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A CONCEPTUAL MODEL OF PARAMETRIC EVALUATION OF LOGISTIC INTEROPERABILITY OF NAVAL BASES IN THE LIGHT OF ALLIED REQUIREMENTS[1]

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Abstract. The article presents two methods for the parametric evaluation of logistic interoperability of naval bases according to NATO requirements. The study is of a conceptual nature. The solutions are based on multi-criteria models developed with reference to functional areas of logistic support, as defined by NATO, and with regard to allied logistic installations developed for ashore support of Multi – national Maritime Forces (MNMF). To provide an evaluation of the logistic interoperability of a naval base, methods used in management and applied logistics have been adopted. The solutions have been verified using an actual evaluation of selected naval bases in NATO countries. The results for both solutions have then been analysed in terms of their correlation to determine the convergence level of the results and the relevance of the suggested models.

Keywords: logistic interoperability; logistic capabilities; naval base; functional areas of logistic support; installations of logistic support; multi-criteria models

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JEL Classifications: F50, F53

Additional disciplines: Management, Military Security

1. Introduction

The notion of logistic interoperability becomes particularly important during allied operations at the level of components and joint forces. The ability of systems, units, or forces to provide and accept services from other systems, units, or forces and use the services so exchanged enables them to operate effectively together (CF.: NATO, 1997) and significantly affects the continuity of ongoing operations. Therefore, logistic interoperability should be viewed as an important operation parameter, next to items such as joint operations area, operational areas of components, intensity of ongoing operations, estimated time of their duration, and the size of involved forces. This article attempts a parametric evaluation of logistic interoperability of selected naval bases in NATO – members countries, using methods typical for management and applied logistics. As such, it has been possible to verify to what extent decision-support tools can be useful in the military. The level of logistic interoperability in naval bases has been analysed in relation to the requirements, set for such installations by selected NATO standardisation publications. The value of logistic interoperability has been defined on the basis of logistic capabilities of the discussed naval bases. Subsequently, two solutions have been suggested. The first

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one refers to a multi-criteria model of logistic capabilities, which has been developed on the basis of functional areas of logistic support, as defined by the NATO standardisation documents. The second solution involves a model based on typical installations of multi-national logistic support provided as ashore support to the maritime components (see: NATO, 2017).

The aim of the article is to suggest adequate solutions and verify them on the basis of the data provided by the real-life naval bases of the selected NATO countries (see: NATO, 2010).

The research problem that needs to be solved to achieve the above-mentioned aim is formulated as the following question: what elements at the particular levels of decomposition of the suggested model solutions decide the level of logistic interoperability of a naval base, according to the NATO standards and how should that level be quantified ?

The working hypotheses is formulated as follows: if the hierarchical structure of a model presenting logistic capabilities of a NATO naval base has been properly decomposed, the application of methods used in management and applied logistics for the evaluation of logistic interoperability, according to that model, makes it possible to provide proper quantification and verification of that solution based on real-life data.

To achieve this aim, solve the research problem, and prove the working hypothesis, the implementation of the following research tasks has been required:

- analysing some selected NATO standardisation documents to define the research field and identify logistic interoperability criteria;
- developing multi-criteria models of logistic capabilities of a naval base and logistic support sheets that describe them, based on the identified criteria;
- assuming a particular methodology for the evaluation of logistic capabilities of a naval base to provide parametrisation of the logistic interoperability level, based on the selected methods of applied logistics and management;
- identifying a set of entities (naval bases) to become the objects of the research and verifying the suggested model solutions;
- implementing the calculation methodology based on the acquired data for both solutions;
- analysing the extent of dependency between the results which have been obtained for the analysed models;
- drawing final conclusions.

In the course of the research, two basic limitations have been identified:

(1) The research refers to NATO unclassified standardisation publications and also to the author's studies related to this topic to acquire information indispensable to solve the research problem;

(2) While implementing the calculation methodology, the results of the questionnaire survey run by the author in the Polish Navy have been applied.

2. Research methodology

The evaluation of logistic interoperability of the selected NATO naval bases based on their logistic capabilities has required specific methodology, as presented in Figure 1.

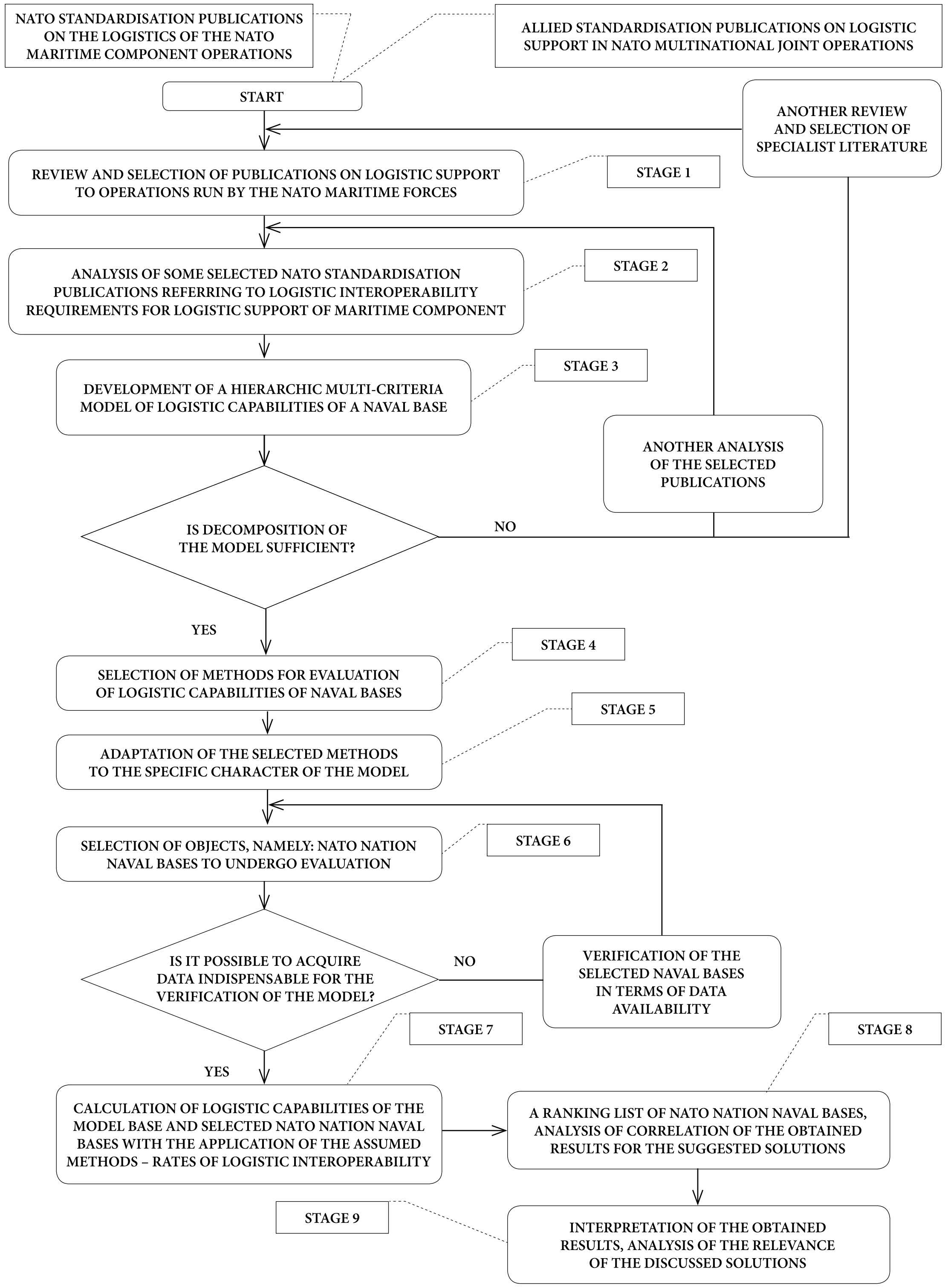

Figure 1. The research methodology

Source: Elaborated by the author

The research process is divided into nine stages.

Stage 1: A review of the current NATO standardisation publications on logistics at the level of the NATO maritime component and logistic support for joint operations. Analysis and selection of the content referring to ashore support, multi-national logistic support, Host Nation Support (HNS), and national support in the field of multi-national maritime force support.

Stage 2: The analysis of selected documents in terms of the interoperability requirements for logistic support of MNMF. A presentation of the above-mentioned requirements in relation to the functional areas of logistic support and allied installations of logistic support engaged as ashore support.

Stage 3: Development of a hierarchical model of logistic capabilities of a naval base in two variants, namely a model referring to the functional areas of logistic support (supply, maintenance, infrastructure, movement and transportation, medical support and services) and a model referring to allied installations of logistic support operated during the engagement of ashore support (Advanced Logistic Support Site/Forward Logistic Site (ALSS/FLS), Battle Damage Repair/Forward Maintenance and Repair (BDR/FMR) Facilities and Petrol Oil Lubricants (POL) Depot);

Stage 4: A review of methods used in management sciences and applied logistics and selection of methods for the evaluation of logistic capabilities of a naval base;

Stage 5: Adaptation of the selected methods to the two variants (solutions);

Stage 6: Selection of the NATO naval bases for the verification of the suggested solutions based on allied standardisation documents (NATO, 2010). To evaluate logistic interoperability, nine naval bases have been selected from the installations belonging to NATO - members countries. There have been European NATO members (i.e. Belgium, Denmark, Germany, Great Britain, Netherlands, Norway and Portugal) taken into consideration. Selected naval bases have been indicated as: NB (Naval Base) 01, NB 02, NB 03, NB 04, NB 05, NB 06, NB 07, NB 08, NB 09.

Stage 7: Calculation of the logistic capabilities values and logistic interoperability rates for a NATO naval base (model base) and the naval bases selected for the verification of the model. During the research project, the above-mentioned bases have been compared to the NATO naval base; it has been assumed that this base offers the allied forces logistic support, meeting the requirements specified for all elements of the suggested model solutions and are identified on the basis of the allied standardisation requirements (NATO, 2010 and 2001).

Stage 8: A ranking list of naval bases provided for the two solution variants and their comparison; calculation of the correlation coefficient for the parameters defining the level of logistic interoperability of the naval bases in the discussed variants.

Stage 9: Interpretation of the obtained results, drawing conclusions referring to the relevance of the suggested solutions.

3. Modelling the logistic capabilities of a naval base

In accordance with the research methodology, an analysis and selection of the NATO standardisation publications have been performed to choose documents, indispensable to achieving the aims of the research. The most significant ones are the following:

- *AJP 4 (B), Allied Joint Doctrine for Logistics,* NATO *Unclassified,* 2018;
- *ALP 4.1, Multinational Maritime Force Logistics Publication,* NATO *Unclassified,* 2017;
- *ALP 4.1. Supp.1, NATO Standard Operating Procedures for the Operation of Advanced and Forward Logistic Sites,* NATO *Unclassified,* 2001;
- *ALP 1 (E) Navy*, *Procedures for Logistic Support between NATO Navies and Naval Port Information,* NATO *Unclassified,* 2010.

Moreover, the two other appropriate US publications, have been used:

- *Manual of the Commander Naval Base Norfolk*, Virginia, 1997;
- Dell F., Fletcher Ch., Parry S., Rosenthal R., *Modeling Army Maneuver and Training Base Realignment and Closure,* Operational Search Department, Naval Postgraduate School. US, Monterey, 1994.

To define the logistic interoperability level on the basis of logistic capabilities of a NATO naval base, two model solutions are suggested:

- under the first solution, the model of logistic capabilities is based on the functional areas of logistic support;
- under the second solution, the model of logistic capabilities is defined based on typical installations of ashore logistic support, which are engaged to support Multi-national Maritime Forces (MNMF).

Considering the first variant, the logistic interoperability level of a naval base is defined as follows:

$$\partial_{NB}^{IntLog} = \{\partial_i^{IntLog};\ i = \overline{1,6}\} \quad (1)$$

where:

- ∂_{NB}^{IntLog} is the logistic interoperability level of a naval base;
- ∂_1^{IntLog} is the logistic interoperability level in the area of supply;
- ∂_2^{IntLog} is the logistic interoperability level in the area of maintenance;
- ∂_3^{IntLog} is the logistic interoperability level in the area of infrastructure;
- ∂_4^{IntLog} is the logistic interoperability level in the area of movement and transportation;
- ∂_5^{IntLog} is the logistic interoperability level in the area of medical support;
- ∂_6^{IntLog} is the logistic interoperability level in the area of services,

i = 6 is the number of the analysed functional areas of logistic support.

Based on the functional areas of logistic support, a model of logistic capabilities of a naval base has been developed to provide a common platform for the evaluation of the logistic interoperability level. For the development of the model, a bottom-up method has been applied. Specifically, on the basis of unclassified NATO standardisation documents (NATO, 2001, 2010 and 2017), a set of diagnostic features has been defined. The diagnostic features (C_{ijk}) undergo evaluation in terms of logistic support and they refer to the logistic resources and assets of a naval base, that can be offered to the operating allied naval forces. Considering their specific character, the features have been grouped into sub-areas of logistic support (S_{ij}) and have been subsequently allocated to the functional areas of logistic support (F_i), which were previously identified. This approach has allowed the author to develop a multi-criteria hierarchical model of the logistic capabilities of a naval base in terms of the functional areas and sub-areas of logistic support (Figure 2) and provide a detailed specification of the diagnostic features in relation to the above-mentioned elements of the hierarchical model, as presented in a logistic support sheet (Table 1).

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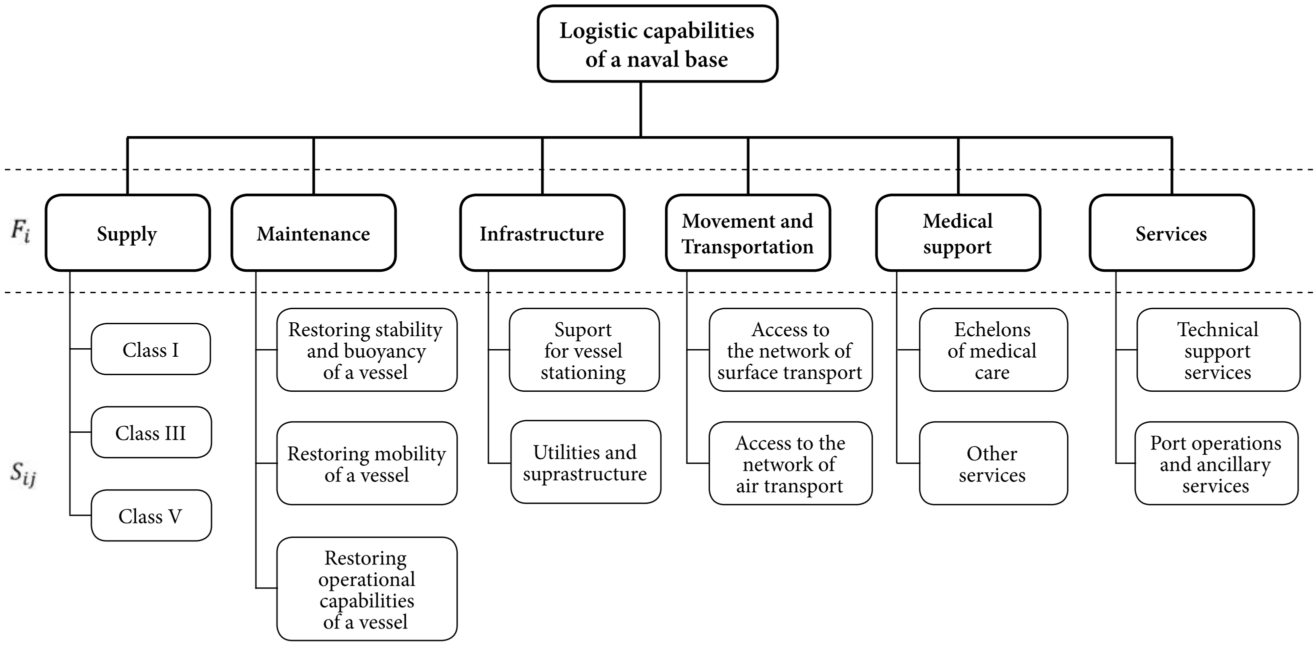

Figure 2. Hierarchical model of logistic capabilities of a naval base, with reference to the functional areas of logistic support

Source: Elaborated by the author based on NATO, 2001, 2017, 2018.

Table 1. The sheet of logistic support of a naval base in reference to the functional areas of logistic support

F_1 – Supply	
S_{11} – Class I	C_{111} – food and water (3)
	C_{112} – access to refrigerated storage (2)
	C_{113} – access to messing facilities (2)
S_{12} – Class III	C_{121} – NATO POL Depot (3)
	C_{122} – fuel F – 75 (3)
	C_{123} – fuel F – 76 (3)
	C_{124} – fuel F – 77 (2)
	C_{125} – fuel F – 44 (3)
	C_{126} – Other POL (lubricating oils) (3)
S_{13} – Class V	C_{131} – AMMO Depot inside or in the vicinity of the naval base (3)
	C_{132} – a transit point for class V materials (munitions) (2)

F_2 – Maintainace	
S_{21} – Restoring stability and buoyancy of a vessel	C_{211} – docks and slipways for destroyers and frigates (3)
	C_{212} – docks and slipways for smaller vessels (3)
	C_{213} – sheet metal working (3)
	C_{214} – pipe working (3)
	C_{214} – hull and structure painting (3)
	C_{214} – diving works assistance (2)
S_{22} – Restoring mobility of a vessel	C_{221} – machinery and mechanical device repairs (including the main propulsion system and auxiliary devices) (3)
	C_{222} – electrical machinery and device repairs (including motor coil rewinding) (3)
	C_{223} – hydraulic device and component repairs (3).
	C_{224} – pneumatic device and component repairs (3)

F_2 – Maintainace (continued)	
S_{23} – Restoring operational capabilities of a vessel	C_{231} – MCM equipment repair capacity (3)
	C_{232} – charging batteries for submarines (3)
	C_{233} – collimation (3)
	C_{234} – degaussing (3)
	C_{235} – MCMV sweep change facilities (3)
	C_{236} – air for diving cylinders (3)
	C_{237} – electronic device repairs (including navigation systems, communication systems and technical monitoring) (3)

F_3 – Infrastructure	
S_{31} – Support for vessel stationing	C_{311} – capability of hosting MNMF vessels (3)
	C_{312} – capability of handling vessels of 210m in length and 11m in draught (3)
	C_{313} – capability of handling destroyers/ frigates (175m in length/9.5m in draught) (3)
	C_{314} – capability of handling minelaying and minesweeping vessels (3)
	C_{315} – no limitations to vessel traffic in terms of tides (3)
	C_{316} – capability of extending the stationing system with civil installations (3)

Source: Elaborated by the author based on NATO, 2001, 2010 and 2017.

Table 1. The sheet of logistic support of a naval base in reference to the functional areas of logistic support (continued)

F_3 – Infrastructure (continued)	
S_{32} – Utilities and suprastructure	C_{321} – Power supply availability: AC – 440 V/60 Hz. (3)
	C_{322} – Power supply availability : DC – 220 V/110 V (2)
	C_{323} – DC regulation (2)
	C_{324} – access to power supply cables ship / shore (2)
	C_{325} – current capacity of cables for I = 400 A (3)
	C_{326} – 2.5”(water coupling refilling from the wharf (3)
	C_{327} – 11”/6” adapter for refuelling from the wharf (3)
	C_{328} – 2.5 ‘’ refuelling coupling from the wharf (3)
	C_{329} – domestic steam supply from the wharf (1)
	C_{3210} – telephone and optical fibre connections from the wharf (2)
	C_{3211} – handling container cargo (3)
	C_{3212} – handling palletized cargo (3)
	C_{3213} – ramps for handling Ro – Ro cargo (3)
	C_{3214} – wharf/floating cranes of the capacity of 27 tones (3)
	C_{3215} – potable water provided from the wharf (3)
	C_{3216} – fresh water for technological purposes provided from the wharf (3)

F_4 – Movement and Transportation	
S_{41} – Access to the network of surface transport	C_{411} – access to the network of roads (3)
	C_{412} – access to the railway lines (3)
	C_{413} – access to the network of inland waterway transport (1)
S_{42} – Access to the air transport	C_{421} – access to an air base(3)
	C_{422} – access to an airport (3)
	C_{423} – C – 5 aircraft handling capability (3)
	C_{424} – C – 17 aircraft handling capability (3)
	C_{425} – C – 130 aircraft handling capability (3)
	C_{426} – support for MPA (Maritime Patrol Aircraft) (2)
	C_{427} – support for LBH (Land-based Helicopters) (3)
F_5 – Medical support	
S_{51} – Echelons of medical care	C_{511} – echelon I (1)
	C_{512} – echelon II (2)
	C_{513} – echelon III (3)
	C_{514} – echelon IV (3)
S_{52} – Other services	C_{521} – support for CASEVAC (3)
	C_{522} – support for STRATEVAC (3)
	C_{523} – Medical pressure chamber treatment (3)
	C_{524} – Medical supply material for vessels (2)

F_6 – Services	
S_{61} – Technical support services	C_{611} – fuel supply from a fuel tank (2)
	C_{612} – fuel supply from a tanker (2)
	C_{613} – potable water supply from a water tank (1)
	C_{614} – potable water supply from a tanker(2)
	C_{615} – boiler feed water supply from a tank(1)
	C_{616} – boiler feed water supply from a tanker (1)
	C_{617} – removal of waste oil / fuel (3)
	C_{618} – removal of bilge and ballast water (2)
	C_{619} – bilge tank cleaning (1)
	C_{6110} – collection of sewage from a vessel (3)
	C_{6111} – collection of refuse and garbage(2)
	C_{6112} – collection of classified waste (2)
S_{61} – Port operations and ancillary services	C_{621} – Pilotage availability (3)
	C_{622} – Horbour tugs availability (3)
	C_{623} – Mooring service (2)
	C_{624} – Fire fighting service (3)
	C_{625} – accommodation facilities availability (2)

Source: Elaborated by the author based on NATO, 2001, 2010 and 2017.

Considering the first variant, the following methods used in management and applied logistics have been used for the evaluation of logistic interoperability, based on logistic capabilities of a naval base:

- a simple score-based method was used to evaluate the particular installations in terms of the requirements presented in the NATO standardisation documents in the specific areas and sub-areas of logistic support;
- a graphical method involving the use of radar charts (see: Tague, 2005), which makes it possible to define the extent to which the analysed entity (naval base) differs from the requirements of the model base (NATO naval base);
- the analytic hierarchy process (AHP) method is used to evaluate the impact (significance) exerted by the particular functional areas of logistic support on the logistic interoperability of a naval base (see: Saaty 1980).

The application of this method has subsequently allowed the author to calculate the total measures of logistic capabilities value and logistic interoperability rates for the analysed naval bases.

To determine the logistic capabilities of a naval base, it is first necessary to quantify the values of the defined diagnostic features based on the evaluation of the impact exerted by the diagnostic features on the logistic support level provided by a naval base, with reference to the results of the questionnaire survey run on a representa-

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tive sample of 80 Polish Navy officers. The respondents represented various command levels of the maritime components, naval units and naval groups, ashore units, and units of the naval aviation.

For the requirements of the research project, a preference scale is assumed (1 = weak impact; 2 = moderate impact; 3 = strong impact), which indicates the impact of the particular features on the logistic support level. The methodology used to evaluate the logistic interoperability of a naval base in the first variant of the solution is presented in Table 2.

Table 2. Logistic interoperability evaluation of a naval base: The sequence of calculations – the first variant

No.	Operation
1.	Calculation of the logistic capabilities value of an individual diagnostic feature: $$Q_{ijk} = q_x \times w_{ijk}, \quad (2)$$ where: Q_{ijk} is the logistic capabilities value of an individual diagnostic feature; q_x is a binary coefficient ($q_x = 1$ – the particular feature is observed in the analysed base, $q_x = 0$ means the particular feature is not observed in the analysed base, in the case of the model base, $q_x = 1$ for all features); w_{ijk} is the score-based evaluation of logistic capabilities of an individual diagnostic feature, accepted as the most frequently observed value (modal value) in the questionnaire survey for the particular features; k is the subsequent diagnostic feature in the j^{th} sub-area of logistic support allocated to the i^{th} functional area of logistic support.
2.	Calculation of the total logistic capabilities value in the sub-areas of logistic support allocated to its particular area (functional area of logistic support): $$\sum_{j=1}^{m} PS_{ij} = \sum_{j=1}^{m}\sum_{k=1}^{n} q_x \times Q_{ijk}, \quad (3)$$ where: PS_{ij} is the value of the logistic capabilities in j^{th} (subsequent) sub-area of logistic support allocated to the i^{th} functional area of logistic support; $\sum_{j=1}^{m} PS_{ij}$ is the total logistic capabilities value in the sub-areas of logistic support allocated to the particular (i^{th}) functional area of logistic support; j = m – the number of the sub-areas of logistic support in the i^{th} functional area of logistic support. n is the number of diagnostic features in j^{th} (subsequent) sub- area of logistic support belonging to the i^{th} functional area of logistic support.
3.	Calculation of the logistic capabilities rate for a naval base in the i^{th} functional area of logistic support: $$WS_i = \frac{\sum_{j=1}^{m} PS_{ij}}{\sum_{j=1}^{m} n_{ij}}, \quad (4)$$ where: WS_i is the logistic capabilities rate for a naval base in the i^{th} functional area of logistic support, as calculated by the simple score-based method on the basis of the values of logistic capabilities indicated by the diagnostic features in the sub-areas belonging to the particular areas of logistic support; $\sum_{j=1}^{m} n_{ij}$ is the number of all diagnostic features in the i^{th} functional area of logistic support
4.	Verification of the real-life bases: achieved through the identification of relations between the logistic capabilities rates in the functional areas of logistic support for the particular bases, analysed in the research project, and the same rate calculated for the model base (NATO naval base): $$\frac{WS_i}{WS_i^{MOD}} \quad (5)$$ where: $WS_i^{MOD} = \frac{\sum_{j=1}^{m} PS_{ij}^{MOD}}{\sum_{j=1}^{m} n_{ij}}$ is the logistic capabilities rate, as calculated for the model base (the NATO naval base) in the i^{th} functional area of logistic support.
5.	Graphical interpretation of the logistic capabilities values for the analysed naval bases and the model base in the particular areas of logistic support, provided by the use of radar charts based on the status of $\frac{WS_i}{WS_i^{MOD}}$ relation (Figures 4 and 5).

6.	Definition of the significance of the particular functional areas of logistic support to the logistic interoperability of a naval base; it has been calculated through the identification of the weight coefficients W_i according to the AHP method, which involves the identification of relations among the compared functional areas of logistic support. The relevant consistency indexes (CI) and consistency ratios (CR) have been calculated for the identified weight coefficients. The above-mentioned CI and CR decide the accuracy of the process of identifying relations, which take place among the functional areas of logistic support (Cf.: Saaty 1980). For all cases the following condition has been met: $CR = \frac{CI}{RI} \leq 0.1$. where: *RI* – is the random index (see: Saaty 1980).
7.	Calculation of the weighted measures of logistic capabilities for the analysed bases at the level of the functional areas of logistic support, according to the following equation: $PF_i = W_i \times \sum_{j=1}^{m} PS_{ij}$, (6) where: PF_i is the weighted measure of logistic capabilities of a naval base at the level of the ith functional area of logistic support; W_i is the weight coefficient of the particular functional area of logistic support with regard to its impact on the logistic interoperability level of a naval base (AHP method).
8.	Calculation of the total value of the logistic capabilities of the analysed (real -life) naval base and the model base (the NATO naval base), in accordance with the following equation: $\Pi_{NB}^{Log} = \sum_{i=1}^{6} PF_i$, (7) where: Π_{NB}^{Log} is the total logistic capabilities value of a naval base
9.	Calculation of the logistic interoperability rate for the analysed naval base: $W_{NB}^{IntLog} = \frac{\Pi_{NB}^{Log}}{\Pi_{MOD}^{Log}}$, (8) where: $\Pi_{\mathbf{MOD}}^{\mathbf{Log}}$ is the total logistic capabilities value of model base (NATO naval base); W_{NB}^{IntLog} is the logistic interoperability rate for the analysed naval base.

Source: Elaborated by the author.

The second variant refers to the model NATO naval base, which is composed of three basic modules of logistic support, namely: ALSS/FLS, BDR/FMR facilities, and POL depot. In this second variant, a method of aggregated evaluation is applied, namely the rate-score-based method (Stabryla 2006); subsequently, a graphical method is applied, with the use of radar charts to indicate the shortage in logistic interoperability of the analysed entities at the particular level of the model decomposition. Hence, the logistic interoperability level of a naval base is defined as follows:

$$\partial_{NB}^{IntLog} = \{\partial_i^{IntLog};\ i = \overline{1,3}\} \quad (9)$$

where:

- ∂_{NB}^{IntLog} is the logistic interoperability level of a naval base;
- ∂_1^{IntLog} is the logistic interoperability level in the field of ALSS/FLS;
- ∂_2^{IntLog} is the logistic interoperability level in the field of BDR/FMR facilities;
- ∂_3^{IntLog} is the logistic interoperability level in the field of POL depot,

i = 3 is the number of the logistic support modules.

As before, in the second solution the bottom-up method is also applied, that is, based on the unclassified NATO standardisation publications (NATO, 2001, 2010, and 2017), a set of diagnostic features with regard to logistic support has been defined. The above-mentioned features (C_{ijk}) have been grouped into components of logistic support (S_{ij}), which have subsequently been allocated to the identified modules of logistic support (M_i). Similarly to the first model, a diagnostic feature should be understood as a logistic resource that can be offered to the operating allied forces. The quantification of the diagnostic features is achieved, using the same method as in the first variant. This approach has allowed the author to develop a hierarchical model of logistic capabilities of a naval base, in terms of the modules and components of logistic support (Figure 3) and to provide the detailed specification of the diagnostic features in the hierarchical model, as listed in the sheet of logistic support (Table 3).

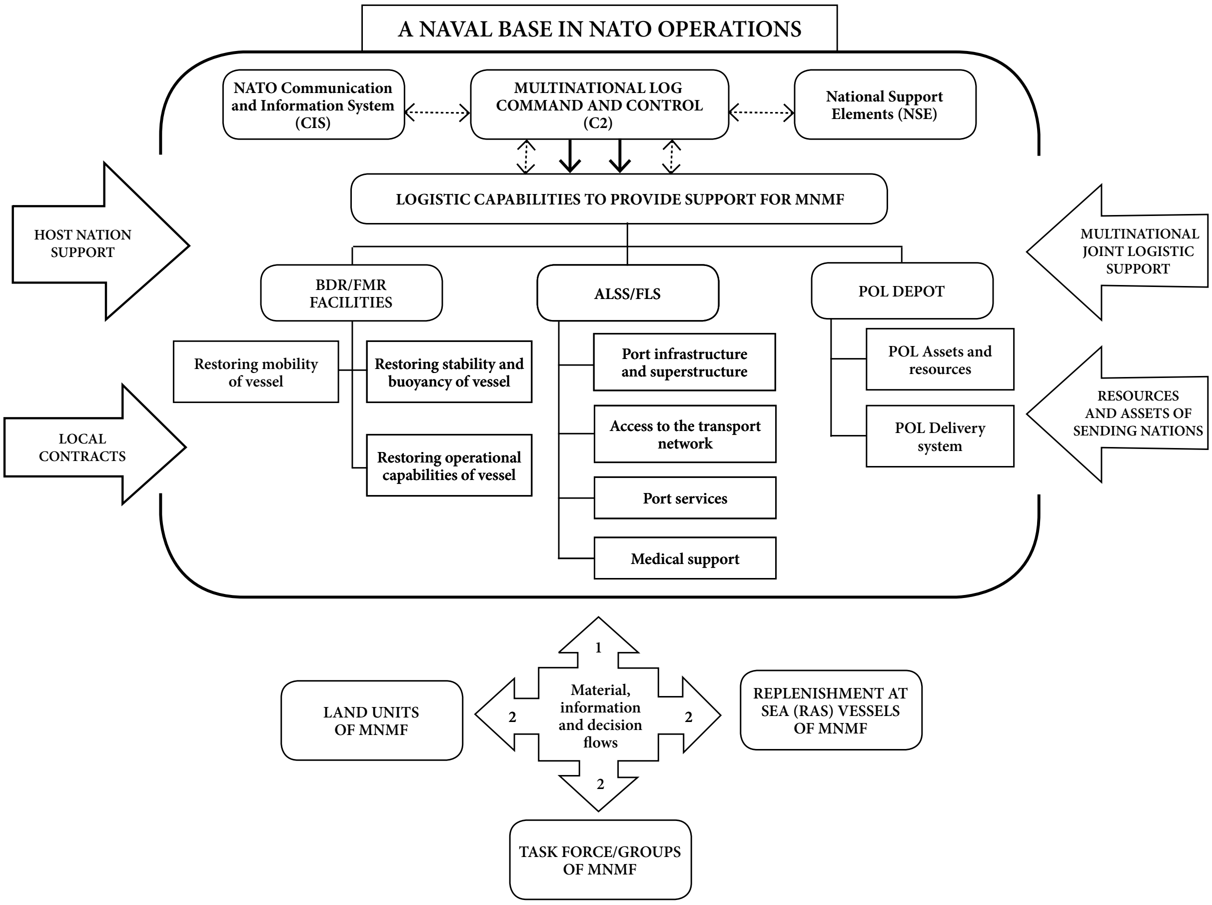

Figure 3. Logistic capabilities of a naval base in allied operations – ashore support

Table 3. The sheet of logistic support of a naval base with regard to installations of ashore support

M_1 – ALSS/FLS

S_{11}	**Port infrastructure and superstructure**
C_{111}	Capability of hosting MNMF
C_{112}	Capability of handling vessels of 210m in length and 11m in draught
C_{113}	Capability of handling destroyers/frigates (175m in length/9.5 m in draught)
C_{114}	Capability of handling mining and minesweeping vessels
C_{115}	No limitations to vessel traffic in terms of tides
C_{116}	Vicinity of large sea ports
C_{117}	AMMO Depot inside the base
C_{118}	A transit point for class V materials (munitions)
C_{119}	Power supply availability: AC – 440 V/ 60 Hz.
C_{1110}	Power supply availability: DC – 220 V / 110 V
C_{1111}	DC regulation
C_{1112}	Access to power supply cables Ship / Shore
C_{1113}	Current capacity of cables for I=200 A
C_{1114}	Telephone and optical fibre connections from the wharf

S_{12}	**Access to the transport network**
C_{121}	Access to the network of roads
C_{122}	Access to the network of railway
C_{123}	Access to inland waterway transport
C_{124}	Access to the pipeline transport
C_{125}	Vicinity of an air base within the range of 50 km
C_{126}	Vicinity of a civil airport within the range of 50 km
C_{127}	Handling strategic air transport
C_{128}	Handling tactical air transport
C_{129}	Support provided to MPA (Maritime Patrol Aircraft)
C_{1210}	Support provided to LBH (Land-based Helicopters)

S_{14}	**Medical support**
C_{141}	Echelon I
C_{142}	Echelon II
C_{143}	Echelon III / IV
C_{144}	Support for CASEVAC

S_{13}	**Port services**
C_{131}	Potable water supply from a water tank (onshore transport)
C_{132}	Potable water supply from a tanker
C_{133}	Demineralized water supply from a water tank (onshore transport)
C_{134}	Demineralized water supply from a tanker
C_{135}	Boiler water supply from a tank (onshore transport)
C_{136}	Boiler water supply from a tanker
C_{137}	Removal of waste oil/fuel
C_{138}	Removal of bilge and ballast water
C_{139}	Bilge tank cleaning
C_{1310}	Collection of sewage from a vessel
C_{1311}	Collection of refuse and garbage
C_{1312}	Collection of classified waste
C_{1313}	Pilotage service availability
C_{1314}	Horbour tugs availability
C_{1315}	Mooring services
C_{1316}	Firefighting service

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C_{1115}	Handling container cargo
C_{1116}	Handling palletized cargo
C_{1117}	Installations for handling Roll on – Ro off cargo
C_{1118}	Access to wharf/mobile/floating cranes of the capacity of 27 tones
C_{1119}	Potable water from the wharf
C_{1120}	Fresh water for technological purposes from the wharf
C_{1121}	Domestic steam supply from the wharf
C_{1122}	2.5 ‘’ water coupling refilling from the wharf

C_{145}	Support for STRATEVAC
C_{146}	Medical pressure chamber treatment
C_{147}	Medical supplies material for vessels

C_{1317}	Accommodation facilities availability
C_{1318}	Access to refrigerated storage
C_{1319}	Access to messing facilities

M_2 - BDR / FMR FACILITIES	
S_{21}	**Restoring stability and buoyancy of a vessel**
C_{211}	Dry/floating docks for destroyers and frigates
C_{212}	Dry/floating docks or slipways for minelaying or minesweeping vessels
C_{213}	Sheet metal working
C_{214}	Pipe working
C_{215}	Diving works assistance
S_{22}	**Restoring mobility of vessel**
C_{221}	Machinery and mechanical device repairs (including the main propulsion system and auxiliary devices)
C_{222}	Electrical machinery and device repairs (including motor coil rewinding)
C_{223}	Hydraulic device and component repairs
C_{224}	Pneumatic device and component repairs

M_2 - BDR / FMR FACILITIES	
S_{23}	**Restoring operational capabilities of vessel**
C_{231}	MCM equipment repair capacity
C_{232}	Charging batteries for submarines
C_{233}	Collimation
C_{234}	Degaussing
C_{235}	MCMV sweep change facilities
C_{236}	Air for diving cylinders – high pressure
C_{237}	Electronic device repairs
C_{238}	Refrigeration system repairs

M_3 - POL DEPOT	
S_{31}	**POL Assets and Resources**
C_{311}	NATO POL depot
C_{312}	F –75 fuel supply
C_{313}	F –76 fuel supply
C_{314}	F – 77 fuel supply
C_{315}	F – 44 fuel supply
C_{316}	Other POL (Lubricating oils)
S_{32}	**POL delivery systems**
C_{321}	Fuel supply/collection from the wharf by a pipeline
C_{322}	Fuel supply from a fuel tank (onshore transport)
C_{323}	Fuel supply from a tanker
C_{324}	2.5 ‘’ refuelling coupling from the wharf
C_{325}	11”/6” adopter for refuelling from the wharf

Source: Elaborated by the author based on NATO, 2001 and 2010.

The logistic interoperability evaluation of a naval base is established with the use of the methodology presented in Tables 4 and 5.

Table 4. Logistic interoperability evaluation of a naval base: The sequence of calculations - second variant

No.	Operation
1.	Calculation of the logistic capabilities value of an individual diagnostic feature $$Q_{ijk} = q_x \times w_{ijk}, \quad (10)$$ where: Q_{ijk} is the logistic capabilities value of an individual diagnostic feature; q_x is a binary coefficient ($q_x = 1$ – the particular feature is observed in the analysed base, $q_x = 0$ – the particular feature is not observed in the analysed base, in the case of the model base, $q_x = 1$ for all the features); w_{ijk} is the score-based evaluation of logistic capabilities of an individual diagnostic feature, accepted as the most frequently observed value (modal value) in the questionnaire survey for the particular features; k is the subsequent diagnostic feature in the j[th] component allocated to the i[th] module of logistic support.

2. Calculation of the logistic capabilities value at the level of the subsequent (j[th]) component in the particular (i[th]) module of logistic support for the model base (benchmarking status) and the real-life bases (actual status):

$$PS_{ij}^{NATO} = \sum_{k=1}^{n} Q_{ijk} \quad (11)$$

$$PS_{ij}^{NB} = \sum_{k=1}^{n} q_x \times Q_{ijk}.$$

where:

PS_{ij}^{NATO} is the logistic capabilities value at the level of the subsequent (j[th]) component in the particular (i[th]) module of logistic support for the model naval base (NATO naval base);

PS_{ij}^{NB} is the logistic capabilities value at the level of the subsequent (j[th]) component in the particular (i[th]) module of logistic support for the analysed (real-life) naval base.

3. Calculation of the rate-based evaluation for each component of the particular logistic support module, for the analysed naval bases (see: Table 5):

$$W_{ij}^{NB} = \frac{PS_{ij}^{NB}}{PS_{ij}^{NATO}} \quad (12)$$

where:

W_{ij}^{NB} is the rate – based evaluation for j[th] component of the particular (i[th]) module of logistic support for the analysed (real-life) naval base.

4. Calculation of weight coefficients (WS_{ij}) which refer to the significance of the logistic support component to logistic interoperability level, in accordance with the rate-and-score-based method and on the basis of opinions provided by 10 experts, who have been selected from the group of the Navy officers participating in the questionnaire survey, based on their military experience in NATO Command Structure; the expert evaluations referring to particular components of logistic support were verified in terms of consistency, based on the classical coefficient of variation (Everit, 1998):

$$\overline{WS_{ij}} = \frac{\sum_{y=1}^{10} W_{ijy}}{10} \quad (13)$$

where:

$\overline{WS_{ij}}$ is the weight coefficient of the logistic support component;

W_{ijy} is an opinion (evaluation) provided by an expert, where y = 10 is the number of the experts selected to provide evaluation. The scale adopted for the expert evaluations is from 1 to 10.

$$v_{ij} = \frac{\sigma_{ij}}{\overline{WS_{ij}}}, \quad (14)$$

where:

v_{ij} is the classical coefficient of variation (as calculated for the particular component);

σ_{ij} is the average standard deviation for each analysed component.

v_{ij}	Preference scope
$v_{ij} \leq 0.1$	Weak differentiation of the coefficient (satisfactory level)
$0.1 < v_{ij} \leq 0.3$	Moderate differentiation of the coefficient (acceptable level)
$0.3 < v_{ij} \leq 0.5$	Strong differentiation of the coefficient (unacceptable level)
$v_{ij} > 0.5$	Very strong differentiation of the coefficient (unacceptable level)

Calculation of the weighted logistic capabilities value for the particular component of logistic support, in accordance with the following equation:

$$PSW_{ij} = \overline{WS_{ij}} \times W_{ij}^{NB}, \quad (15)$$

where:

PSW_{ij} is the weighted logistic capabilities value for the particular component of logistic support.

6. Calculation of the total logistic capabilities value at the level of the particular module of logistic support for a naval base, in accordance to the following equation:

$$PM_i = \sum PSW_{ij}, \quad (16)$$

where:

PM_i is the total logistic capabilities value at the level of the particular module of logistic support for a naval base.

7. Calculation of the total logistic capabilities value of a naval base

$$\Pi_{NB}^{Log} = \sum PM_i, \quad (17)$$

where:

Π_{NB}^{Log} is the total logistic capabilities value of a naval base

8.	Graphical interpretation of the logistic interoperability at the level of the modules (Figures 7 and 8), provided with the use of interoperability triangles (radar charts) for the analysed bases and the logistic interoperability rates of the naval bases at the level of the i[th] module: $$WM_i^{int} = \frac{PM_i}{PM_i^{NATO}},\qquad (18)$$ where: WM_i^{int} is the logistic interoperability rate at the level of the particular module of logistic support PM_i^{NATO} is the total logistic capabilities value at the level of the i[th] module of logistic support for the model base.
9.	The overall evaluation of logistic interoperability of the analysed bases, provided with the use of the logistic interoperability rate of a naval base. $$W_{NB}^{int} = \frac{\sum_{i=1}^{3} WM_i^{int}}{3},\qquad (19)$$ where: W_{NB}^{int} is the logistic interoperability rate of a naval base; i = 3 is the number of modules of logistic support.

Source: Elaborated by the author

Table 5. The mode of the calculation of the W_{ij}^{NB} (for the Naval Base 01 as example).

Evaluation criteria (components of particular modules of logistic support)	Logistic capabilities value at the level of logistic support component		Rate-based evaluation $W_{ij}^{NB} = \frac{PS_{ij}^{NB}}{PS_{ij}^{NATO}}$
	Benchmark status $PS_{ij}^{NATO} = \sum_{k=1}^{n} Q_{ijk}$	Actual status (Naval Base 01) $PS_{ij}^{NB} = \sum_{k=1}^{n} q_x \times Q_{ijk}$	
I. ALSS/FLS			
1. Port infrastructure and suprastructure	56	43	0.78
2. Access to the transport network	24	15	0.62
3. Port services	37	31	0.84
4. Medical support	17	17	1.00
II. BDR / FMR FACILITIES			
1. Restoring stability and buoyancy of vessel	14	11	0.78
2. Restoring mobility of vessel	12	12	1.00
3. Restoring operational capabilities of vessel	23	20	0.87
III. POL DEPOT			
1. POL Assets and resources	17	9	0.53
2. POL delivery system	13	11	0.85

Source: Elaborated by the author

4. Results

In the first variant, the evaluation of the logistic interoperability level of the model base and the selected real-life naval bases requires indicating three basic parameters (see: Tables 6), based on Table 1:

- $\sum_{j=1}^{m} PS_{ij}$ is the total logistic capabilities value in the sub-areas of logistic support allocated to the subsequent (i[th]) functional area of logistic support;
- WS_i is the logistic capabilities rate for a naval base in the i[th] functional area of logistic support;
- $\frac{WS_i}{WS_i^{MOD}}$ expresses the relations between the logistic capabilities rates in the functional areas of logistic support for the particular bases, analysed in the research project, and the same rate calculated for the model base (NATO naval base).

Table 6. List of the basic parameters required for the logistic interoperability evaluation of a naval base: Functional areas of logistic support

Logistic interoperability in the particular functional areas	Evaluation parameters: $\sum PS_{ij}/\ WS_i/\ \frac{WS_i}{WS_i^{MOD}}$	Naval Base 01	Naval Base 02	Naval Base 03	Naval Base 04	Naval Base 05
∂_1^{IntLog}	$\sum PS_{1j}/\ WS_1/\ \frac{WS_1}{WS_1^{MOD}}$	21 / 1.91/ 0.72	19 /1.73 /0.66	19 /1.73/ 0.66	21 / 1.91/ 0.72	21 / 1.91 / 0.72
∂_2^{IntLog}	$\sum PS_{2j}/\ WS_2/\ \frac{WS_2}{WS_2^{MOD}}$	43/ 2.53/ 0.88	46/2.71 /0.94	37/2.17/ 0.76	43/ 2.53/ 0.88	34/2/0.69
∂_3^{IntLog}	$\sum PS_{3j}/\ WS_3/\ \frac{WS_3}{WS_3^{MOD}}$	47 / 2.14/ 0.78	55 / 2.5 / 0.92	50 / 2.27 / 0.83	48 / 2.18 /0.80	42 / 1.82/ 0.70
∂_4^{IntLog}	$\sum PS_{4j}/\ WS_4/\ \frac{WS_4}{WS_4^{MOD}}$	15 / 1.66/ 0.60	14 / 1.55 / 0.56	20 / 2.22 / 0.8	24 / 2.66 /0.96	6 / 0.66/0.24
∂_5^{IntLog}	$\sum PS_{5j}/\ WS_5/\ \frac{WS_5}{WS_5^{MOD}}$	17 / 2.43 / 1.0	17 / 2.42 / 1.0	17 / 2.42 / 1.0	14 / 2 / 0.82	11/1.57/ 0.65
∂_6^{IntLog}	$\sum PS_{6j}/\ WS_6/\ \frac{WS_6}{WS_6^{MOD}}$	29/ 1.53 / 0.78	28 / 1.47 / 0.75	27 / 1.42 / 0.73	29/ 1.53 / 0.78	30/ 1.58/ 0.83
Logistic interoperability in the particular functional areas	Evaluation parameters: $\sum PS_{ij}/\ WS_i/\ \frac{WS_i}{WS_i^{MOD}}$	Naval Base 06	Naval Base 07	Naval Base 08	Naval Base 09	NATO Naval Base
∂_1^{IntLog}	$\sum PS_{1j}/\ WS_1/\ \frac{WS_1}{WS_1^{MOD}}$	24 / 2.18 / 0.83	22 / 2/ 0.77	19 / 1.73 / 0.66	20 /1.82 / 0.69	29 / 2.64 / 1.0
∂_2^{IntLog}	$\sum PS_{2j}/\ WS_2/\ \frac{WS_2}{WS_2^{MOD}}$	34/2/ 0.69	31/1.82/ 0.63	33/ 1.94/ 0.67	46 /2.71/ 0.94	49 / 2.88 / 1.0
∂_3^{IntLog}	$\sum PS_{3j}/\ WS_3/\ \frac{WS_3}{WS_3^{MOD}}$	47 / 2.14/ 0.78	47 / 2.14/ 0.78	48 / 2.18 / 0.8	49 / 2.23 / 0.82	60 / 2.73/ 1.0
∂_4^{IntLog}	$\sum PS_{4j}/\ WS_4/\ \frac{WS_4}{WS_4^{MOD}}$	15 / 1.66/ 0.60	19/ 2.11 / 0.76	25 / 2.77/1.0	12 / 1.33 / 0.5	25 / 2.77/ 1.0
∂_5^{IntLog}	$\sum PS_{5j}/\ WS_5/\ \frac{WS_5}{WS_5^{MOD}}$	17 / 2.42 / 1.0	14 / 2 / 0.82	17 / 2.43 / 1.0	14 / 2 / 0.82	17 / 2.43 / 1.0
∂_6^{IntLog}	$\sum PS_{6j}/\ WS_6/\ \frac{WS_6}{WS_6^{MOD}}$	29/ 1.53 / 0.78	28 / 1.47 /0.75	28 / 1.47 / 0.75	30 / 1.58 / 0.81	37/ 1.95/ 1.0

Source: Elaborated by the author

A presentation of the graphical interpretation of the logistic capabilities level for the particular naval bases in the identified functional areas of logistic support is provided by the radar chart method (see Figures 4 and 5).

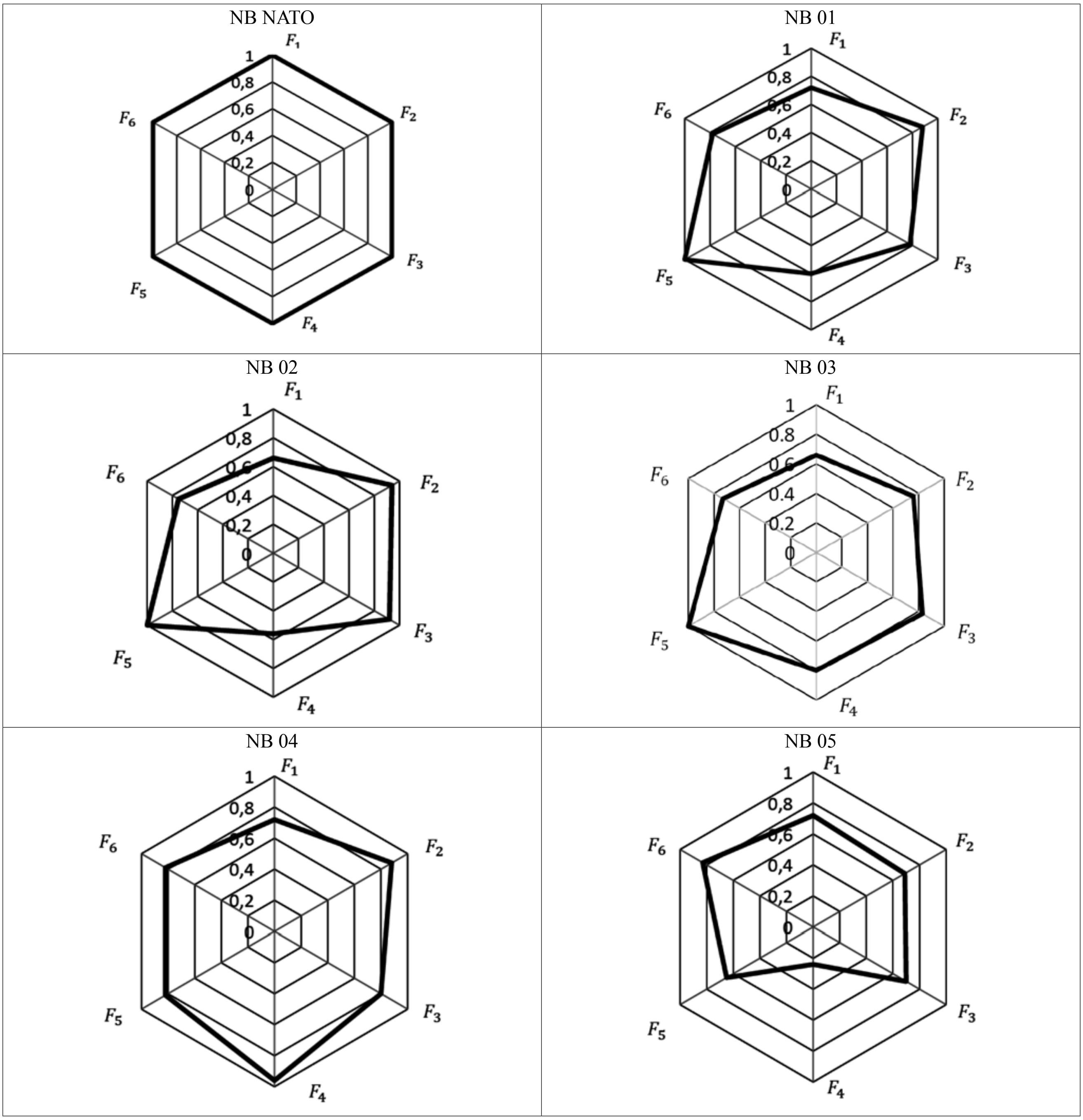

Figure 4. Graphical interpretation of the logistic capabilities levels of the analysed naval bases in the particular functional areas of logistic support based on the $\frac{WS_i}{WS_i^{MOD}}$ relation.

Source: Elaborated by the author.

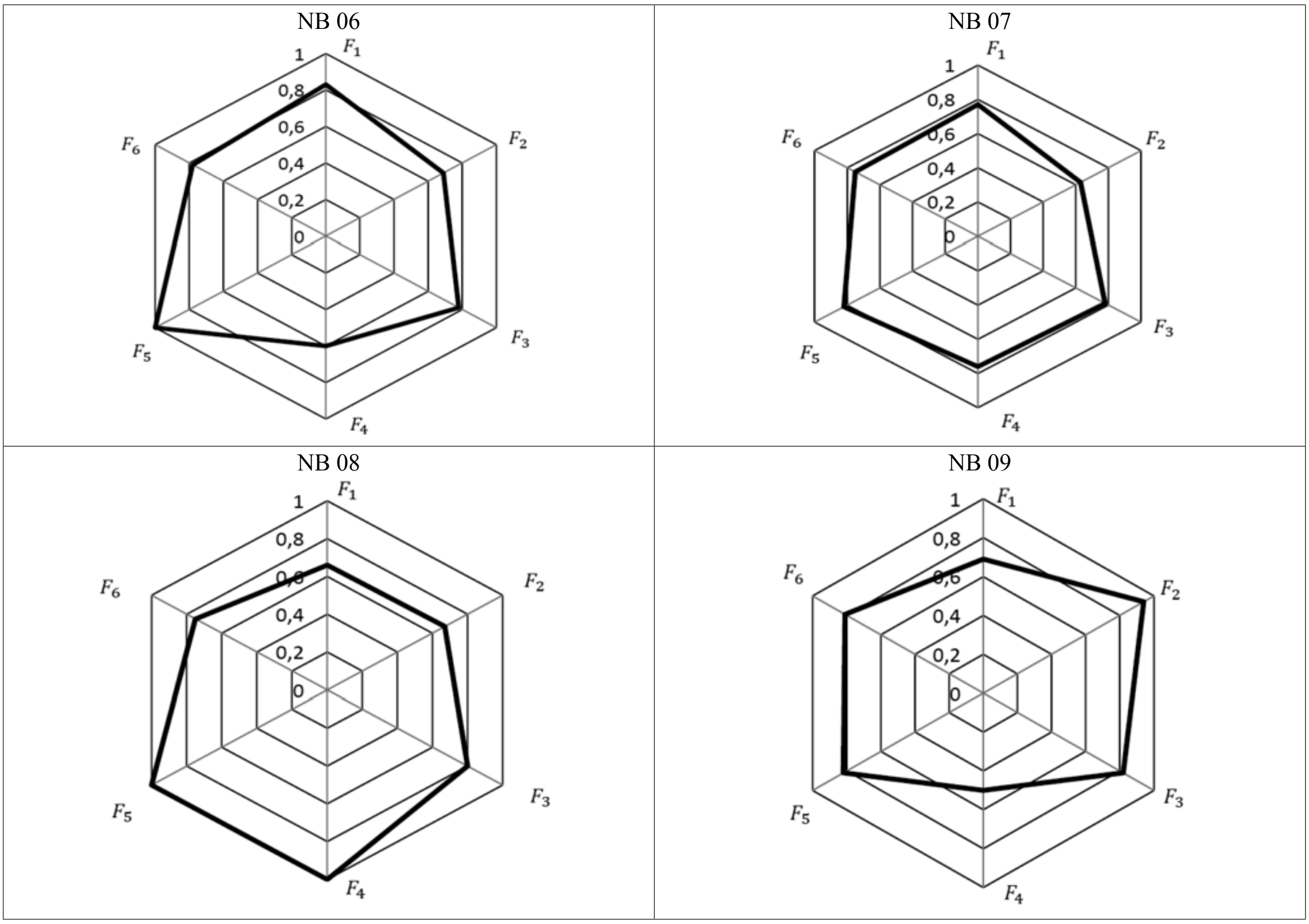

Figure 5. Graphical interpretation of the logistic capabilities of the analysed naval bases in the particular functional areas of logistic support based on the $\frac{WS_i}{WS_i^{MOD}}$ relation (continued).

Source: Elaborated by the author

This interpretation has allowed the author to identify the shortage indicated by the analysed entities (naval bases) in the particular areas of logistic support in comparison to the model base, that is, the NATO naval base. While considering this problem in more detail, it is possible to state that:

- in terms of supply, the highest level of logistic capabilities has been achieved by the Naval Base 06;
- in terms of maintenance, the top positions in the field of logistic capabilities have been occupied by the Naval Base 02 and the Naval Base 09;
- in terms of logistic infrastructure, the highest evaluation has been awarded to the Naval Base 02 and the Naval Base 03;
- in the field of movement and transportation, the top positions have been occupied by the Naval Base 04 and the Naval Base 08;
- in terms of medical support, the logistic capabilities level is similar for most of the analysed bases, with some disadvantage for the Naval Base 05;
- the highest logistic capabilities level in terms of services (technical support services, port operations, and ancillary services) has been achieved by the Naval Base 05 and Naval Base 09.

The comprehensive evaluation of the analysed entities (naval bases) in terms of their logistic interoperability, after the calculation of the weighted measure of logistic capabilities of a naval base at the level of the ith functional area of logistic support (PF_i) is presented in Figure 6.

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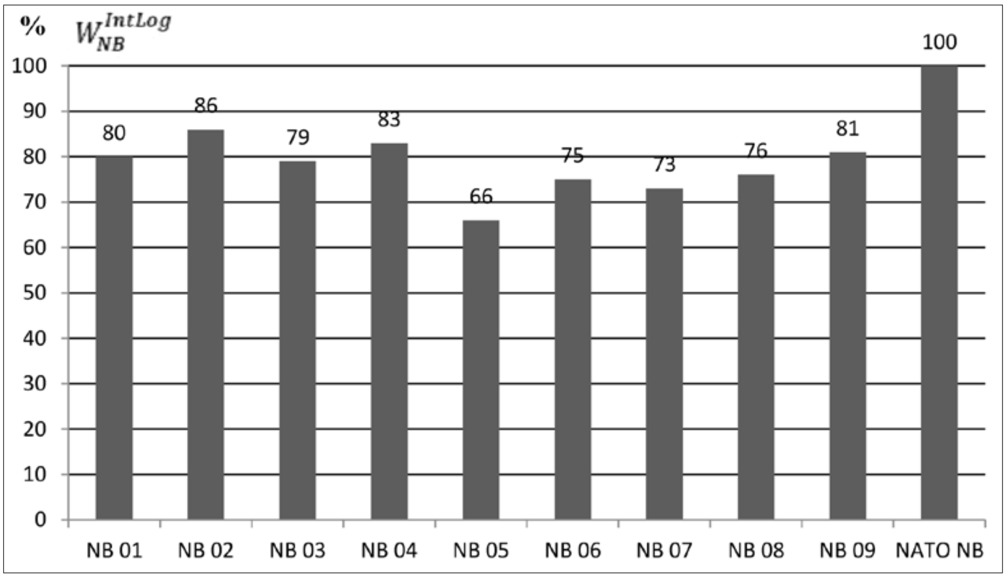

	W_i	NB 01		NB 02		NB 03		NB 04		NB 05	
		$\sum PS_{ij}$	PF_i	$\sum PS_{ij}$	PF_i	$\sum PS_{ij}$	PF_i	$\sum PS_{ij}$	PF_i	$\sum PS_{ij}$	PF_i
F_1	0.1536	21	3.23	19	2.92	19	2.92	21	3.23	21	3.23
F_2	0.27375	43	11.77	46	12.59	37	10.13	43	11.77	34	9.31
F_3	0.27375	47	12.87	55	15.06	50	13.69	48	13.14	42	11.50
F_4	0.1536	15	2.30	14	2.15	20	3.07	24	3.69	6	0.92
F_5	0.0890	17	1.51	17	1.51	17	1.51	14	1.25	11	0.98
F_6	0.0563	29	1.63	28	1.58	27	1.52	29	1.63	30	1.69
		Π_{NB}^{Log}	33.31	Π_{NB}^{Log}	35.81	Π_{NB}^{Log}	32.84	Π_{NB}^{Log}	34.71	Π_{NB}^{Log}	27.63
	W_{NB}^{IntLog}		80%		86%		79%		83%		66%
	W_i	NB 06		NB 07		NB 08		NB 09		NATO NB	
		$\sum PS_{ij}$	PF_i	$\sum PS_{ij}$	PF_i	$\sum PS_{ij}$	PF_i	$\sum PS_{ij}$	PF_i	$\sum PS_{ij}$	PF_i
F_1	0,1536	24	3.69	22	3.38	19	2.92	20	3.07	29	4.45
F_2	0,27375	34	9.31	30	8.21	33	9.03	46	12.59	49	13.41
F_3	0,27375	47	12.87	47	12.87	48	13.14	49	13.41	60	16.43
F_4	0,1536	15	2.30	19	2.92	24	3.69	12	1.84	24	3.69
F_5	0,0890	17	1.51	14	1.25	17	1.51	14	1.25	17	1.51
F_6	0,0563	29	1.63	28	1.58	28	1.58	30	1.69	37	2.08
		Π_{NB}^{Log}	31.31	Π_{NB}^{Log}	30.21	Π_{NB}^{Log}	31.87	Π_{NB}^{Log}	33.85	Π_{MOD}^{Log}	41.57
	W_{NB}^{IntLog}		75%		73%		76%		81%		100%

Figure 6. Classification of the analysed naval bases in accordance with the logistic interoperability rate for a naval base (first variant)

Source: Elaborated by the author

Based on the evaluation and in accordance with the logistic interoperability rate for a naval base (W_{NB}^{IntLog}), the analysed entities achieve the values ranging from 66% to 86% (see: Figure 6). In the areas of maintenance and infrastructure, the high level of logistic capabilities of the Naval Base 02 has resulted in the fact, that this base holds the first position in terms of logistic interoperability, slightly above the Naval Bases 04 and 09.

In the second variant, the evaluation of logistic interoperability of a naval base, performed with the use of aggregated methods, has required the calculation of weight coefficients for the evaluation criteria (logistic support components), in accordance with the methodology presented in Tables 4 (equations 13 and 14) and 7.

Table 7. Verified weigh coefficients ($\overline{WS_{ij}}$) based on the consistency of the experts' opinions

Experts - E_y $(y = \overline{1,10})$	Components of logistic support								
	S_{11}	S_{12}	S_{13}	S_{14}	S_{21}	S_{22}	S_{23}	S_{31}	S_{32}
	Preference values given by the experts (WS_{ijy} *values*)								
	W_{11}	W_{12}	W_{13}	W_{14}	W_{21}	W_{22}	W_{23}	W_{31}	W_{32}
E_1	10	8	5	7	8	10	7	8	5
E_2	10	9	6	7	9	10	7	9	5
E_3	10	6	5	7	10	6	7	9	5
E_4	9	7	4	5	7	7	10	7	4
E_5	8	8	6	6	8	8	6	8	6
E_6	10	8	5	5	8	8	10	8	5
E_7	9	8	6	7	8	8	7	8	6
E_8	9	9	4	10	9	9	5	9	4
E_9	10	7	4	6	10	7	6	7	4
E_{10}	8	7	4	6	10	7	6	7	4
Calculations									
$\sum WS_{ijy}$	93	77	49	59	87	68	71	81	48
$\overline{WS_{ij}}$	9.3	7.7	4.9	5.9	8.7	6.8	7.1	8.1	4.8
σ_{ij}	0.78	0.9	0.83	1.526	1.01	1.74	1.82	0.781	0.717
$v_{ij} = \frac{\sigma_{ij}}{\overline{WS_{ij}}}$	0.084	0.117	0.169	0.257	0.115	0.256	0.256	0.096	0.149
Verified weight coefficient of logistic support component ($\overline{WS_{ij}}$ verified)	9.3	7.7	4.9	5.9	8.7	6.8	7.1	8.1	4.8

Source: Elaborated by the author

After verification, the weight coefficients ($\overline{WS_{ij}}$) have been applied to establish the levels of weighted logistic capabilities values for the components (PSW_{ij}) in the particular modules of logistic support for the analysed naval bases.

It has been done based on the benchmarking status and the actual status of the values of logistic capabilities at the component level (see: equations 11 and 12 in Table 4). In the calculations, the reference level is logistic capabilities of the model base (the NATO naval base), for the components, modules, and the entire bases.

Table 8 provides a comprehensive presentation of the actual status of logistic interoperability of the analysed entities, in accordance with the following parameters:

- rate – based evaluation for the particular component of logistic support (W_{ij}^{NB});
- weighted logistic capabilities value for the particular component of logistic support (PSW_{ij});

Table 8. Actual status of the logistic interoperability levels for the analysed naval bases: NATO installation of ashore support

Evaluation criteria	$\overline{WS_{ij}}$	Naval Base 01		Naval Base 02		Naval Base 03		Naval Base 04		Naval Base 05	
		W_{ij}^{NB}	PSW_{ij}	W_{ij}^{NB}	PSW_{ij}	W_{ij}^{NB}	PSW_{ij}	W_{ij}^{NB}	PSW_{ij}	W_{ij}^{NB}	PSW_{ij}
I. ALSS/FLS											
1. Port infrastructure and suprastructure	9.3	0.78	7.25	0.92	8.56	0.71	6.60	0.80	7.44	0.64	5.95
2. Access to the transport network	7.7.	0.62	4.78	0.54	4.16	0.79	5.31	0.96	7.39	0.37	2.85
3. Port services	4.9	0.84	4.12	0.81	3.97	0.78	3.82	0.84	4.12	0.84	4.12
4. Medical support	5.9	1.0	5.9	1.0	5.9	1.0	5.9	0.82	4.84	0.65	3.83
PM_1			22.05		22.59		21.63		23.79		16.75
WM_1^{int}			0.79		0.81		0.78		0.85		0.60
II. BDR / FMR											
1. Restoring stability and buoyancy of vessel	8..7	0.78	6.79	1.0	8.7	1.0	8.7	0.78	6.79	0.78	6.79
2. Restoring mobility of vessel	6..8	1.0	6.8	1.0	6.8	1.0	6.8	1.0	6.80	1.0	6.80
3. Restoring operational capabilities of vessel	7.1	0.87	6.18	0.87	6.18	0.61	4.33	0.87	6.18	0.52	3.69
PM_2			19.77		21.68		19.83		19.77		17.28
WM_2^{int}			0.87		0.96		0.88		0.87		0.79
III. POL DEPOT											
1. (POL) Assets and resources	8.1	0.53	4.29	0.53	4.29	0.53	4.29	0.53	4.29	0.53	4.29
2. POL delivery system	4.8	0.85	4.1	0.69	3.31	0.84	4.03	0.85	4.08	0.54	2.59
PM_3	12.9		8.39		7.6		8.32		8.37		6.88
WM_3^{int}			0.65		0.59		0.64		0.65		0.53
Π_{NB}^{Log}			50.21		51.87		49.78		51.93		40.91
W_{NB}^{int}			0.77		0.79		0.76		0.79		0.64

Source: Elaborated by the author

- total logistic capabilities value at the level of the particular module of logistic support for the analysed (real -life) naval base (PM_i);
- total logistic capabilities value of a naval base (Π_{NB}^{Log});
- logistic interoperability rate at the level of the particular module of logistic support (WM_i^{int});
- logistic interoperability rate of a naval base (W_{NB}^{int}).

Table 8. Actual status of the logistic interoperability levels for the analysed naval bases: NATO installation of ashore support (continued)

Evaluation criteria	$\overline{WS_{ij}}$	Naval Base 06		Naval Base 07		Naval Base 08		Naval Base 09		The NATO Naval Base	
		W_{ij}^{NB}	PSW_{ij}	W_{ij}^{NB}	PSW_{ij}	W_{ij}^{NB}	PSW_{ij}	W_{ij}^{NB}	PSW_{ij}	W_{ij}^{NB}	PSW_{ij}
I. ALSS/FLS											
1. Port infrastructure and suprastructure	9.3	0.83	7.72	0.78	7.25	0.80	7.44	0.76	7.07	1.0	9.3
2. Access to the transport network	7.7.	0.62	4.77	0.79	6.08	1.0	7.7	0.50	3.85	1.0	7.7.
3. Port services	4.9	0.84	4.12	0.86	4.21	0.73	3.58	0.86	4.21	1.0	4.9
4. Medical support	5.9	1.0	5.90	0.82	4.84	1.0	5.90	0.82	4.84	1.0	5.9

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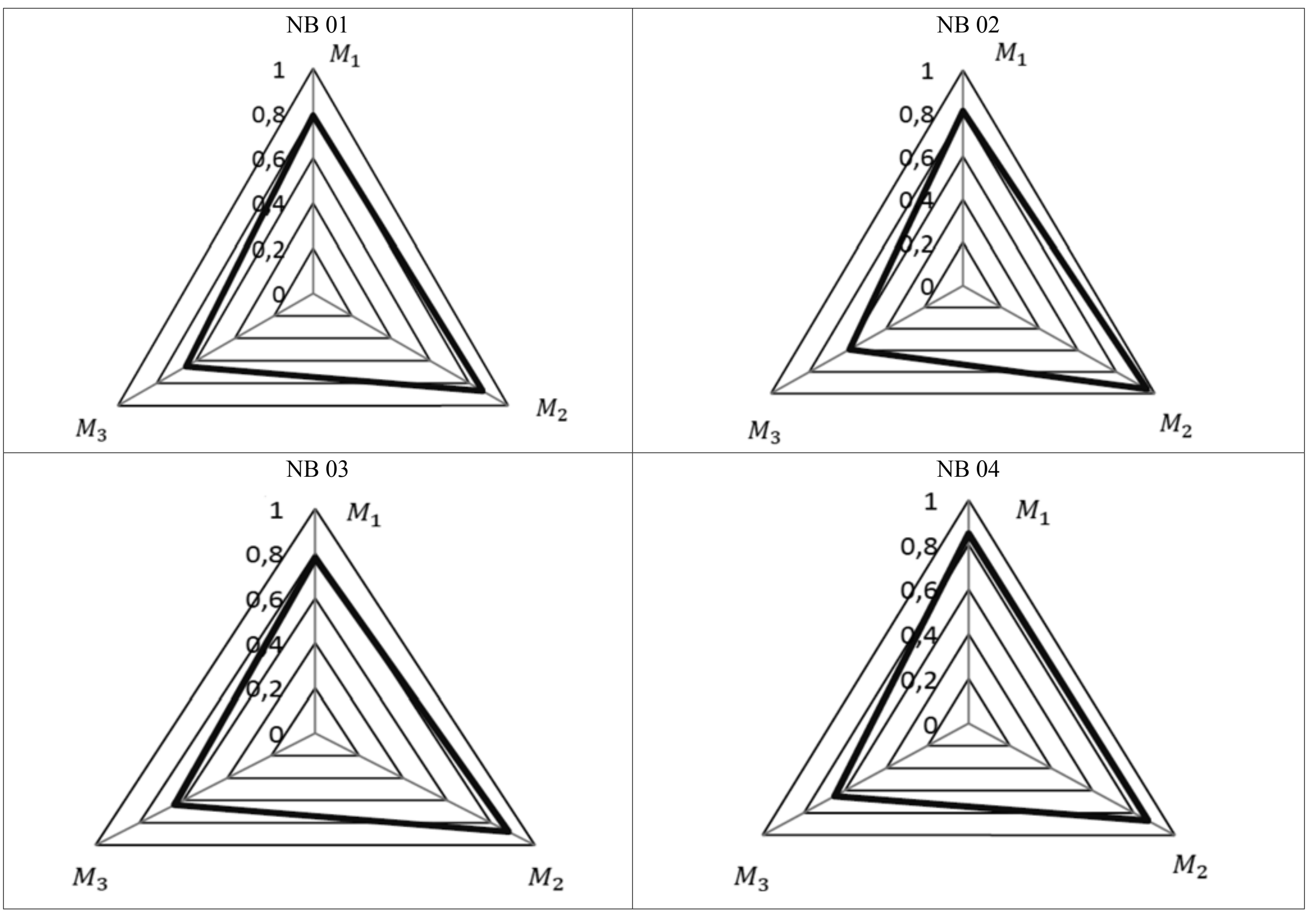
PM_1			22.51		21.88		24.62		19.97		27.8
WM_1^{int}			0.81		0.79		0.88		0.72		1.0
II. BDR / FMR											
1. Restoring stability and buoyancy of vessel	8.7	0.57	4.96	0.78	6.79	0.86	7.48	1.0	8.7	1.0	8.7
2. Restoring mobility of vessel	6.8	0.75	5.1	1.0	6.8	1.0	6.8	1.0	6.8	1.0	6.8
3. Restoring operational capabilities of vessel	7.1	0.74	5.25	0.35	2.48	0.39	2.77	0.87	6.18	1.0	7.1
PM_2			15.31		16.07		17.05		21.68		22.6
WM_2^{int}			0.68		0.71		/ 0.75		0.95		1.0
III POL DEPOT											
1. (POL) Assets and resources	8.1	O.71	5.75	0.53	4.29	0.71	5.75	0.65	5.27	1.0	8.1
2. POL delivery system	4.8	0.85	4.08	0.69	3.31	0.69	3.31	0.85	4.08	1.0	4.8
PM_3			9.83		7.60		9.06		9.35		12.9
WM_3^{int}			0.76		0.59		0.70		0.72		1.0
Π_{NB}^{Log}			48.07		46.8		50.81		50.56		63.3
W_{NB}^{int}			0.75		0.69		0.77		0.79		1.0

Source: Elaborated by the author

A graphical interpretation of the logistic interoperability rates at the module level (WM_i^{int}) is presented in Figures 7 and 8.



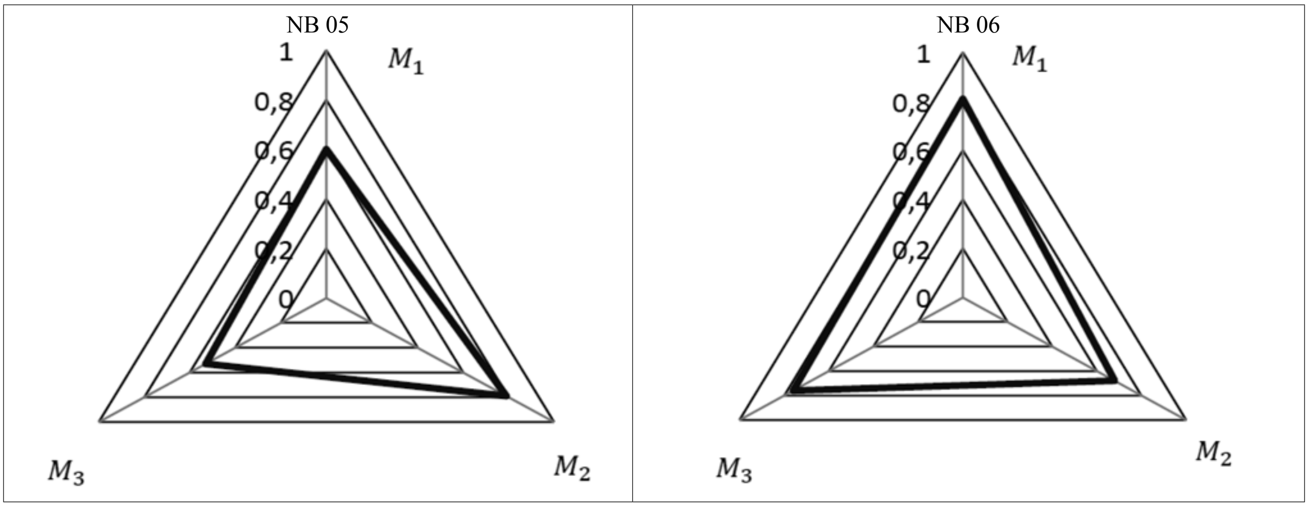
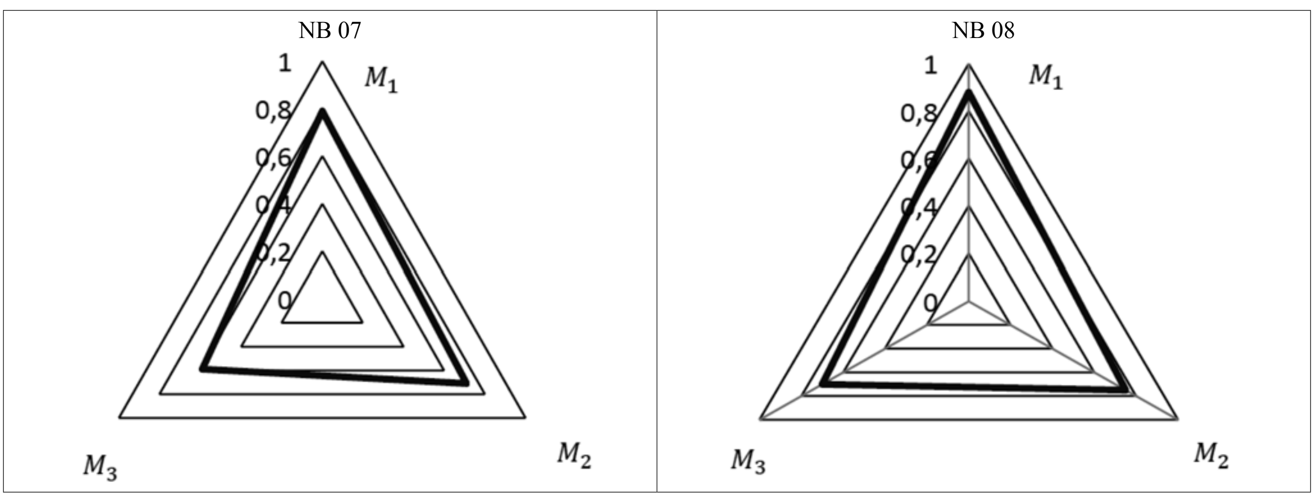


Figure 7. The logistic interoperability level of the naval bases in terms of the modules (WM_i^{int})

Source: Elaborated by author

In those figures, the tops of the triangles refer to the particular modules, whereas the values referring to the logistic interoperability levels are presented as percentages or as decimal fractions, in reference to the model base. This approach allowed the author to standardise the method applied to evaluate the logistic interoperability level in the field of the particular modules, regardless of the number of allocated components and diagnostic features. The analysis of the logistic interoperability triangles for the selected naval bases indicates, that all of them have the lowest capabilities in the field of the POL depot. This may have resulted from some limitations in the field of the assortment offered; however, it does not refer to the basic fuel types, such as F 75 and F 76. The top modules for all the analysed naval bases are *ALSS/FLS* and *BDR/FMR facilities*.



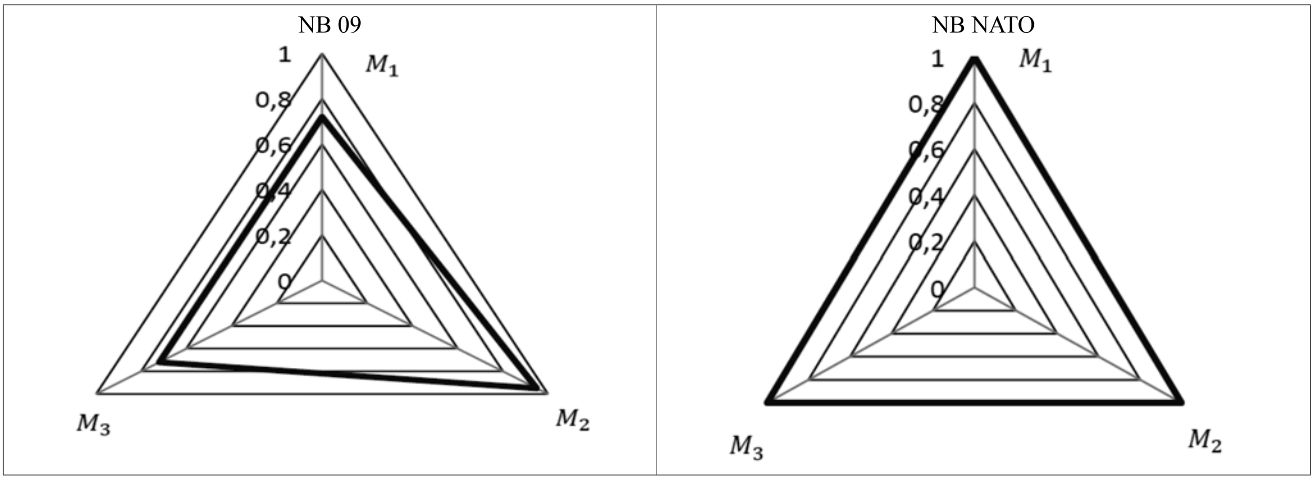


Figure 8. The logistic interoperability level of the naval bases in terms of the modules (WM_i^{int}) (continued)

Source: Elaborated by the author

Figure 9 presents a classification of the analysed naval bases, in accordance with the criterion of logistic interoperability, where the basic parameter is the logistic interoperability rate of a naval base (W_{NB}^{int}).

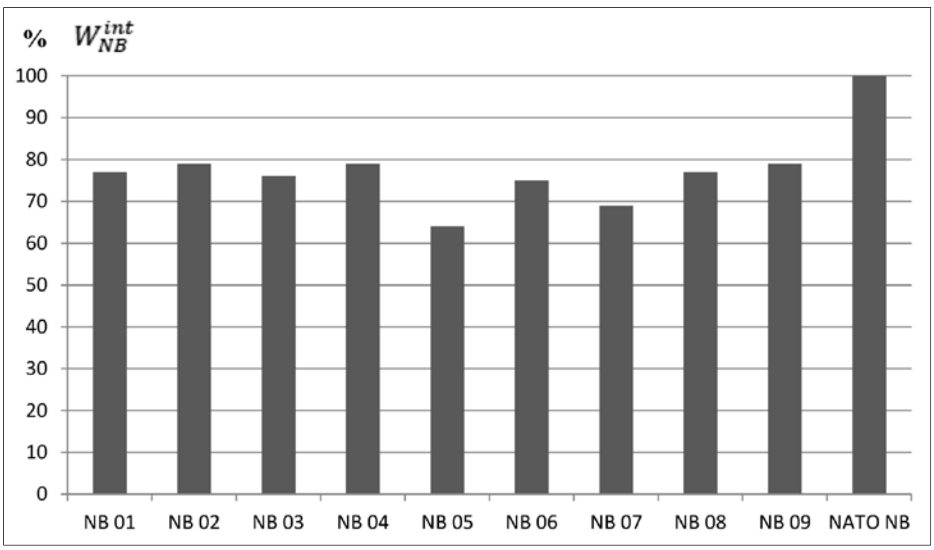


Figure 9. Classification of the naval bases in terms of their logistic interoperability rate (second variant).

Source: Elaborated by the author

As indicated in Figure 9, the logistic interoperability levels (see: W_{NB}^{int}) are similar for most naval bases; however, the discussed parameter for the particular entities ranges from 0.64 to 0.79. The top positions in the classification are taken by the Naval Bases 02, 04, and 09 due to large resources in the field of port infrastructure and superstructure and the components related to BDR/FMR facilities (see: Table 8).

5. Evaluation of solution relevance

Summing up the results of the research which has been presented above, for both solutions, the Naval Bases 02, 04, and 09 have the highest values of the analysed logistic interoperability rates. In the case of other analysed bases, the achieved logistic interoperability parameters place the discussed entities on similar positions in the ranking. This proves the proper identification of the diagnostic features and their allocation to higher levels of decomposition of the multi-criteria models (Table 9) and, hence, the relevance of the models presented in the article.

Table 9. Ranking of the naval bases in terms of logistic interoperability

Position	The naval bases arranged in accordance with the functional areas of logistic support	Position	The naval bases arranged in accordance with the NATO installations of logistic support – ashore support
1.	The Naval Base 02	1.	The Naval Base 02
2.	The Naval Base 04	1.	The Naval Base 04
3.	The Naval Base 09	1.	The Naval Base 09
4.	The Naval Base 01	4.	The Naval Base 08
5.	The Naval Base 03	4.	The Naval Base 01
6.	The Naval Base 08	6.	The Naval Base 03
7.	The Naval Base 06	6.	The Naval Base 06
8.	The Naval Base 07	8.	The Naval Base 07
9.	The Naval Base 05	9.	The Naval Base 05

Source: Elaborated by author

To verify the above-mentioned solutions, a correlation analysis of the obtained logistic interoperability parameters for the discussed naval bases has been performed. Pearson correlation coefficient R has been determined where: $R \in [-1; +1]$ (see: Kendal, Stuart, 1973). For verification, the logistic interoperability rate, W_{NB}^{IntLog} (the first variant) has been indicated as X_i. The logistic interoperability rate, W_{NB}^{int}, (the second variant) has been indicated as Y_i, where $i = \{1, 2, \dots, 9\}$ is the number of the analysed entity (naval base). The strength of correlation has been defined on the basis of the value of the R coefficient, as presented in Table 10.

Table 10. Values of the R coefficient

The R value	Significance	The R value	Significance
$0.9 \le R \le 1.0$	Strong positive correlation	$-0.4 < R \le -0.2$	Weak negative correlation
$0.7 \le R < 0.9$	Considerable positive correlation	$-0.7 < R \le -0.4$	Moderate negative correlation
$0.4 \le R < 0.7$	Moderate positive correlation	$-0.9 < R \le -0.7$	Considerable negative correlation
$0.2 \le R < 0.4$	Weak positive correlation	$-1.0 \le R \le -0.9$	Strong negative correlation
$-0.2 < R < 0.2$	No correlation		

To define the correlation coefficient, the calculations presented in Table 11 have been performed.

Table 11. Calculation of the R coefficient in reference to the logistic interoperability parameters of the naval bases in the discussed variants

No.	Naval Base	X_i	$\bar{X}$	Y_i	$\bar{Y}$	$(X_i - \bar{X})^2$	$(Y_i - \bar{Y})^2$	$(X_i - \bar{X}) \times (Y_i - \bar{Y})$
1	NB 01	0.80	0.7766	0.77	0.75	0.548×10^{-3}	0.400×10^{-3}	0.468×10^{-3}
2	NB 02	0.86		0.79		6.955×10^{-3}	1.6×10^{-3}	3.334×10^{-3}
3	NB 03	0.79		0.76		0.179×10^{-3}	0.1×10^{-3}	0.134×10^{-3}
4	NB 04	0.83		0.79		2.852×10^{-3}	1.6×10^{-3}	2.136×10^{-3}
5	NB 05	0.66		0.64		13.59×10^{-3}	12.1×10^{-3}	12.826×10^{-3}
6	NB 06	0.75		0.75		0.707×10^{-3}	0	0
7	NB 07	0.73		0.69		2.172×10^{-3}	3.6×10^{-3}	2.796×10^{-3}
8	NB 08	0.76		0.77		0.275×10^{-3}	0.400×10^{-3}	-0.332×10^{-3}
9	NB 09	0.81		0.79		1.116×10^{-3}	1.6×10^{-3}	1.336×10^{-3}
where: S_X –standard deviation of the X feature S_Y – standard deviation of the Y feature COV_{XY} – covariance						$S_X = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n}} = 0.0562$	$S_y = \sqrt{\frac{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}{n}} = 0.0488$	$COV_{Xy} = \frac{\sum_{i=1}^{n}(X_i - \bar{X}) \times (Y_i - \bar{Y})}{n} = 0.0025$
Pearson correlation coefficient R						$R = \frac{COV_{xy}}{S_X S_Y} = 0.912,$		

Source: Elaborated by the author

Based on the data in Table 11, the value of Pearson correlation coefficient *R* is defined, as follows:

$$R = \frac{cov_{xy}}{s_X s_Y} = 0.912, \quad (20)$$

which indicates a strong positive correlation of the logistic interoperability parameters (W_{NB}^{IntLog} and W_{NB}^{int}), which have been defined for the particular analysed naval bases.

Conclusions

According to the author's knowledge and research analysis, the problem involving the evaluation of logistic interoperability of allied naval bases has not been considered in such way so far. That is why, the study is of a conceptual nature. The use of methods typical for management and applied logistics in the evaluation of logistic interoperability of naval bases is a highly practical approach to the problem of their use in operational activities. This allows the interested parties to quickly define a general level of relevant parameters with the use of the rates of logistic interoperability, as well as their detailed characteristics (e.g., using radar charts). The suggested set of methods applied to evaluate logistic interoperability is however not free from some shortcomings. As such, it is important to find a proper and competent panel of experts to represent a spectrum of logistic and operational experiences at various levels of command. Another key problem is access to sensitive and updated data; however, considering the evaluation of logistic interoperability in the case of any real-life operations, the access to sensitive and current data should not be limited. Therefore, a more precise and detailed evaluation is possible if the research process assumes access to classified information. Considering no such possibility existed, some limitations have been assumed, as stated in the Introduction.

A similar method can be applied to evaluate numerous logistic installations engaged during military operations, namely air bases or Seaports of Embarkation/Disembarkation (SPOE/SPOD) and Airports of Embarkation/ Disembarkation (APOE/APOD). The only change refers to the evaluation criteria.

As the research process is based on the available unclassified standardisation documents that cannot contain any precise data and information on the analysed entities, it certainly affects the actual (real-life) classification, however, it does not undermine the methodology presented here. Summing up, methods from the fields of management and applied logistics can be useful not only for evaluation of the logistic interoperability level or logistic capabilities of a particular object of military significance for military operations, but these methods can also be applied to evaluate the level of the entire system of logistic support at the tactical or operational levels when using the proper aggregation of partial values.

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