N	N	N	N
	WCV	N	N	N	G	N	S	G	N	N	S	S
	TCV	N	N	S	G	S	S	G	N	N	S	S
Tovačov	OPC	G	G	G	G	G	G	G	S	G	G	G
	OT	N	S	G	G	G	G	G	N	S	G	G
	WCV	G	G	G	G	G	G	G	S	G	G	G
	TCV	G	G	G	G	G	G	G	S	G	G	G
Štětovice	OPC	N	G	G	G	S	G	G	S	G	G	G
	OT	N	N	G	N	S	S	S	N	N	S	G
	WCV	N	G	G	S	S	G	G	S	S	G	G
	TCV	N	G	G	G	S	G	G	S	G	G	G
Olšany	OPC	G	G	G	G	S	S	G	N	S	G	G
	OT	G	G	G	G	S	S	G	N	N	G	G
	WCV	G	G	G	G	S	S	G	N	S	G	G
	TCV	G	G	G	G	S	S	G	N	S	G	G
Křtiny	OPC	N	N	G	S	S	N	S	N	N	N	S
	OT	N	N	S	N	N	N	N	N	N	N	N
	WCV	N	N	G	S	S	N	S	N	N	N	S
	TCV	N	N	G	S	S	N	S	N	N	N	G

Across all locations, varying capabilities of vehicles to traverse a given site can be observed. The passability fluctuates on different dates for individual vehicle groups. There are instances when some groups of vehicles can navigate without any issues, while others have a limited number of passages, or the site is generally impassable due to the low bearing capacity of soils. This is primarily attributed to weather conditions, agricultural activities in the case of cultivated soils, or a combination of both. To evaluate the passability of soils for individual groups, the following limiting conditions have been adopted. These conditions allow the passability of the territory to be defined for a given group of vehicles in terms of the influence of soils as follows (Table 3):

- GO – all vehicles in a given group can make at least 50 passes;
- SLOW GO – all vehicles in a given group can make at least single passes;
- NO GO – at least one type of vehicle in a given group will not pass at all.

Under such defined conditions, the passability of individual locations varies significantly. The results clearly indicate that trucks represent the most problematic group of vehicles. Upon detailed examination of the results for individual vehicles, the T815 4×4 emerges as the least suitable vehicle for off-road driving. Owing to its chassis layout and relatively large weight, it frequently encounters prerequisites for getting stuck due to the low bearing capacity of soils.

4. Conclusions

The comparison of soil bearing capacity, determined based on field-measured data, with the passability ascertained by the GEOSL2000 model, demonstrated the low reliability of the modeled soil passability. From the analysis of the results, several conclusions can be drawn:

1. Modelling soil passability in general, without addressing a specific type of vehicle or vehicle category, is inappropriate and cannot yield valid results to support decision-making. A modified or new soil passability model must consider this fact and classify soil passability based on at least vehicle groups of similar parameters.
2. The current model, which assesses passability based on the amount of precipitation over three consecutive days, does not align with reality. The measured passability values showed that precipitation is a significant factor influencing soil passability, but likely not a decisive one. Similarly, an interval of three days is probably not optimally chosen. According to available sources dealing with the evaluation of soil passability [23, 24, 25, 26], soil moisture is the decisive factor. Therefore, to create a model, it is necessary to analyze the influence of soil moisture on soil passability, as well as meteorological elements and phenomena that affect it.
3. The accuracy of the drawing and classification of soil areas in the SPSD does not correspond to the real situation. Given the time of creation of this database, the base map, and the technology of creation, this finding is expected. For this reason, it would be appropriate to replace the SPSD with a more accurate soil database.

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Understanding and Awareness Among the Czech Public Regarding the Potential Deployment of Biological Weapons on their Territory

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Abstract

This study, conducted in the Czech Republic, undertakes a multidisciplinary examination of public perceptions regarding biological weapons, identifying significant gaps in educational and preventative measures. Although general awareness of biological weapons is relatively high, there is a significant lack of in-depth understanding and knowledge about the specific aspects and consequences of their use. The analysis included a quantitative survey that illuminated the insufficient public knowledge about specific biological agents and strategies for defense and response to biological threats. The study also identified a significant gap in media coverage of this topic, resulting in a low level of public discussion and perceived urgency. Furthermore, the role of educational programs and information campaigns that could significantly contribute to increasing awareness and preparedness for potential bioterrorist attacks was explored. The study recommends intensifying educational activities and integrating the topic of biological weapons into broader security and health education programs. Emphasizing the significance of a holistic strategy toward public enlightenment and bolstering national readiness against biological hazards, this research lays a foundation for continued dialogue and measures. It aims to evaluate the level of awareness and preparedness among Czech Republic citizens for potential incidents involving biological weapons, amidst growing attention to biological risks fuelled by geopolitical tensions and advancements in biotechnology. The conclusions of this work highlight the urgent need for deepening national and international cooperation in monitoring, prevention, and response to threats associated with biological weapons, to increase society's resilience against these invisible, yet devastating, threats.

KEY WORDS: *biological weapon, weapons of mass destruction, biological agents, security, bioterrorism*

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1. Introduction

In today's world, marked by rapid technological advancements and complex global security challenges, the specter of biological weapons (BW, "B-agens") looms large in the strategic considerations of national and international security entities. The recent global events, most notably the COVID-19 pandemic, have not only highlighted the vulnerabilities of modern societies to biological threats but have also accelerated the pace of biological research, raising both hopes and fears about the future of biotechnology. This juxtaposition of advancements and their potential misuse underscores the critical need for heightened awareness and preparedness at all levels of society.

Humanity's journey through the ages has been punctuated by incredible discoveries that have gradually permeated all aspects of life. While science achieves remarkable breakthroughs daily across various disciplines, not all outcomes of scientific endeavor—especially applied sciences—prove beneficial or positive for mankind. A prime example of this is the development of weapons of mass destruction (WMDs), including nuclear, chemical, biological, and radiological weapons, which represent a colossal global risk due to their potential to cause widespread destruction and disrupt peace.

Biological weapons hold a unique and insidious place within the arsenal of WMDs due to their ability to harness pathogens to incapacitate or kill large populations discreetly and effectively. Despite their devastating potential, there is a general underestimation of the significance of BW compared to their nuclear and chemical counterparts. This oversight might largely be attributed to the limited use of biological agents in contemporary warfare and terrorist activities, which paradoxically reduces their visibility in public discourse and media coverage.

The underestimation of biological threats, combined with the underwhelming media presence and the minimal emphasis on educational programs addressing BW, propels this study. It aims to delve into the multifaceted perceptions of BW among the Czech public, identify the prevalent gaps in knowledge and preparedness, and foster a dialogue that could lead to better-informed public policies and stronger defensive measures against biological hazards.

This study specifically tests two hypotheses: H1, that people under 30 consider the use of biological weapons as a current topic less often than those over 30, and H2, that men are more likely to know how to act in the event of a biological attack than women. Examination of these aspects sets the stage for a comprehensive analysis of the role of BW in contemporary security environments and emphasizes the need for a holistic strategy towards enhancing public enlightenment and national readiness against the threats posed by biological agents.

2. Technical overview of BW

Biological weapons are distinct from other types of weaponry due to their diversity. Various agents can be exploited as BW, each differing significantly in terms of their effects. These differences include factors such as infectivity, incubation periods, environmental survivability, the dosage required for successful infection, and the severity and progression of the resulting illness, including potential lethality. Viral diseases pose the greatest challenge in treatment as they cannot be treated with antibiotics and antivirals are only limitedly effective. Additionally, viruses continually evolve, often undergoing frequent mutations during replication [1].

Globally, numerous pathogenic organisms can cause or transmit diseases, all of which could potentially be weaponized under certain conditions. Key criteria that determine whether a pathogen is suitable for use as a biological agent include its resilience in external environments, its ability to spread, stability, toxicity, potential lethality, ease of storage, and the costs and accessibility associated with its production [2].

These criteria are significant when selecting pathogens for use by terrorist groups. According to Table 1, the production costs of biological agents are negligible compared to chemical weapons, yet they can still achieve a significant destructive impact, earning them the nickname "the poor man's weapon". See Table 1 for a comparison [3].

The most critical component of a biological weapon is the pathogen itself, exclusively used in combat and categorized as a WMDs the term "biowarfare" (BWA) is commonly used internationally. Misuse of biological agents is prohibited by the 1975 Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and their Destruction, classifying them as a specific type of combat weapon among WMDs [4]. For a more detailed description, see Table 2, which tracks the Application possibilities of biological agents [2].

Table 1.

Comparison of basic characteristics of chemical and BW [3]

Characteristic	Chemical Weapons	Biological Weapons
Area	<10 km^2	100-1000 km^2
Coverage/km^2	500-1000 kg	1-5 kg
Cost/km^2	600 USD	1 USD
Duration of effect	Minutes (nerve agents) to hours	Hours (toxins) to weeks (Q-fever)
Form	Gas or liquid	Solid

3. The various categories of biological agents according to the CDC classification

The Center for Disease Control and Prevention (CDC) has categorized biological agents into three distinct groups based on the risk they pose to the general population and national security of the United States:

1) Category A: These pathogens are easily transmissible from person to person. Their deployment can lead to high mortality rates and rapid spread through the population, requiring intensive control measures which may not always be effective. Societal disruption is expected as social structures become compromised. Examples include Bacillus anthracis, which causes anthrax; Clostridium botulinum, the agent of botulism; and Yersinia pestis, responsible for the plague.
2) Category B: Compared to Category A, these pathogens spread less efficiently and are associated with lower mortality rates. Nonetheless, significant efforts are necessary to manage potential outbreaks. This category includes Coxiella burnetti, causing Q fever; Brucella spp., responsible for brucellosis; Burkholderia mallei, the agent of glanders; Ricinus communis, known for ricin intoxication.

3) Category C: This category comprises emerging pathogens that are considered a high priority due to their potential for mass exploitation in the future, facilitated by their accessibility and ease of production. High mortality and morbidity rates are anticipated with these agents. Notable examples are the Nipah virus and Hantavirus [5].

Table 2.

Application possibilities of biological agents [2]

Application possibilities	B-agens as a Biological Weapon	B-agens as a Means of Terrorism	B-agens as an Imported Infection
Primary Objectives of Impact	Destruction of the enemy's living force through lethal or incapacitating means	Inducing fear and uncertainty, possibly causing the deaths of high-profile individuals	Accidental, but possible introduction into the general population
Target Group	Military	Civilian population	Civilian population
Who Protects Against Attack	Special military units	Civil state security and health institutions	Civil institutions
Duration of Impact	Short-term effect, short incubation period leading to rapid death, epidemic spread	Long-term effect, relatively long incubation period, limited spread	Mostly short-term effect and limited spread

4. BW and B-agens from the perspective of national and international policy

The Biological and Toxin Weapons Convention (BTWC) is a key international document in the field of BW protection. It was the first multilateral treaty to categorically ban a class of weapons. The treaty prohibits the development, accumulation, production, or transfer of biological materials and toxins in types and quantities that have no justification for protective or peaceful use. It also prohibits the development of weapons, equipment, or delivery systems for the dissemination of such substances or toxins. If a state owns any such substance, toxin, or delivery system, it has nine months from the entry into force of the treaty to destroy its stocks or divert them for peaceful use. All details are described in 25 individual articles of the Convention. The Convention was signed on April 10, 1972, in Moscow, London, and Washington. After ratification, it entered into force on March 26, 1975. For interest, I am also including two current images that illustrate the historical development and use of biological weapons (Figure 1), as well as the current state of biological weapon activities as of 2022 (Figure 2) [6].

The Convention stipulates that states will cooperate bilaterally or multilaterally in addressing compliance issues. States may also submit complaints to the UN Security Council resolution if they believe another state is violating the treaty. However, there is no BTWC enforcement body that would allow sanctioning for apparent violations, as was the case in the past. Every five years, a review conference is held to review the implementation of the convention and to establish confidence-building measures [7].

As the Czech Republic is a signatory to the Convention on the Prohibition of BW, it is obliged to fulfil the duties related to it. The Convention is thus a key document that has also been reflected in our valid legislation. The Convention was signed by the then Czechoslovak Socialist Republic on April 10, 1972, and ratified on April 30, 1973. The Czechoslovak Socialist Republic issued it in the Collection of Laws as Decree of the Minister of Foreign Affairs No. 96/1975 Coll. After the dissolution of Czechoslovakia, two separate states were created. The effective date of succession by the CR is January 1, 1993.

The CR is one of the current 185 treaty states that have decided to incorporate the obligations set by the Convention into their legal system. The central norm relating to the Convention is Act No. 281/2002 Coll., on Certain Measures Related to the Prohibition of Bacteriological (Biological) and Toxin Weapons and on Amending the Trade Licensing Act, as amended. The CR has been a strong advocate of non-proliferation, disarmament, and arms control policies since its independence. Since 2004, when the CR joined the European Union, it has been guided by the policy of the European Union in these matters.

The CR is also among the treaty states that have incorporated the obligations set by the Convention into their legal system. The central norm relating to the Convention is Act No. 281/2002 Coll. on Certain Measures Related to the Prohibition of Biological and Toxin Weapons and on Amending the Trade Licensing Act, as amended. Based on this, the State Office for Nuclear Safety (SÚJB) has been the national authority for fulfilling the Convention since 2002 [8].

Fig. 1. Historical BW activity [8].

Fig. 2. Current BW activity [8].

5. Description of the research investigation

A thorough examination of existing Czech and international academic literature on BW was undertaken as part of the theoretical groundwork. The objective was to summarize essential insights on BW by utilizing pertinent data from online databases and current legal frameworks. This comprehensive approach facilitated a detailed exploration of the fundamental attributes and obstacles linked with BW within scholarly discourse. In the empirical phase, a quantitative research methodology was adopted, employing a survey questionnaire to gauge public sentiment on BW matters in the CR. The survey was administered in 2022. Distribution was carried out through direct web links and across diverse demographic segments via social media and email channels. The survey was conducted anonymously using a web application. Data analysis was conducted using R software, employing contingency tables to compare categorical variables. Hypothesis testing utilized the $\chi 2$ independence test to ascertain the presence or absence of relationships between observed variables. The study encompassed 301 respondents, constituting a representative sample of the general populace, aimed at illuminating their perspectives and stances regarding BW.

6. Discussion of results

In the framework of the survey, 27 distinct questions were formulated. However, for the purposes of the article, we have elected not to include all the findings but to focus more closely on those that we subjectively perceive as the most significant or those that most distinctly delineate the status of BW within the CR as well as their perception from the perspective of the civilian population.

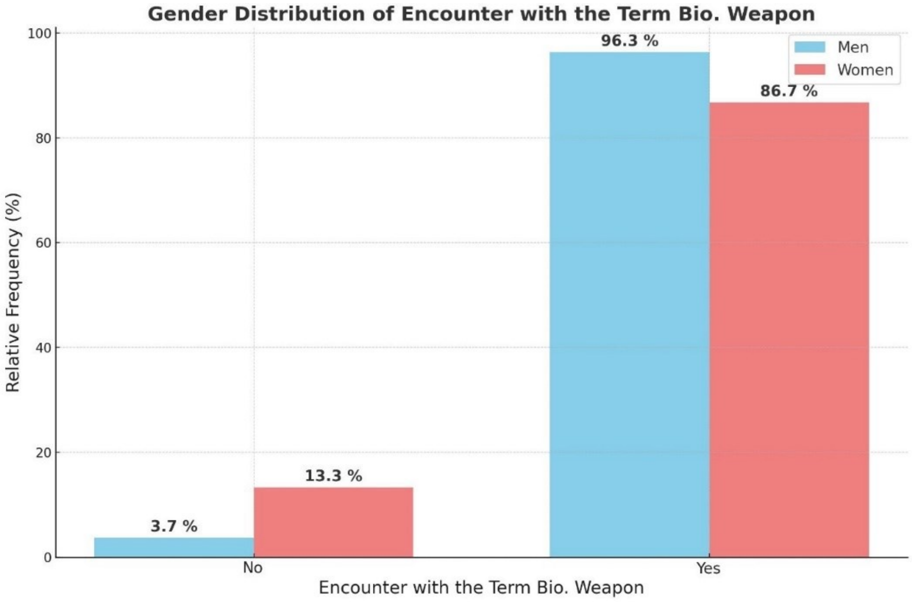

Fig. 3. Encounter with the term "Biological Weapon" in relation to the gender of respondents [source: own].

Majority participants recognized the term “biological weapon”, with men slightly exceeding women in awareness, see Figure 3. An open-ended question sought their interpretation of the term, which was complex due to subjective responses without strict right or wrong criteria. Responses, categorized broadly, showed that 218 participants (72.4%) aligned with the accurate definition, referencing pathogen-based weapons for mass destruction. Another category had 64 responses (21.3%) showing a disconnect, while 19 (6.3%) confused biological with chemical or nuclear weapons. Thus, 91% knew the term, with 72.4% correctly articulating its meaning.

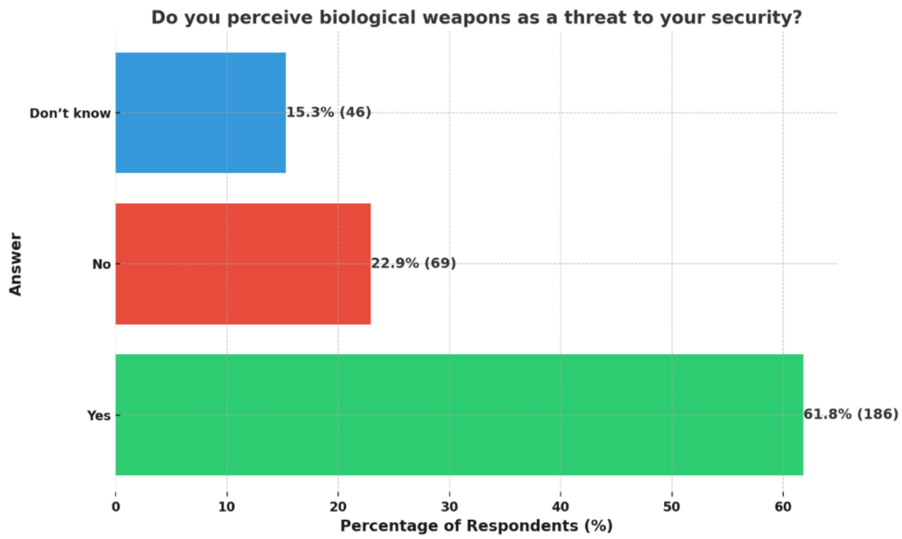

Fig. 4. Results from the question investigating whether respondents perceive a biological weapon as a threat to their security [source: own].

In the survey component assessing the perception of BW as a threat to personal security, a clear majority of respondents (61.8%) affirmed such concerns, see Figure 4. Considering the inclusion of BW within the category of WMDs one might subjectively expect a somewhat higher percentage aligning with this viewpoint. The observed response rate can be attributed to several factors. The likelihood of a BW attack on our territory is relatively low compared to other countries, partly due to the low probability of a terrorist act (bioterrorism is currently deemed most likely—refer to previous discussions), and the risk of a biological war occurring within our borders is also minimal. Media coverage does not allocate sufficient attention to the issue of BW (a finding that was also reflected in public opinion on one of the survey questions), leading to its marginalization in societal discourse. As a result, people may not perceive BW as an immediate threat in most cases, but rather only in a slightly more than half of the instances.

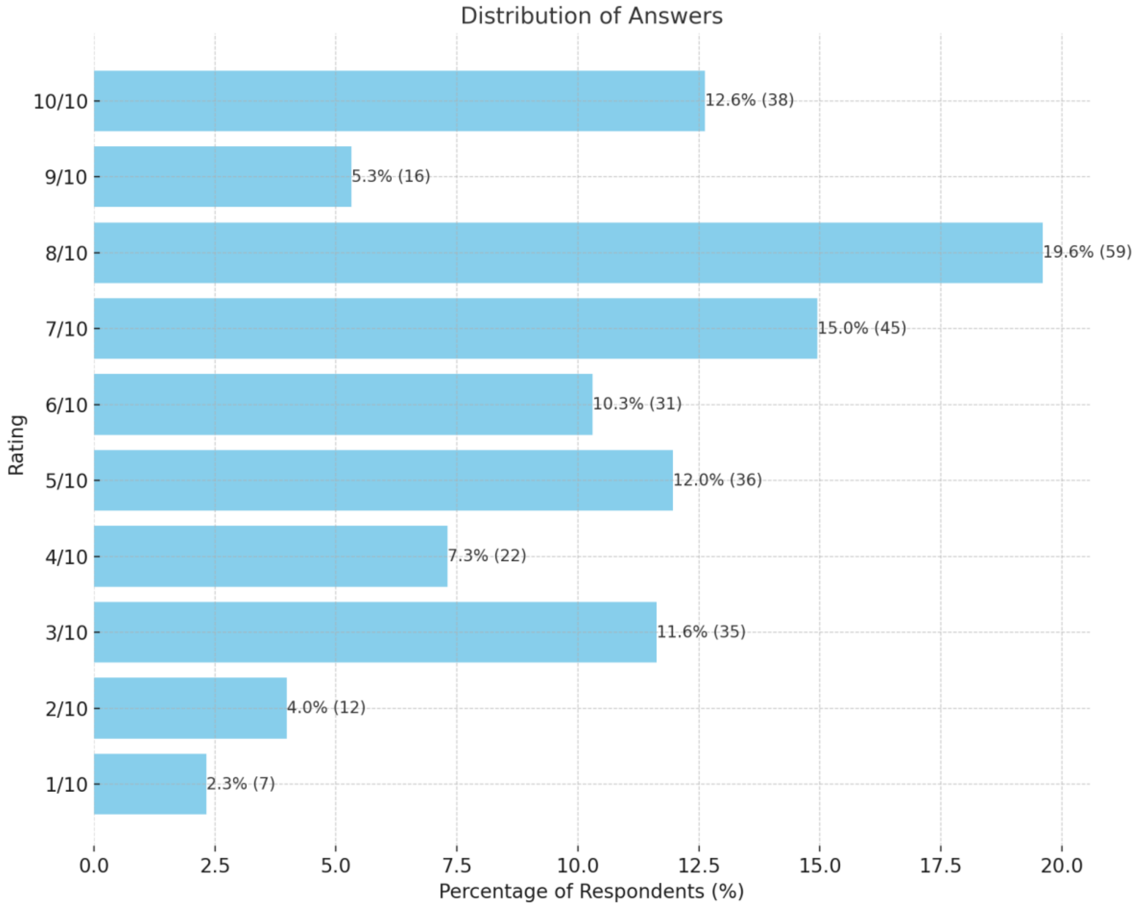

Fig. 5. Perception of the current relevance of BW on a scale of 1-10 [source: own].

The survey gauged the perceived relevance of BW on a scale from 1 to 10, where 1 denoted 'not relevant' and 10 denoted 'highly relevant', ss shown in the Figure 5. This parameter was instrumental in substantiating the study's conclusive evaluation. The distribution of responses did not show any option exceeding a 20% share, with a relatively even spread across all ten points on the scale. The option rated 8/10 emerged as the most represented, with 59 responses (19.6%), while the least represented was the option rated 1/10, with 7 responses (2.3%). Due to the evaluative complexities, the data were aggregated into three final categories:

- 1-3 for 'Not Relevant',
- 4-7 for 'Relevant',
- 8-10 for 'Highly Relevant'.

An arithmetic mean of 6.3 placed the consensus within the 'Relevant' category. Considering the timing of the survey, amidst the backdrop of the Ukrainian conflict, it was subjectively expected that respondents would rank the issue as 'Relevant' to 'Highly Relevant.' Although the average score of 6.3 is somewhat reassuring, it prompts further inquiry as to whether it ought to have been higher, especially considering an escalating European conflict with the potential to extend beyond borders, wherein weapons of mass destruction, including BW, might be employed.

Mass media are the dominant source of information in today's world, and it would be remiss not to consider whether they allocate adequate attention to BW as part of the broader category of weapons of mass destruction. Most survey participants selected 'no', with a total of 211 responses (70.1%), indicating that the subject of BW is not given much space. The 'yes' and 'don't know' options had very similar statistics—14.3% and 15.6%, respectively. These results, as shown in Figure 6, suggest that most people feel that the topic of biological weapons does not receive an ample coverage.

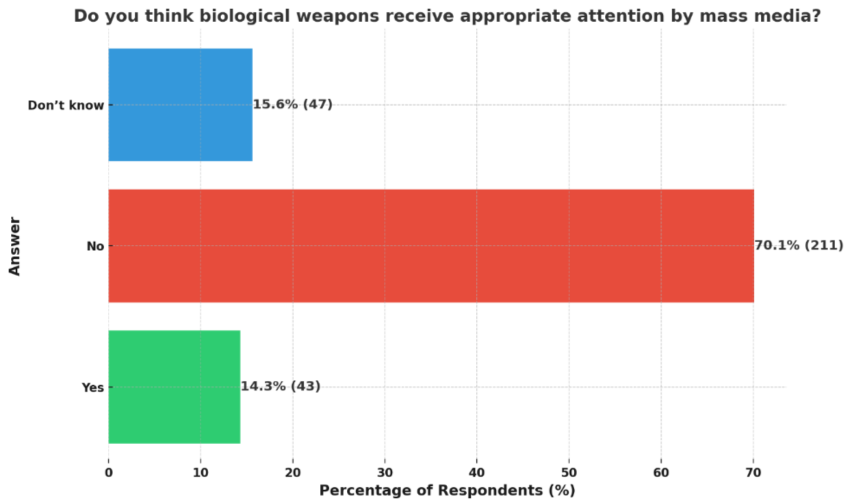

Fig. 6. Perception of media activities regarding the topic of BW [source: own].

The outcome could have been partially influenced by the ongoing war conflict, yet still, 70% of respondents leaned towards 'no'. Here we see a fundamental issue where this topic has been consistently neglected by mass media, resulting in a general lack of basic awareness regarding BW, such as protection against them. Due to the lack of media interest, it's challenging to obtain even rudimentary information on BW. This subject is not directly encountered in educational curriculums at the elementary or secondary school level. There is no unified online platform that comprehensively educates readers about BW in a digestible manner. Although there are several verified online sources, they primarily serve those who have a personal interest in seeking information on the topic. Therefore, an impartial citizen rarely comes across a consolidated overview of information, even though our survey indicated that over 91% of respondents have encountered the term 'BW' in some form in their lives.

Given the dynamic developments in the world and the current geopolitical climate, where conflicts rage in various regions and terrorist organizations are active, the deployment of BW cannot be entirely ruled out, despite the near-global restriction on their development and use under the BTWC. Also noteworthy is the technological advancement that could potentially facilitate the easy and inexpensive cultivation of dangerous pathogens for warfare purposes. These facts alone raise the question of whether future generations will need to pay closer attention to the issues surrounding the use of BW. The finding that 232 respondents, accounting for 77.1% of the total, view the relevance of BW as likely to increase over time is quite compelling. Thus, it can be asserted that participants generally believe the issue of BW use will gain progressively more relevance as time goes on.

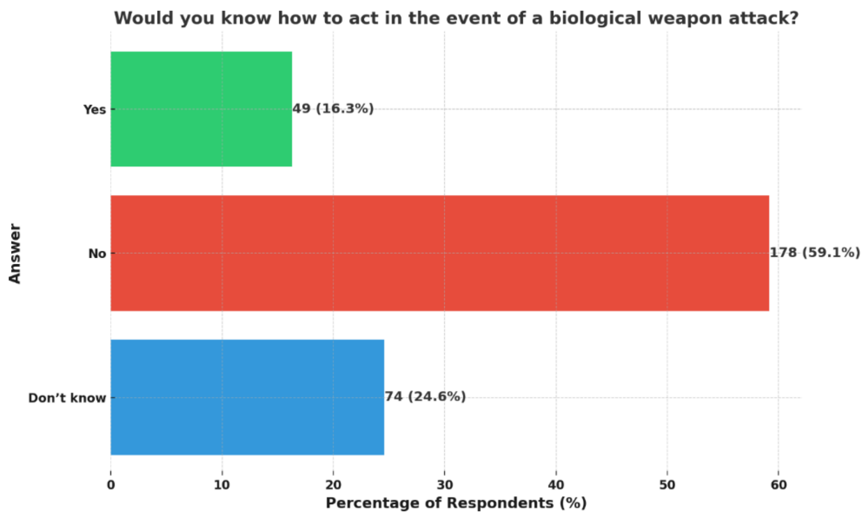

Fig. 7. Awareness of how to act in the event of a BW attack [source: own].

The survey results concerning preparedness for a BW attack brought somewhat troubling, albeit expected insights. Only 16.3% of respondents indicated that they would know how to react in the event of a BW attack, see Figure 7. This is considered a critical piece of information, as knowledge of basic protective measures, whether professional or improvised, is essential for survival in the event of a biological weapon deployment, a laboratory leak, or any other related emergency among the civilian population. Addressing this deficiency should be a target for remediation in the coming years. For the sake of interest, we also present the ratio of responses across genders. While 27.9% of men would know how to respond in the event of a BW attack, only 6.7% of women would likewise be able to act adequately. We did not investigate the cause of this disparity further, so we can only estimate the various factors that might influence it.

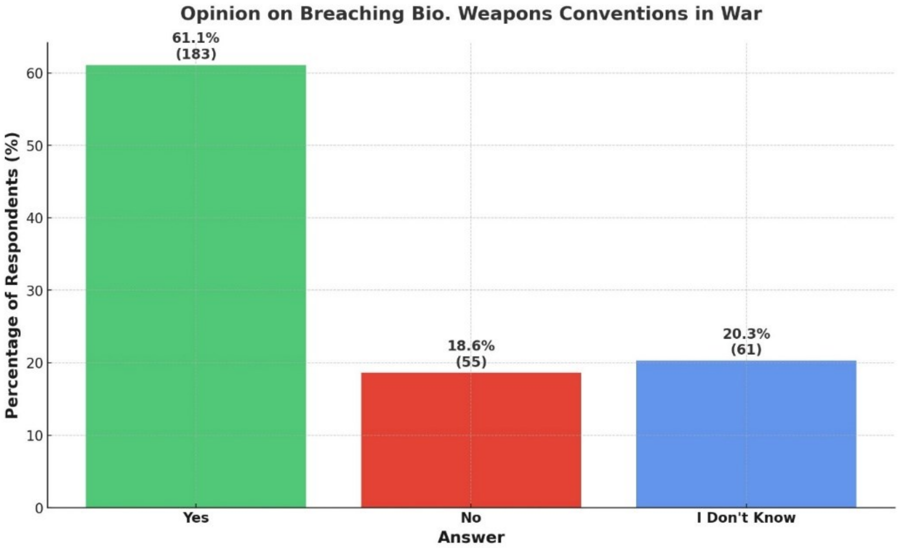

Fig. 8. Public trust in international conventions in case of war conflict [source: own].

We presented respondents with a simplified statement based on Cicero's quote, "In war, law falls silent": in the event of a wartime conflict, valid conventions and international treaties would be breached to gain an advantage over the enemy. As can be seen in Figure 8, we sought to assess how much the respondents agreed or disagreed with this proposition. Despite the existence of legal frameworks like the BTWC, 61% of respondents believed that such conventions would be widely violated to secure advantages, a perspective that reflects deep-seated skepticism about the effectiveness and significance of international agreements during significant military and humanitarian crises affecting Europe—the most extensive since World War II. This finding underscores the serious concerns about the actual effectiveness of such international treaties and raises questions about the real weight of legal documents in times of crisis.

7. Evaluation of the research hypothesis

Two research hypotheses were formulated as part of the research investigation. Their evaluation is presented below.

H1: People under 30 consider the use of BW as a current topic less often than those over 30.

When conducting a chi-square test of independence, the p-value came out to 0.737 > 0.05 – there is no significant relationship between age and responses and further testing in the test set does not proceed. No statistically significant correlation was demonstrated between age and perception of the topic's currency. The hypothesis was not confirmed.

H2: Men are more likely to know how to act in the event of a biological attack than women.

To verify the second hypothesis, data from Question 20 were used. As illustrated in Figure 9, only 27.9% of men would know how to act in the event of a biological weapon attack. This result suggests an alternative hypothesis, which I have chosen for these purposes: “Men are more likely to know how to act in the event of a biological attack than women." For a definitive answer to this hypothesis, it is necessary to focus on the subset of respondents who did not select the "I don't know" option—those who indicated they would know how to act and those who indicated they would not know how to act in the event of a biological weapon attack. We then conducted a chi-square test of independence on these responses based on the respondents' gender. The resulting p-value was <0.001, indicating the rejection of the null hypothesis (that the gender of the respondents does not influence whether they would know how to act in the event of a biological weapon attack).

As shown in Figure 10, men are indeed more likely to know how to act than women, and this difference is significant given the test results. Therefore, the alternative hypothesis ("men are more likely to know how to act in the event of a biological weapon attack") cannot be rejected. It is also important to mention that, to minimize undesired high variability in the results caused by the small group of respondents who answered "yes," the data were not pre-split into testing and training sets. For better visualization of the results, the complete dataset was tested together.

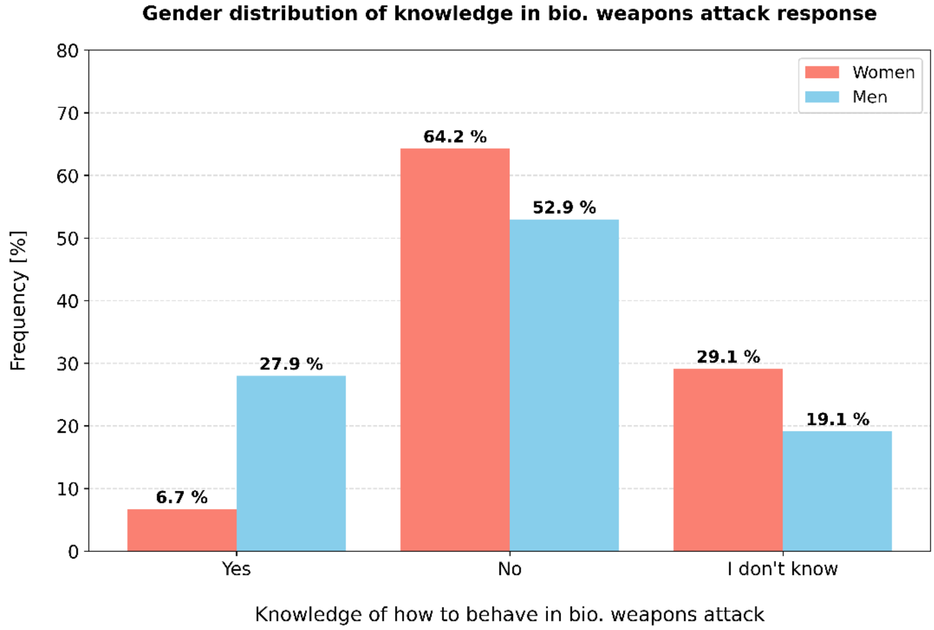

Fig. 9. Results from the second confirmed hypothesis [source: own].

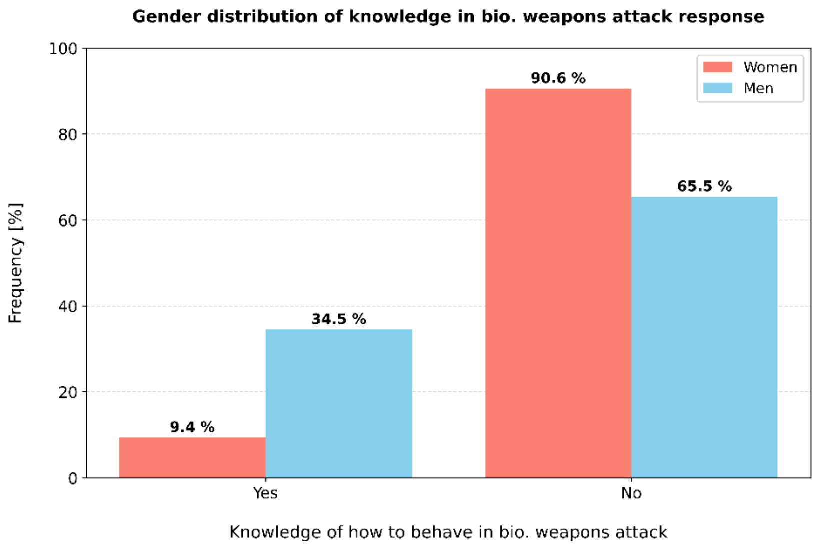

Fig. 10. Results from the second confirmed hypothesis [source: own].

8. Conclusions

Based on the obtained results, the implementation of extensive awareness programs and educational initiatives is recommended to inform the public about the risks [9,10], prevention, and protective measures associated with BW. It is imperative to enhance media coverage of the BW topic, support the integration of relevant information into school curricula, and develop targeted media campaigns aimed at expanding public awareness. Furthermore, strengthening international cooperation and transparency within control mechanisms is proposed to increase public trust in the effectiveness of international agreements. The creation of a unified online platform providing access to verified information and resources on BW could significantly contribute to demystifying the topic and increasing public awareness. Additionally, it is crucial to incorporate this issue into awareness and educational programs within the broader context of weapons of mass destruction. This approach can significantly contribute to overall public awareness of risks and protective strategies in the current security situation.

Similar conclusions were reached by authors Nenadic and Teodorovic (2020)., whose study focused on the understanding and perception of bioterrorism among the public in Serbia. The results demonstrated an overall poor comprehension of bioterrorism and a significant lack of distinction between bioterrorism and infectious agents in general. The study highlighted substantial mistrust in government institutions and news media, suggesting that these factors should be considered when designing prevention and preparedness strategies as well as interventions through knowledge communication [11].

Conversely, Sterling et al. (2005) examined healthcare professionals in industrial settings, emphasizing that industry health professionals are well-positioned for early recognition, surveillance, and isolation of bioterrorism-related incidents. Despite heightened awareness of bioterrorism risks following the September 11, 2001, attacks, there remained a significant lack of local preparedness. Sterling et al. underscored the necessity of targeted education to improve the ability of these professionals to respond to bioterrorism threats effectively [12].

Pollard (2003) analysed data from national surveys conducted before and after the anthrax bioterrorist attacks in the fall of 2001. Their findings underscored the importance of local television, radio, and national health officials as trusted sources of information during bioterrorist incidents. This insight is crucial for effective communication planning during such events [13].

Shadel et al. (2003) conducted a national needs assessment of infection control practitioners (ICPs) in the United States between October 2000 and August 2001. Their study revealed significant regional differences in the perceived threat of bioterrorism and showed that only half of the respondents had prior training in bioterrorism preparedness. The study highlighted the urgent need for more resources and opportunities for clinical education in this area to provide continuing education credit. Shadel et al. recommended various instructional designs and media delivery methods to meet ICPs' educational preferences and needs [14].

In summary, the comparison of various studies indicates that awareness and preparedness for biological weapons and bioterrorism are generally insufficient across different regions and among different groups of healthcare professionals and the public. A common theme among these studies is the need to enhance education and training in this area, underscoring the importance of implementing extensive awareness programs and educational initiatives as recommended by the results of this study. This approach can significantly contribute to increasing overall public awareness of risks and protective strategies in the current security situation. Additionally, future research should focus on incorporating more objective measures of knowledge and awareness to address the limitations of subjective self-reported data used in this study.

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Exploring the Defence Industry´s Macroeconomic and Microeconomic Perspectives under New Security Conditions

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Abstract

The purpose of this paper is to explore the economic aspects of the defense industry under new security conditions. The paper utilizes data from SIPRI. To address the impact of the defense industry, descriptive and comparative analysis methods were employed. From statistical methods, regression analysis was applied to selected countries for the years 2014 and 2022. GDP per capita, military expenditures, arms exports, and the granting of military licenses are interconnected. Arms exports, along with issued arms export licenses, can be considered a driving force for gross domestic product growth.

KEY WORDS: *defence industry, arms export, arms import, military spending, defence expenditures, new security conditions, arms trading, economic growth, national security*

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1. Introduction

In the presented analysis, aspects of the defence industry under new security conditions are examined from both macroeconomic and microeconomic viewpoints. At the macroeconomic level, it is investigated how the export of arms can be conducive to the stimulation of gross domestic product (GDP) growth, augmentation of public sector revenues, and the bolstering of foreign trade [1]. At the microeconomic level, attention is given to the exploration of research, development, employment, and issues pertaining to fixed capital.

As part of the current paradigm, the focus is primarily on examining the impact of military expenditures on economic development. This paper focuses on arms exports and the impact of the defense industry on GDP. This constitutes the novelty within the neoliberal paradigm, and the practical significance lies in supporting the defense industry as a means of economic growth and enhancing national security.

Since arms transactions are essentially long-term, and the acquisition of major weapon systems is commonly followed by years of support and the supply of spare parts, suppliers aiming to maximize profit over the entire lifecycle of the transaction are prepared to offer major weapon systems at low prices, seemingly unrelated to costs. They take advantage of the buyer´s subsequent dependency (on spare parts, etc.) to charge highly profitable prices in the later stages. This leads to an increase in the volume of military exports of dual-use goods.

Government involvement in the arms trade is derived not only from purely economic circumstances and sometimes supports transactions lacking economic justification. If a sale is not profitable for the company but is in the interest of the government's strategy and policy, the government may subsidize the transaction in various ways. Conversely, if a sale is profitable for the company but undesirable for other reasons, the government can prevent the sale through administrative means. Thus, government policy and involvement affect arms supplies no less than the fundamentals of comparative advantage. National economies are required to incessantly adjust to global shifts that encompass financial aspects, climate change, warfare conflicts, migration waves, economic cycles, among others. Numerous analyses that portray global trends and the adaptation of the defense industry to these trends are also reviewed. Analyses conducted post-2008 [5] and 2021 [3] imply a substantial necessity for the restructuring of the defense industry and defense policy. Such restructuring is suggested to encompass the identification of critical technologies and competencies for national security and defense, the establishment of acquisition agencies for the centralization and enhancement of public procurement, as well as the mitigation of the habitual underestimation of the defense sector´s significance in comparison to other sectors [3]. Mainly the current war in Ukraine has been identified as an influential factor contributing to the macroeconomic and microeconomic fortification, as well as to an improvement in the industry´s reputation. Increased support for arms manufacturing by the banking sector is observed. The standing of the arms business has transitioned to becoming pivotal post the invasion by Russia, indicating a shift in the approach of governments and society towards the growth in military expenditures.

2. The Mathematical Background

The data for this paper were sourced from Stockholm International Peace Research Institute´s databases (SIPRI databases [6], [7]. These databases contain comprehensive information about companies involved in the manufacturing of weapons and the provision of military services. This includes both, public and private entities but excludes production or maintenance units of armed forces. Access to these databases enabled the acquisition of data for arms companies based on open sources. The sources included annual corporate reports and articles in journals and newspapers. Data for all years are revised annually based on new information. Since the early 1990s, an increasing number of governments have decided to publish national reports on their arms exports. Currently, there are no data series comparing the values of arms exports between countries, apart from SIPRI yearbooks. Methods for generating data series are largely based on already available data series relevant for arms production [2]. This pertains to the import and export of weapons, state contracts, and the turnovers of the world´s largest arms companies. Various methods employ different definitions of the scope of arms production; therefore, it was necessary to adhere to a single definition, namely SIPRI.

For addressing the behavior of the defense industry in new security conditions, the method of descriptive and comparative analysis was employed. From statistical methods, regression analysis and statistical representation of arms exports of selected countries between 2014 and 2022 were employed. The results of this study were subjected to literary verification within the framework of the Popperian paradigm. It asserts that for a theory to be considered scientific, it must be able to be tested and potentially proven false.

For a comprehensive assessment of the impact of arms production on economic development, it would be suitable to create a multivariable model used by Yesilyurt et al. [1].

$$Q_{it} = \delta_i + \beta 1 * \ln(MILEX_{it}) + \beta 2 * \ln(GDPPC_{it}) + \beta 3 * \ln(X_{it}) + \beta 4 * \ln(M_{it}) + \lambda_t + \varepsilon_{it} \quad (1)$$

where: Q – arms production; $MILEX$ – military expenditures; $GDPPC$ – real gross domestic product (GDP) per capita; X – arms exports; M – arms imports; δ_i and λ_t – country-specific and time-specific effects; indexes i – country; t – time; $\beta 1$-4 – parameters; X – arms export that includes export of approved military licenses.

When using this equation (1), it follows that arms production depends on the level of government military expenditures, i.e., the state´s demand for arms production, the standard of living in that state, the level of arms production exports, the level of arms production imports, and specific parameters of the given state.

In this paper, the analysis of the economic determinants of arms production in selected countries over the period from 2020 to 2022 was conducted using regression analysis. The findings indicate that the magnitude of GDP per capita, military expenditure, arms exports, and military licensing are interrelated. These factors mutually influence arms production.

3. Investigation Results

The macroeconomic perspectives of the defence industry under new security conditions reveal a significant impact of increased defense expenditures on national economies. According to SIPRI, 2023 has experienced the steepest year-on-year increase in global military expenditure since 2009. The impact of influence on the national economy is confirmed by studies from authors in Spain, published in the journal Defense and Peace Economics, titled “The Determinants of Arms Production”. These studies utilized a wide spectrum analysis [1]. World military spending per person has been the highest since 1990, amounting to $306 [10]. The rise in global military spending in 2023 can be attributed to the new security conditions, primarily the ongoing war in Ukraine and the escalating geopolitical tensions in Asia and Oceania and the Middle East. Elevated investment in defense often leads to real GDP growth as it stimulates domestic production capabilities and supports employment within the sector. States are compelled to reallocate substantial resources from other public expenditures such as healthcare and education, potentially leading to fiscal strain. Additionally, increased defense spending can drive inflation, especially if financed through borrowing. On an international level, sustained growth in military expenditures can bolster a nation´s geopolitical position but simultaneously deepen international tensions and the arms race. Thus, the overall macroeconomic impact of new security conditions on the defense industry is intricate and requires careful management and coordination.

At the microeconomic level, the defence industry under new security conditions is facing significant changes affecting individual firms and market dynamics. The increased demand for advanced defense technologies pushes companies to invest in research and development, which escalates their costs, and the risks associated with new projects. For many firms, it is crucial to diversify their customer bases and develop export markets to mitigate reliance on domestic government contracts. New competitive pressures emerge, where smaller and more agile companies can compete with traditional defense giants through innovation and specialization. Additionally, there is an increase in regulatory and compliance requirements that can pose significant challenges for some actors. Companies in the defence sector must adapt swiftly to changing security conditions and market demands, shaping their strategic decision-making and operational practices.

In addition to the analysis of the microeconomic and macroeconomic aspects of arms production, a regression analysis for selected countries was conducted, yielding the following results:
Arms Export: Trend-indicator value: p-value: 4.726e-09 and Pearson: 0.9904353
Regression analysis for selected countries in 2014 and 2022 is presented in Fig. 1.

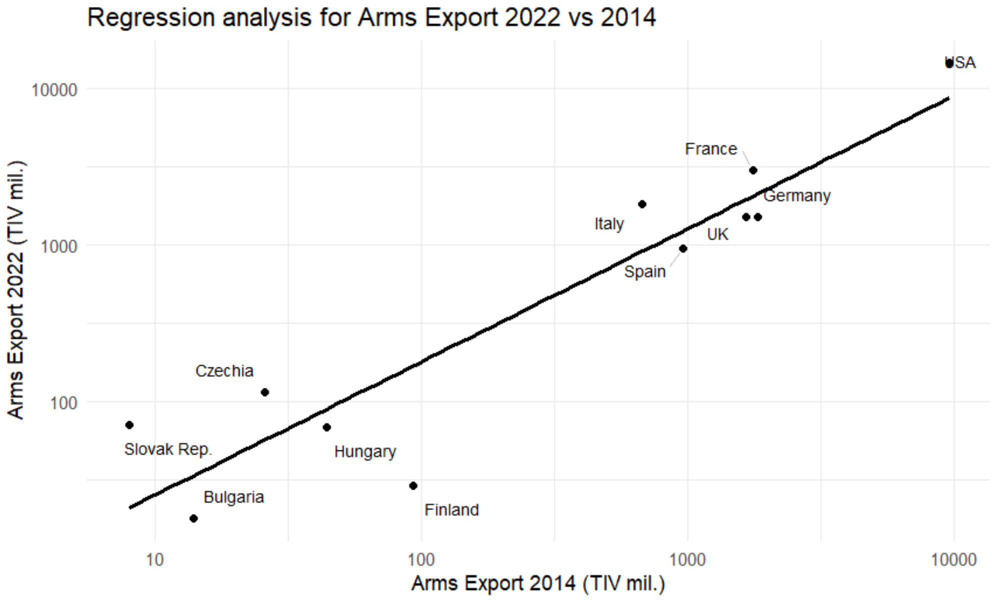

Fig. 1. Regression analysis of arms export in selected countries in 2014 and 2022

Fig. 1 shows an increase in arms exports for most of the examined countries during the period of 2014 to 2022. The greatest growth in arms exports has been recorded by Slovak Republic, Czechia, Italy, France and USA. The results of this survey indicate that the size of arms exports is influenced by the economic development associated with the technological innovativeness of the industry. Table 1 shows that during the analyzed period, only UK, Spain, Finland and Germany of examined counties decreased their arms exports in 2022 compared to 2014.

Table 1.
Arms export in selected countries in 2014 and 2022

E – Arms Export (TIV mil.)	Country	Hungary	Slovak Rep.	Finland	Bulgaria	Czechia	German y	Spain	Italy	France	UK	USA
	2014	44	8	93	14	26	1 822	962	677	1 755	1 658	9 588
	2022	68,36	71	29	18	116	1 510	950	1 825	3 021	1 504	14 515

TIV = Trend-indicator value, it is used by SIPRI to measure the volume of international arms transfers, it reflects trends in arms flows between countries and is not directly related to financial transaction values but rather indicates the volume of arms transfers
Source of data: SIPRI, 2024

The size of arms exports is also influenced by the licensing policy of arms production. Arms exports together with issued licenses for the export of weapons can be seen as a driver of gross domestic product growth. The European Union´s licensing policy regarding the export of arms applies to individual arms transactions and serves as a permit for trading military goods. The licensing policy also covers the trade of dual-use goods. Each arms transaction should obtain a license, although the procedure may slightly differ in various countries. Hence, the term "arms export license" is used. Some authorities do not specify the volume of sold goods and services, but rather the number of approved licenses for these transactions. An arms export license refers to the permission granted by the national export licensing authority. Export licenses represent the authorization for arms manufacturers to export projects, technologies, and materials. The licenses also pertain to the sale of information that could have military or dual use. Some countries, instead of reporting the actual transfers of arms goods, publish the number of issued licenses, within which the values of the exported goods are also mentioned [9]. The sale of military licenses supports arms exports. In all developed countries, such as the USA, UK, France, Italy, Spain, Germany, and Finland, there has been an increase in the volume of military licenses. Countries like Slovakia and the Czech Republic had lower military license sales in 2020 compared to 2014. Military licenses then have a multiplicative effect on economic development. Fig. 2 shows regression analysis of arms licenses in selected countries between 2014 and 2022.

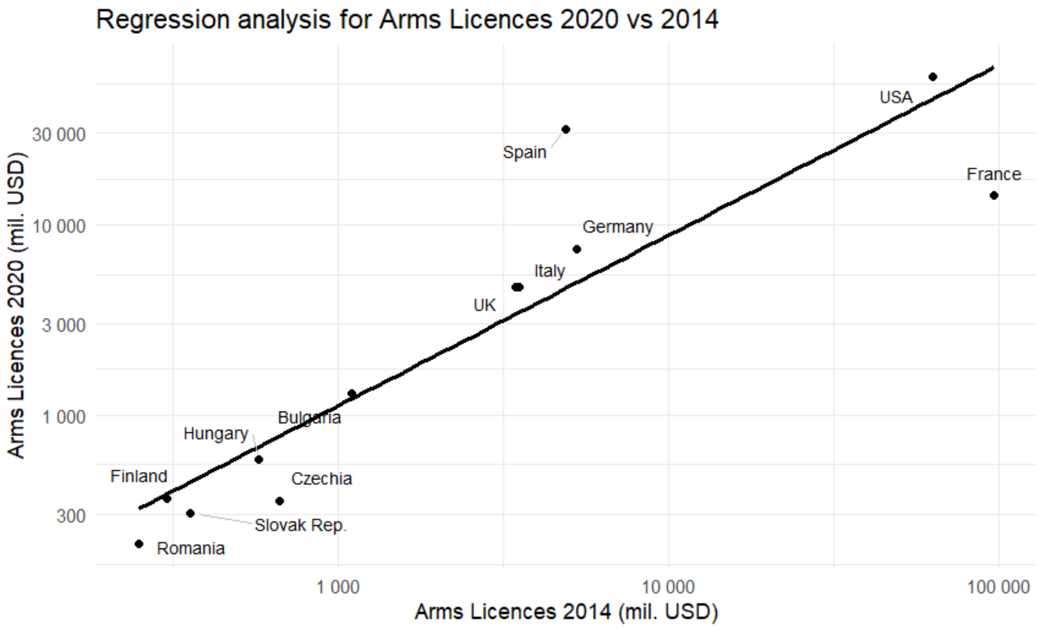

Fig. 2. Regression analysis of arms licenses in selected countries in 2014 and 2020

Table 2 presents the values of the volume of military licenses from selected countries for the regression analysis shown in Figure 2. "License" typically refers to the authorization granted by the National Export Licensing Authority, signifying that the goods, projects, and technologies approved for export in the arms industry are permitted. This includes weapons, explosives, goods, technology, software, parts, and equipment modified for military use (such as vehicles), as well as dual-use items. Licenses also cover the sale of information that could have military or dual-use applications – such as technology, training manuals, plans, and projects. They are required for information in all its forms. Instead of reporting on the actual transfers of arms goods, some countries disclose the number of licenses issued, under which the values of the exported goods are also indicated.

Table 2.
Selling of military licenses in selected countries in 2014 and 2020

Selling of Military Licenses (mil. USD)	Country	Hungary	Slovak Rep.	Bulgaria	Finland	Czechia	Germany	Spain	Italy	France	UK	USA
	2014	573	355	1 098	301	664	5 271	4 862	3 516	97 211	3 429	63 034
	2020	585	304	1 301	366	355	7 453	31 782	4 702	14 152	4 664	59 577

Source of data: UK Parliament (2023), Council of the European Union (2023), SIPRI (2024)
Manufacturing technologies used in arms production are less widespread than in other industries. As a result, this sector is dependent on domestic resources for its transformation. Significant investments in industrial research and development are essential to maintain an advanced technological level and continuous production. Arms production in the implementation of licenses can have a positive impact on real product growth in economies if it contributes to increased employment and technology development. Arms production of dual-use goods can create jobs in the manufacturing of weapons and military equipment. It can also contribute to technological progress, as it requires the development of new technologies to produce weapons and military equipment. These technologies can later be utilized in other sectors of the economy, which can contribute to their growth. This phenomenon is known as the diffusion effect.

The production of weapons constitutes a separate sector in the economy, which employs many workers and creates business opportunities, as noted by Britz [8]. This sector can include the manufacturing of weapons, their distribution, sales, maintenance, etc. Military licenses contribute to the growth in the volume of weapons and thus can also contribute to increased employment in areas where this production is concentrated. The production of weapons can support investments and innovations in the technological sector. The development of new weapons, highly specialized technologies, and other related industrial fields can stimulate progress and growth in the broader economic context.

Arms trade is considered a special case of international trade under conditions of imperfect competition, where suppliers make decisions about sales not only based on economic profit but also in terms of their security implications. Arms transfers that have a positive effect on the security of suppliers in the short term may turn into a negative effect in the long term, and vice versa. For example, arms transfers that are initially intended for legitimate self-defense can accumulate to the point where the recipient gains offensive capability, thereby threatening the interests of the supplier. From the perspective of individual corporations, the first group is only interested in economic profit and its maximization, while the second group of corporations seeks to maximize the aggregate present value of economic profit and aims for the best possible security implications over time. Time is also significant for the recipient: they see the supplier's willingness and ability to maintain long-term relationships as crucial, especially regarding the supply of spare parts and re-supply during times of conflict. Defense companies and other advocates of arms exports argue that suppliers must ignore the externalities arising from sales, or the security implications, due to competition. It is often stated that if they do not sell weapons, someone else will do so in the competitive market.

Conclusions

The defense industry is undergoing a far-reaching process of adaptation because of changes in the security environment [8]. Based on our study, the following main trends can be distinguished:

• defense production markets in several countries have been affected by greater market freedom, competition, and exhaustion of arms deliveries for Ukraine; the sustained support for Ukraine has led to a depletion of existing arms stockpiles, necessitating rapid production to meet ongoing demands. This situation has pressured manufacturers to not only ramp up their production capacities but also to ensure that their supply chains are robust and flexible, consequently, there is a growing need for diversified sourcing of raw materials and advanced components to mitigate vulnerabilities and maintain steady production flows, the interplay between increased market freedom and the urgency of replenishing defense inventories underscores the complex and evolving landscape of the defense production markets;

• new conditions are leading to transformations in the traditionally close relationship between the state and producers [3]; the evolving geopolitical landscape and increasing emphasis on cost-efficiency and technological advancement have prompted governments to re-evaluate their ties with defense contractors. Instead of the previous model that heavily relied on long-term contracts and guaranteed government backing, there is now a shift towards more competitive bidding processes and performance-based assessments;

• the military conflict in Ukraine is driving the modernization and expansion of the defense industry[4]; the exigencies of the conflict have highlighted the need for advanced technological capabilities and state-of-the-art equipment, prompting countries to accelerate the development and deployment of next-generation defense systems, this modernization effort encompasses a wide range of innovations, including enhanced cyber warfare tools, autonomous vehicles, precision-guided munitions, and advanced surveillance technologies;

• increased defence budgets are triggering a crisis in the defense industry, which is now operating in a much more complex environment than before and is seeking new resources for production – bank loans, raw materials; the substantial infusion of funds has led to an unprecedented demand for rapid expansion and modernization, but this surge has also exposed significant challenges within the industry; companies are finding it increasingly difficult to secure the necessary raw materials due to global supply chain disruptions and geopolitical tensions, which drive up costs and delay production timelines; to finance the scale-up of operations and meet production goals, many defense firms are turning to financial institutions for substantial loans, increasing their financial risk and debt burden.

Additionally, the economic impacts of these changes cannot be overlooked. The intensification of defense activities has led to significant economic ramifications, including job creation and technological advancements that benefit civilian sectors. However, it also raises ethical and sustainability concerns, particularly regarding the environmental impacts of defense manufacturing and the potential for an arms race. Addressing these issues requires a balance between national security interests and responsible stewardship of resources, underscoring the need for comprehensive policies that guide the future trajectory of the defense industry.

Limitations

Restrictions were set on the number of countries for the analysis of developments in the arms industry and arms exports, relying on available data. In the future, the availability of published data for 2023 and subsequently 2024 will benefit this analysis.

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Specific consequences of using WMD: Radioactive contamination of foodstuffs and its potential health effects

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Abstract

The excessive presence of radionuclides in foodstuffs can potentially pose health risks. Under normal conditions, the content of radioactive substances in food is very low, resulting in only a small fraction of the total dose caused by natural radiation. This may be substantially different in the case of radiological accidents or terrorist attacks, resulting in increased levels of radioactivity in the environment, which may contribute significantly to the radioactivity of food. The situation must be monitored to assess the contribution of internal exposure coming from ingesting contaminated food. The paper discusses the occurrence of radioactivity in various foods, including its origin and effect on the total population exposure due to radioactive contamination of the environment following the use of WMDs (Weapons of Mass Destruction). To minimise the potentially harmful consequences of such events, the radioactivity in food has to be controlled. The probability of threats of possible radiological attacks in the contemporary geopolitical situation has recently increased.

KEY WORDS: *Weapons of Mass Destruction, food, radioactive contamination, ingestion, long-term effects, population safety, committed effective dose, Chernobyl, Fukushima.*

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1. Introduction

In everyday life, people are exposed to both natural and artificial radiation sources. Radionuclides are inhaled and ingested through air, food, and water on a daily basis. Most of these radionuclides naturally exist in our environment, though some portion comes from medical and industrial radiation use [1,2]. During nuclear or radiological emergencies, additional radioactive materials can contaminate food. These materials can settle on the surface of foods like vegetables or animal feed from the air, rain, or snow. Over time, radionuclides can migrate from the soil into crops and animals, accumulating in the food supply. Through the contaminated water, radioactive material may reach fish and seafood. Eating food contaminated with radionuclides during such emergencies increases the body's radioactivity, thereby elevating health risks associated with radiation exposure. The level of risk depends on the specific properties of radionuclides ingested and the amount of radioactivity absorbed. The radioactive contamination of the environment may lead to an increase in the radioactivity of foodstuffs. Consequently, this will cause additional exposure to consumers above the radiation background. This is why it is necessary in such situations to pay increased attention to monitoring the content of radioactivity in all products used for the preparation of food.

Ionising radiation, a form of energy released by atoms as electromagnetic waves or particles, is omnipresent. People are constantly exposed to natural sources of radiation, such as soil, water, and vegetation, as well as human-made sources like X-rays or charged particle accelerators during medical examinations and treatment. The contribution to the overall exposure from the medical use of ionising radiation is becoming higher and higher, and now in most industrialised countries, it is comparable with the exposure to all natural radiation sources (around 3 mSv/y). On this occasion, it is worth emphasising the importance of using appropriate quantities and units to quantify radiation exposure [1,2].

Based on the radiation protection philosophy, exposure to people should be kept as low as reasonably achievable and always below the set limits for the population, workers and patients. Another rule of radiation protection is to avoid any emergencies and if they occur, to try to minimise their consequences.

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The regulatory requirements also aim to reduce even small exposure that can result in stochastic health effects. These effects, such as cancer and genetic effects, may occur later with the probability proportional to the dose. Health effects related to the consumption of radioactively contaminated food belong to this category since consuming such food could increase the risks associated with stochastic effects. It is very difficult to epidemiologically detect stochastic effects due to radiation exposure at low doses below the range of 100 to 200 mSv, but the ICRP [3] specifies the standards for radiological protection for low-dose exposures, assuming that effects would appear depending on dose levels (linear dose-response).

Under some circumstances, when the intake of radioactive substances into the body is substantial, deterministic effects may appear, which are also referred to as harmful tissue reactions. They include, for example, skin burns, damage to the lens of the eye, and at very high doses, around (6-10 Gy), the exposed person dies. These effects do not appear below a dose threshold. Above this threshold, the higher the dose, the more severe the effect.

In assessing severe radiation levels resulting in deterministic effects, quantities developed for evaluating stochastic effects, such as dose equivalent, equivalent dose, effective dose, committed effective dose and other quantities based on dose equivalent, cannot be used. This refers also to units, where in this case of low exposure, the unit of Sv (sievert) should be used, while for high dose assessment, the units Gy (gray) or Gy-Eq (gray-equivalent) must be applied. This is not always the case; inappropriate use of quantities and units may cause some difficulties in assessing real radiation protection situations.

The information necessary to assess the radioactivity of common foodstuffs was studied from different sources, mainly from scientific papers and some specific reports presenting the results of measurement of radioactivity in various agricultural and other products used for food preparation. The situation is obviously slightly different in various parts of the world. During the last few decades, a visible increase in environmental radioactivity has resulted from some significant nuclear accidents that happened in Chornobyl (1986) and Fukushima (2011).

2. Natural and Artificial Exposure

Radioactivity has existed on Earth naturally since its inception. More recently, humans have introduced artificial radionuclides for various beneficial applications. All radioactive elements in the environment are either naturally occurring or man-made. Humans have always been exposed to natural radiation, with the global average exposure being around 2.4 mSv per year (world average). Since the early 20th century, the use of radioactivity in industry and medicine has resulted in the release of artificial radionuclides into the environment. Fig. 1 illustrates the worldwide average public exposure from various radiation sources, showing that ingestion of naturally occurring radionuclides in food accounts for about 9.6% of the total exposure, approximately 0.23 mSv annually [3].

Several types of exposure to radioactive compounds exist. A distinction is made between radioactive contamination and exposure to ionising radiation. One has distinguished between internal exposure, which is the case of dealing with the impact of contaminated food, and external exposure. In general, internal contamination corresponds to the penetration of radioactive material by incorporation into the body. This can occur through ingestion, inhalation, skin diffusion, or absorption through a contaminated wound.

Everyone is constantly exposed to radiation from natural sources. This natural background radiation is an unavoidable part of our environment, though its levels vary significantly around the world. For instance, people living in granite-rich areas or on mineralised sands experience higher levels of terrestrial radiation, while those at high altitudes are exposed to more cosmic radiation. It is important to consider both external and internal exposure to radiation, as illustrated in Fig. 2 (based on [3]).

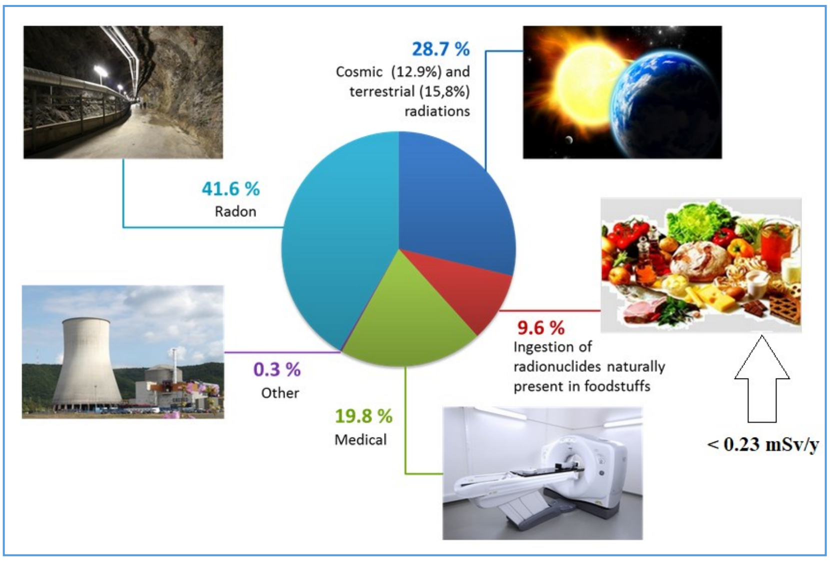

Fig. 1. Main radiation sources contributing on average to the world population.

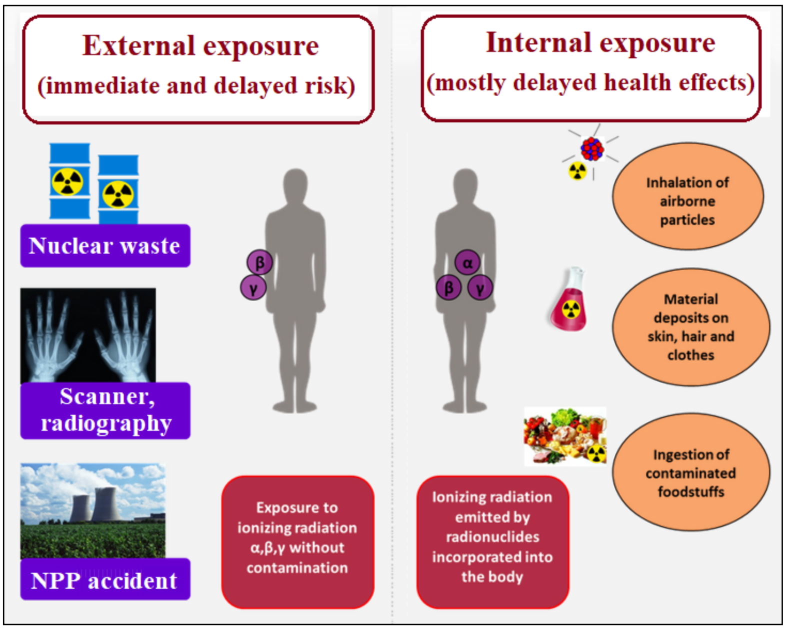

Fig. 2. Schematic view of differences between exposure and contamination. Several types of exposure to radioactive compounds exist. A distinction is made between internal and external radiation exposure (based on [3]).

2.1 Natural Radioactivity

The human body contains small amounts of naturally occurring radioactive materials, primarily derived from radioactive nuclides in the food and air we inhale. These include radionuclides like tritium (3H), carbon-14 (14C), and potassium-40 (40K). About 11% of our radiation exposure is due to these internal radioactive materials, with the majority of this dose coming from the radioactive isotope of potassium. Radionuclides such as 40K and 14C are found in air, water, and soil and become part of our diet and body tissues.

Background radiation largely originates from natural radioactive materials and cosmic rays from space. Continuous exposure to this environmental radiation results in an annual effective dose of about 3 mSv. Radon gas is the most significant source of this background radiation, contributing an average of about 2 mSv per year. Other sources include cosmic radiation, uranium and thorium dissolved in water, and internal radiation.

Besides medical imaging, artificial sources of radiation include construction materials, fuels like gas and coal, smoke detectors, luminous watches, tobacco, certain ceramics, and more. The human body maintains a balance between the radioactivity entering through food and air and the radioactivity exiting the body. Potassium-40 is the major contributor to internal radiation exposure, with natural radionuclides such as 14C also being integrated into our environment and bodies. Background radiation is a continuous exposure primarily due to natural sources like radon gas, which accounts for about 2 mSv per year and includes contributions from artificial sources like building materials and various consumer products [4].

It is evident that natural radionuclides and various harmful elements are inherent components of our surroundings. Geological and geographical factors influence the levels of these substances in the environment. Additionally, human actions like mining, smelting operations, processing phosphate ore, coal ash and industrial discharges, vehicle emissions, atmospheric deposition of particles, utilisation of biosolids, and the use of soil fertilisers can contribute to elevated concentrations of naturally occurring radionuclides and toxic elements in both the environment and food sources. Natural radioactivity in food manifests primarily through three key processes:

a. Uptake: Plant roots absorb radionuclides from the soil.

b. Deposition: Radioactive particles from the air settle on crops.

c. Bioaccumulation: Animals that consume plants, feed, or water with radioactive material accumulated radionuclides.

Bananas and Brazil nuts are two well-known instances of naturally occurring radionuclides in food. Bananas contain a small fraction of radioactive potassium, emitting a minute amount of radiation (0.1 µSv per banana). To contextualise, consuming about 100 bananas equals daily exposure to natural radiation in the United States. Brazil nuts, in addition to potassium, contain a trace amount of radium from the soil. It's crucial to differentiate natural radiation in food from food irradiation. The latter is a process employing radiation to prevent foodborne illnesses and spoilage without rendering the food itself radioactive. In a radiological event, animals may ingest radioactive materials, which could pose a risk if consumed by humans. Public guidance on food restrictions would be issued in such scenarios. To safeguard the public, regulatory authorities globally mandate testing for contaminants, including radioactivity, in food. Stringent limits and restrictions on imported foods are set to ensure public safety.

2.2 Artificial Radioactivity

Artificial radioactivity involves converting a stable nucleus into an unstable one by bombarding it with atomic particles like alphas, neutrons, or protons. This phenomenon was first identified by I. Curie and F. Joliot in 1934. Lighter elements such as boron and aluminium can be induced to become radioactive when exposed to radiation like charged particles or neutrons. This process results in the emission of radiation and elementary particles. During the disintegration, the original nucleus is termed the 'parent nucleus,' while the resulting nucleus is called the 'daughter nucleus.' When the atomic projectile collides with the parent nucleus, it triggers the transformation into an unstable nucleus, leading to spontaneous decay and the release of the daughter nucleus along with an ejected particle. The distinctions between natural and artificial radioactivity are outlined in Table 1 (based on [5]).

Table 1.
Main features characterizing natural and artificial radioactivity

Natural radioactivity	Artificial radioactivity
Emission of radiation due to self-disintegration of a nucleus	Emission of radiation due to the disintegration of a nucleus through induced process
Alpha, beta and gamma radiations are emitted	Mostly elementary particles such as alphas, betas, neutrons, positrons, etc. are emitted
It is a spontaneous process	It is an induced process
Exhibited by elements with atomic number more than 83	Exhibited by elements with atomic number less than 83
The process cannot be controlled	This process can be controlled

Many people may not realise that their highest dose comes from their medical examinations. There are some indications that not all medical examinations are fully justified. The responsibility for justification lies with the relevant professions. Relevant medical practitioners need to have special training in radiation protection to take responsibility for justification. The main purpose for justifying all radiologic procedures is to assess the benefits and risks of a requested radiographic procedure and determine whether exposure will continue. Furthermore, justification helps to prevent unnecessary radiation exposure and reduce the chances of harmful effects of ionising radiation. Various studies reported that radiological examinations are not always justified [6], and in some cases, about 50 %r reported radiological examinations were not fully justified [7].

Table 2.
Approximate mean doses relevant to societal low-dose radiation exposures and to low-dose radiation risk estimation (based on [8]):

Exposure specification	Approximate average effective dose (mSv)
Some societally relevant exposures:	
Round-trip flight, New York to London	0.1
Single screening mammogram (breast dose)	3
Single screening mammogram (breast dose)	3/y
Dose (over 70 years) to 0.5 million individuals in rural Ukraine in the vicinity of the Chornobyl accident	14
Dose range over a 20-block radius from a hypothetical nuclear terrorism incident, scenario 1: medical gauge containing cesium	3 - 30
Pediatric CT scan (stomach dose from abdominal scan)	25
Radiation worker exposure limit	20/y
Exposure on the international space station	170/y
Some low-dose epidemiological studies:	
Medical x-rays (breast dose in scoliosis study)	100
Nuclear workers (mean dose from major studies)	20
Individuals diagnostically exposed *in utero*	10

Typical radiological exams produce doses ranging from 3 to 30 mSv. It's clear that high radiation doses (over 100 mSv) significantly increase cancer risk, while the relationship at lower doses is less certain. Epidemiological studies show that the lowest dose of radiation associated with a noticeable increase in cancer risk in humans is about 10–50 mSv for acute exposure and around 50–100 mSv for prolonged exposure.

The biological effects of low radiation levels have been studied and debated for over a century. There is no doubt that intermediate and high doses of radiation (>100 mSv), whether acute or prolonged, have harmful effects on humans, including cancer. However, the situation is less clear at lower doses.

Compared to higher radiation exposure, the potential risks associated with lower doses are likely reduced. Extensive epidemiological studies are essential to accurately measure these risks. For instance, if the excess risk is directly proportional to the radiation dose, a sample size of 50,000 would be needed for a 100 mSv exposure and about 5 million for a 10 mSv dose. Essentially, to maintain statistical accuracy and power, the required sample size increases inversely proportional to the square of the dose. This trend reflects a decrease in the signal (radiation risk) to noise (natural background risk) ratio as the dose decreases.

Table 2 provides examples of radiation exposure in various situations, helping to assess and compare risks from radioactive contamination in foods. This data can be used to communicate radiation risks to the public, who often overestimate or underestimate these risks. The complexity of the many quantities used in radiation protection and the unclear definitions and measurements by some radiation monitors (often in Gy or Sv), further complicates this communication. It looks like the current system of radiation protection quantities is too complex and has to be simplified.

3. Overview of radioactivity contamination in some plants and animals

Naturally occurring radioactive elements in the environment are the main source of radiation exposure for humans and other living beings. Human activities, such as using radiation in industry and medicine, coal mining, making phosphorus fertilisers, and managing radioactive waste, affect how radiation spreads in the environment and how much people are exposed to it. Once released, radioactive materials can enter the food chain, taken up by plants or eaten by animals, which become part of human diets. Certain plants like mosses, lichens, and mushrooms can accumulate high levels of radioactive substances and are useful for identifying areas at risk of radiation. They can also indicate air, water, and soil quality. More research is needed to understand how radionuclides move through different parts of the environment and how they end up in food and herbal products that humans consume.

Radiation can be harmful to living tissue when absorbed, so understanding how radionuclides move through the environment and enter the body is important for minimising exposure. Radionuclides can enter the body through ingestion, inhalation, or skin absorption. Food and drinking water contains natural radionuclides from soil and water sources, but these levels are usually low and considered safe for consumption. However, the amount of natural radionuclides in food can vary depending on factors like agricultural practices and environmental conditions. Monitoring radiation levels in food and informing consumers about any potential risks is important. Generally, the radiation dose from natural radionuclides in food is low, contributing about 10% of the total annual radiation dose from all natural sources received by an individual. However, the situation may be completely different when the environment is radioactively contaminated as a result of the use of WMDs [11,12].

In addition to radioactive materials released in the case of the explosion of a "dirty bomb" as one type of "radiological dispersal device (RDD), the use of WMDs such as nuclear bombs can lead to the creation of huge radioactive cloud which can spread and severely contaminated an area of hundreds of square kilometres [13,14].

3.1 Radioactivity in Plants

Plants extract water, nutrients, and minerals from the soil via their roots, and they can also absorb minerals and radionuclides from their environment, which is essential for assessing potential risks to human health. This accumulation of radionuclides in plants acts as a monitoring system in the environment, occurring through two main methods: absorption by plant components such as leaves and shoots or uptake through the roots from the soil. There are three primary pathways through which radioactive materials from the environment reach the edible parts of plants.

Firstly, radioactive materials can directly adhere to the surfaces of edible plant parts from the air, particularly immediately following an accident or release.

Secondly, through a process called translocation, where nutrients or metabolites absorbed by leaves or bark are transported to other parts of the plant, radioactive materials can be transferred to new leaves and fruits.

Thirdly, radioactive materials in the soil can be absorbed by plant roots, especially after the release of radioactive materials into the air ceases. This route is significant for farmland, as radioactive materials absorbed into the soil can be taken up by crops through their roots.

A visual representation of these pathways is in Fig. 3, based on information provided [9].

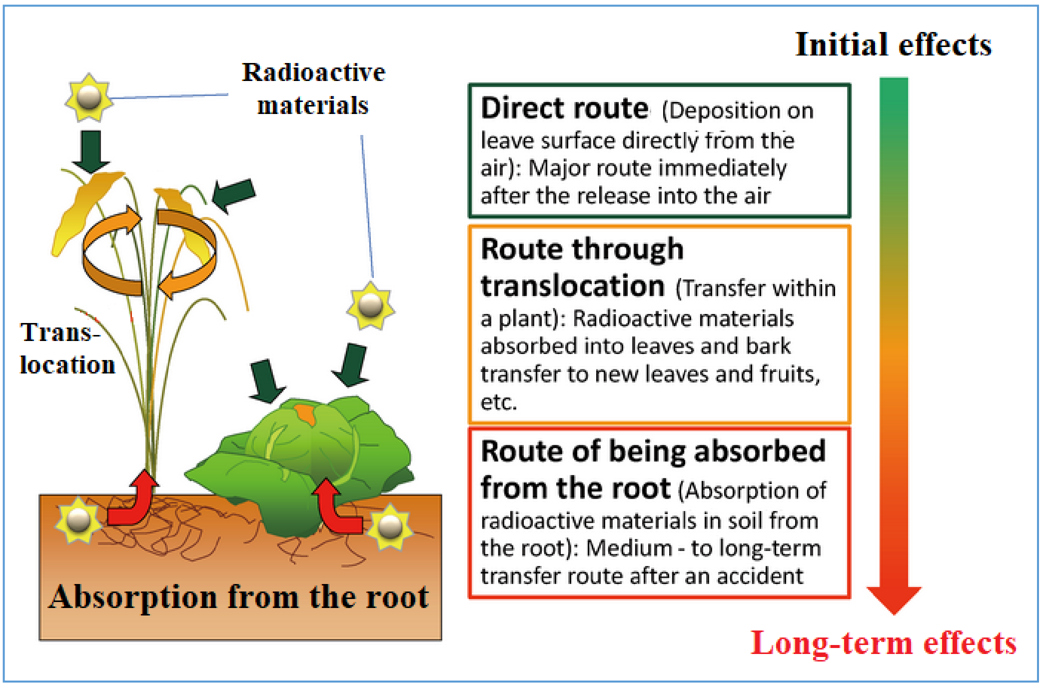

Fig. 3. Main pathways of transferring radioactive materials to plants

One commonly overlooked source of natural radiation stems from bananas, which possess higher levels of 40K due to their naturally occurring potassium content. Additionally, many fertilisers used in tobacco cultivation contain varying levels of natural radioactivity. Tobacco plants are known to accumulate natural radionuclides, particularly 238U. Phosphate fertilisers, found to have elevated radioactivity, can contribute to increased radioactivity in soil and tobacco leaves. This poses significant radiological risks for tobacco consumers, whether through snuffing or smoking, resulting in effective doses surpassing those received annually by the general public from inhaling natural radionuclides. The study suggests that the use of phosphate fertilisers amplifies natural radioactivity in soil, affecting its uptake by tobacco plants. The activity concentrations of various radionuclides in fresh produce can correlate with the annual effective dose. However, these values may vary depending on factors such as location and region. The content of some important radionuclides in specific samples is given in Fig. 3.

Table 3.

Examples of the activity concentration in Bq/kg of Ra-226, Pb-210, Th-232 and K-30 in some vegetables and fruits, including annual effective dose (based on [10]):

Samples	Ra-226	Pb-210	Th-232	K-40	Consumption kg/y	Effective dose µSv/y
Vegetables						
Tomato	ND	0.03	0.02	93.0	4.2	0.082
Potatos	ND	0.07	0.06	131.7	23.9	17.53
Carrot	0.29	ND*	0.05	126.2	3.7	3.0
Lettuce	0.18	ND	ND	59.8	0.6	0.25
Cabbage	0.21	ND	0.24	76.8	0.96	0.48
Pepper	0.01	0.07	0.07	52.3	0.1	0.03
Onion	0.25	0.44	ND	79.7	24.2	15.1
Fruits						
Apple	0.09	0.13	0.01	26.7	6.9	1.42
Orange	0.35	0.22	0.04	64.6	8.1	41.3
Banana	0.30	0.39	ND	197/6	10.6	14.0
Strawberry	0.05	0.08	0.02	52.6	9.58	3.25
Figs	0.05	0.01	0.10	37.3	0.68	0.161

ND* - is not detected

3.2 Radioactivity in animals

Similar to plants, we must consider scenarios where animals could be exposed to radiation from two main sources: the natural background radiation in their environment and radioactive contamination caused by human activities, such as accidents, terrorism, or sabotage involving radionuclides. When humans consume meat from contaminated animals, they face additional exposure to ingested radionuclides. Animal products play a crucial role in transferring radionuclides through the food chain to humans, with grazing animals being a major pathway for contamination acquired from plants. Various factors, including the metabolic characteristics of specific nuclides and agricultural practices, influence the extent of radionuclide exposure in farm animals, affecting their health and leading to higher contamination levels compared to the human populations consuming them.

As in the case of plants, we have to consider circumstances where we expect the contamination of animals from two major sources of radioactivity: background of natural radioactivity in the environment and radioactive contamination as a result of the use of radionuclides in many areas of human work and the consequences of accidents or other intentional interference, for example, terrorist attacks or sabotage. People consuming meat from contaminated animals receive some additional exposure from radionuclides if ingested. Animal products play a crucial role in the food chain as a pathway for radionuclides to reach the human population. Grazing animals effectively accumulates contamination from plants, serving as a significant link. Various factors, including the metabolic properties of specific nuclides and farming practices, influence the extent of farm ***animal exposure to radionuclides***. This exposure impacts the well-being of animals, resulting in higher body burdens compared to the human populations relying on them.

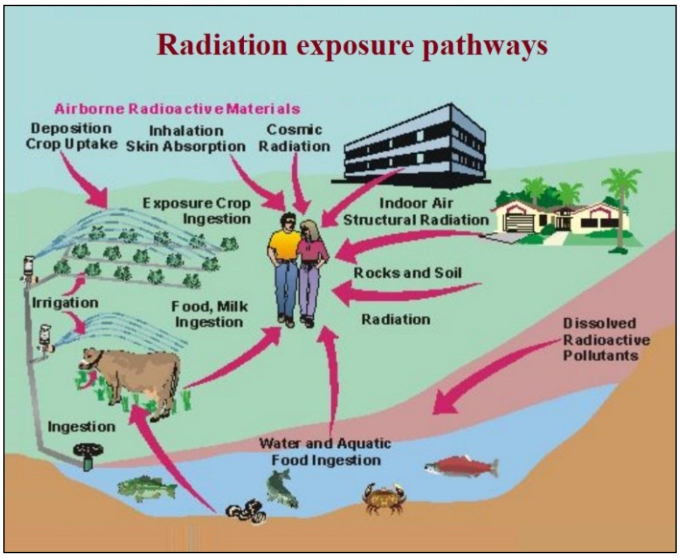

Fig. 4. Pathways of natural radioactivity into food (based on [15]).

All types of food contain natural radionuclides that are transferred from the soil to crops and from water to fish in bodies of water like rivers, lakes, and seas. The levels of natural radionuclides in food and drinking water are typically very low and do not pose a significant risk to human health. The illustration of some important factors affecting radiation protection pathways, which include how radioactivity can be transferred from animals to people, is shown in Fig. 4.

In terms of occurrence, animals can be affected by radioactivity through their flesh, skeletal structures, dairy products, and eggs. When fresh radioactive substances enter a cow's system, certain elements like iodine, molybdenum, strontium, and barium can be found in their milk. Iodine is especially critical, and if grazing fields have been exposed to radioactive fallout, cows should be transitioned to stored feed. Studies indicate that chicken eggs can accumulate significant levels of radioactive elements, with iodine-131 uptake accounting for up to 8% of daily intake. The yolk might contain 20-50 times more radioactivity than the egg whites. Importantly, promptly washing eggs laid during early fallout can eliminate a considerable portion of radioactivity from the shell.

Various radioactive elements accumulate in different tissues. Muscle tissue is particularly significant in the food chain of many nations, with more extensive data available compared to other accumulating tissues.

Following the Chernobyl nuclear disaster, there were notably elevated levels of 137Cs and 134Cs activity in the muscle tissue of ruminant animals within a few weeks, prompting intensive monitoring of meat from cattle, goats, sheep, reindeer, game, and fish. Numerous countries have reported data on the transfer of radiocaesium to different animals post-Chernobyl. There's notably more data available for beef than any other livestock. The transfer of radiocaesium to meat exceeds that to milk. Animals raised for meat production in contaminated areas cannot be sampled as quickly as dairy animals. The development of equipment suitable for real-time monitoring of animals in these regions was crucial in managing the situation and devising appropriate remediation strategies.

4. Conclusion

Living tissues often encounter varying levels of radiation from natural and human-made sources. The potential dangers of radioactive materials depend on factors like the type of radiation, absorption rate, type of organs exposed, and the overall exposure received in terms of effective dose. Given their heightened sensitivity, research on the biological effects of radiation and preventative measures has primarily focused on humans. It is essential to note that many animal-based foods can transmit radionuclides to humans, potentially increasing exposure levels. While typically low, this exposure can become significant during emergencies with large releases of radioactivity. Hence, it is vital to assess radiation effects on animals, which are crucial in the human food chain, and implement preventive measures. Understanding radioactivity and how key radionuclides behave in livestock and plants is valuable for management and consumer decision-making.

Under normal circumstances, natural radionuclide levels in food, water and air are generally low and safe for human consumption. Food consumption contributes about 10% to an individual's average radiation exposure from all natural sources. However, natural radionuclide concentrations vary widely within food categories like vegetables, fruits, meat, and fish. Thus, monitoring and informing consumers about radioactivity levels in food is essential. Most countries have food monitoring programmes aimed at monitoring natural radionuclides; these programmes primarily focus on artificial radionuclides from sources like nuclear power plants, radiation accidents, or nuclear weapons tests.

The global average effective dose from ingested radionuclides is relatively low (about 0.3 mSv/y) compared to the acclaimed public reference dose of 1 mSv/y. Monitoring suggests a low health risk from radioactivity in food intake. However, ongoing assessment remains crucial, especially in accidents leading to heavy pollution in affected areas. Such contamination can lead to increased radioactive concentrations in food from contaminated plants and animals consumed by people.

The analysis of the recent monitoring and measurement results of radioactive concentration in the most commonly used food has shown some increase in its radioactivity. The situation may be quite different in the areas close to the places where radioactive materials were released in significant amounts. In some locations, radioactivity in plants, water, fruit, and animal meat may be so high that national law and other regulations prohibit or substantially limit their use. On some occasions, the approach of relevant authorities was too strict and not fully justified and supported by scientific analysis.

The presented assessment of the radioactivity in various foodstuffs contributing to the exposure of consumers is important for better selection of all relevant factors which have to be continuously monitored and assessed in order to reduce the impact of contaminated nutriments to the overall exposure to the population. This process has to continue in the future where we may expect some new sources of radioactive contamination of the environment which may also affect content of radioactivity in various foodstuffs. Therefore, it is necessary to pay systematic attention to the level of radioactive concentration in all products and materials used for the preparation of food.

Acknowledgments

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Advancements in Additive Manufacturing Technologies for Enhancing Efficiency and Sustainability in Military Logistics Operations

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Abstract

This research aims to present a well-rounded analysis of additive manufacturing technologies in the context of military logistics by systematically identifying their potential applications, examining the barriers to adoption, and providing actionable solutions. By highlighting the transformative potential of additive manufacturing technologies in military logistics, this study will contribute to a deeper understanding of how emerging technologies can be connected to improve the efficiency, flexibility, and resilience of military supply chains in the 21st century. The conducted study highlights that overcoming these challenges requires strategic managerial interventions, including aligning the perceived and actual benefits of additive manufacturing, fostering inter-organizational cooperation, and addressing legal and technological limitations. Through targeted decision-making strategies, organizations can mitigate the negative impacts of these issues and leverage the disruptive potential of additive manufacturing to improve efficiency, cost-effectiveness, and operational resilience. By doing so, they can enhance overall performance and position themselves to thrive in a rapidly evolving technological landscape.

KEY WORDS: *Additive manufacturing, 3D printing, military logistics, Lithuanian Armed Forces, technology integration, readiness enhancement.*

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1. Introduction

In the current era, we are approaching the dawn of the Fifth Industrial Revolution, driven by breakthrough innovations in advanced artificial intelligence, robotics, nanotechnology, and biotechnology [1-3]. These emerging technologies are expected to confer unprecedented advantages in the contemporary business landscape. Nevertheless, we are still in the critical phase of integrating and testing key innovations from the Fourth Industrial Revolution, which are foundational to modern logistics systems [4,5].

Globally, logistics remains a critical sector for efficiently managing the flow of goods, ensuring timely deliveries, and optimizing costs to maintain high levels of customer satisfaction [6]. To further enhance these logistics processes, innovations under the banner of "Logistics 4.0" are gaining traction. These involve the integration of cutting-edge digital and information technologies, including the Internet of Things (IoT), big data analytics, artificial intelligence (AI), block chain, additive manufacturing, cloud computing, and cybersecurity [7,8]. However, the adaptation of these trends is not uniform across industries, with the military sector being one example where adoption may be slower, particularly in military logistics systems [9-11].

Given these circumstances, it becomes imperative to explore the potential application of "Logistics 4.0" technologies within military logistics. According to NATO's science and technology trends for the years 2023–2043, additive manufacturing technologies (AMT) hold a high significance coefficient and are classified as disruptive technologies [12, 13]. These technologies have the capacity to radically alter traditional manufacturing processes and supply chain operations [14, 15]. By enabling the on-demand production of complex parts and components, AM provides considerable advantages in flexibility, cost-effectiveness, and shorter lead times.

In military contexts, additive manufacturing could enable rapid prototyping, customization, and the repair of critical equipment, leading to improved operational readiness and resilience [16, 17]. These technologies have already reached an advanced development stage and have been demonstrated in relevant environments. It is projected that between 2025 and 2030, the full potential of additive manufacturing will be realized in military logistics operations (NATO Science & Technology Organization, 2023) [18,19].

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This paper delves into the role of additive manufacturing technologies—commonly referred to as 3D printing—within military logistics. The military environment presents unique complexities, which pose both challenges and opportunities for the application of "Logistics 4.0" innovations, particularly in terms of implementing additive manufacturing technologies.

2. Conducted Research Design

The object of this research was chosen the additive manufacturing technologies (AMT), widely known as 3D printing. These technologies represent a cutting-edge approach to manufacturing that constructs objects layer by layer from digital models. The range of materials used in additive manufacturing, from polymers to metals, allows for the creation of highly complex, custom components. AMT is revolutionizing various industries, offering key benefits such as rapid prototyping, reduced production time, minimized waste, and the ability to produce highly customized parts on-demand. The adaptability and decentralized nature of 3D printing make it particularly attractive in contexts where traditional supply chains face significant constraints—such as in military operations and logistics.

Notable, the military logistics environment is characterized by its need for flexibility, efficiency, and the ability to operate under time-sensitive and resource-constrained conditions. Also, AMT, with its ability to produce spare parts, components, or even entire structures on-site and on-demand, offers a disruptive opportunity for military logistics to become more self-sufficient and responsive in the face of changing operational demands. So, the overarching purpose of this study was to critically evaluate the feasibility and potential of additive manufacturing technologies in the field of military logistics. This study was focused on identifying how these technologies can modernize logistical processes, reduce supply chain weaknesses, and enhance the overall readiness of military forces by enabling rapid part production in the field. By evaluating existing applications and exploring potential future implementations, the study directed to clarify how AMT can be integrated into military operations to increase operational efficiency and flexibility.

To reach mention study goals there were raised up a few tasks: (i) identify the application possibilities of 3d printing in military logistics; (ii) identify the problem areas of applying 3d printing in military logistics: (iii) provide reasonable solutions for the application of additive manufacturing technologies in military logistics.

The first task was focused on the possible uses of additive manufacturing within the complex domain of military logistics. This task involved the examining current and prospective applications, such as the production of spare parts for military equipment, customized tools, and the ability to create specialized components for mission-specific needs. Additionally, the research explored the potential for AMT to enable on-site production of critical supplies, which could substantially reduce dependence on traditional supply chains, especially in forward-operating bases or remote areas. Through this task, the study built a comprehensive framework that categorizes the various ways in which 3D printing can be employed to enhance military logistics processes. Also was included exploration how these technologies can complement existing logistical infrastructure, providing flexibility, cost reduction, and enhanced responsiveness.

The second task was focused on how to identify and analyze the barriers and challenges that may impede the successful application of additive manufacturing in military logistics. While AMT offers numerous benefits, its implementation within military contexts is not without challenges. These may include technical issues, such as material limitations (e.g., availability of durable, high-performance materials suitable for military environments), production speed limitations, quality control, and ensuring the reliability of printed parts in harsh conditions. Moreover, logistical challenges such as integrating AMT into existing military supply chains, training personnel, and overcoming organizational resistance to adopting new technologies must also be considered. Through a detailed analysis of these problem areas, the study was able offer a realistic assessment of the obstacles to widespread adoption and suggest potential ways to mitigate these issues.

The final task involved developing practical, evidence-based solutions to address the challenges identified in the previous task and proposing strategic application cases for additive manufacturing in military logistics. These solutions will be based on a thorough evaluation of the current state of AMT and best practices from both civilian and military sectors. The study was also exploring how logistics processes could be optimized to integrate AMT efficiently, offering a roadmap for military organizations seeking to implement these technologies into their logistical frameworks.

Finally, the research process was divided into three phases. In the first phase of the study, expert interviews were carried out to identify the applicability of 3D printing in military logistics. In the second phase of the study, a root- cause analysis was applied to identify problem areas and to provide valid suggestions for the application of 3D printing in military logistics. The third stage of the study was aimed at identifying applications of additive manufacturing technologies in LC logistics and formulating managerial solutions.

1. **Expert interviews**. Semi-structured, individual, expert (informant) interviews were conducted in order to meet the first research objective and to fill the gaps in the analysis of secondary data for the application of 3D printing in military logistics. The interviews were conducted anonymously, with the informants answering individually the pre-defined questions asked of them, but with the possibility of additional questions not included in the interview schedule, if these could enrich the research. At any point during the interview, the informants could refuse to answer the questions asked and could terminate the interview process.
2. **Analysis of the origins of the problems.** A root-cause analysis was carried out to address the second objective of the study and to summarise the information obtained from the secondary data and interviews. "The 'fishbone' diagram is a graphical representation of the causes of problems. "The fishbone diagram can be used to group individual problems into problem areas and is therefore useful in the initial stages of 3D printing integration to

prepare for potential risks that may arise and can be used for managerial decision making. "The 'fishbone' diagram visually represents hierarchical structures with a central element (the main problem) and distinct smaller lines representing sub-elements (problem areas and causes of problems). It simplifies complex information and reveals hierarchical relationships [20]. The analysis of the root causes of the problems allows for the formulation of valid suggestions for the application phases of 3D printing in LC logistics.

3. **Practical applications and decisions**. In order to meet the third objective of the study, specific applications of additive manufacturing technologies in Lithuanian Military Logistics (LML) were identified and sound managerial solutions were presented. Based on the LML and NATO doctrinal publications, specific applications of additive manufacturing technologies in LML were identified. Based on the root cause analysis data, informants' responses and secondary data collected from the authors [21-25], valid managerial solutions for the application of additive manufacturing technologies in military logistics were formulated.

3. The Study Results

3.1. Root Cause Analysis Interpretation

As was mention in the methodology section the root cause analysis was used to identify problem areas for the application of additive manufacturing (ADM) technology in military logistics (ML). The conducted analysis helped to clarify three main problem areas: (i) the lack of correlation between the potential of additive manufacturing and the benefits generated, (ii) the lack of cooperation in the application of additive manufacturing technologies, and (iii) the technological and legal constraints of additive manufacturing. The study let to look deeper into the problem areas that can appear and to identify their specific causes (see Fig. 1).

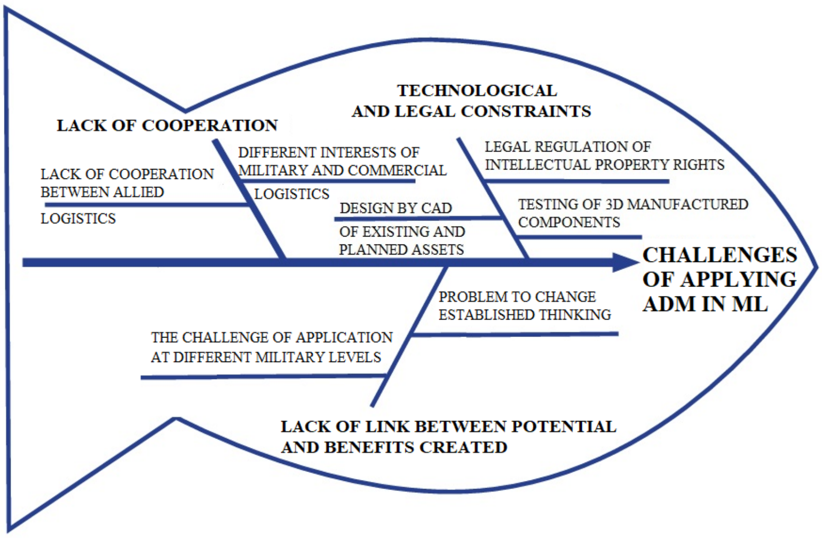

Fig. 1. Root cause analysis diagram of the problems in the application of additive manufacturing (ADM) in military logistics (ML).

The identified three main causes can be clarified more detailed. The identified "*Technological and Legal Constraints of Additive Manufacturing*" foundations can be explained by the slow integration of additive manufacturing technologies (AMT) in military logistics. As was recognized the 3D is slowed down by several technological and legal constraints, which create specific challenges for its widespread adoption.

The first cause in this group is the need for testing of 3D-Printed Components. A critical challenge is the reliability and safety of 3D-printed components in mission-critical military operations. While additive manufacturing offers flexibility in producing parts on-demand, military-grade components must adhere to strict standards regarding durability, strength, and performance. This necessitates extensive testing and validation procedures to ensure that printed parts meet military specifications and can withstand the extreme conditions often encountered in the field. The testing process adds time, cost, and complexity to the use of AMT in military settings, potentially offsetting the on-demand benefits. The challenge here is not just about testing individual parts, but also developing standardized testing protocols that ensure uniformity across different types of military equipment and across different branches of the military.

The second cause in this group is stringent intellectual property rights (IPR) requirements for additive manufacturing. Many parts and components used in military equipment are protected by patents or other forms of IPR. So, IPR is a significant legal barrier to the use of additive manufacturing in military logistics. Reproducing these components through 3D printing without proper legal clearance can lead to IP infringements, limiting the ability of military forces to leverage AMT for spare parts production. Navigating the complex landscape of licensing agreements for 3D printing technology and proprietary parts requires specialized legal frameworks and processes. Moreover, military organizations may need to establish collaborative agreements with private-sector manufacturers to secure the rights to produce proprietary components using additive manufacturing, which could slow down the adoption of this technology.

The third cause is CAD development of existing and planned assets. Notable, the additive manufacturing relies seriously on Computer-Aided Design (CAD) models to create 3D-printable components. One of the key technological challenges is the development and digitization of CAD models for both existing military assets and newly planned systems. Many older military systems were designed long before CAD technology became standard, meaning there may not be readily available digital files to replicate parts. Creating CAD models of these legacy systems requires reverse engineering, which can be a time-consuming and resource-intensive process. Even for new systems, designing parts with additive manufacturing in mind necessitates a shift in design philosophy, which poses a challenge for military engineers and manufacturers accustomed to traditional methods.

"Lack of link between the potential for additive manufacturing and the benefits generated" can be represented as one more important cause group. This situation can be represented as a significant barrier to the adoption of additive manufacturing in military logistics is the discrepancy between the potential of the technology and the concrete benefits it can provide. This cut off demonstrates in several ways, but it is important to mention main two:

- The complexity of changing established thinking that can be explained as traditional conservative of military in adopting new technologies, especially those that challenge established logistical processes. The shift toward additive manufacturing requires a fundamental change in mindset and operational procedures. Military leaders and logisticians must overcome the entrenched belief in traditional manufacturing processes and supply chain methodologies. This resistance to change stems not only from institutional inertia but also from the perceived risks associated with adopting a relatively new technology in critical operations. For additive manufacturing to be fully integrated, there needs to be broader cultural and organizational acceptance within military logistics, which requires education, training, and demonstrable success stories.
- Also, the challenge of adapting additive manufacturing at different military levels can be seen as a cause. Because the application of additive manufacturing technologies is not uniformly beneficial across all levels of military operations. While frontline units may benefit from the on-site production of spare parts and tools, higher-level strategic logistics functions may see less immediate value. For example, central supply depots that already operate with efficient traditional logistics systems may not see a significant return on investment from adopting AMT. This discrepancy in the perceived utility of additive manufacturing at different levels of military operations complicates its widespread adoption. There is a need for tailored strategies that account for the specific logistical needs and capabilities of different military units, from tactical to strategic levels.

"Lack of cooperation in the application of additive manufacturing technologies" can be characterized as important cause group. Remarkable, the successful integration of additive manufacturing technologies in military logistics also depends on cooperation between different military entities and allied nations. However, several issues arise in this area are:

- Lack of cooperation between allied military logistic systems (LS). Effective military logistics often depend on joint operations and standardization across allied forces. The lack of coordinated efforts to implement additive manufacturing across different military forces creates fragmentation in how the technology is applied. Allied military forces may have different priorities, logistical needs, and approaches to integrating AMT, which leads to inconsistencies in application and missed opportunities for collaboration. This lack of cooperation hinders the potential for shared resources, such as joint 3D printing facilities or common AMT protocols, which could reduce costs and improve efficiency across allied forces.
- Different interests between KLS and military logistics. Within the military, different entities may have divergent interests when it comes to the application of additive manufacturing technologies. For instance, Key Logistic Stakeholders (KLS) may prioritize long-term investments in centralized 3D printing facilities or focus on the development of highly specialized components, whereas field units may emphasize the need for mobile, deployable 3D printers for immediate on-site use. These differing priorities can create a disconnect between strategic goals and operational needs, further complicating the adoption of AMT within the broader military logistics framework. For AMT to be effectively integrated, there must be alignment between strategic, tactical, and operational stakeholders.

By addressing these challenges, military logistics can harness the transformative potential of additive manufacturing technologies to improve efficiency, flexibility, and resilience in complex, dynamic operational environments. Through strategic solutions that tackle both technological and organizational barriers, the military can position itself to benefit from the disruptive advantages that additive manufacturing offers.

3.2. Strategic Managerial Solutions

Overcoming the identified challenges that complicate the adoption of Additive Manufacturing Technology (AMT) within the broader military logistics framework requires a multi-faceted approach involving strategic managerial interventions. These interventions are essential to addressing the key obstacles: the misalignment between the perceived and actual benefits of additive manufacturing, the lack of inter-organizational cooperation, and the legal and technological limitations that hinder its broader application.

One of the primary challenges in integrating AMT into military logistics is the disconnect between the perceived and actual benefits of the technology. Established mindsets within military organizations may resist change due to uncertainty about how AMT can enhance efficiency and improve mission outcomes. Strategic managerial intervention in this context involves an educational and awareness campaign that emphasizes the tangible benefits of AMT. This can include case studies that demonstrate cost savings, improved operational readiness, reduced lead times, and enhanced capabilities for on-demand manufacturing in mission-critical situations. Managers must facilitate knowledge sharing across military levels, from tactical units to strategic decision-makers, to ensure a unified understanding of the technology's potential. Regular training programs, workshops, and simulations can also be used to familiarize personnel with the practical applications of 3D printing in military logistics. The mention solutions are presented in the Table 1.

Table 1.

Lack of link between the potential for additive manufacturing and the benefits generated

Cause	Losses	Solutions
The complexity of changing established thinking.	- Slow process of adapting additive manufacturing to military logistics. - Untapped potential of additive manufacturing.	- Develop a three-phase roadmap for the application of additive manufacturing in military logistics. - Start with simplified additive manufacturing equipment in the first phase.
The challenge of adapting additive manufacturing at different military levels.	- Different interpretations of the benefits of additive manufacturing and the dissatisfaction of lower levels	- Re-promoting and re-imagining the benefits of additive manufacturing through visualisation and hands-on approaches

A second significant challenge is the lack of cooperation between allied military logistics systems and the divergent interests between civilian and military logistics sectors. Inter-organizational collaboration is crucial for unlocking the full potential of AMT. This requires creating platforms for open dialogue and joint projects between military allies to align logistics strategies, standardize 3D printing technologies, and share knowledge on best practices. Establishing joint training programs, shared research initiatives, and cross-functional task forces can foster cooperation and help overcome the siloed nature of military logistics operations. By pooling resources and expertise, allied military forces can collectively develop more robust and responsive logistics systems powered by additive manufacturing. Moreover, cooperation between military and civilian sectors is also essential, as civilian industry often drives innovation in AMT. Military organizations can benefit by forming partnerships with industry leaders to accelerate the adoption of cutting-edge technologies (see Table 2).

Table 2.

Lack of cooperation in the application of additive manufacturing technologies

Cause	Losses	Solutions
Lack of cooperation between allied military logistic systems (LS).	- No exposure to allied good practices in the application of additive manufacturing in military logistics.	- Provide opportunities for logistics professionals to attend international courses/seminars on additive manufacturing.
Different interests between KLS and military logistics.	- Unprofessional maintenance of additive manufacturing equipment and unplanned failures.	- To launch a call for tenders for the selection of a professional additive manufacturing KLS company (for the purchase, ongoing maintenance and troubleshooting of equipment).

The legal and technological limitations of AMT, such as intellectual property (IP) issues and the need for advanced Computer-Aided Design (CAD) models, present another layer of complexity. Addressing these constraints requires a comprehensive strategy to streamline regulatory compliance and protect sensitive information. Military organizations must collaborate with legal experts to develop frameworks that facilitate the secure use of AMT while respecting IP rights and preventing dual-use technology risks. Technologically, investments must be made to develop or acquire the necessary infrastructure for high-quality 3D printing, such as deformation testing equipment, motion sensors, and CAD development tools. By fostering partnerships with professional companies that specialize in these technologies, military organizations can ensure that components produced through AMT meet stringent quality standards. Additionally, military institutions should explore the use of optical 3D scanning technologies to create accurate digital models of existing components, reducing the dependency on original equipment manufacturers (OEMs) for spare parts.

Table 3.
Technological and Legal Constraints of Additive Manufacturing

Cause	Losses	Solutions
The need for testing of 3D-printed components.	- Limited use of 3D-printed components. - Lack of information on the resistance of 3D-printed parts to deformation and temperature changes.	- Perform deformation testing of critical equipment components produced with a 3D printer. - Purchase 3D motion and strain sensing equipment.
The challenge of adapting additive manufacturing at different military levels.	- Possible legal infringements due to the use of the CAD created.	- To take into account the CAD intellectual property rights (IPR) credentials of CAD-ready components for military logistics in peacetime and wartime for equipment in use or planned for acquisition.
Creating a CAD for existing and planned assets.	- Limited use of additive manufacturing in military logistics.	- Use optical 3D scanning equipment to create original CAD. - Exploit the potential of additive manufacturing experimentation and CAD prototyping.

Based on this study results of the in-depth interview study, it can be specified that it takes time and effort to solve the all stated causes. But in summarizing the managerial decisions related to the integration of additive manufacturing technologies (AMT) into military logistics, four key strategic actions can be preferred. These decisions are aimed at overcoming operational challenges and maximizing the benefits of AMT within the context of military supply chains and logistics operations. The following four managerial decisions are pivotal for the successful application of additive manufacturing in this domain:

1. Development of a three-phase implementation plan. A structured, phased approach is critical for the gradual integration of additive manufacturing into military logistics systems. This three-phase plan should begin with pilot testing of 3D printing technologies in controlled environments to assess operational feasibility. The second phase should involve scaling-up production to include more complex components and broader logistics operations, with continuous monitoring and adjustments. The final phase focuses on the full integration of AMT into standard military logistics procedures, enabling real-time, on-demand manufacturing of critical components, thereby enhancing supply chain resilience and flexibility.

2. Facilitating access to international additive manufacturing courses for logistics professionals. Knowledge acquisition and continuous training are essential for the effective application of emerging technologies such as additive manufacturing. Logistics professionals must be empowered to attend international training programs and courses focused on additive manufacturing to stay abreast of the latest advancements and operational methodologies. These courses provide insights into best practices, technological innovations, and global trends that can be adapted to military logistics, ensuring that personnel are equipped with the necessary skills to implement and manage AMT effectively.

3. Mandatory deformation testing for critical components. Ensuring the structural integrity and reliability of 3D-printed components is of paramount importance in military operations, where equipment failure can have severe consequences. Therefore, all critical components produced using 3D printing must undergo rigorous deformation testing to verify their durability and performance under stress. This testing can be outsourced to professional firms specializing in component testing, or alternatively, military organizations can invest in 3D motion and deformation sensing equipment to conduct in-house testing, ensuring compliance with safety and performance standards.

4. Utilization of optical 3D scanning technology for CAD development. The adoption of optical 3D scanning equipment is critical for the creation of accurate Computer-Aided Design (CAD) models, both for the replication of existing components and the design of experimental prototypes. This technology enables the precise capture of physical objects' dimensions and geometries, which can then be used to develop original CAD models or improve existing designs. By integrating optical 3D scanning into the workflow, military logistics can streamline the reverse engineering process, enhance the customization of parts, and expedite the development of prototypes that are fit for purpose in military applications.

Together, these four managerial decisions form a cohesive strategy that addresses both the technological and operational aspects of additive manufacturing in military logistics. By developing a phased implementation plan, promoting continuous education, ensuring rigorous testing, and leveraging advanced scanning technologies, military organizations can fully realize the potential of AMT. These actions not only improve logistics efficiency but also increase the flexibility, responsiveness, and resilience of military supply chains in the face of evolving operational demands.

4. Discussions

Summing up the research conducted, it can be said that the responses provided by the experts align with most of the scientific literature discussed. When defining the concept of innovation, the primary focus is on performance improvement, which corresponds with the definitions provided by Paksoy [26]. The innovations related to "Logistics 4.0" from the KLS (Key Logistics Systems) are also applicable in military logistics. However, based on the experts' responses, greater emphasis is placed on innovations related to the functional logistics field. The functional logistics field is responsible for the execution of direct logistics activities, as discussed by Shi [27]. The experts' opinions also coincide with Paksoy's [26] discussions on the innovations of "Logistics 4.0," specifically that innovation should consistently enhance military capabilities and efficiency, though the main drawback is the time required for adaptation.

The experts consistently agree that in the adaptation of "Logistics 4.0" innovations, significant attention is also given to innovations in the supporting logistics field. For instance, they mention the development of the "Logistics IT System," which aims to integrate allied military logistics systems into a unified network to improve interaction. This aligns with Paksoy's [26] definition. However, experts' opinions differ when discussing the challenges arising from the application of "Logistics 4.0" innovations in military logistics. These challenges include issues with cooperation between allied military logistics systems and conflicting interests with KLS. Moreover, according to Rahman [28], challenges in the application of "Logistics 4.0" also include concerns about data security, costs, and realizing the full potential of the innovations.

This study experts' views also align regarding additive manufacturing technology (AMT) and its implications for military logistics. They believe that 3D printing will essentially change the approach to military logistics by offering a more decentralized capability. This innovation disrupts the traditional logistics model by introducing decentralized, on-demand production, reducing the need for storing unnecessary parts at military bases [29]. Experts recommend that 3D printing has the potential to reduce the logistical footprint and enhance international operations, such as deploying a container with a 3D printer and storing designs on a universal USB flash drive, a perspective that matches the understandings of Thong [31].

Additionally, study experts mostly agree on the potential applications of additive manufacturing in military logistics, including the production of replacement parts for temporary battle damage repairs, components that are no longer manufactured (old-fashioned parts), experimental prototypes, and UAV components. These uses are consistent with the perspectives of Valtonen et al. [30]. However, some of the experts raised points that diverge from the scientific literature, such as the need for pre-production CAD planning for military equipment or encouraging OEMs (Original Equipment Manufacturers) to prepare CAD files. This aspect is crucial in military logistics due to the time and procurement delays involved in purchasing equipment, which necessitates having CAD files ready for part manufacturing alongside the equipment itself.

The scientific literature does not extensively discuss the primary challenges of integrating additive manufacturing into military logistics systems (MLS). Experts identified several key challenges, such as the complexity of changing traditional mindsets and the difficulty of implementing additive manufacturing across different military levels. They suggested that the adoption of additive manufacturing in military logistics should follow a phased approach, starting with experimentation and prototyping at military academies and progressing to political decisions regarding the incorporation of these innovations into military logistics systems. This step-by-step approach echoes Thong's [31] recommendations. However, experts did not emphasize Mattox's [32] statement regarding the prevention of dual use of 3D printing technology.

Finally, this study experts' understanding on the future scenarios of 3D printing largely coincide with the existing literature. The increasing availability of metal 3D printing enhances the possibilities for additive manufacturing in military logistics, a view that corresponds with Srivastava's [33] conclusions. However, one future vision not discussed in the scientific literature is the adherence to the European strategy for the extraction of critical raw materials by changing solid metals into innovative polymers. Additive manufacturing technologies could play a vital role in this process, as suggested by the experts.

5. Conclusions

This study proved, the three main problem areas delaying the application of additive manufacturing technology in military logistics are interconnected. Technological and legal constraints, such as testing, IP rights, and the need for detailed CAD models, pose foundational challenges. The lack of correlation between additive manufacturing's potential and its perceived benefits highlights the difficulty in changing established mindsets and adapting to various military levels. Finally, the lack of cooperation between allied military logistics systems and the divergent interests between civilian and military logistics further complicates the technology's integration into military operations. Addressing these areas requires strategic managerial decisions, cross-functional collaboration, and ongoing education on the potential benefits of additive manufacturing.

Study highlights the tactical potential of additive manufacturing within the logistics framework of the Lithuanian Armed Forces (LAF), with future prospects for its application at the operational level and during international operations. Integration of 3D printing technology into LAF logistics operations aligns with principles of rationality, efficiency, and the 4T approach, offering the promise of providing high-quality equipment to combat units and enhancing their operational effectiveness. Specific applications of additive manufacturing in military logistics within the LAF encompass a range of critical functions, including expedient repair of battle damage, production of spare parts, prototyping and experimentation, addressing component obsolescence issues, and the fabrication of UAV components. These applications signify the diverse capabilities of additive manufacturing to address logistical challenges and ensure the readiness of military units.

Moreover, the adoption of additive manufacturing by LAF logistics units has the potential to catalyze the development of a more decentralized logistics approach, thereby reducing logistical footprint and enabling a shift from a traditional "push" model to a more responsive "pull" approach as necessitated by operational demands.

Based on the formulated managerial decisions, military logistic system can adopt and plan the course of action for the application of additive manufacturing technologies, assess the potential risks and develop solutions to the problems that arise. To facilitate the effective implementation of additive manufacturing in military logistics, a comprehensive three-phase plan or project should be developed. Such a plan would outline the necessary steps and milestones for the successful integration of additive manufacturing technologies into LAF logistics operations, ensuring seamless adoption and maximizing the technology's benefits for military readiness and operational efficiency.

In summary, the strategic adoption of additive manufacturing holds significant promise for enhancing logistic capabilities of the Lithuanian Armed Forces, enabling them to adapt to evolving operational requirements and maintain a high level of readiness in dynamic security environments.

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Some Problems with the CBRN Risk Quantification in Terms of Stochastic and Deterministic Effects Taking into Account the Health Impact of Individual Agents

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Abstract

The total risk of Chemical, biological, radiological, and nuclear defense (CBRN) has to be expressed using relevant quantities and units introduced for each of their components, t.e., chemical (C), biological (B), radiological (R) and nuclear (N). Their specific properties characterise their ability to move in the environment and inflict harm on persons affected. While in the case of R and N components, the danger is induced by radiation, the assessment of the hazards from C and B agents is much more complicated. The paper discusses the quantification of CBRN risk as a whole, paying attention to two possible consequences of exposure-initiating harms: stochastic (late) and deterministic effects (tissue reactions). The main aim of the paper was to point out the inconsistencies between the concept of risk assessment of the group of agents C and B and the group R and N of the CBRN family including the lack of the rigorous evaluation of deterministic and stochastic health effects of chemical and biological substances.

KEY WORDS: *CBRN threats, population safety, biological effects, stochastic effects, deterministic effects, risk, radiation exposure.*

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1. Introduction

Efforts to assess and quantify the harmful effects of dangerous substances are directed mainly towards single agents. In contrast, real-world environmental and personal exposures under everyday situations, especially in case of an accident or terrorist attack, may present several different difficulties simultaneously. The combined exposures may lead to health risks that differ from those expected from the simple addition of the individual risks. This can also be applied to CBRN (C-chemical, B-biological, R-radiological, and N-nuclear) agents whose individual components, such as C and B on one side and R and N on the other, interact with living tissues quite differently [1,2]. Whether processes and modes of interactions occurring at high exposure levels (depending on concentration, intake or external exposure) are important, as well as at the low exposure levels set for the public, workers, or rescue teams, is difficult to answer. A scientifically sound extrapolation from these high to low-dose levels should be based on dose-effect relationships of the relevant agents alone and in combination. In general, so far, this information is not fully recognised and available. The existing database on combined effects is rudimentary, mainly descriptive and rarely covers exposure ranges large enough to make direct inferences about present-day low-dose exposure situations.

The paper discusses problems in quantifying overall CBRN biological effects where specific damage of separate components can differently contribute to the total harm of the affected persons caused by different agents. Even in scientific literature, one can find expressions such as CBRN risk without mentioning the contributions from specific components.

Chemical hazards and toxic substances pose a wide range of health hazards (such as irritation, sensitisation, and carcinogenicity) and physical hazards (such as flammability, corrosion, and explosibility).

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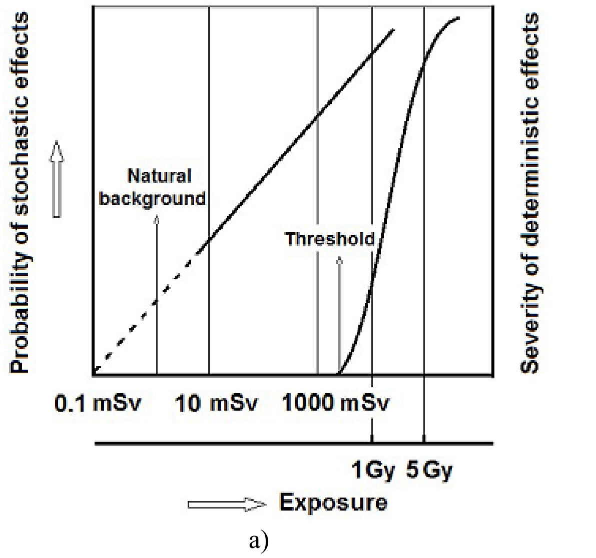
In order to ensure CBRN safety of people, information about the identities and hazards of the agents must be available and understandable to all who may be in the place contaminated. Various international and national standards have been developed to control these substances so that their impact on people and the environment is minimised to an acceptable level. However, in the case of the mixture of various CBRN substances, it is more difficult to take into account the contribution to the total risk at both low and high levels of exposure, which may lead to stochastic (probabilistic, late) effects and evaluate total deterministic (acute) effects.

In principle, this concept should be similar to the effects of radiation, which have been studied in more detail than the effects of chemical or biological agents. This was possible due to a very sophisticated system of quantities and units that reflected both physical and biological responses to radiation exposure in terms of relevant biological effects. Here, there is a specific quantity of effective dose with the unit of Sv (sievert), which reflects the measure of overall stochastic effects. Other quantities distinguish between the contribution of external radiation (ambient dose equivalent) and internal exposure (committed effective dose). Their sum then represents the total exposure. Both doses can be assessed based on modelling or monitoring by sophisticated detection and spectrometry techniques with extremely high sensitivities which are far below the radiation background.

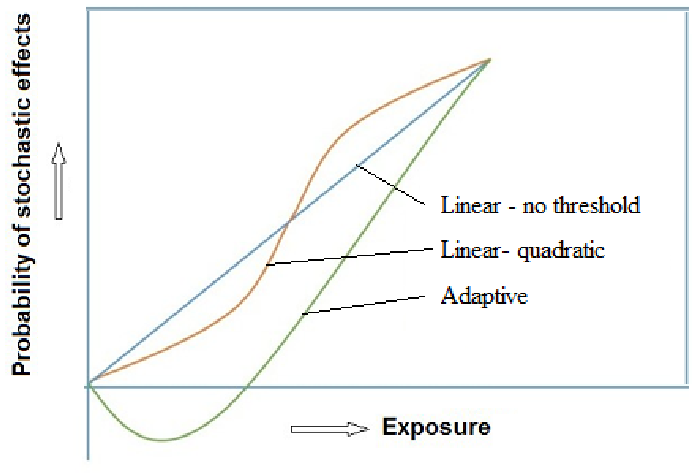
The present situation in quantifying and assessing stochastic effects due to the R and N agents is discussed and analysed in order to find a way in which experience from this area can be used in the evaluation of the danger of C and B components where, so far, attention was mainly concentrated on protection against deterministic effects. The preliminary results based on many statistical reviews of results published in scientific literature and other available data clearly indicate that low-level exposure to C and B agents may also produce stochastic (late) effects.

At very low exposure, no visible harm is observed. Still, it has been proved that even these exposures are harmful since they contribute to the increased level of cancer occurrence with a certain probability, which is proportional to the dose received. At much higher levels (above a threshold) of radiation exposure, deterministic effects occur with the probability of 100% with severity proportional to the exposure. The health effects of low-dose radiation, less than 100 mSv, have been debated as to whether they are beneficial or detrimental because sample sizes were not large enough to allow epidemiological detection of excess effects, and there was a lack of consistency among the available experimental data.

In addition to stochastic effects usually characterised by a linear relationship between the probability of effect occurrence and the exposure, the deterministic effects appear only above a certain threshold. Below this value of exposure, this probability is zero [3,4]. Above the threshold level, the probability is one, but the severity is approximately linear in relation to the dose in Gy. This is illustrated in Fig. 1 (based on [3]).



a)



b)

Fig. 1. Relationship between the probability of stochastic effects and low exposure (a) and the severity and high exposure level (b). Compared to the situation with R and N agents, there has been nothing like this studied in such detail regarding C and B components.

The probability of stochastic effects at very low exposures (comparable with natural background and lower) cannot be established reliably since the probability of occurrence is very low (Fig. 1a). This approach implies that all exposure to ionising radiation is harmful, regardless of how low dose is, and that the effect is cumulative over a lifetime. A linear no-threshold (LNT) model is usually applied in routine radiation protection applications. According to this concept, the approximation of linearity is usually adopted here, although, in principle, the shape of the response may show both linear-quadratic or adaptive forms (Fig. 1b).

2. Some characteristics of CBRN agents

Characteristics of effects of any CBRN agent depend on its type, amounts (exposure) and interactions with the human tissues. Assessment starts with identifying and classifying hazards, which must be related to the dose-effect and dose-response information available for the identified risks. Once the potential for exposure has been characterised, it should be quantified and compared with an established safe exposure level. The degree to which it exceeds that level is a measure of the risk. Even if the assessed risk is regarded as acceptable, there is the possibility that the situation will change with time, so it is important to monitor potentially harmful exposures.

Dangerous materials can be silent killers. Almost every household and workplace has varying amounts of chemicals that, if spilt or combined, will cause great harm and even death. One must know how to recognise these agents, where they may be found, and what to do or not do about hazardous material spills. The situation is much more complicated if dangerous materials belong to the CBRN category and are uncontrollable because of accidental or intentional release.

A common characteristic of most CBRN agents is that they are difficult to recognise or detect once released. For example, they may be an odourless, colourless chemical, biological agent, or radioactive material emitting radiation that cannot be seen or felt. One also has to recognise the difference between dangerous materials used in industry, research and other fields where they are beneficial. There are special legislative, administrative and technical mechanisms to control them and minimise their deleterious effects on workers, population and the environment. On the other hand, some CBRN agents have been specifically developed for military use.

A common characteristic of most CBRN agents is that they are difficult to recognise or detect once released. For example, they may be odourless, colourless chemical or biological agents or radioactive material emitting radiation that cannot be seen or felt.

The CBRN agents are considered to be part of weapons of mass destruction (WMD), weapons with the capacity to inflict death and destruction on such a massive scale and so indiscriminately that their very presence in the hands of a hostile power can be considered a grievous threat.

2.1. Chemical Agents

Chemical toxic substances pose a wide range of health hazards (such as irritation, sensitisation, and carcinogenicity) and physical hazards (such as flammability, corrosion, and explosibility). Chemical agents fall into four categories: choking agents, blister agents, blood agents, and nerve agents. Choking agents irritate the nose, throat, and lungs when inhaled and include chlorine (Cl), chloropicrin (PS), diphosgene (DP), and phosgene (CG) [5,6,7,8].

VX is one of the nerve agents which are the most toxic of the known chemical warfare agents. It is tasteless and odourless. Exposure to VX can cause death in minutes. As little as one drop of VX on the skin can be fatal.

Chemical Warfare Agents (CWAs) are designed to restrict and disrupt operations. They can affect everyone whose skin or respiratory system is exposed. CWAs are far more dangerous than toxic industrial chemicals (TICs) but are more restricted in manufacture. In a terrorist incident, the exact CWA present may not initially be known, so the extent of the exposure of first responders requires expert assessment at the scene based, among other things, on sensors, eyewitness accounts and the symptoms of casualties.

In the case of chemical accidents or the use of dangerous chemicals for terrorist attacks, mainly deterministic effects are studied. Many kinds of stochastic effects, including an increased rate of cancer occurrence among those who inhaled or were in contact with chemical agents, were not scrutinised in the way done with ionising radiation sources. This is mainly because so many chemicals have a very specific impact on the human organism that it is almost impossible to consider all possible factors. Moreover, such studies require the evaluation of statistical data collected under strict conditions for many decades. In any case, the deterministic effects of most chemical agents are well known and serve as a basis for developing relevant protection measures to minimise the consequences of exposure to chemical agents.

2.2. Biological agents

Biological hazards vary in how they transfer from host to host -some through inhalation and ingestion, others through skin cuts or abrasions. The hazard presented to first responders and medical staff by blood-borne viruses such as HIV, hepatitis and viral haemorrhagic fever is unrelated to terrorism [9].

The response to biological attacks involves several distinct steps depending on the specific circumstances of the biological attack. It may include early warning and detection measures/systems, identification of the agent(s) involved, epidemiology, first response, law enforcement, the response of the public health system/veterinary system/systems in the area of plant protection/systems related to food chain security, decontamination, incident investigation and forensics, and measures needed to ensure short and long-term recovery.

The targets of a biological attack can be humans, animals or plants. That includes the possibility of biological attacks on the food chain. Second, biological agents are disease factors (living organisms that infest a host and multiply there)—their effect is normally delayed by several days (latency period), and the onset of symptoms may or may not be specific to the disease. Thirdly, contact between infected victims and healthy individuals (animals, crops) can spread disease. This creates a broad range of possible scenarios for biological weapons attacks that need to be taken into account when addressing response strategies.

Historically, biological weapons were often used clandestinely. In such an attack, recognising that a deliberate agent release has occurred is often difficult. The features of the outbreak may not differ much from a natural disease outbreak, particularly if the disease is endemic in the region where the attack occurred. In case of food chain contamination, it can take days to weeks to identify the original source of the contamination, and sometimes, it may never be possible.

Because of the spread of the infection during the latency period, the disease spreads from its origin to remote locations—quite different from a radiological or chemical incident. This has a major impact on the pattern of a disease outbreak and its spread, given today's global transportation systems for humans and animals as well as crops and related products. Biological agents can be released by using specially designed dissemination devices that create a localised primary contamination of air, water or on surfaces (spraying devices, certain types of bombs, etc.). Such devices can be improvised, but the effective dissemination of biological agents remains a technical hurdle that terrorists have so far found difficult to master.

2.3. Radiological agents

Ionising radiation is a type of energy released by atoms in the form of electromagnetic waves or particles. People are exposed to natural sources of ionising radiation, such as in soil, water, and vegetation, as well as in human-made sources, such as x-rays in medical devices. Ionising radiation has many beneficial applications, including its use in medicine, industry, agriculture, and research. As the use of ionising radiation increases, so does the potential for health hazards if not properly used or contained. Acute health effects such as skin burns or acute radiation syndrome can occur when doses of radiation exceed very high levels [4,10].

Radiological agents include radioactive materials that emit ionising radiation, which have applications in many fields, especially in industry and medicine. They include high-activity radionuclides, which may attract the attention of potential terrorists (Fig. 2).

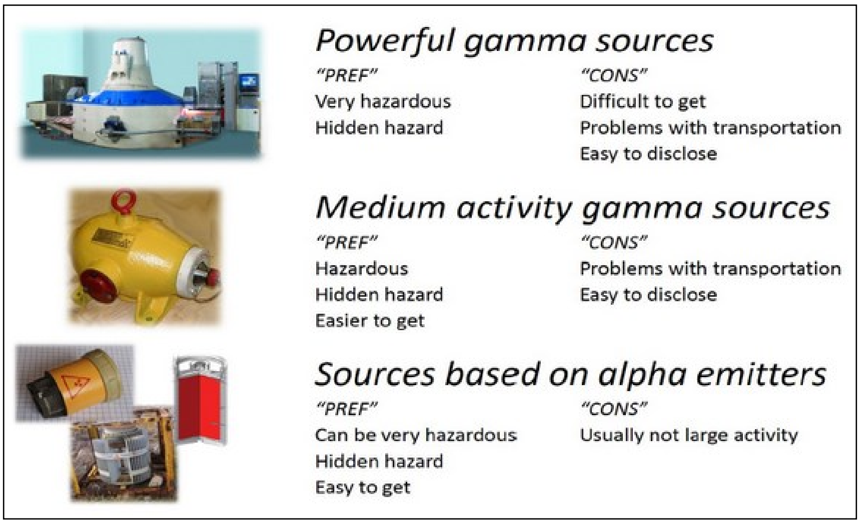


Fig. 2. Radioactive sources are likely to be attractive to terrorists. "Pref" refers to reasons terrorists might prefer each source, and "con" refers to reasons a source is less likely to be selected [11].

It includes only radioactive sources; other radiation sources, such as X-ray machines or charged particle accelerators, are not included in this category of agents. Radiological agents include radioactive materials that emit ionising radiation, which have applications in many fields, especially in industry and medicine. It includes only radioactive sources; other radiation sources, such as X-ray machines or charged particle accelerators, are not included in this category of agents. This may cause some confusion because radiology is usually based on both types of radiation sources. We would suggest changing this term when using it in relation to CBRN from radiological to radioactive agents.

2.4 Nuclear agents

These agents are attributed to fissionable materials used in nuclear reactors, where fission is controlled and used to produce energy. Since the process is accompanied by high-intensity radiation and the production of vast amounts of radioactive materials, such installations should be used under strict safety and security conditions. Under normal situations, the release of radioactivity to the environment contributes only a fraction of the doses that the population receives from other radiation sources, including environmental radioactivity and cosmic radiation. However, in the case of an accident, sabotage or terrorist attacks, many high-activity radionuclides are spread into the surrounding areas. The exposure near such a damaged reactor can reach such levels that ionising radiation can reach doses, causing death to affected people. The main components of the nuclear reactor and other essential parts of NPP are shown in Fig. 3.

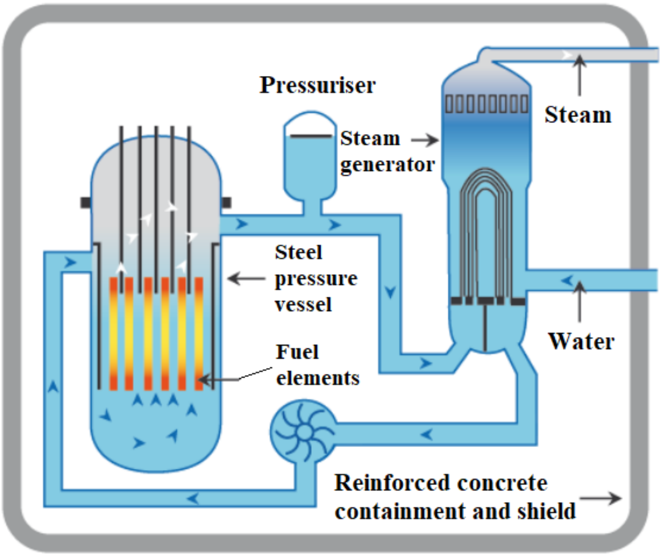


Fig. 3. An example of a typical pressurised water reactor used at a nuclear power plant (based on [12]).

In principle, but at a much lower level, a similar situation is characterising nuclear modular reactors and research reactors used for scientific experiments, training of nuclear personnel, and production of radionuclides.

From what has been mentioned above, it is clear that component N within the CBRN group represents radioactive materials with the same consequences as radiological agents. Component N is also associated with people's exposure. Some of them, in close vicinity to the explosion, will be irradiated immediately by radionuclides released from the damaged nuclear reactors or by the explosion of nuclear weapons based on spontaneous fission or fusion. In principle, we have to be ready for potential danger from using these weapons based not only on fission but also on fusion, which is utilised in hydrogen bombs. Such a thermonuclear bomb produces enormous explosive power, including the release of vast amounts of radioactive materials.

As to the consequences of atomic bomb explosions, there are warnings from the use of these weapons in bombing two Japanese cities - Hiroshima and Nagasaki - at the end of the Second World War in 1945 [13,14]. The bombings of these two cities killed between 129,000 and 226,000 people, most of whom were civilians. The resulting deterministic effects also included more than 100,000 directly affected people. At least the same number of people were affected by stochastic effects, contributing to the increase of cancer and hereditary damage by far above their normal incidence among the population.

Other valuable data related to the radiation exposure and radioactive contamination of vast areas were obtained from nuclear power plant (NPP) accidents in Chernobyl in the former USSR (1986) [15] and Fukushima in Japan (2011) [16,17].

3. Biological effects

It has already mentioned the importance of distinguishing between stochastic and deterministic biological effects. Stochastic (random) – health effects that occur randomly and for which the probability of the effect occurring, rather than its severity, is assumed to be a linear function of dose without threshold. Hereditary effects and cancer incidence are examples of stochastic effects.

Deterministic (non-stochastic) –health effects, the severity of which varies with the dose and for which a threshold is believed to exist. The severity of these effects (rather than probability) increases with dose. The time of health harm initiated by severe exposure always occurs, although the time of its appearance may differ depending on the individual agents used, as illustrated in Fig. 4 (based on [18]). While in the areas of R and N components, there has been developed a compact system of quantification of health impact, so far, no such system is available for the quantification of biological effects resulting from C and B agents in terms of distinguishing between stochastic and deterministic effects.

Conclusions

Our approach to assessing stochastic effects reflects some ideas expressed in recent publications. In the case of chemical agents, where understanding stochastic processes is particularly relevant to genotoxic carcinogenesis, the assumption of a linear dose-response relationship at low dose (exposure) has often been adopted. However, more complicated quantification of stochastic effects is related to the effects of chemical and especially biological materials, which include very specific agents such as bacteria, viruses, fungi, and internal human parasites.

It is well known that the R and N components (in both cases, radioactive materials emitting ionising radiation) of the CBRN family are well studied, including their stochastic and deterministic effects (non-stochastic). On the other hand, C and B agents have completely different origins and cause health effects in entirely altered processes. This is why we cannot consider that CBRN agents present a homogenous group of dangerous substances. When more components are involved, assessing the total CBRN impact in a unified is difficult.

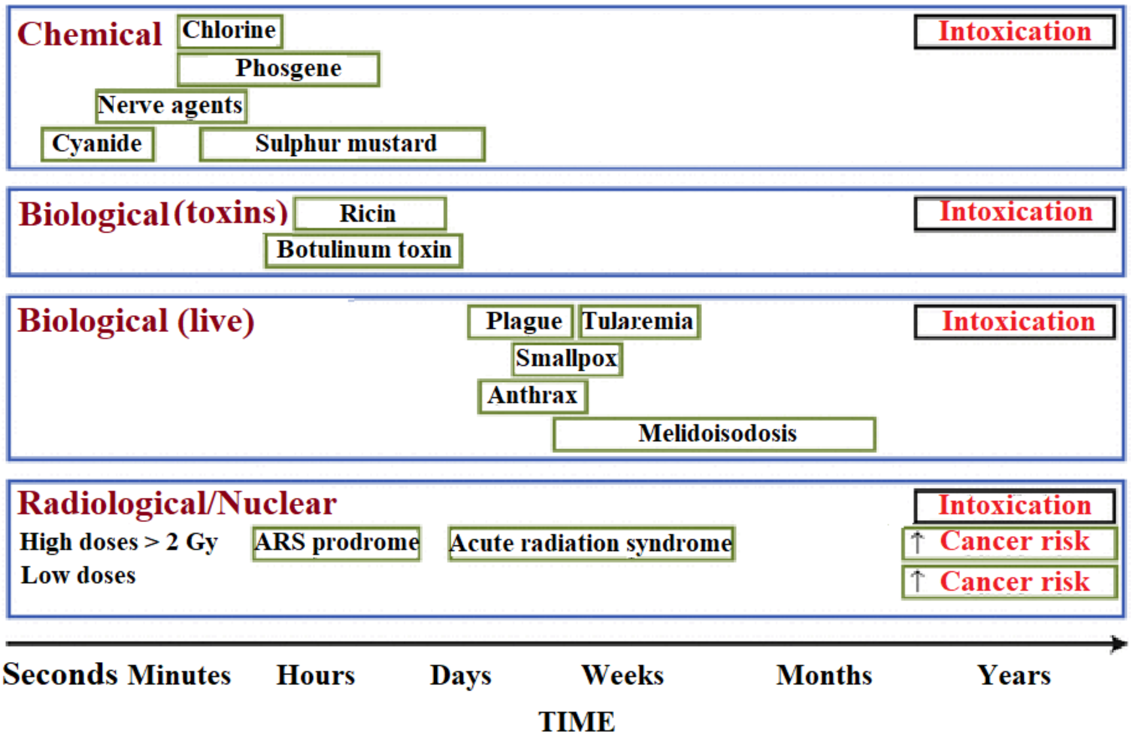


Fig. 4. A summary of the latency and incubation periods for specific CBRN agents (ARS – Acute Radiation Syndrom).

The paper discussed the quantification of CBRN agents as a whole, paying attention to two possible consequences of exposure-initiating effects appearing later, with a certain probability, and the effects that occur shortly after the interaction with CBRN agents.

To summarise all of the above, although the group of CBRN hazardous substances is quite often taken as a single unit, the quantification of the degree of health damage caused by components C and B is still inconsistent. Especially when it comes to comparison with R and N components, where there is a scientifically conceived system of quantities and units that reflects both stochastic and deterministic effects. The authors of the article point to these inconsistencies and justify the need for a more balanced approach to all CBRN agents. Therefore, it will be necessary to assess the overall risk as a result of the effects of CBRN comprehensively as a whole.

Acknowledgments

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The Role of Mathematics and Physics as Essential Foundations for Future Armed Forces Officers

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Abstract

The aim of this paper is to get acquainted with the form of teaching physics at the Department of Mathematics and Physics, Faculty of Military Technology, University of Defence. A good knowledge of mathematics and physics is a prerequisite for coping with the demands placed on future officers of the armed forces. Further, the article presents conclusions that show that mentoring, updating textbooks to a form close to the current generation, and targeted practice of more demanding physics topics together with modernized classroom and laboratory equipment, including extensive use of e-learning, gradually leads to better learning results. This contribution also presents the analysis of students results and the form of teaching physics.

KEY WORDS: *sustainable education, cadet's motivation, knowledge of physics, student achievement*

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1. Introduction

Teaching physics is essential for the future understanding of students within their military specialties. Thus, the main purpose and importance of teaching physics is to use the acquired skills of students in their military specialties.
The Department of Mathematics and Physics (Faculty of Military Technology, University of Defence, Brno, Czech Republic) educates future officers in technical fields, as well as civilian experts for the national security system and the defence industry.

This paper aims to spark a discussion about how to teach physics in today's modern era at specific military universities. We describe how to help students in their understanding of physics with new, interesting, intuitive literature and what an essential role individually focused mentoring plays in the training of students. The military requires university graduates to be not only soldiers and commanders, but also educated professionals in their specialties.

Unlike civil universities, our students cannot choose some subjects independently, all subjects of the study programs are mandatory for them. Students take exams for individual subjects during the exam period, which usually lasts four weeks, on dates set by the examining teacher. Each student has one regular deadline and two remedial deadlines for successfully completing the exam. If he is not successful in these terms, then his studies at our school end.

Physics is taught in almost all specializations, especially in the military-technical field of mechanical and electrical engineering [1].

Students from various types of secondary schools come to our faculty. This means that students' knowledge of physics is very different. At the beginning of the study, we try to balance the level of knowledge of physics with an individual approach.

The subjects in the individual study programs are adapted to the fact that it is a military university. That is why the subjects Physical Education, English Language, Preparation in the Field are reinforced hourly. But even the subjects Mathematics and Physics, which belong to the theoretical basis of the study programs, are well subsidized per hour. Physics is taught in the form of lectures, computational and laboratory exercises.

We strive to innovate teaching methods by introducing modernized textbooks and new laboratory tasks while using information technologies [2]. Whether our efforts have positive results can be judged from the results of students in physics exams over the past several years.

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2. Form of physics teaching

Physics has been taught at the University of Defence in Brno (and their predecessors) for more than 70 years. In this long period, different degree programs were rotated according to the army's requirements. Currently at the Faculty of Military Technology, courses are accredited for master's, bachelor's, follow-up master's studies and doctoral studies. In this contribution we will focus on the master's study program in which future officers of the Czech Army are raised. As of the 2019/2020 academic year, the master's study program includes a total of 168 hours of physics instruction.

Physics is taught in the second and third semesters, a total of 84 hours of lectures, 44 hours of computational exercises and 40 hours of laboratory exercises. As an example we present the laboratory exercise “Measurement of thermal length expansion” that is important for engineering military specialization, especially for the construction of engineering structures or the exercise “Measurement of the specific charge of electron” that is crucial for military electrical engineering specialization in terms of understanding the effect of the magnetic field on the movement of charged particles in electronic devices. (see Fig. 1, Fig. 2 and Fig. 3).

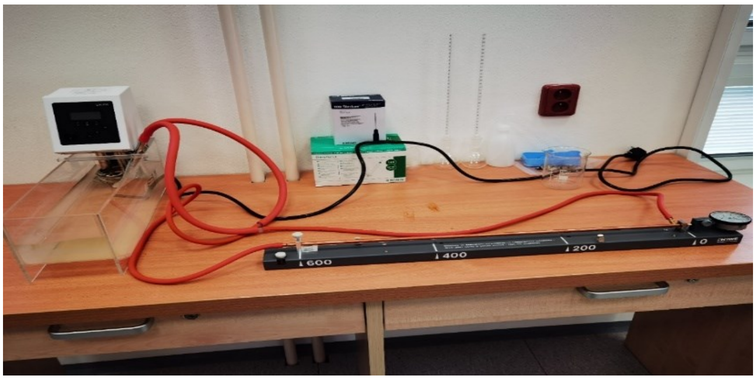


Fig. 1. Measurement of thermal length expansion

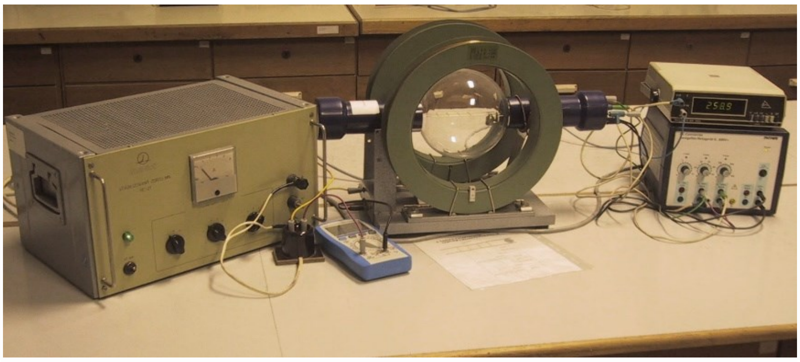


Fig. 2. Measurement of the specific charge of electron.


Fig. 3. Measurement with an optical spectrometer.

Physics lessons include, for example, the following topics: kinematics, dynamics, work, force, energy, gravitational field, special relativity, fluid mechanics, thermodynamics, electrostatic field, electric current, magnetic field, electromagnetic field, oscillations, waves, optics, quantum optics, quantum mechanics and nuclear physics.

As part of computer exercises, teaching takes place in groups of approximately 15 students. Physical examples from the mentioned topics are solved here. Approximately 10 students work in pairs on laboratory exercises. During the measurement, physical laws are verified here (Measurement of the specific heat capacity of the material, Temperature dependence of the thermistor), values of physical constants (Measurement of the specific charge of the electron, Determination of the value of gravitational acceleration), physical properties of materials (Measurement of the index of refraction of glass, Passage of gamma rays through various materials) and measurement results are processed on computers, including reporting. The classrooms and laboratories for teaching physics underwent a major renovation a few years ago, which included the purchase of new computer technology and new modern laboratory measuring instruments. We are currently preparing a new Physics textbook. During our many years of teaching practice in the field of physics, we often met, when introducing students to this exact science, with unpleasant reactions, such as: "Physics is only formulas and laws.", "What will I need it for in my life?" , "I never understood physics and I will never understand it.", "That physics is boring."

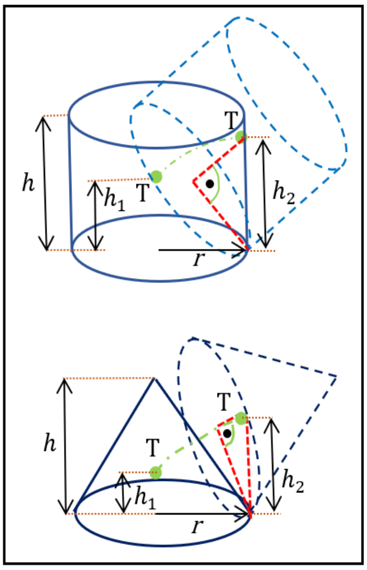
Příklad 5.4.1

Na vodorovné rovině stojí dvě homogenní tělesa: válec a rotační kužel vyrobené ze stejného materiálu. Obě tělesa mají stejné podstavy a stejné výšky. Které z nich má větší stabilitu? Poloměr podstavy $r = 0{,}5$ m a výška $h = 1$ m.

Řešení:

Pro hodnocení stability obou těles použijeme první kritérium. Vypočítáme, jak velkou práci je třeba vykonat pro uvedení těles do polohy vratké.

Těžiště válce při stabilní poloze je na jeho ose ve výšce $h_1 = \frac{h}{2}$. Pokud se válec dostane do po-



Obr. 5.11 *Určení stability válce a kužele.*

Fig. 4. Sample No. 1 of the upcoming physics textbook.

Úloha 5.3

K čemu slouží provazochodci dlouhá tyč, kterou drží při chůzi po laně v rukou?

Úloha 5.4

Když ponesete na zádech těžký baťoh, proč se budete při chůzi předklánět?

Úloha 5.5

Máte za úkol osekaný kmen stromu rozřezat na dvě poloviny, které budou mít stejnou hmotnost. Zavěsíte pomocí lana strom na jeřáb tak, aby se nacházel v rovnováze (osa kmene je rovnoběžná s vodorovnou podložkou) a v místě, kde se nachází lano, strom rozřežete. Budou mít obě poloviny stejnou hmotnost?

Fig. 5. Sample No. 2 of the upcoming physics textbook.

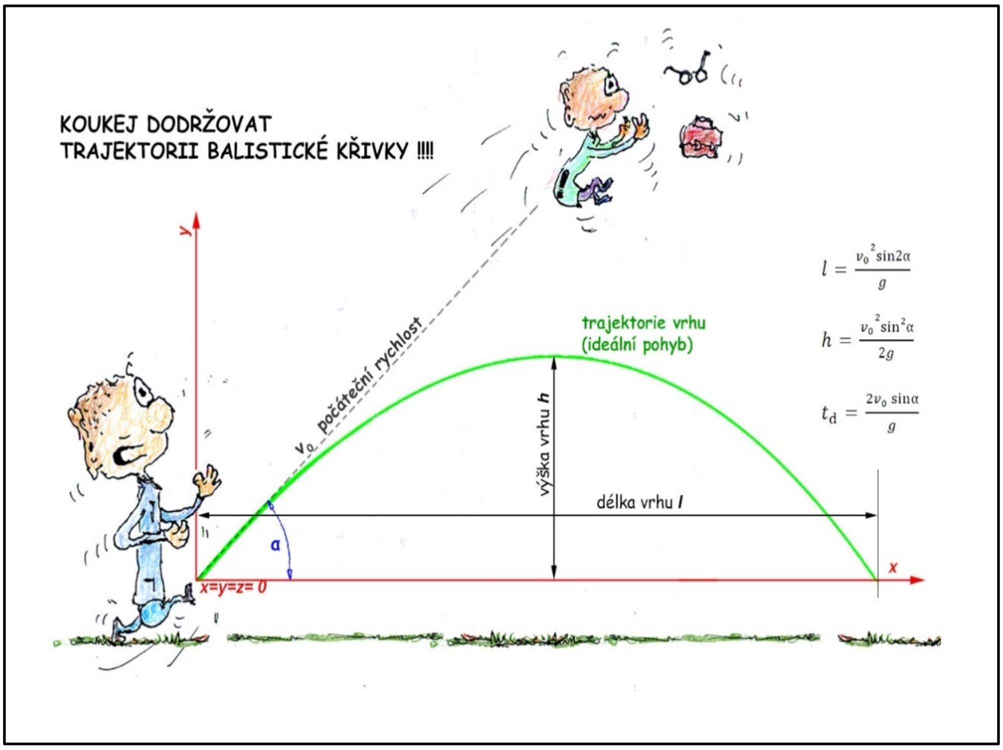


Fig. 6. Sample No. 3 of the upcoming physics textbook.

Therefore, our effort, in this publication, was to bring physics closer to students so that it becomes more interesting and fun for them. Tasks from practice, including their solutions and examples solved in detail, should contribute to this. The textbook also contains qualitative questions on which students can check their correct understanding of basic physical principles, as well as funny illustrations to complement the technical text (see Fig. 4, Fig.5 and Fig 6). This textbook corresponds to the new study texts for computational exercises and laboratory exercises. The physics exam at the end of both semesters is written and consists of six theoretical questions and four examples to be solved. A student can get a maximum of one hundred points from the paper. A student who gets at least fifty points will pass the exam. During the semester, students are continuously tested on their knowledge of physics in computational exercises. Based on the results of these continuous tests, it is therefore possible to react in time and, depending on the circumstances, to focus on specific topics in physics teaching. Ongoing tests also allow special mentoring sessions to take place if required.

3. Mentoring method and analysis of students results

Students from different types of high schools are coming to our faculty. This means that their knowledge of physics differs fundamentally when they enter college. The period of covid caused long-term closure of schools, teaching was only on-line, which brought a lot of subsequent problems related to students' readiness for university studies. Students do not have a good knowledge of secondary schools and did not receive good study habits. Students and teachers are struggling with all this, especially in the first two semesters of study at the university. Not only for these reasons was introduced mentoring at our faculty.

Due to the fact that students from different types of secondary schools come to the University of Defence and their knowledge of mathematics, physics, and other subjects varies greatly, the Faculty of Military Technology has also introduced the so-called guided preparation of students (mentoring). Students with a low number of mathematics and physics classes in secondary school, for example, had a difficult time completing tasks at the beginning of their studies, and gradually this often led to their resignation from studies.

The goal of mentoring is to provide students with support, especially at the beginning of their studies, so that they do not lose contact with teaching, manage to supplement the knowledge they did not acquire in secondary school, and so they do not feel that they will not be able to handle a certain subject. Mentoring also has a motivating effect on students where with the help of continuously completed tasks, they gain greater self-confidence in subjects and a desire to study.

The mentoring of students consists in the guided preparation of students through mentors and pedagogical leaders according to the preferred study specialization, through consulting services, and teachers of departments providing instruction. Over the course of the academic year, mentors continuously monitor and evaluate the fulfillment of students' study obligations, organize and manage their study preparation, manage the compilation of the exam schedule during the exam period, continuously check the status of the fulfillment of study obligations during the exam period, and also keep an overview of students' participation in mentoring. Mentors also meet with students regularly to get feedback, which allows them to individually adjust the care for individual students.

All students are required to attend guided study preparation in the first semester of their studies. In the following semester, those students who had a grade point average of less than 2.00 in the first semester and who were classified with grade E, as well as all those who do not meet the minimum requirements from the interim tests, participate in mentoring. Those students who have met the conditions and no longer need to participate in mentoring, have self-study sessions during guided preparation.

The guided preparation of students makes it possible to balance the differences between students, especially at the beginning of their studies, but it is also essential for its further course. It motivates students to prepare regularly and participates in minimizing the dropout rate of students due to not being able to cope with their study obligations.

To sum it up, mentoring represents regular meetings of students and teachers. Teachers practice repetition of high school skills and focus primarily on those areas in which students have the greatest difficulty. With which students have the biggest problems. In addition to repetition of high school physics, mentoring also focuses on new topics on the ongoing teaching at the university.

Is mentoring useful for students? To find out, we collected data on students' results in physics exams from the last few years, when lessons are run according to the latest study programs. We analyzed these study results with a focus on the influence of an individual approach to students [3-9], the gradual introduction of innovative methods into teaching with the use of new laboratory equipment, the modernization of study materials and the use of information technology.

Table 1.
Average evaluation of students in semester exams.

Academic year	Second semester	Third semester
2019/2020	2.37	2.20
2020/2021	1.75	1.52
2021/2022	1.82	1.70
2022/2023	2.16	1.70

Table 1 shows the average physics ratings of master's students over the last few years. The assessment of the students shows that in the third semester of study (second semester of physics teaching), the results are regularly better, which is mainly associated with the better habits of the students they acquired in the previous semester. After the introduction of mentoring, average student outcomes improved. In the following years the results stagnated, which is linked to a period of covid when teaching was predominantly online. Table 1 does not include the significant fact that the number of students who took the physics exam on the first or second term decreased.

In the first year of study, there is a high dropout rate of students. The reasons are various. The most common is that the student applied to the school with certain ideas about studying at a military college, but the reality disappoints him. Another reason is that he does not successfully pass the exam in the subjects of the first year of study, which are mainly mathematics, physical education and physics.

Table 2.
Student dropout rate due to physics exam failure.

Academic year	Second semester	Third semester
2019/2020	5	1
2020/2021	0	0
2021/2022	1	1
2022/2023	2	2

For us physics teachers, the goal is to have as few students as possible who end their studies because they did not pass the physics exam. Table 2 shows the number of students who dropped out because they failed the physics exam. It can be seen that the given numbers correspond to the numbers in Table 1.

Both tables confirm that after the introduction of mentoring in the 2019/20 school year, when students are given increased care, academic results and dropout rates gradually improved. It is possible to compare the differences between the entry knowledge of students who graduate from different secondary schools. It goes without saying that a prerequisite for the success of mentoring is the effort of the students themselves to improve their knowledge.

Analysis of the results of physics exams over the past few years also shows a positive effect on student results in relation to their division into smaller groups in laboratory and computational exercises. An individual approach to students also plays an important role, especially at the beginning of studying physics.

4. Conclusions

In recent years, the Department of Mathematics and Physics underwent a major reconstruction of the equipment used for teaching physics. The building, which houses the Department of Mathematics and Physics, was reconstructed both externally and internally. In the laboratory exercises, many laboratory tasks were replaced with new equipment and new computer technology was installed in the classrooms. Study texts for students are gradually being exchanged, and significant progress has also been made in the field of electronic study materials. The group of academic workers - physicists - is gradually getting younger.

Students have the option of choosing to study physics in English as well. For teaching in the English language, students also have the corresponding study materials at their disposal.

The aim of the mentioned text was to point out that the introduction of mentoring and care for students from the beginning of teaching physics, which begins in the second semester of study, leads to improved study results, facilitates acclimatization of students in a new study environment and teaches them to study at university. A big role in our effort to bring physics closer to students and to interest them is played by new study literature, both in printed and electronic form. We try to make the form of the teaching texts close to the current generation of young people, to engage them with a non-traditional approach. We know from feedback from students that they positively evaluate the modernization of our laboratories, where they stop working with old measuring devices and start using modern computer technology to process measured values. The results for the last five years, based on the analysis of the students' performances in the semester exams, confirm their gradual improvement in studying physics.

Our aim is that improving the individual approach to students, innovation of study literature and modernization of classrooms and laboratories at the Department of Mathematics and Physics will contribute to increasing the interest of young people in studying at the University of Defense.

Acknowledgements

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Applications in Engineer and Artillery Support: Mathematical Modeling of Symphatetic Detonation

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Abstract

The work deals with the symphatetic detonation from active to passive charge, which is an area in both engineer and artillery support. The aim of the work is to mathematically model the effect of the active charge on the passive charge due to the variable mass of the active charge and the distance from the active to the passive charge. This modelling is then applicable in all engineer support tasks where explosives are involved. The contribution of the work lies in suggestions for the reduction of firing mechanism and also in suggestions for the establishment of passage lines in obstacles. The calculations become the basis for determining proposals for establishing passage lines in minefields by artillery.

KEY WORDS: *fire support, engineer support, explosive charge, regression model, mobility, counter-mobility.*

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1. Introduction

Symphatetic detonation is one way to initiate the explosion of a passive charge. This means that in the context of this activity there will always be two charges - active and passive. The purpose of an active charge detonation is to transfer sufficient initiating pressure to the explosive in the passive charge. This design can be used in military work as well as in the civilian sphere [1]. As a rule, this is done depending on the sensitivity of the detonator which is embedded in the passive charge [2]. The detonator contains a sufficient quantity of the primary explosive which is capable of transferring the explosion to the secondary explosive of the detonator and thus serving as the initation for the entire charge. Primary explosives are generally very sensitive to external stimulus. This can be caused by either an external mechanical stimulus (impact, shock, friction) or by the delivery of energy (heat, spark) [3].

The aim of this work is to calculate and extend the data for symphatetic detonation. Currently, these data are limited to only a few values [4]. As the war in Ukraine shows further possibilities of using munitions (mobility and counter-mobility tasks) it is appropriate to consider data with active charge weights approaching artillery, engineer (e.g. engineer mines) and aerial munitions (from 5 kg).

Artillery, rocket or e.g. aerial ammunition is one of the options for active charges. Passive charges may be those explosives which contain a detonator. These are engineer munitions (e.g. mines, charges). Symphatetic detonation without a detonator in a passive charge is also possible, but the distance between these charges is significantly reduced. However, this correlation is not the aim of the paper.

2. Methodology

Authors used the basic scientific methods for processing and analysing the available sources of information and drawing conclusion. The values are examined using a linear regression model, which provides a basic estimate of the

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dynamics of detonation transport. The estimation of the true model is determined using bootstrap sampling from a uniform distribution.

The values examined are based on a literature search where the authors focused on mathematical modelling of detonation transfer and its application to the creation of passages in minefields by artillery fire and engineer work. The fundamental source is the regulation *Žen-2-6 Demolition works* [4], which defines the currently set procedures and safety standards for engineer work with explosives. Key literature sources are the professional books *Mathematical Modeling and Simulation. Introduction for Scientists and Engineers* [5], which focus on the theoretical aspects of mathematical modeling and statistical methods in engineering. Based on this information, the authors developed appropriate mathematical models for detonation transfer. Scientific publications *Creating of Minefield Breaches with Artillery* [6], Multiple round simultaneous impact fires and possibilities of its application in Czech Army [7], *Selection of Mobility Support Engineering Devices of NATO Armies Usable in the Czech Armed Forces Combat Operations* [8], *The Evaluation of the Possibilities of New Organizational Structures of Engineer Troops in the Field of Engineer Mobility Support* [9] and *Influence of Quality of Remote Sensing Data on Vegetation Passability by Terrain Vehicles* [10] provide an overview of innovative technologies and new methods leading to increased efficiency of engineer work, including the creation of passages in minefields using land artillery forces. In the development of the models, the authors make use of the data from article *Modelling fragmentation of a 155 mm artillery shell IED in a buried mine blast event* [11], where a numerical model of artillery munition fragmentation is described.

3. Combat Support

Combat support units make conditions for combat forces in selected tactical activities and thus form temporary task groups whose structure corresponds to the task to be performed. In the conditions of the Czech Armed Forces (CAF) it is usually in the strength of a battalion or brigade task group. They support mobility, counter-mobility or survivability. This enables faster, safer and more complex task execution by individual soldiers or units of the combat forces. Combat support units are limited in the activities they perform by their organic equipment and are thus augmented, supplemented, or supported by combat support force assets. Depending on the nature of the support, they are responsible for determining the mission and prioritizing the tasks to be performed. Combat support units retain responsibility for selecting the mode and execution of support in accordance with established priorities.

The symphatetic detonation can be used by units of combat forces in certain circumstances (e.g. demolition of objects of a smaller nature, especially in built-up areas, demolition of enemy equipment, during mobility measures – passage in an obstacle, etc.). This activity, as well as the method of rapid demolition, is particularly useful in those places and tasks where the units are limited by time, the amount of ammunition and the establishment of more demanding firing mechanism.

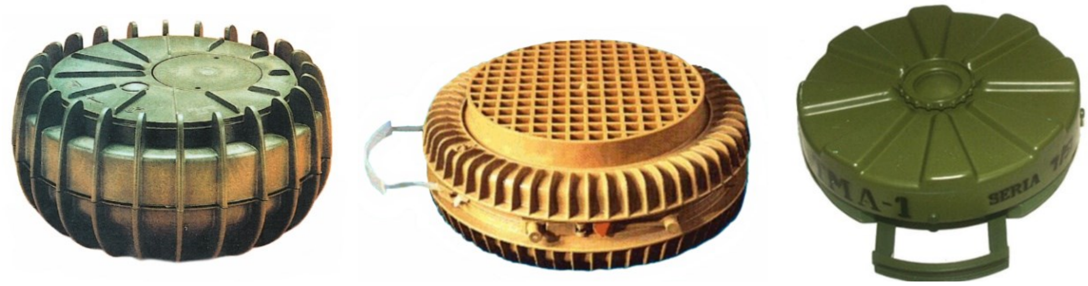
3.1 Engineer Support

One of the specialized tasks of engineer units is to support other units by performing demolition operations to achieve the intended effect of combat or support of the firing system. Demolition work can be divided according to the complexity of the work. There is simple demolition work, which is mastered by members of the combat forces, and more complex demolition work, which is only within the expertise of engineer units. However, symphatetic detonation is a method of initiation and can be applied in any range of demolition work.

In military engineering, the symphatetic detonation can be used, provided that the distance is shorter and auxiliary firing mechanism is lacking. On the other hand, this activity requires a greater number of detonators, as each must be in a single charge. Detonators contain a primary explosive that is sensitive to the transfer of energy and pressure from the active to the passive charge. Examples of the use of symphatetic detonation include the demolition of timber piles, structural elements of bridges and buildings, disposal of ammunition, etc.

In the context of the troop workload, engineer support may not be sufficient, and therefore it is advisable to look for other means of support [9]. One such capability is the ability to establish passages in explosive obstacles. By this is meant minefields, booby traps, or improvised explosive devices. A passage in minefields can be established manually, mechanically, or by remote means. Each of the options involves the use of explosives, and this is done through, for example, rocket-propelled deminers, explosive deminers, or towed charges [8]. The war in Ukraine shows that minefields are usually of non-standardized size and type, they also contain booby traps, and therefore establishing a passage, let alone conducting a full area mine clearance, is very problematic. There are not enough demining assets in this war, especially for first-line combat, and Ukraine is and will be supplied by NATO states with artillery ammunition. These are munitions of different calibre, with different fuzes and different predeterminations. The fact remains that the establishment of a passage in obstacles can also be implemented by artillery fire, where can be used of symphatetic detonation. The engineer units can then be used for other tasks and, above all, human resources are not exposed to such danger from enemy fire.

Engineer mines retain some similar characteristics, namely the body and the explosive charge, while the fuze may be of a different nature. The body of the mine is made of various types of plastic, metal or wood. Mines produced today are usually with a plastic body (see Figure 1). Manufacturers produce mines with different thicknesses and may also support the structure with struts or ribbing. This will then vary the mine's resistance to overpressure at the pressure wave front. The explosive charge contains explosives which are themselves resistant to mechanical and energy stimulus compared to primary explosives. Thus, a mine can go into detonation in two ways (in addition to the conventional detonator method): 1) by applying initiating pressure to the primary explosive of detonator or 2) by applying sufficient initiating pressure directly to the explosive charge of the mine itself. In both cases, however, it is necessary that the initiating pressure of the active charge deforms the mine body and also makes symphatetic detonation either to the detonator or directly to the explosive charge of the mine itself.



(a) Andrushy Landmine (b) MATS-2 Landmine (c) TMA-1 Landmine

Fig. 1. Selected anti-vehicle mines with plastic body

3.2 Fire Support

A possible way of creating passages in minefields is to use artillery fire. It is in this context that the problem of transfer of detonation from active to passive charges can be applied in the field of artillery fire support. The transfer of detonation is one of the important factors enabling the evaluation of effectiveness and determination of artillery ammunition consumption for this method of overcoming explosive roadblocks.

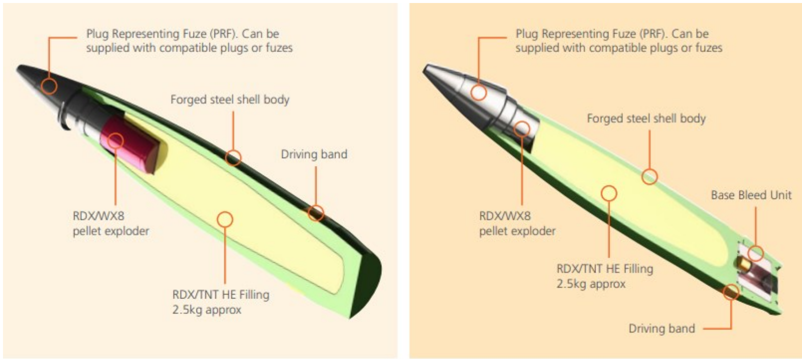
Artillery units in Ukraine have a wide range of ammunition available, both in standard NATO calibers (155 mm, 81 mm, etc.) and in calibers of Eastern provenance (152 mm, 122 mm, 120 mm, etc.). Artillery ammunition can be fitted with different types of fuses. The types of fuzes are impact, delayed, non-contact and smart fuzes The function of the fuzes can have a high impact on the detonation transfer capability. The choice of the type of projectile fuze will depend on the design of the mines used, the size and density of the minefield, and the distance over which the artillery units will conduct fire. Impact or delayed fuzes will be used to destroy roadblocks with buried and more resistant mines. Non-contact fuses may be used to destroy minefields where mines are spread out on the surface and are easily damaged. Smart fuses will be used for small minefields and in situations where artillery units will be destroying minefields at long range. As the firing distance increases, accuracy decreases and smart fuzes will guide the missile to the exact desired location.

Another option to achieve the desired effectiveness in destroying minefields is to conduct the firing mission using Missile Ready Single Impact (MRSI). MRSI is a method of firing in which the weapon fires multiple rounds at different barrel diameters and powder charge sizes within a short time interval and then all the rounds fired in this manner strike the target at the same moment. Artillery units are time-constrained in conducting firing missions in a single firing position because of potential enemy counterbattery activity. The use of MRSI can reduce this risk by reducing the time required to fire the required number of all rounds or, conversely, can increase the number of rounds that can be fired in a specified time interval. [7]

The accuracy of fires also has a direct influence on the effectiveness of creating passages in minefields. At the moment when the artillery units of the Czech army do not have automated artillery, it is necessary to conduct survey of firing positions and subsequent preparation of firing positions [12]. Precision in the preparation of firing positions for artillery and their available quantity contributes in the process of correction calculation for firing with manual methods to remain competitive even among autonomous weapon systems [13]. Last but not least, meteorological data from meteorological units must be included in the calculations. The ability to obtain or produce a meteorological report allows elements to be prepared for firing with such accuracy that effective fire can be conducted without adjusting [14]. In the case where artillery units can fire without adjust fires, the enemy's ability to return fire is limited. In the case of a firing mission with rocket artillery, the enemy air defence response to this fire is reduced and the impact on the target will achieve a higher percentage of success [15].

The design of the standard fragmentation ammunition (Figure 2), which is the basic ammunition of artillery of all armies of the world, shows the large volume of the bursting charge enclosed in the projectile body. The bursting charge can have different compositions, e.g. TNT, TNT in combination with RDX, and act as an active charge when detonated. When the missile is initiated, the detonation will be transferred to the mines in the vicinity of the explosion, thereby achieving their destruction.

In the case of artillery fires on explosive obstacles, it is necessary to assess, in addition to the shrapnel effect, the effect of the symphatetic detonation, which may result in a chain reaction and a subsequent series of detonations [11].



(a) L31 HE (b) XL32E1

Fig. 2. The cross-section of a BAE Systems 105 mm Artillery Shell [16]

4. Symphatetic Detonation

Limitation of the data used in this work is due to the fact that they were created with the assumption of using moulded TNT. For this issue the following principles apply:

- Direct distances between charges without obstruction;
- The detonators are oriented so that their open ends face the active charges;
- The detonator serves as a fuze and is not included in the total weight;
- Symphatetic detonation is valid for land use.

Currently, the limiting values for the distances between active and passive charges are set to lengths between 0.5 m and 2.5 m [4]. The research question for mathematical modelling becomes – how do the variables (charge mass vs. distance between charges) differ for values up to 0.5 m and above 2.5 m? There are cases where symphatetic detonation is not desirable (e.g. own minefields). The opposite is true for situations where the nature of the task requires it (e.g. the demolition of timber piles or enemy minefields [10]).

For any munition, it is necessary to convert its explosive composition to the equivalent of moulded TNT (coefficient 1). This is achieved by using the ballistic and sealing coefficients in addition to the explosive efficiency coefficient. This coefficient is particularly necessary to take into account for artillery munitions whose total mass is primarily composed of a metal body.

In the case of artillery ammunition, sypmhatetic detonation may also occur by the detonator being affected by the mechanical stimulus of the shrapnel from the active charge. It is not the purpose of this work to determine the extent, size and spread of shrapnel from the detonation of artillery munitions.

5. Mathematical Modeling of Symphatetic Detonation

The examined data were obtained from a military document dealing with demolition works [1] and their limitation lies in their small quantity and short range. The aim is to construct a model describing the data and to extrapolate the values beyond the given range. Statistical modeling is used to describe the relationship between the weight of the explosive charge and the distance between the active and passive explosive charges.

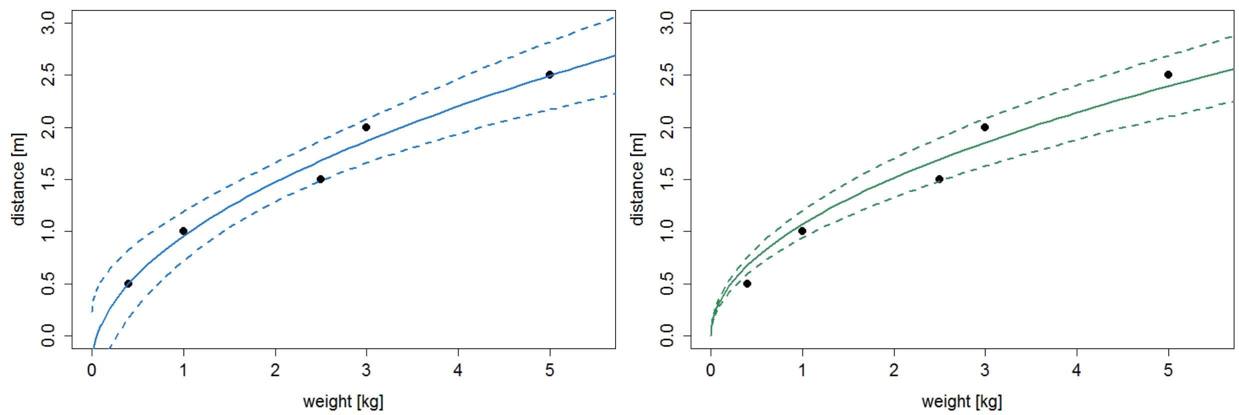
A linear regression model [5] is proposed based on the typical blast characteristics. The distance increases with the increasing weight of the explosive charge, however, characteristics of the environment have to be taken into account, e.g. the decrease of the pressure wave with the increasing distance. Therefore, we applied a linear regression model using a square root function to capture the behavior of the explosive charge: $distance = a + b \cdot (weight)^{1/2}$, where a, b are parameters of the regression function. The regression model based on the measured data is summarized in Table 1.

Table 1.

Linear regression model in its two possible forms

Model	Equation	Model significance	Residual std. error	Coef. of determination
full	$distance = -0.285 + 1.243 \cdot (weight)^{1/2}$	$p = 0.001$	$s = 0.134$	$R^2 = 0.972$
submodel	$distance = 1.071 \cdot (weight)^{1/2}$	$p < 0.001$	$s = 0.163$	$R^2 = 0.990$

In evaluating the square root model, it was found out that the intercept is not statistically significant and a simpler model (i.e., a model without the intercept) could be applied. The summary of the submodel is also included in Table 1 and both models are presented in Fig. 3.



(a) full model

(b) submodel without the intercept

Fig. 3. Linear regression models – full model using the square root function (left panel) and its submodel dropping the intercept (right panel), both accompanied by a 95% confidence band (dashed lines).

We can see that both models provide a very satisfactory fit to the data, as shown by the residual standard errors, which are small, and the coefficient of determination, which is close to one. However, for the prediction outside the range of the given data, the two models differ, see Fig. 4, where both models are superimposed. Therefore, to evaluate how the weight of the explosive charge influences the distance for values up to 0.5 m, and especially for the values above 2.5 m, the expert advice or field measurement has to be used.

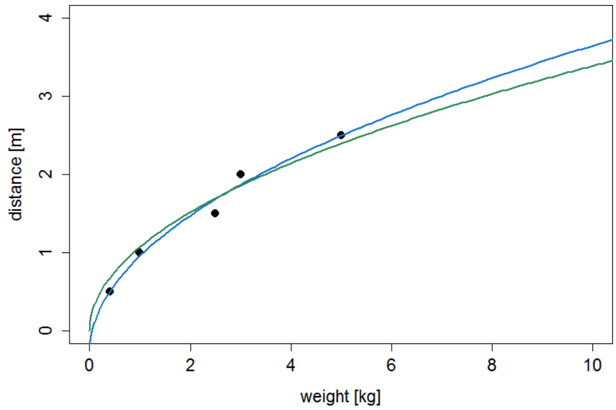


Fig. 4. Extrapolation of the linear regression models – full model (blue line) and its submodel (green line).

6. Discussion

The range, size, and direction of spread of munition fragments (e.g., artillery, rocket, or aerial) mechanically affect passive charges. This means that, although the pressure induced by the explosion of an active charge may not cause symphatetic detonation in a passive charge, it can happen due to the effect of shrapnel [17]. These have a much larger radius of action than the radius of detonation of the explosive. Thus, initiation may occur when a shrapnel hits the pusher disc of an engineer mine. Therefore, the mathematical modelling in this work becomes the basis for further calculations that will also take into account the effects of shrapnel.

As a first step, it is necessary to verify the mathematical model proposed in Chapter 5. This will be done in the following period on the blasting pit. It becomes the basis for determining the design of procedures and methodologies for establishing passages in minefields by artillery. In particular, they will be used to evaluate theoretical ammunition consumption and to determine the duration of artillery support [].

Furthermore, the dimensions of the detonator body have an influence on the initiation by symphatetic detonation. "Ž" detonators used in the CAF are characterised by their narrow width. In addition, the primary explosive of the detonator is protected by an aluminium cover and the detonator itself is usually held in the detonation receptacle by a detonating screw in the charge. All this reduces the net diameter of the hole to the primary explosive to 2 mm. For symphatetic detonation, on the other hand, it is preferable for the detonator to be closer to the outer edge of the charge, provided that both the primary and secondary explosives are always embedded in the body of the charge, i.e. the detonator is shorter and larger in diameter. This becomes a prerequisite for further investigation and verification of this hypothesis.

7. Conclusions

The results of this modeling study show that the linear regression model with the square root function describes the data quite well and the bootstrap resampling with the uniformly distributed errors characterizes the unknown rounding errors. The resulting lower confidence curve can then be taken as the optimal combination of distance and the weight of the explosive charge. This modeling is then applicable to all tasks of engineer support where explosives are involved. Examples include the disposal of unexploded ordnance, setting up or removing obstacles, and more.

The contribution of the work lies in the proposals for the reduction of detonation nets (counter-mobility) and in the determination of the distance of detonation during the explosion of artillery munitions in the case of establishing passages in engineering obstacles using artillery fire (mobility). Damage of wires is a common failure of a fuze (whether by detonating cord or by electrical fuze). Other benefits include the possibility of applying this predictive model to other types of explosives, thus creating a comprehensive data set for use in military engineering. Currently, there are no explosives that retain the sensitivity of a primary explosive while being as safe as explosives (e.g., trinitrotoluene) against impact, friction, and thermal effects.

Symphatetic detonation is based on the energy transfer and pressure of the explosion. The presence of shrapnel or other fragments is not taken into account. These can, of course, also initiate the detonator in a passive charge. The probability of shrapnel spread location and detonation of the passive charge by shrapnel can then be evaluated statistically. The explosion of active charges also affects the distance of shrapnel spread location with respect to their weight. Thus, artillery fragmentation munitions or hand grenades can become active charges to symphatetic detonation under certain circumstances.

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Enhancing Tactical Readiness in Law Enforcement: Analysis of psychophysiological response in close quarter engagements

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Abstract

This study aims to elucidate the autonomic and psychophysiological responses of professional soldiers subjected to high-stress, close-quarter combat simulations facilitated by the Redman system. The research enlisted a cohort of 67 male professional soldiers with extensive experience in international conflict zones including Lebanon, Afghanistan, Bosnia, Kosovo, and Iraq. Through a detailed examination, this study tracked the participants' heart rate (HR) and heart rate variability (HRV) before, during, and after engaging in a series of controlled combat scenarios that alternated between periods of rest and active confrontation with both male and female adversaries. This methodical approach enabled a nuanced analysis of the autonomic nervous system's reactions under varied stress levels. Results showed pronounced alterations in physiological markers post-simulation, notably a substantial increase in heart rate and a significant decrease in heart rate variability parameters such as the Average of the RR intervals, the RMSSD, and the PNN50. These changes underscore the heightened autonomic arousal and reduced heart rate variability associated with the stress of close-quarter engagements, reflecting the body's acute stress response. Thus, present research contributes to the understanding of the complex interplay between physiological stress responses and tactical readiness. By providing empirical evidence on how simulated combat impacts the autonomic nervous system, the study underscores the importance of integrating psychophysiological insights into training protocols to enhance the tactical efficacy and resilience of military personnel in high-stress environments.

KEY WORDS: *Heart Rate Variability; Autonomic Modulation; Stress; Tactical Readiness; Psychophysiological response; Police; Military.*

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1. Introduction

The realm of research within military and police domains encompasses a diverse spectrum of critical inquiries, contributing significantly to the advancement of these crucial sectors. Studies in these areas have far-reaching implications for the safety, preparedness, and effectiveness of military personnel and law enforcement officers. This body of research delves into multifaceted aspects, ranging from the psychophysiological responses of soldiers and police officers during high-stress operations [1,2], to the fine motor skills and cognitive readiness of elite forces in urban combat simulations [1]. It extends to explore the impact of experience, equipment, and tactical actions on psychophysiological responses and memory of personnel [3]. Furthermore, research has examined the effects of acute stress on the psychophysiology and physical performance of personnel serving in armed tactical occupations, shedding light on the intricate relationship between stress and performance [4]. Additionally, studies have explored the psychophysiological response of soldiers in combat situations, providing insights into the challenges faced by personnel in high-stress combat environments [5,6]. These investigations collectively contribute to the development of evidence-based practices and policies aimed at optimizing the capabilities and well-being of military and law enforcement professionals.

Understanding the psychophysiological response of individuals in combat situations holds paramount significance in the realms of both police and military operations [7]. The dynamic and high-stress nature of these environments necessitates a comprehensive examination of how the human body and mind react under duress. Research has shown that acute stress, such as that experienced in combat situations, can have profound effects on the psychophysiology of individuals. There were discussed the implications of acute stress on the psychophysiology and physical performance of personnel serving in armed forces, highlighting the need to understand how stress influences physiological responses in such contexts [4,8]. In this line, it was emphasized the importance of gaining knowledge about psychophysiological changes in high-stress situations to optimize training for combat scenarios, underscoring the relevance of studying the psychophysiological response in combat and simulation situations [9]. In addition to combat, psychophysiological responses have also been studied in other high-stress contexts, such as parachute jumps and ultra-endurance situations [10,11]. Understanding these responses can provide valuable insights into human performance and resilience under extreme stress, benefiting both military and police operations.

In this line, accidents and injuries in real police and military events and training are critical concerns within the domains of law enforcement and military operations [12]. The inherent risks associated with these professions necessitate a comprehensive understanding of the factors contributing to accidents and injuries, as well as the development of effective prevention strategies. Research has shown that police officers and military personnel often face high-stress situations and physical hazards, increasing the likelihood of accidents and injuries [13]. These incidents not only impact the well-being of individuals but also have broader implications for mission success and public safety. Recent works have shed light on the challenges faced by first responders, highlighting the need for research in this area [14–16]. Among the interventions that both police and military have to carry out, interventions in closed areas and hand-to-hand are the most stressful and those that can potentially harm personnel the most. The training for these events is complicated and entails risks to the physical integrity of the participants, both those who use systems like the "Redman" and those who have to face it [17–19].

Therefore, this manuscript aims to delve into the multifaceted aspects of accidents and injuries in real-world police and military contexts. By examining the causes, consequences, and preventive measures related to accidents and injuries, this research contributes to the enhancement of safety protocols, training methods, and overall operational effectiveness in these crucial domains. The comprehensive examination of psychophysiological responses, cognitive functions, and performance in high-stress scenarios continues to advance our understanding of how individuals in these critical roles navigate challenges, make decisions, and execute tasks under pressure. This knowledge plays a pivotal role in enhancing training protocols, operational strategies, and support systems for military and police personnel, ultimately contributing to the effectiveness and resilience of these essential sectors.

Specifically in Portugal, the General Directorate of Justice Policy (DGPJ) has released data indicating a significant rise in crime rates, reaching a ten-year peak in 2023. A total of 371,995 incidents were documented by the Portuguese police and criminal police bodies (OPC), underscoring a concerning uptrend in criminal activities [20]. The report further highlights a 5.5% increase in violent crimes in 2023 compared to the previous year, with the OPC registering 14,022 incidents of violent crime. The OPC plays a pivotal role in ensuring public safety and security, making the surge in violent crimes against them even more alarming. The Minister of Internal Administration, in an October 2023 interview with "Diário de Notícias", revealed that over 1,300 Portuguese police officers faced assaults in just the first six months of 2023 [21]. This escalation in crime and violence poses significant challenges to law enforcement and underscores the urgent need for enhanced strategies and measures to protect both the public and the officers tasked with their safety.

Then, the primary aims of this study are to comprehensively investigate the autonomic response of participants engaged in training simulations facilitated by the Redman systems. This research seeks to delve into the intricacies of how participants' autonomic nervous systems react during these training sessions, shedding light on the physiological aspects of their responses. Furthermore, the study aims to analyze and understand the contextual factors that may exert influence on these autonomic responses within the training environment. By addressing these three key objectives, this research aspires to provide a comprehensive understanding of the autonomic dynamics of individuals immersed in Redman system-based training simulations, ultimately contributing valuable insights to the field of training and simulation science.

2. Methods

2.1. Participants

We analyzed one Redman (male, 34 years, 179 cm, 86 kg, 26.8 kg/m2) and a total sample of 67 professional soldiers that faced Redman actions (male; 33.3±5.7 years; 174.7±7.2 cm; 73.5±2.2kg). Experience in actual theaters of operations as Lebanon, Afghanistan, Bosnia, Kosovo or Iraq. An informed consent was obtained from all participants for being included in the study according to the Declaration of Helsinki guidelines. The study protocol was approved by the GNR Command with Reference S026629/2024/CDF/GAB and Process Number 080.30.04 authorized on 15/03/2024.

2.2. Redman intervention:

In the study's procedures section, it was noted that Redman encountered ten distinct situations, with the odd-numbered situations designated as 'Rest' periods lasting one minute each, during which there were no stimuli. The even-numbered situations involved active confrontations with an adversary, alternating between male and female opponents. Specifically, encounters 2, 6, 10, 12, 14, 16, and 18 featured male opponents, while encounters 4, 8 and 20 presented female adversaries. This alternating pattern provided a balanced approach to assessing Redman's physiological and psychological reactions across various controlled scenarios, juxtaposing passive recovery with active engagement.

2.3. Design and procedure.

Given the relatively small sample size, a cross-sectional pre-post design was employed to minimize individual differences and better account for changes in the autonomic nervous system response. The independent variable (IV) in this study was the Redman intervention.

The following dependent variables (DV) were used to explore the changes due to the combat simulation:

Hearth rate (HR) was measured during the entire manoeuvre by a Polar V800 with RR function to analyze heart rate variability (HRV). We analyzed 20 minutes of HR and HRV before the Redman intervention with participants lie in a strecher as HRV and HR baseline values [22]. HRV and HR were recorded during the entire Redman intervention. We used the Kubios HRV software (University of Kuopio. Kuopio, Finland) in line with previous studies [23,24] to analyze the HRV time-domain parameters of average of the time between RR intervals (Average RR, ms) Average RR: Average of the RR intervals, which represent the time between successive heartbeats, measured in milliseconds (ms), RMSSD: Root Mean Square of Successive Differences. It is a measure of the variability of the RR intervals and is used to estimate the activity of the autonomic nervous system, measured in milliseconds (ms), and PNN50: Percentage of successive differences between adjacent RR intervals that are greater than 50 ms.

2.4. Data analysis

The data were analyzed using the SPSS statistical software (version 19.0; SPSS, Inc., Chicago, IL). We checked for assumptions of normality and homoscedasticity using the Kolmogorov-Smirnov test. Differences between the pre- and post-samples were determined using a dependent t-test for all variables, as they exhibited a parametric distribution. The effect size was measured using Cohen's d. A significance level of $p \leq 0.05$ was set for all comparisons.

3. Results

Post-intervention, we observed a substantial increase in heart rate (HR) and significant reductions in the Average RR interval, RMSSD, and PNN50 values (Figure 1). All changes were statistically significant with p-values below 0.001. The effect sizes for these changes varied, with HR and Average RR showing particularly large effect sizes (Table 1).

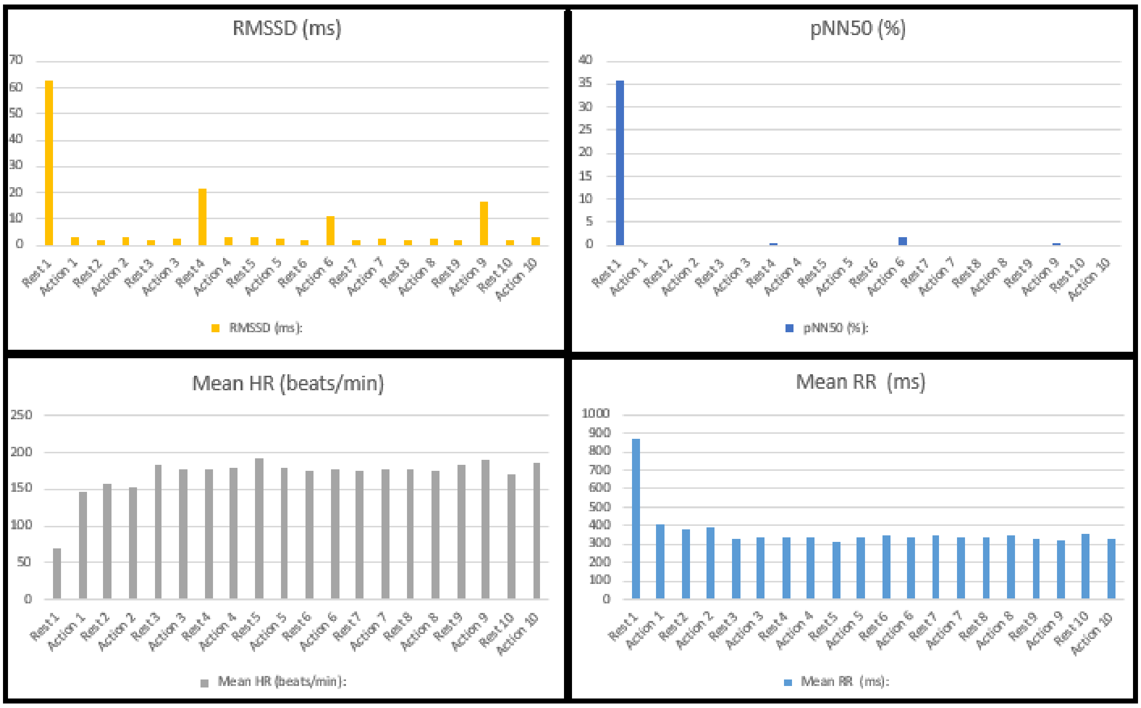

Figure 1. Heart rate variability changes in al actions and rest Redman intervention. Mean HR: Average Heart Rate (beats/min), Mean RR: Average of the RR intervals (ms); RMSSD: Root Mean Square of Successive Differences (ms); PNN50: Percentage of successive differences between adjacent RR intervals that are greater than 50 ms (%).

Table 1.
Heart rate variability changes after Redman intervention.

Variable	Unit	PRE	POST	% Change	t	p	Effect Size Cohen's D
HR	bpm	62.9±12.3	138.2±12.4	119.6	-33.85	.000	6.02
Average RR	ms	956.4±135.3	387.4±54.1	-59.5	-31.94	.000	5.52
RMSSD	ms	42.4±9.9	8.5±4.4	40.1	6.97	.000	0.91
PNN50	%	23.5±11.3	5.3±3.8	77.5	27.67	.000	2.16

Heart Rate (HR), Average RR: Average of the RR intervals; RMSSD: Root Mean Square of Successive Differences; PNN50: Percentage of successive differences between adjacent RR intervals that are greater than 50 ms.

4. Discussion

This research presents acute autonomic and psychophysiological responses of professional soldiers in high-stress situations, simulated close-quarter combat scenarios using the Redman system, The findings were characterized by a significant increase in HR and substantial reductions in HRV metrics, which indicates a pronounced autonomic arousal response. These physiological shift, indicative of a predominance towards sympathetic nervous system activation.

Similar to previous research [9,24,25] these findings showcase the intricate responses of the autonomic nervous system to stress. Emerging as a critical factor for performance in military personnel. Throughout military operations, as showcased by our findings and previous research [26], there is a decrease in parasympathetic activity translating shifting autonomic modulation towards a "fight or flight" response represented by an increased HR together with decreased HRV. Characteristic of military contexts. Further on, the concept of autonomic flexibility is gaining momentum amongst experts as it permits military personnel to seamlessly shift between autonomic modulation stations states depending on conditions [27]. Given the nature of military operations, which frequently require quick transitions between periods of high exertion and recovery, such autonomic adaptability could become a critical determinant of both the immediate effectiveness and sustained well-being of military personnel. Moreover, for military personnel to reach enhanced autonomic flexibility an integrative approach is essential combining physical training, psychological support, and the implementation of technology-based interventions aimed at fortifying the body's stress response mechanisms. Notably, biofeedback and HRV training programs have demonstrated efficacy in enabling individuals to consciously modulate their autonomic state [28], thereby bolstering their resilience to stress and enhancing overall emotional regulation. Further on, this technologically advanced approach could aid in the identification of personnel who may exhibit a heightened risk of negative stress reactions or who could benefit from supplementary support to augment their resilience.

Further on, the collective body of evidence underscores HRV as a measure of an individual's capacity for stress adaptation [29]. Assuming critical significance within the ambit of military operations where there are plenty of high-stakes situations demanding rapid decision making. Additionally, HRV serves as a pivotal monitoring instrument for training interventions designed to augment stress resilience allowing the customization of training regimens [28]. Individualized training regimens, allows soldiers to be systematically exposed to escalating stress levels, thereby refining their stress response mechanisms therefore enhancing autonomic modulation. Furthermore, the integration of HRV monitoring into routine training protocols enables the provision of real-time feedback, facilitating the fine-tuning of training intensity and concentration to optimize autonomic balance [28]. Permitting the identification of personnel potentially susceptible to adverse stress reactions allowing for timely and targeted interventions. Thus, mitigating the onset of stress-related health complications. Moreover, research has shown association between greater HRV and improved decision-making capabilities under stress [30] showcasing the importance of greater HRV within operational deployment, justifying the importance of autonomous modulation training which can directly influence on operational efficacy on both simulated and real combat scenarios. This correlation shows a shift form classic training methodologies to methodologies based on last research findings [8,31] which advocate for the elevation of physiological benchmarks such as HRV to a status commensurate with that of physical and tactical competencies. This approach necessitates of the use of technological and methodological innovations for the effective execution of HRV-centric training. Therefor, the use of wearable technology capable of accurately capturing HRV metrics in real-time and through non-invasive means is indispensable for this endeavour. Additionally, the formulation of algorithms capable of deciphering HRV data within the specific context of military tasks and stressors could yield critical insights, enabling strategic refinement of training and operational procedures to maximize soldier resilience and operational performance.

Furthermore, PTSD and the modulation of autonomic responses via virtual reality (VR)-based simulations, manifests profound connotations for the domains of military training and health management [32]. On this line, a correlation between diminished HRV and the precursory symptoms of PTSD [33,34] accentuates a pivotal concern within military health, positioning HRV as a potential indicator of susceptibility to stress-induced pathologies. The implementation of VR-based combat simulations for the fortification of stress resilience emerges as a methodology aimed at acclimating soldiers to the physiological and psychological exigencies of combat [35]. These interventions promote a controlled environment which soldiers can navigate stressors that meticulously replicate real-world adversities, thereby facilitating the development of adaptive coping strategies within a safe and controlled setting. This training modality emerges as a great tool in the enhancement of autonomic regulation granting soldiers with the tools to enhance their stress response modulation techniques in the face of simulated provocations, potentially culminating in the amplification of HRV and, by extrapolation, an augmented resilience to stress [36]. Moreover, the symbiosis between VR simulations and HRV monitoring engenders a tailored training experience where can detect the specific areas where soldiers may necessitate support. The prioritization of early detection and intervention for stress-induced vulnerabilities enables military organizations to adopt a proactive posture in forestalling the onset of PTSD and other stress-related afflictions. This preventive strategy not only holds the potential to elevate the quality of life for soldiers but also to mitigate the long-term implications associated with the management of chronic mental health conditions. Thus, underscoring the exigency for persistent research and innovation within military psychophysiology. Furthermore, the cultivation of synergies among researchers, military training specialists, and healthcare providers facilitates the establishment of a comprehensive support ecosystem, adept at addressing both the immediate and protracted consequences of combat stress.

The synthesis of empirical data from the referenced studies [18,28,37] lays an essential groundwork for the evolution of military training procedures. This holistic perspective on stress response and autonomic regulation illuminates the complex array of challenges confronting military personnel, underscoring the necessity for a comprehensive, multidisciplinary strategy towards training and intervention initiatives [38]. Such programs are imperative not only for boosting immediate operational efficiency but also for safeguarding long-term health and fostering resilience among soldiers, thereby comprehensively addressing the spectrum of acute and chronic stress effects resultant from combat engagements. To expand upon this integrated approach, military training regimes could combine aspects from physical conditioning, cognitive-behavioural methodologies, and VR simulations. Tailoring physical conditioning programs, with an emphasis on cardiovascular health enhancement, could significantly influence HRV, thus promoting autonomic regulation. Moreover, cognitive-behavioural strategies, including the practice of mindfulness and stress inoculation training, are poised to equip soldiers with vital psychological competencies for efficacious stress response management [39]. Concurrently, the implementation of technology-enhanced simulations, possess authentic and controlled settings for soldiers to hone and refine their stress management techniques, facilitating a comprehensive understanding of individual stress catalysts and effective coping strategies [35]. Furthermore, the integration of biofeedback systems within training protocols presents a direct mechanism to augmenting autonomic regulation. Enabling individuals to identify their unique stress signatures and master control over them through techniques such as regulated breathing, meditation, and other strategies [40]. This engagement with physiological stress markers proves a profound comprehension of stress response on a personal level, paving the way for tailored autonomic regulation strategies. In addition, by normalizing discourse pertaining to stress, resilience, and mental health within military contexts, organizations can produce a supportive environment within the military which motivates personnel to seek assistance as needed, and exchange stress management tactics freely.

4.1. Limitation of the study

This study, focusing on training simulations facilitated by the Redman systems, provides valuable insights but has several inherent limitations. Firstly, the results may not be fully generalizable to all real-world combat or police situations due to the controlled nature of training environments. Individual physical and psychological differences that can influence reactions under stress were not controlled for, leading to potential variability in the results. Participants who are already familiar with the Redman training systems might have reactions different from those new to the system. While the study offers an understanding of autonomic responses, it might not capture the full spectrum of physiological and psychological measures that can provide a comprehensive view of participants' states during simulations. The awareness of participants that they are in a simulated environment might also lead to the "Hawthorne Effect", influencing their behavior and responses. The findings are specific to the Redman system, and variations in results might arise if other training systems or methods are used. Additionally, factors such as the duration and intensity of training, participants' prior sleep quality, nutritional status, personal stressors, and other external factors can influence results but were not comprehensively accounted for in this research. Thus, while the study offers significant insights, these limitations should be kept in mind when interpreting and generalizing the findings.

4.2. Practical applications

The study's findings on the psychophysiological reactions during Redman training simulations can lead to the refinement of training regimens for law enforcement and military personnel. Tailoring training scenarios based on the autonomic responses can ensure that personnel are not only physically but also psychologically prepared for real-world confrontations. Insights into the nuances of the autonomic nervous system's reaction during high-intensity training can guide the development of recovery and stress-relief protocols. Understanding the triggers and physiological markers can allow trainers to implement cooldown or debrief sessions more effectively. The observed physiological responses can be used to set benchmarks or indicators for training progression. As individuals become more adept and experienced, their psychophysiological responses might stabilize or change, indicating readiness or the need for further training. By understanding the specifics of how individuals react under stress during simulations, more personalized training approaches can be developed. For example, individuals who show extreme stress responses can undergo additional resilience and stress-management training.

The data can also guide the technological development of more advanced simulation systems. By pairing this psychophysiological data with virtual or augmented reality simulations, developers can design systems that adapt in real-time to the user's stress levels, creating a more dynamic and responsive training environment. Using the insights from this study, training sessions can be scheduled optimally. If certain times of day or conditions amplify stress responses, trainers can adjust schedules to ensure that training is both challenging and effective without being overwhelmingly stressful. This research can also help in the development of post-training interventions. For those showing heightened or prolonged stress responses post-training, additional support, counseling, or interventions can be provided to ensure their mental well-being. Finally, understanding the detailed psychophysiological responses can be crucial for medical teams associated with law enforcement or military units. In case of injuries or incidents during real-world operations, having baseline data on how individuals react under stress can guide medical interventions, ensuring rapid and effective responses. Overall, the practical applications of this research are vast, influencing not just training methodologies but also well-being protocols, technological developments, and medical support systems for law enforcement and military personnel.

Conclusions

This study significantly advances our understanding of the psychophysiological responses of professional soldiers to high-stress, close-quarter combat scenarios, employing the Redman system for simulated engagements. The documented changes—increases in heart rate (HR) and decreases in heart rate variability metrics like the Average RR, RMSSD, and PNN50—underline a heightened autonomic arousal and a diminished heart rate variability, signalling the body's acute stress response to such simulated combat conditions. These findings are crucial for informing and enhancing tactical readiness and resilience training programs within military frameworks. By demonstrating the profound impact of simulated combat on autonomic responses, this research emphasizes the importance of incorporating comprehensive psychophysiological insights into military training protocols. The goal is to not only prepare soldiers for the physical aspects of combat but also to equip them with the psychological fortitude necessary to manage and adapt to stress. Ultimately, this study contributes valuable empirical evidence to the field, underscoring the intricate relationship between physiological stress responses and tactical performance, thereby offering a foundation for developing more effective training strategies that address both the physical and psychological demands faced by military personnel.

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Statistical Analysis of Youth Physical Fitness as an Important Factor for the Defence of the Czech Republic

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Abstract

Physical fitness is an important part of military service and significantly affects the successful performance of combat tasks. The aim of the study is to determine the current state of physical fitness of adolescents so that the recruitment and training system of the Czech Army is prepared for the expectations of future participants and can be updated and supplemented with new elements.

For this purpose, physical fitness testing of 1,135 (699 males and 436 females) Czech secondary school students aged 15-18 was carried out in the period 2021-2023. The testing was conducted in the area of strength and endurance disciplines in 16 different secondary schools. The percentage of total body fat in relation to body weight was measured as an indicator of the morphological component of physical fitness. Respondents were categorically rated according to their physical performance and the amount of total body fat. The age and gender of the respondent were considered. The method and form of assessment was designed in accordance with European standards.

The findings will be used to develop adequate recruitment conditions, including the content and limits of relevant tests, and to modernize the overall recruitment policy.

KEY WORDS: *fitness testing; body composition analysis; adolescents; statistical evaluation; recruitment of soldiers*

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1. Introduction

The Army of the Czech Republic replenishes its ranks with adult citizens of the Czech Republic with appropriate education, skills, age and health. Post-entry training requires the use of methods and means that are adequate to the level of the entering soldiers and ensure at least a minimum level of their overall readiness.

The Czech Republic, like other European countries, faces the problem of declining physical fitness of youths not only in the context of the COVID-19 pandemic in 2020-2021 [1–4]. The Army must respond to this situation by adjusting its approach. In order to make this adjustment systemic and to respond to the current state of the population in society, the BODY project (Physical fitness of the population as a risk factor for ensuring defensive capacity of the Czech Republic) included, among other things, testing the physical fitness and body composition of adolescents as potential candidates for entry into the army. The aim of this study is to determine the level of physical fitness of youths and to assess their current status in strength and endurance disciplines. This knowledge can be used to prepare adequate recruitment conditions, including the content and limits of relevant tests, as well as to modernize overall recruitment policies.

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2. Data and methods

The Body project tested the physical fitness of 1,135 Czech secondary school students aged 15-18 years (699 males: of which 15 years old: 66, 16 years old: 204, 17 years old: 211, 18 years old: 218 and 436 females of which 15 years old: 24, 16 years old: 125, 17 years old: 162, 18 years old: 125) between 2021 and 2023. The data were collected in such a way that the sample was sufficiently representative of the target population. Fifteen civilian and one military secondary school were included in the project in a systematic way to cover all regions of the Czech Republic. Physical testing consisted of endurance (W170/kg test, 4x10 m shuttle run) and strength disciplines (long jump from a standing position with push-off, handgrip strength). The disciplines used were chosen to sufficiently characterize the level of basic movement abilities and to be easy to learn and objective [5]. The disciplines included in the testing are used, for example, in the Eurofit or Unifittest test batteries.

An important part of the fitness evaluation of the test subjects was the W170 endurance test, which determines the power (W) that the test subject is able to achieve at a heart rate of 170 beats/min. For interpersonal data comparisons, power was converted to kilograms of weight (W/kg). The test was performed on a Cycle Ops - Phantom 5 bicycle ergometer (USA). The subject pedalled for 13 min in varied load mode and their heart rate was monitored by a sensor placed on the chest. The heart rate dynamics are used to infer the level of endurance. The second endurance discipline measured was a 4x10m shuttle run, in which the subject runs repeatedly and as fast as possible through marked sections. Time achieved, speed of movement and agility are measured. Explosive leg strength and a certain level of agility was determined by a long jump from a standing position. The jump was performed 3 times and the best performance was counted. Using an electronic force meter Multi Myometer (manufactured by Medical Research Ltd), left- and right-handgrip strength was tested and the average grip was calculated. As an indicator of the morphological component of physical fitness, the percentage of total body fat in relation to weight was measured on a special body composition analyser TANITA - BC 601.

Respondents were categorically rated on their performance in each sport discipline, but also on the percentage of body fat. The age and gender of the respondent were taken into consideration. The categorization allows comparison of results between genders, different age groups and within years. In individual analyses, the numbers of categorized students do not always match completely due to mismeasurements or non-participation in a given test. The assessment was designed by the Physical Training and Sport Centre at the University of Defence, in accordance with European standards [6, 7] see Tables 1 and 2. Statistical analysis of the survey data was performed using IBM SPSS version 28 and Matlab software.

Consider a general table of size $r \times s$ and denote the marginal row and marginal column frequencies sequentially $n_{i.}, n_{.j}$. Pearson chi-square test was used to detect differences in scores between genders, but also between years. In addition, the Eta coefficient $\eta = \sqrt{\chi^2/n}$ was calculated, the square of which indicates the strength of the effect of gender or the period of observation on the scores obtained. Adjusted residuals

$$Res = \frac{n_{ij} - \frac{n_{i.}n_{.j}}{n}}{\sqrt{\frac{n_{i.}n_{.j}}{n}\left(1-\frac{n_{i.}}{n}\right)\left(1-\frac{n_{.j}}{n}\right)}} \ \forall i = 1, \dots, r, j = 1, \dots, s,$$

were calculated to get a better idea of which category contributed most to rejecting the hypothesis of equality of distribution. These show the differences between the expected and observed frequencies. The larger the absolute value of the adjusted residual, the more significant the difference. A negative sign indicates a decrease, a positive sign an increase in frequencies compared to the expected frequencies [8].

Individuals participated in this study voluntarily and signed an informed consent form if they were 18 years old. For the minors, the consent was signed by their legal representative. Respondents were also assured of the confidentiality of the information obtained.

Table 1.

Performance evaluation for discipline W170/kg

C	Men 15–18 years	Men over 18 years	Women 15–18 years	Women over 18 years
1	< 1.96	< 2.28	< 1.3	< 1.63
2	[1.96,2.28)	[2.28,2.61)	[1.3,1.63)	[1.63,1.96)
3	[2.28,2.61)	[2.61,2.94)	[1.63,1.96)	[1.96,2.28)
4	[2.61,2.94)	[2.94,3.26)	[1.96,2.28)	[2.28,2.61)
5	≥ 2.94	≥ 3.26	≥ 2.28	≥ 2.61

Legend: C 1-5 – Performance categories: 1 – poor; 2 – medium; 3 – good; 4 – very good; 5 – excellent

Table 2.
Performance evaluation of the handgrip strength, standing long jump, shuttle run and assessment of the morphological component of physical fitness through body fat %

	Men					Women			
	C	15 years	16 years	17 years	18 years	15 years	16 years	17 years	18 years
Handgrip strength	1	< 28.1	< 33.0	< 37.4	< 41.8	< 20.7	< 21.2	< 22.2	< 23.2
	2	[28.1,32.5)	[33.0,37)	[37.4,40.9)	[41.8,44.7)	[20.7,23.2)	[21.2,23.6)	[22.2,24.6)	[23.2,25.5)
	3	[32.5,43.1)	[37,46.9)	[40.9,49.6)	[44.7,52.2)	[23.2,29.5)	[23.6,30)	[24.6,31.2)	[25.5,32.5)
	4	[43.1,47.9)	[46.9,51.5)	[49.6,53.7)	[52.2,55.9)	[29.5,32.6)	[30,33.2)	[31.2,34.8)	[32.5,36.4)
	5	≥ 47.9	≥ 51.5	≥ 53.7	≥ 55.9	≥ 32.6	≥ 33.2	≥ 34.8	≥ 36.4
Standing jump	1	< 151.9	< 162.2	< 169.4	< 176.6	< 111.6	< 114.8	< 118.6	< 122.4
	2	[151.9,170.1)	[162.2,180.6)	[169.4,189.1)	[176.6,197.6)	[111.6,127.2)	[114.8,130.1)	[118.6,133.5)	[122.4,136.9)
	3	[170.1,208.6)	[180.6,217.4)	[189.1,225.5)	[197.6,233.6)	[127.2,163)	[130.1,165)	[133.5,168)	[136.9,170.9)
	4	[208.6,224.4)	[217.4,231.8)	[225.5,239)	[233.6,246.2)	[163,179)	[165,180.4)	[168,183.4)	[170.9,186.4)
	5	≥ 224.4	≥ 231.8	≥ 239	≥ 246.2	≥ 179	≥ 180.4	≥ 183.4	≥ 186.4
Shuttle run	1	≥ 12.7	≥ 12.3	≥ 12.4	≥ 12.5	≥ 14.4	≥ 14.2	≥ 14	≥ 13.8
	2	[12,12.7)	[11.6,12.3)	[11.6,12.4)	[11.6,12.5)	[13.5,14.4)	[13.4,14.2)	[13.4,14)	[13.3,13.8)
	3	[10.7,12)	[10.4,11.6)	[10.3,11.6)	[10.3,11.6)	[12,13.5)	[11.9,13.4)	[12,13.4)	[12,13.3)
	4	[10.2,10.7)	[9.9,10.4)	[9.9,10.3)	[9.9,10.3)	[11.4,12)	[11.3,11.9)	[11.4,12)	[11.5,12)
	5	< 10.2	< 9.9	< 9.9	< 9.9	< 11.4	< 11.3	< 11.4	< 11.5
Body fat %	I	≥ 25	≥ 24.3	≥ 23.9	≥ 23.6	≥ 33.8	≥ 34.1	≥ 34.4	≥ 34.8
	II	[20.7,25)	[20.3,24.3)	[20.1,23.9)	[20.1,23.6)	[29.9,33.8)	[30.1,34.1)	[30.4,34.4)	[30.8,34.8)
	III	[10.4,20.7)	[10.1,20.3)	[9.8,20.1)	[9.6,20.1)	[15.7,29.9)	[15.5,30.1)	[15.1,30.4)	[14.7,30.8)
	IV	< 10.4	< 10.1	< 9.8	< 9.6	< 15.7	< 15.5	< 15.1	< 14.7

Legend: C 1-5 – Performance categories: 1 – poor; 2 – medium; 3 – good; 4 – very good; 5 – excellent; C I-IV– Evaluation of body fat %: I – obese; II – overweight; III – normal; IV – undernourished

3. Results and discussion

Statistically significant differences in results between men and women were found in all sports disciplines (p-values<0.01), with women performing better in all sports disciplines in comparison to standards presented in Tables 1 and 2. Test results along with frequencies and values of adjusted residuals for performance categories 1-5 are presented in Table 3. Cases that were statistically significantly different from the expected frequencies using the Bonferroni correction, i.e. those that contributed most to rejecting the hypothesis of a matching distribution, are highlighted in green. For example, in the hand grip, males have a statistically significantly higher proportion of poor ratings (25.8%) compared to females (13.8%), and in the W170/kg performance test, males have a statistically significantly lower proportion of excellent ratings (30.7%) compared to females (41.5%).

The results of the physical performance assessment for both men and women for the years 2021-2023 are presented in Tables 4 and 5. Statistically significant differences were found in the handgrip strength and shuttle run during the study period. No statistically significant differences were found in the disciplines of standing long jump and W170/kg. In the hand grip, there was a statistically significant worsening in the results of both women (χ^2=19.465, df=8, p-value=0.013) and men (χ^2=33.873, df=8, p-value<0.001) over the three years. However, it was not as pronounced for women as for men. On the other hand, an improvement of the results during the period of conducting the study occurred in the discipline of the shuttle run. For men, a statistically significant increase in the proportion of excellent results and a decrease in the proportion of good results was found in 2023 (χ^2=63.907, df=8, p-value<0.001). Women also improved in the shuttle run discipline, but due to the low frequencies in the medium and poor results categories, it was not possible to perform a Pearson chi-square test.

The frequencies of performance categorised for age and for each year of measurement are shown in Figure 1. Over the measurement period, both males and females in all age categories performed better in the W170/kg test than in the shuttle run. The sum of very good and excellent results exceeds 50% of all scores in the W170/kg stress test in most cases for all years and age categories. In the strength disciplines, both males and females achieved better results in the standing long jump than in the handgrip strength in all age categories.

Table 3.

Performance evaluation of the handgrip strength, standing long jump, shuttle run and W170/kg test by gender

		Handgrip strength χ^2=29.21, df=4, p<0.001, Eta=0.161						Standing long jump χ^2=23.24, df=4, p<0.001, Eta=0.149					
		1	2	3	4	5	Total	1	2	3	4	5	Total
Men	N	180	89	259	87	83	698	22	41	231	133	203	630
	%	25.8	12.8	37.1	12.5	11.9	100	3.5	6.5	36.7	21.1	32.2	100
	Res	4.8	- 1.0	- 3.6	- 0.8	1.4		2.6	1.9	2.7	- 2.9	- 1.8	
Women	N	60	65	209	61	40	435	4	16	121	122	158	421
	%	13.8	14.9	48.0	14.0	9.2	100	1.0	3.8	28.7	29.0	37.5	100
	Res	- 4.8	1.0	3.6	0.8	- 1.4		- 2.6	- 1.9	- 2.7	2.9	1.8	
Total	N	240	154	468	148	123	1133	26	57	352	255	361	1051
	%	21.2	13.6	41.3	13.1	10.9	100	2.5	5.4	33.5	24.3	34.3	100
		Shuttle run χ^2=58.231, df=4, p<0.001, Eta=0.235						W170/kg χ^2=15.476, df=4, p=0.004, Eta=0.117					
		1	2	3	4	5	Total	1	2	3	4	5	Total
Men	N	37	76	371	92	57	633	77	101	141	161	213	693
	%	5.8	12.0	58.6	14.5	9.0	100	11.1	14.6	20.3	23.2	30.7	100
	Res	0.7	3.0	4.7	- 3.7	- 5.7		- 0.3	1.5	1.2	2.0	- 3.7	
Women	N	20	27	183	98	90	418	50	49	75	78	179	431
	%	4.8	6.5	43.8	23.4	21.5	100	11.6	11.4	17.4	18.1	41.5	100
	Res	- 0.7	- 3.0	- 4.7	3.7	5.7		0.3	- 1.5	- 1.2	- 2.0	3.7	
Total	N	57	103	554	190	147	1051	127	150	216	239	392	1124
	%	5.4	9.8	52.7	18.1	14.0	100	11.3	13.3	19.2	21.3	34.9	100

Legend: % – percentage representation; N – absolute (empirical) frequencies; Res – values of adjusted residuals; Performance categories: 1 – poor; 2 – medium; 3 – good; 4 – very good; 5 – excellent

Table 4.

Performance evaluation of the handgrip strength, standing long jump, shuttle run and W170/kg for men from 2021-2023

		Handgrip strength χ^2=33.873, df=8, p<0.001, Eta=0.186						Standing long jump χ^2=8.854, df=8, p=0.355, Eta=0.085					
		1	2	3	4	5	Total	1	2	3	4	5	Total
2021	N	52	28	87	33	53	253	8	13	87	51	61	220
	%	20.6	11.1	34.4	13.0	20.9	100	3.6	5.9	39.5	23.2	27.7	100
	Res	- 2.4	- 1.0	- 1.1	0.3	5.6		0.1	- 0.4	1.1	0.9	- 1.8	
2022	N	68	31	95	29	15	238	11	15	72	39	68	205
	%	28.6	13.0	39.9	12.2	6.3	100	5.4	7.3	35.1	19.0	33.2	100
	Res	1.2	0.2	1.1	- 0.2	- 3.3		1.8	0.6	- 0.6	- 0.9	0.4	
2023	N	60	30	77	25	15	207	3	13	72	43	74	205
	%	29.0	14.5	37.2	12.1	7.2	100	1.5	6.3	35.1	21.0	36.1	100
	Res	1.3	0.9	0.0	- 0.2	- 2.5		- 1.9	- 0.1	- 0.6	- 0.1	1.4	
Total	N	180	89	259	87	83	698	22	41	231	133	203	630
	%	25.8	12.8	37.1	12.5	11.9	100	3.5	6.5	36.7	21.1	32.2	100
		Shuttle run χ^2=63.907, df=8, p<0.001, Eta=0.297						W170/kg χ^2=9.08, df=8, p=0.336, Eta=0.089					
		1	2	3	4	5	Total	1	2	3	4	5	Total
2021	N	14	26	159	20	2	221	31	27	50	54	85	247
	%	6.3	11.8	71.9	9.0	0.9	100	12.6	10.9	20.2	21.9	34.4	100
	Res	0.4	- 0.1	5.0	- 2.9	- 5.2		0.9	- 2.0	- 0.1	- 0.6	1.6	
2022	N	18	27	109	35	16	205	28	38	46	62	64	238
	%	8.8	13.2	53.2	17.1	7.8	100	11.8	16.0	19.3	26.1	26.9	100
	Res	2.2	0.6	- 1.9	1.3	- 0.7		0.4	0.8	- 0.5	1.3	- 1.6	
2023	N	5	23	103	37	39	207	18	36	45	45	64	208
	%	2.4	11.1	49.8	17.9	18.8	100	8.7	17.3	21.6	21.6	30.8	100
	Res	- 2.6	- 0.5	- 3.2	1.7	6.0		- 1.3	1.3	0.6	- 0.7	0.0	
Total	N	37	76	371	92	57	633	77	101	141	161	213	693
	%	5.8	12.0	58.6	14.5	9.0	100	11.1	14.6	20.3	23.2	30.7	100

Legend: % – percentage representation; N – absolute (empirical) frequencies; Res – values of adjusted residuals; Performance categories: 1 – poor; 2 – medium; 3 – good; 4 – very good; 5 – excellent

Table 5.

Performance evaluation of the handgrip strength, standing long jump, shuttle run and W170/kg for women from 2021-2023

		Handgrip strength χ^2=19.465, df=8, p=0.013, Eta=0.2						Standing long jump					
		1	2	3	4	5	Total	1	2	3	4	5	Total
2021	N	17	17	84	26	20	164	0	5	50	46	59	160
	%	10.4	10.4	51.2	15.9	12.2	100	0.0	3.1	31.3	28.8	36.9	100
	Res	- 1.6	- 2.1	1.0	0.9	1.7		- 1.6	- 0.6	0.9	- 0.1	- 0.2	
2022	N	23	27	83	28	16	177	2	6	45	51	64	168
	%	13.0	15.3	46.9	15.8	9.0	100	1.2	3.6	26.8	30.4	38.1	100
	Res	- 0.4	0.2	- 0.4	0.9	- 0.1		0.4	- 0.2	- 0.7	0.5	0.2	
2023	N	20	21	42	7	4	94	2	5	26	25	35	93
	%	21.3	22.3	44.7	7.4	4.3	100	2.2	5.4	28.0	26.9	37.6	100
	Res	2.4	2.3	- 0.7	- 2.1	- 1.9		1.4	0.9	- 0.2	- 0.5	0.0	
Total	N	60	65	209	61	40	435	4	16	121	122	158	421
	%	13.8	14.9	48.0	14.0	9.2	100	1.0	3.8	28.7	29.0	37.5	100
		Shuttle run						W170/kg χ^2=8.762, df=8, p=0.363, Eta=0.09					
		1	2	3	4	5	Total	1	2	3	4	5	Total
2021	N	6	12	91	33	18	160	24	17	32	30	59	162
	%	3.8	7.5	56.9	20.6	11.3	100	14.8	10.5	19.8	18.5	36.4	100
	Res	- 0.8	0.7	4.2	- 1.1	- 4.0		1.6	- 0.4	1.0	0.2	- 1.7	
2022	N	11	11	55	49	42	168	13	23	31	32	77	176
	%	6.5	6.5	32.7	29.2	25.0	100	7.4	13.1	17.6	18.2	43.8	100
	Res	1.4	0.1	- 3.7	2.3	1.4		- 2.3	0.9	0.1	0.0	0.8	
2023	N	3	4	37	16	30	90	13	9	12	16	43	93
	%	3.3	4.4	41.1	17.8	33.3	100	14.0	9.7	12.9	17.2	46.2	100
	Res	- 0.7	- 0.9	- 0.6	- 1.4	3.1		0.8	- 0.6	- 1.3	- 0.3	1.0	
Total	N	20	27	183	98	90	418	50	49	75	78	179	431
	%	4.8	6.5	43.8	23.4	21.5	100	11.6	11.4	17.4	18.1	41.5	100

Legend: % – percentage representation; N – absolute (empirical) frequencies; Res – values of adjusted residuals; Performance categories: 1 – poor; 2 – medium; 3 – good; 4 – very good; 5 – excellent

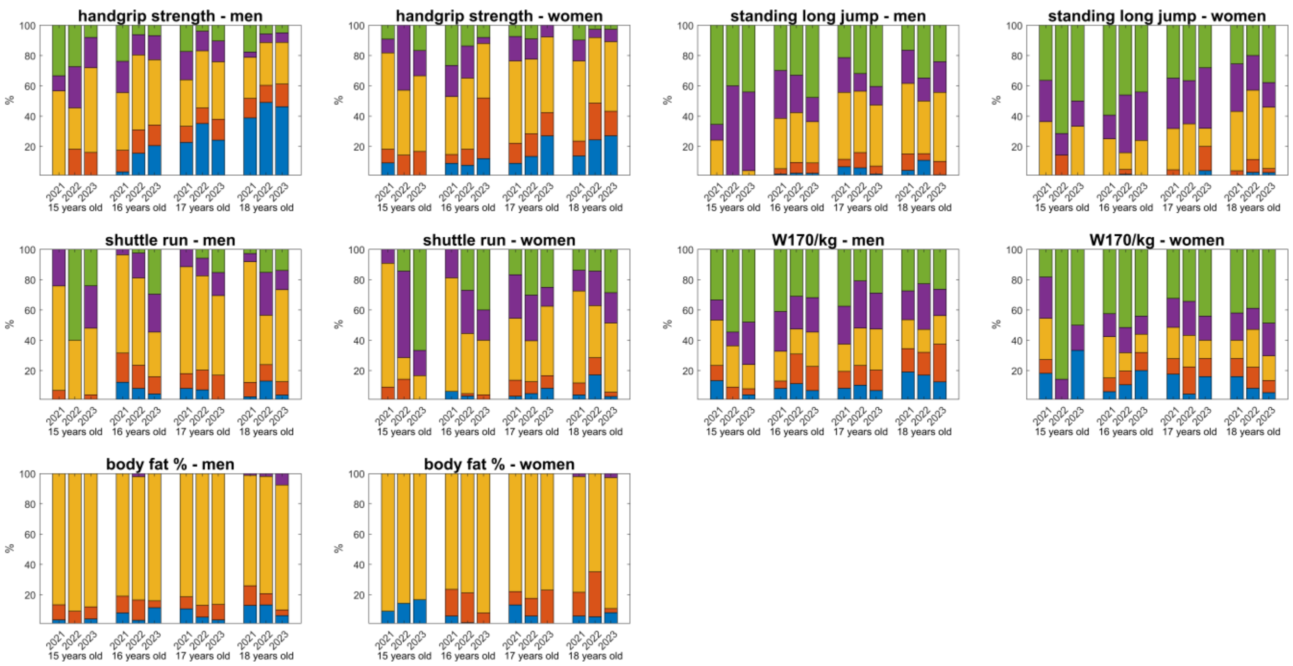

Fig. 1. Performance evaluation of the handgrip strength, standing long jump, shuttle run, W170/kg test and body fat % for men and women according to age categories. Performance categories: poor – blue, medium – red, good – yellow, very good – purple, excellent – green; Evaluation of body fat %: blue – obese; red – overweight; yellow – normal; purple – undernourished

Over the three-year period, there were no statistically significant differences in the percentage of subcutaneous fat in either men or women. Nevertheless, it can be concluded that there was an improvement in the results over the follow-up period. In 2021, 9.9% of men and 9.1% of women were obese, while in 2023, only 6.3% of men and 4.3% of women were obese. A Pearson chi-square test at the 0.05 significance level showed a statistically significant difference in body fat percentage scores between the gender (p-value=0.03). The largest difference was found in the category of overweight students. Body fat measurements showed that 6.2% of females and 7.4% of males of all tested over the three years were obese and a total of 14% of females and 9.2% of males were overweight. The frequencies for categories I-IV together with the result of the Pearson chi-square test are shown in Table 6.

Table 6.
Evaluation of the amount of body fat in relation to weight

		Body fat % χ^2=8.925, df=3, p<0.03, Eta=0.089				
		I	II	III	IV	Total
Men	N	52	64	573	10	699
	%	7.4	9.2	82.0	1.4	100
	Res	0.8	- 2.5	1.1	1.6	
Women	N	27	61	346	2	436
	%	6.2	14.0	79.4	0.5	100
	Res	- 0.8	2.5	- 1.1	- 1.6	
Total	N	79	125	919	12	1135
	%	7.0	11.0	81.0	1.1	100

Legend: % – percentage representation; N – absolute (empirical) frequencies; Res – values of adjusted residuals; Evaluation of body fat %: I – obese; II – overweight; III – normal; IV – undernourished

Conclusions

Motivated, competent, well-trained and therefore qualified military personnel are essential to the success of any army. Therefore, for planning and management of training it is necessary to have information about the physical condition of selected target groups from among the citizens of the Czech Republic. In accordance with European standards, the Physical Training and Sport Centre of the University of Defence designed an assessment of the physical fitness of youth (handgrip strength test, standing long jump from a standing position with a push-off, W170/kg stress test and 4x10 m shuttle run) and body composition (amount of body fat in the body). Subsequently, an assessment of physical performance and body fat mass, respectively, was performed.

The best results were achieved in the W170 test and in the standing long jump. Performance in these two disciplines did not change significantly over the time period. Statistically significant differences in performance were found over the three years in the handgrip strength and shuttle run disciplines. Improvements in performance over the time period were observed in both the men's and women's shuttle run disciplines. In the hand grip, on the other hand, there was a deterioration of results for both women and men, but the deterioration was not as pronounced for women as for men.

Significant differences in scores between genders were found in all tested sports disciplines. In all sports disciplines, females performed better than males. A total of 53.5% of females and 41.9% of males met the required standards in all sports disciplines tested. In addition, if the percentage of body fat is considered as an indicator of the morphological component of physical fitness, 43.9% of women and 37.3% of men meet the requirements. The measurements showed that most of the respondents have fat percentages within the norm. A total of 6.2% of the women and 7.4% of the men tested over the three years were obese and a total of 14% of the women and 9.2% of the men were overweight. The proportion of adolescents who are overweight or obese decreased during the period.

The analysis of the current state of physical fitness of secondary school students will allow to direct the process of recruitment and training of personnel in the resort of the Ministry of Defence. The findings can be used in the preparation of future military professionals prepared in all educational institutions of the Czech Armed Forces, but also in the educational process of the population.

Limitations

It is important to note that these data have methodological limitations. Respondents completed other measurements as part of the BODY project, including questionnaire surveys, so fatigue from these parts of the project may have played a role in the physical testing results. It should also be noted that some events, particularly the long jump from a standing position or shuttle run, require professional supervision and training. If students have not encountered this discipline before, they may perform significantly worse and vice versa.

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