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TOWARDS: EFFICIENT USE OF RESOURCES IN MILITARY: METHODS FOR EVALUATION ROUTES IN OPEN TERRAIN

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Abstract. A good knowledge of terrain characteristics and movement possibilities within it are crucial conditions for operations success. If a commander and his staff have enough information about the terrain, he can optimize a combat formation and its movement in an open terrain. Such as optimization can finally spare manpower as well as equipment and decrease probability of loss of life. This paper deals with a complex mathematical model of terrain passability, which respects both geographical and meteorological conditions in the terrain and with its adaptation to calculation in the environment of geographic information systems (GIS). Such a model can be directly implied into command and control system to support decision-making processes.

The main problem of an off-road vehicle movement in an open terrain consists in considering the properties of a given surface; also, technical properties of a particular off-road vehicle have to be considered. The model of terrain passability is based on measurable factors that characterize the natural environment, which is possible to calculate using the data saved in GIS databases. While calculating parameters for a complex model, it is necessary to consider data quality, which influences the level of vagueness of the resulting calculations. In order to express this level of vagueness, a method of fuzzy functions was selected and applied while calculating the individual deceleration coefficients given by the natural factors. The method of cost map was selected for the final evaluation of possibilities of vehicles movement. The complete procedure was debugged in the environment of ArcGIS 10.

Keywords: Geography, Meteorology, GIS (Geographic Information System), CCM (Cross-Country Movement), Modelling and Simulation, Off-road vehicle, fuzzy sets

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JEL Classification: O32, O33, H0

1. Introduction

For a variety of rescue and military activities taking place in the field various types of off-road vehicles are used. Their efficient application requires good knowledge of the natural environment in which they are moving or will move. However, this is not just about knowledge of this environment, but understanding its impact on the behavior of specific types of vehicles as well. If there are adequate technical vehicle data and corresponding digital landscape models, it is possible to model the behavior of vehicles in the terrain.

If a commander and his staff have enough information about the terrain and its impacts on manoeuvre of units, they can optimize a combat formation and its movement in an open terrain. Such as optimization can spare man power as well as equipment and decrease probability of loss of lives.

Topographic maps and thematic maps focused on Cross Country Movement (CCM) were often used for terrain evaluation. However, such as evaluation is very time consuming and it is impossible to obtain precise and detail information. Digital landscape models and digital elevation models enable to gain information about movement that is more detail in a shorter time. Moreover, is possible to create several different variants of movement that will be included into complex decision-making system. In such a decision making system are evaluated also other impacts as tactical situation, danger zone, etc.

It is necessary to consider two basic conditions for a model of the behaviour of vehicles in the terrain creation – the technical parameters of the vehicles that are important because of their behavior in the terrain on the one hand, and the content, properties and quality of digital spatial data describing the terrain on the other hand.

If both conditions are fulfilled, it is possible to derive the physical models of the behavior of vehicles in a terrain (Rybansky, 2009) or (STANAG 2999, 2012) could be mentioned as the examples of such physical models. Physical models usually determine conditions of the terrain in which the vehicles can be used, or, where appropriate, to set limits for these conditions. The conditions laid down then represent the basis for the applications in a computer environment and it is possible to create computer models, often in a form of spatial analysis. The spatial analyses form a part of most of present Command and Control Systems (C2S) in which they support the decision-making processes. When limits of physical models evaluation are not considered, the final results of spatial analyses are influenced by content, precision and quality of digital spatial data used in the given model.

Complex models of terrain features can be found in geospatial databases in which all features have given properties (shape, size, location, thematic and time properties, etc.). Additional properties can be derived, for example a slope from digital elevation model. There are two different views on digital features and their properties – with or without consideration data quality and mainly their certainty or uncertainty. For example, position of a given feature stored in the geospatial database is determined by its coordinates. But its real position in the terrain may be different depending on its natural properties. Building footprints can be measured with an accuracy of centimeters, but borders of various types of soils are quite indeterminate. If uncertainty of feature properties is not considered in spatial analyses, the final results can be a bit out of reality and using them in decision-making process may cause difficulties in the future. To decrease the possibility of a wrong decision, the uncertainty of digital features must be taken into account. Application of fuzzy logic in spatial analyses is one possible and quite frequent way and it is possible to find many examples of using general fuzzy logic (Zadeh, 1965), (Ahmad & Kharal, 2009), (Sunila & Hottanainen, 2004), or its application in decision-making processes(Di Martino & Sessa, 2011), (D´Amico, Di Martino, & Sessa, 2013), (Kainz, 2007), (Svatonova & Rybansky, 2014), (Talhofer, Hoskova-Mayerova, & Hofmann, 2012).

However, it is necessary to verify thoroughly the quality of physical models, data, mathematical models, and their computer realization in practice. Only detailed verification will enable to obtain usable models suitable for implementation in the Command and Control Systems (C2S). Rybansky in his works (Rybansky, 2009) (Rybansky & Vala, 2010) states the basic physical principles vehicle movement along the ground, as well as methods for testing this movement in real geographic conditions and also respect individual properties of the landscape to assess the overall impact of the geographical environment on the move. Our goal is to model the possibilities of movement in the environment of digital geographic databases, including consideration of the quality of the data. Default models were developed to assess the possibility of moving the vehicle along the ground, and these models were subjected to comprehensive verification testing.

The following text presents the current status of development and verification of the Cross-Country Movement (CCM) model being developed at the Department of Military Geography and Meteorology of the University of Defence.

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2. Materials and methods

2.1. Creation of Cross Country Movement models using fuzzy logic

Borders of many geographic elements are, however, only a consequence of human perception, not real state of things. Even in case there is a real discreet border, the borderline can be inaccurate as a result of data ambiguity or their interpretation. Vegetation or soil types are a typical example of geographic elements where there are no natural borders in space. Here, the traditional classification fails completely. However, spatial units are usually represented by sharp borders. (Brown & Hauvelink, 2007) suggests 2 types of inaccuracy that have special meaning in the area of GIS – attribute *ambiguity* and *spatial vagueness.* In the former case we are not able to confirm the occurrence of the given subject matter in the given place, the latter case is the inability to find the exact location of the given subject matter. Spatial and thematic data should not be evaluated independently. Using the theory of "*soft classifications"*, where *"fuzzy" approaches* also belong to, is a possibility how to solve these problems.

Fuzzy sets (Zadeh, 1965) offer frameworks for processing predicates, whose level of veracity is given in degrees ("true up to certain level") and uncertainty is expressed also in degrees. The concept of fuzzy sets deals with representation of classes, whose borders are not clearly (sharply) set. When a sharp border dividing the set from the surroundings is absent, there appears a problem of definite setting of affiliation of the element into the set and its supplement. (Hoskova, 2012), (Cristea, Hoskova, 2009).

Blurred or fuzzy files are then files, or classes, that do not have sharp borders. With spatial data it means that on considered places, the transition between being a part or not being a part of the file can be gradual. A fuzzy file can be characterized by fuzzy levels lying in the interval from 0.0 to 1.0, which express a gradual increase of membership up to complete membership. It can be defined using the function of affiliation.

In the environment of GIS, we distinguish three basic types of geo-elements: point, lines and areas. With lines and areas, we sometimes ask a question, how to set exact borders of the given geo-element. If there is an area layer that notes ecological stability of a certain area, we only have two possibilities how to express the stability: stable x unstable. Such classification is very difficult and depends on the person of the decision-maker and on the concrete area.

One of the basic features that can be defined when creating and saving geographical objects is topology. Topologic relations characterize relative placement of two spatial objects with regards to its mutual position – e.g. if they touch, overlay, or contain each other. In GIS they are important especially to define spatial queries and selections and play a significant role in using SQL language. In case of fuzzy objects, however, traditional topological predicates fail and their fuzzy variants that are able to answer queries such as the following ones come into account:

- *Do areas A and B overlay at least partly?*
- *Does area A contain area B, at least partly?*
- *Which areas are partly inside area B?*

The fact that affiliation of an element to fuzzy topological predicate is expressed by a set [0,1], however, complicates its direct use in SQL language and thus in the potential spatial queries.

Relations between created fuzzy sets are then *analyzed* using *fuzzy overlay operation.*

Six basic models were created in order to find a route. Using these models helps to create so-called Cost Map, which is a raster file that is a basic input underlying for creation of a file of the looked-for route. A cost map is created by application of overlaying operations, in this case using so-called Map algebra, which gives tools for working with raster files. To set the complete deceleration coefficient when moving through terrain, relations stated in the elaborated methodologies were used.

Models for calculation of the individual coefficients were formed using basic operations with raster data by means of in-built tools of “Spatial Analyst” module, which is an extension of ArcGIS system, and also using tools of map algebra – file of operators and functions to work with raster data. (Talhofer, et. al., 2009).

Raster layers which were formed by calculation (e.g. raster elevation model) or by conversion of vector data according to appropriate attributes were used as input data. This data base was formed as definite data with clearly defined objects and their borders.

Another step when solving CCM issue is the introduction of some uncertainty causing bigger activity when making decisions about using the gained results. For each deceleration coefficient there was a new process model created, which applied the principles of fuzzy logic. For the solution of the individual models, various approaches had to be used regarding the character of its input data and the result which was supposed to be reached. The common denominator of a solution for all coefficients is the use of linear fuzzification function and calculation of distance for blurring the borders of objects (e.g. 100 meters for soils) (Talhofer, et. al., 2015).

2.2. Theory of Cross Country Movement

The main goal of the Cross Country Movement (CCM) is to evaluate the impact of geographic conditions on of a movement of vehicles in terrain. For the purpose of classification and qualification of geographic factors of CCM, it is necessary to determine (Rybansky, 2009), (Rybansky & Vala, 2009), (Rybansky, 2013), (Svatonova & Rybansky, 2014):

- particular degrees of CCM
- typology of terrain practicability by kind of military (civilian) vehicles
- geographic factors and features with significant impact on CCM

As a result of the geographic factors impact evaluation we get three degrees of CCM: passable terrain, passable terrain with restrictions, or impassable terrain.

The impact of geographic factor can be evaluated as a coefficient of deceleration ‘Ci’ from the scale of 0 to 1. The coefficient of deceleration shows the real (simulated) speed of vehicle v in the landscape in the confrontation with the maximum speed of given vehicle v_{max}. The impact of the whole 7 basic geographic factors can be expressed by the formula:

$$C = [\max(C_1, C_2, \dots, C_6)]C_7 \qquad (1)$$

The main coefficients of deceleration are listed in Table 1.

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Table 1. Main coefficients of deceleration

Basic coefficient	Geographic signification and impact
C_1	Terrain relief (gradient of terrain relief and micro relief shapes)
C_2	Vegetation cover
C_3	Soils and soil cover
C_4	Weather and climate
C_5	Hydrology
C_6	Build-up area
C_7	Road network
C_8	Other factors

The impact of the C_8 factor is not precisely determined yet.

These coefficients will be thereinafter indexed and classified into particular discrete factors as it is given in Table 2:

Table 2. Particular coefficients of deceleration

Particular coefficient	Description
C_{11}	Slope gradient
C_{12}	Microrelief
C_{21}	Spacing between stems
C_{22}	Stem diameter
C_{23}	Tree height
C_{24}	Type of tree
C_{25}	Nature of root system
C_{31}	Soil type
C_{32}	Kind of soil
C_{33}	Soil-forming substrate
C_{41}	Dry season
C_{42}	Moist season
C_{43}	Wet season
C_{51}	Kind of waters
C_{52}	Depth
C_{53}	Width
C_{54}	Flow speed
C_{55}	Characteristics of bottom
C_{56}	Characteristics of bank (bank slope)
C_{61}	Block built-up area
C_{62}	Uptown
C_{63}	Cottage built-up area
C_{71}	Highway
C_{72}	1st category road
C_{73}	2nd category road
C_{74}	3rd category road
C_{75}	Hardened way, forest and cart way
C_{81}	Technical factors
C_{82}	Personnel factors
C_{83}	Environment
C_{84}	Characteristics of activity

The individual deceleration coefficients C_1 - C_8 are computed as the products of particular coefficients within each group. The overall coefficient C is calculated with respect of formula (1) while it ranges from 0 to 100 %. It can be therefore stated, that resulting speed of the vehicle movement is a function of all the deceleration coefficients:

$$v = f(v_{max}, C_1, C_2, \dots, C_8) \quad (2)$$

For given vehicle (its technical properties) the values of deceleration coefficients are calculated from ascertained properties of geographic objects stored in the spatial geo-database. Using formula (1) it is possible to create a cost map in which the value of each pixel is the final (modeled) speed. The cost map can be used as a source for calculation of the fastest path, the most reliable path etc.

2.3. Creation of process models for deceleration coefficients

According to CCM theory (Rybansky & Vala, 2010), individual coefficients of deceleration C1 to C7 were calculated, based on which the complete cost map fora given vehicle was calculated. The simulated speed of the given vehicle in the given pixel was once again taken as a pixel cost in the cost map. In the cost maps the cheapest - in this case the fastest paths - from the initial point to the destination was calculated. The destination was purposely set away from settlements in free terrain and away from communications.

The complete calculation was based on the mathematical model and programmed in the environment `Model Builder` of ArcGIS system. In the picture (Figure 1) is the example of model of calculation.

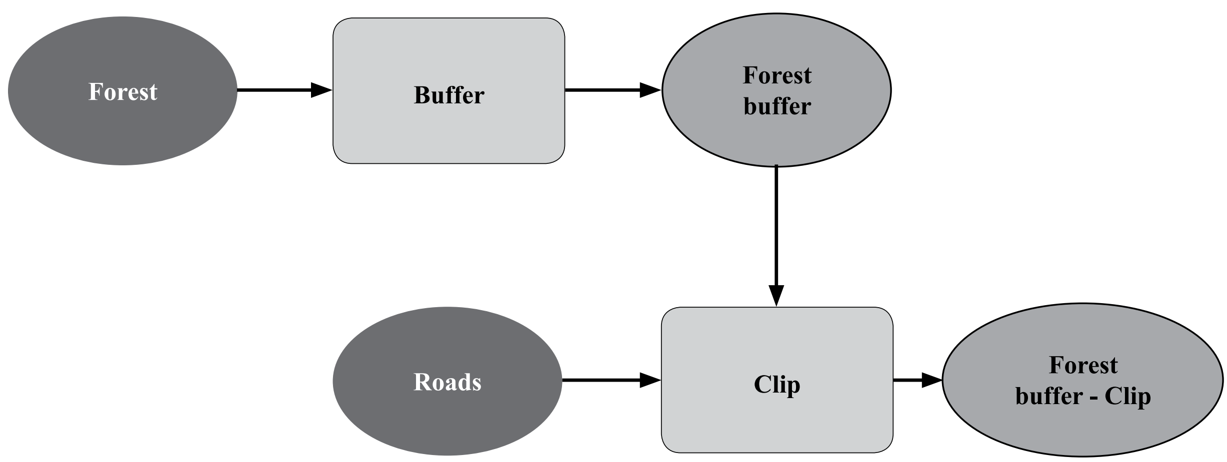

Figure 1. Example of data procedure model in ArcGIS ModelBuilder

In the model, there are next shapes and colors:

- Dark gray oval — Input data in vector or raster format
- Rectangle — Designation of various types of processes or operations with data
- Gray oval — Output of processes

Furthermore, there are stated specific procedures of calculations of individual coefficients.

2.4. Calculation of the individual coefficients

Certain processes that differ only in the input conditions repeat with all coefficients. These are selection processes as well as conversional ones, etc. For solution of vagueness, in-built processes `FuzzyMembership (FuMeSh)` and `FuzzyOverlay` are used. While the use of `FuMeSh` is different, `FuOv` are the same for all coefficients. Conditions for FuMeSh are dependent on geometric accuracy that show the types of geographical objects in the database. Calculation of coefficients $C_1 - C_3$ was published at (Hofmann, Hoskova-Mayerova, Talhofer, & Kovarik, 2014). Just for illustration, we present calculation of C_2 coefficient. Coefficient C_4 has not been calculated yet because the system is not connected to the on-line meteorological data (Dejmal & Repal, 2010), (Dejmal, Hudec, Novotny, & Repal, 2010).

Except coefficient C_7 the rest coefficients are calculated similarly. As the calculation of C_7 coefficient is a bit complicated and different, we present it in the following paragraph.

2.4.1. Calculation of coefficient C_2- Vegetation cover

The input layer for calculation of coefficient is a polygonal layer of forest units `a_lesy_a`, in which forest units are classified according to species of trees (parameter of kind of vegetation and trees `VE1` a `VE2`), according to trunk diameter (parameter Stem Diameter SDS) and spacing between trees (parameter `Tree Spacing - TSC`). In the first step, separation of objects from the surroundings is done and the resulting layer is saved as a polygonal layer `a_lesy_a_Select`. Then there are three parallel branches. The first branch works with a trunk diameter, the second with spacing between trees and the third considers uncertainty in the position.

The first branch begins with a conversion of vector format into a raster where the result is saved in layer `lessds`. With the help of `Raster Calculator` all pixels that do not display any values (`NoData`) are eliminated and the result is saved into file `rastercalc1`. This step is dependent on the way data are digitalized. It is necessary in case of using an older version of `ARC/INFO`; if the version `ArcGIS` is used, it is possible to skip it. This file is ready for the subsequent fuzzification according to possible `SDS`values and for the fuzzification itself function `FuMeSh` is used, with the help of which the associated values in the area of fuzzification lie in the range 0.09−0.14, since tree cross-sections of up to 0.09 m do not present a problem for passability. In the range between 0.09 – 0.14 m, they enable only a limited passage. For SDS the conditions are as follows:

$$\mu(x) = \begin{cases} 0, & x \leq 0{,}09 \\ \dfrac{0{,}14 - x}{0{,}14}, & 0{,}09 < x < 0{,}14 \\ 1, & x \geq 0{,}14. \end{cases}$$

The result is saved in file `c22`.

In the second branch, the polygon is also transformed into a raster depending on parameter `TSC`and the result is saved on a raster layer`lestsc`. The resulting raster layer is tested for belonging to the object. If a cell lies in an object, it is given value 1. If the cells contain value `NoData`, the value of the cell is changed into 0. The resulting raster layer containing now only values 0 or 1 is saved in layer `ratrcalc9`. Then a selection test of existence of parameter TSC itself is done, it is possible to describe it in the following expression:

$$if\ x = \begin{cases} 0, & x = 0 \\ TSC, & otherwise. \end{cases}$$

The result is saved in file `con_rasterca9`. As for further calculations real numbers are necessary, the previously obtained integral values are divided by 10 with the help of command `Divide`. The result is saved in file `Divide_Recla1`.Vegetation is considered to be passable if the spacing between trees is more than 5 meters, and completely impassable if the spacing between trees is less than 3 meters. That is why with the help of `Fuzzy Membership` function, fuzzification is carried out according to TSC with the range of values 0.3 – 0.5 in this way:

$$\mu(x) = \begin{cases} 0, & x \leq 0{,}3 \\ \dfrac{0{,}5 - x}{0{,}5}, & 0{,}3 < x < 0{,}5 \\ 1, & x \geq 0{,}5. \end{cases}$$

The result is saved in file `c21`.

The third branch begins with the calculation of Euclidean distance from the outer border of polygon of forest areas. The result is saved in file `EucDist_a_le1`. Then the process of fuzzification follows with the help of linear `FuMeSh` function. As the real uncertainty in the position of forest borders is up to 20 meters, fuzzification is done in the range between 0-20 meters from the forest perimeter with associated values 0-1 in this way:

$$\mu(x) = \begin{cases} 1, & x = 0 \\ \dfrac{20 - x}{20}, & 0 < x < 20 \\ 0, & x \geq 20 \end{cases}$$

The fuzzified layer is saved in file `FuzzyMe_EucD1`.

The results of all three branches now with the help of `Fuzzy Overlay` function overlay in such a way that a choice of maximal value of the given pixel is made with the help of `OR` function. The complete result of calculation of coefficient C_2 is saved in file `c2fuzzy`.

2.4.2. Calculation of coefficient C_7 - Road network

The input layer for the calculation of coefficient is a line layer of communications (`a_kom_l`) in which communications are classified according to categories given by parameter `TUC (Traffic User Code)`. (Talhofer &Hoskova-Mayerova, 2015).With regards to the fact that within this layer all communications – including water, air, etc. - are saved, in the first phase it was necessary to choose only land communications. The selection was done by the function `SELECT` with logical operators `OR` and a vector layer `a_kom_l`_Select was obtained. This vector layer was transformed into a raster layer with a pixel size of 5 meters in the first phase, 1 meter in the second one. The value of a pixel was value `TUC`, for empty pixels value NODATA was automatically filled in. As the number of significant TUC was maximally 8, this layer was then reclassified to values2 to 8, `NODATA` was reclassified to value 20.See Figure 2:

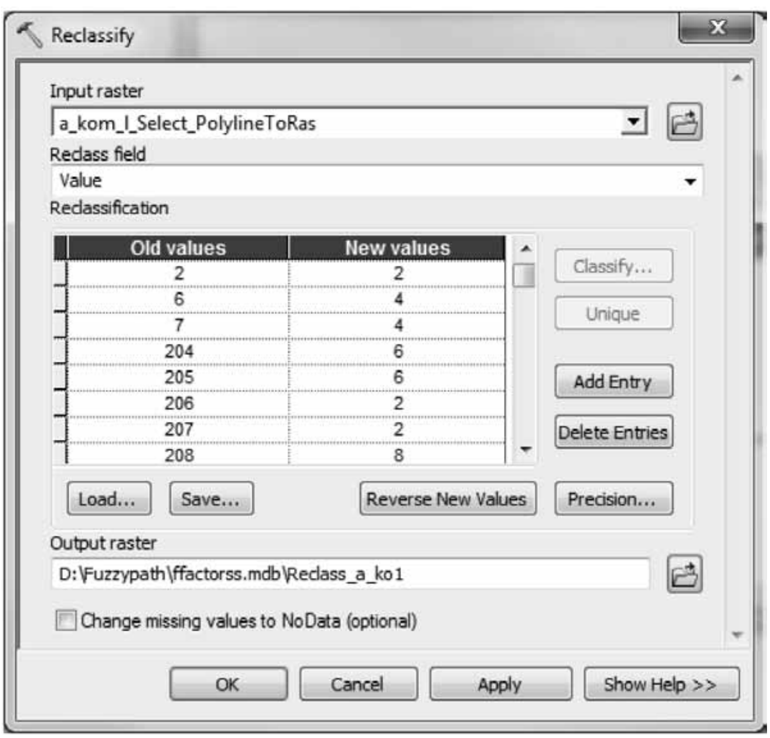

Figure 2. Reclassification

The result of the reclassification was saved in the layer `Reclass_a_kol`. Division by 10 followed, which created another reclassified raster layer `Divide-Recla4`, where pixel values lie in the range between 0 and 2. At the very end, it was divided once more, this time by 2, where pixel values lie in the required range between 0 and 1.

As the used data had the positional accuracy given by a standard error of 5 meters, in a parallel branch for modelling of vagueness in position, fuzzification with the help of a linear function was used. For the layer `a_kom_l_Select` the zone of vagueness was calculated with the help of a distant function `Euclidean_Distance` which created covering buffer of both sides of definition polygon. We did not use the possibility of limitation of buffer calculation into a certain number of meters because doing that would create pixels with `NODATA` information which would have to be removed in the following course. The result of the calculation was saved in the raster layer `EucDist_a_kol`. Within 10 meters from the axis of communications a new raster layer `FuzzyMe_Euc11` was created with the help of Fuzzy Membership tool as follows:

$$f(x) = \begin{cases} 1, & x = 0 \\ \dfrac{10 - x}{10}, & 0 < x < 10 \\ 0, & \geq 10. \end{cases}$$

It does not have any significant meaning for communications; unlike for forests or lands, nevertheless, from the point of view of work methodology it was considered.

The raster layer of communications `Divide_Recla4` was – with the help of `FuzzyOverlay` function – joined with the layer of membership `FuzzyMe_Euc11` using logical operator `OR` in such a way so that the resulting relation ensured the most favorable cost of a pixel for communication (i.e. maximal value is chosen). The result of the relation was saved in layer `FuzzyOv_Divil`. As deceleration coefficient C_7 gets values in an interval <0,1>, in the end it was necessary to divide layer `FuzzyOv_Divi1` by 10. The resulting value of coefficient C_7 was in layer `c7fuzzy`.

2.4.3. Calculation of the total deceleration coefficient

The final deceleration coefficient is calculated from the individual files `cxfuzzy` with the help of tool `Fuzzy Overlay` (see Figure 3). The first 6 coefficients enter the calculation with the help of relation $\max\{C_1, C_2, C_3, C_5, C_6\}$. The resulting value is multiplied by a raster of coefficient C_7 by reason of assigning meaning of the individual communications according to traffic importance (highways, first-class roads, forest roads, etc.). The result is the cost map that can be an input for searching of an optimal route in a decision-making process in CCM.

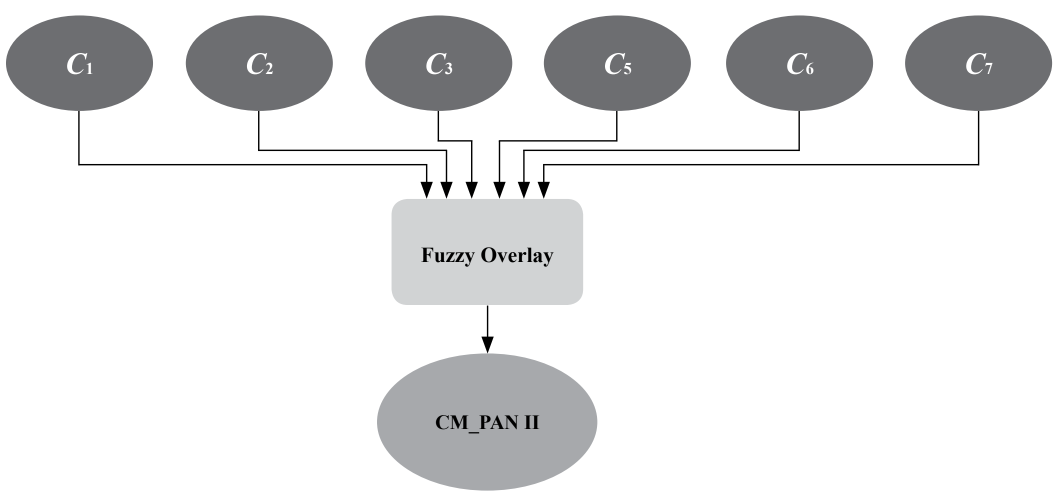

Figure 3. Model of final coefficient of deceleration evaluation

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The final deceleration coefficient is calculated from the individual files with the help of the `Fuzzy Overlay` tool. The first five coefficients enter the calculation with the help of relation max$\{C_1, C_2, C_3, C_5, C_6\}$. The resulting value is multiplied by a raster of coefficient C_7 by reason of assigning meaning of the individual communications according to traffic importance (highways, 1st class roads, forest roads, etc.). The result is the cost map that can be an input for searching of an optimal route in a decision-making process in CCM (Figure 4).

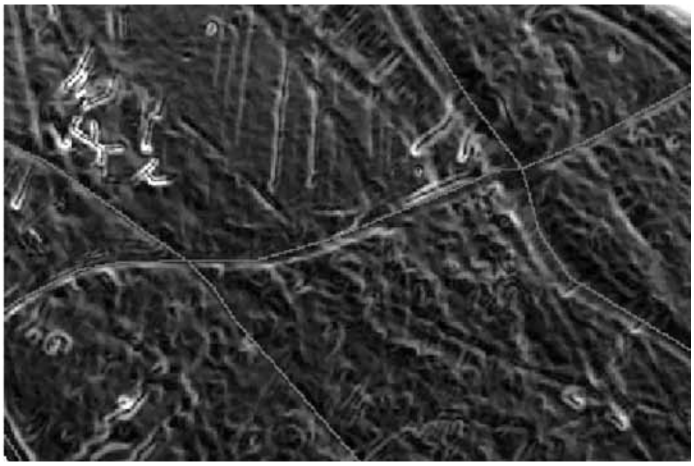

Figure 4. A part of the cost map calculated for PANDUR II

3. Methods used for verification of data and model quality

Current research in this domain is usually focused on assessing partial characteristics of vehicles and their interaction with geographic environment. The aim of our work was to verify behavior of the whole model in the real environment in which the Czech Army units currently operate or might operate in the future.

3.1. Preparation phase

The vehicle movement models were verified in terrain tests in the Brezina military training area that is located about 40 kilometers northeast of Brno. The aim of the tests was to evaluate whether the models are functional or not. The tests were prepared in a way that selected vehicles can move anywhere within the area of 5 by 5 km. That area is commonly used for tactical training of small military units therefore the ground is covered with a number of trenches, lowered and elevated areas for placing targets, and other terrain obstacles. The area is partially covered with vegetation with a height of up to 3 m. There are also a number of tracks whose positions are not permanent and vary over the years (Rybansky, et. al., 2015), (Talhofer&Hoskova-Mayerova, 2016).

The following types of military vehicles were used for testing:
- the cross country vehicles UAZ 469.
- the medium lorry TATRA 810;
- the armoured personnel carrier PANDUR II;

Selected technical and operational parameters of the vehicles are shown in the Table 3.

Table 3. Selected technical and operational parametres of tested vehicles

Vehicle type	UAZ 469	T810	PANDUR II
Length [m]	4	7,49	7,84
With [m]	1,8	2,55	2,77
High [m]	2	3,36	3,77
Weight [kg]	2400	13000	20800
Maximum climbing capability [°]	30	45(30)	30
Maximum road speed [kmph]	105	101	95
Maximum speed on dry soil [kmph]	45	45	60

The fundamental goal of testing was to find the degree of usability of modelling results using the above mentioned physical, mathematical, and information models in the real application in decision-making processes in the C2S systems. This goal was complemented by several collateral goals that were to specify partial coefficients of general capabilities of particular drivers and their ability to drive at difficult night conditions, and also to specify the coefficient of weather conditions. One of the goals was checking the quality of geographic data using the independent surveying in the field.

During the preparation phase of testing it was necessary to generate cost maps of a given area for each tested vehicle. Computations were performed using the following data: the DMU25 vector database; the digital elevation models DMR3, DMR4, and DMR5; and the soil database. The combinations of used data are presented in Table 4.

Table 4. List of combinations of used data

Combination Code	Used data
K3	DMU25 + DMR3 + SD
K4	DMU25 + DMR4 + SD
K5	DMU25 + DMR5 + SD

Computations resulted in 15 different cost maps keeping the values of model deceleration coefficient in each pixel. The maps contained also highlighted waypoints. The optimal routes were computed between these points and the drivers were to follow these routes during field tests. The total length of the routes was approximately 13 kilometers.

3.2 Field testing

Field tests took place 6 and 7 May 2014. (Hoskova-Mayerova & Hofmann, 2016). Each vehicle drove through given waypoints several times at different times of the day and they were to follow the assigned routes according to the following scenario:

- Routes calculated from combination K5:
  - the first pass of a vehicle using the assigned route and recording of the actually passed route in GPS - recognition pass
  - repeated passes of a vehicle using the assigned route and recording of the actually passed route in GPS - pass at maximum speed possible, the same driver
  - pass of a vehicle using the assigned route at degraded visibility conditions (dark) and recording of the actually passed route in GPS - pass at maximum speed possible, the same driver
- Routes calculated from combination K3 and K4:
  - passes of a vehicle using the assigned route and recording of the actually passed route in GPS

Each vehicle has been thoroughly documented in advance and all their current performance characteristics were measured using dynamometry. Also, the required characteristics of all drivers (military personnel) were recorded, especially their age and the length of their experience with a particular vehicle.

The soil samples were collected at various locations of the testing area for the purposes of the soil database verification. In the laboratory, these samples were analyzed for their actual composition and their humidity. Also the current meteorological elements were measured during testing, i.e. air temperature and humidity, visibility and light intensity. Unfortunately, just at the time of testing, there was a long-term drought at the area, which significantly affected the opportunity to verify the coefficient of meteorological conditions.

The actually passed routes were recorded at the time interval of 2 seconds using the three GPS Trimble receivers with the external antennas - Geoexplorer XT, XT3000, and XT6000 - and the TerraSync software suite. Collected data were later post processed and corrected using the CZEPOS permanent reference station network and the PathFinder software suite. The typical accuracy of obtained points after all corrections was 1.8 meters.

A total of 34 passes were made. During the tests or shortly after them the locations with very difficult terrain conditions were selected in the area. These locations were mapped in detail using the total stations Leica Tc 1500 and the numerical tacheometry method in order to obtain the independent surveying for the data quality check.

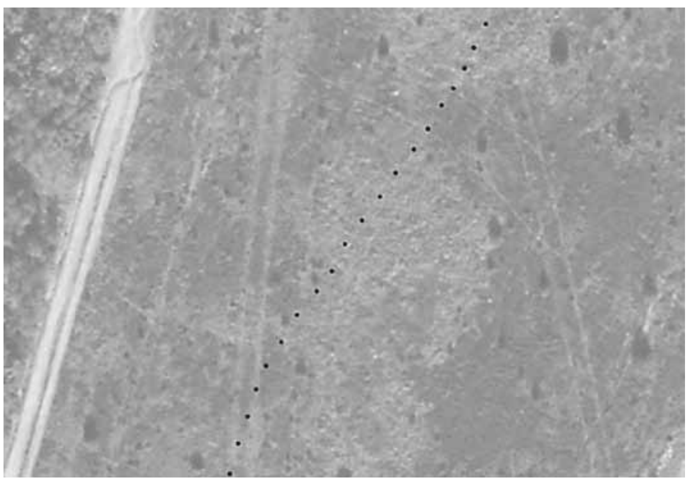

Figure 5. Part of measured track of TATRA 810 (black dots are GPS positions)

3.3 Data analysis

The data from the terrain represent a rich material which is currently being analyzed. The following text presents only partial results of quality evaluation of the system of deceleration coefficient computation (Hoskova-Mayerova & Hofmann, 2016).

The individual points of actually passed routes were obtained from corrected GPS data where each point kept parameters such as current UTM coordinates, UTC time, distance traveled, horizontal speed, or speed on a physical surface (Hoskova-Mayerova & Talhofer, 2016).

These points were transformed into a raster of resolution of 1 by 1 meter with horizontal speed as a pixel value. Using a map algebra the differences were derived between modelled and real speed of a given vehicle in a given cost map data combination (see Figure 6).

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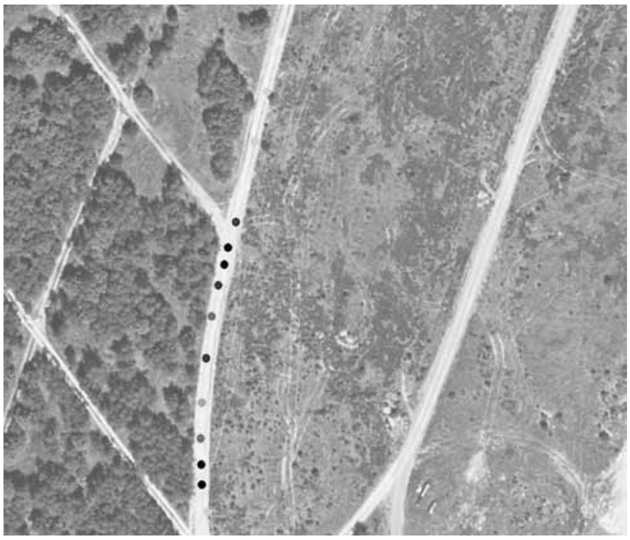

Figure 6. Differences between real and modelled speed (grey scale of points reflex the speed difference)

Differences were stored into Attribute Table. Its structure illustrates following picture (Figure 7):

Table

Final_X050618A_K5pan_1937

OB	Shape*	Joi	TARG	No	E	N	H	Track	Comb	Vehicle	Time	Cum Hz	Vel Hz	Cum P	Vel P	pointid	grid code	E var	N var
2	Point Z	2	2	2	642316,06	5466384	488,56	TRASA	K5	Pandur	17:37:14	2	3,2	2	3,3	330	84,52916	642316	546638
3	Point Z	2	3	3	642318,19	5466386	488,8	TRASA	K5	Pandur	17:37:16	5	5,3	5	5,3	328	77,79863	642318	546638
4	Point Z	1	4	4	642321	5466392	488,68	TRASA	K5	Pandur	17:37:18	11	11,9	11	11,9	327	73,208473	642321	546639
5	Point Z	1	5	5	642310,44	5466417	488,93	TRASA	K5	Pandur	17:37:22	38	24,4	39	24,4	324	59,615417	642310	546641
6	Point Z	1	6	6	642286,5	5466439	484,89	TRASA	K5	Pandur	17:37:25	71	39	71	39,3	322	56	642286	546644
7	Point Z	1	7	7	642270,25	5466456	483,38	TRASA	K5	Pandur	17:37:27	95	42,3	95	42,4	320	52,700001	642270	546645
8	Point Z	1	8	8	642254,75	5466471,5	483,07	TRASA	K5	Pandur	17:37:29	116	39,5	117	39,5	318	55,5	642255	546647
9	Point Z	1	9	9	642242,63	5466484	482,67	TRASA	K5	Pandur	17:37:31	134	31,3	134	31,4	316	63,700001	642243	546648
10	Point Z	1	10	10	642230,63	5466495	481,2	TRASA	K5	Pandur	17:37:33	150	29,3	151	29,4	314	60,410419	642231	546649
11	Point Z	1	11	11	642218,56	5466505	480,48	TRASA	K5	Pandur	17:37:35	166	28,2	166	28,2	312	50,911793	642219	546650
12	Point Z	1	12	12	642207,06	5466515,5	478,71	TRASA	K5	Pandur	17:37:37	181	28	182	28,2	310	46,015465	642207	546651
13	Point Z	1	13	13	642196,38	5466526,5	477,89	TRASA	K5	Pandur	17:37:39	197	27,6	197	27,6	308	53,822281	642196	546652
14	Point Z	1	14	14	642185,31	5466539	477,09	TRASA	K5	Pandur	17:37:41	213	30	214	30,1	306	53,073395	642185	546654
15	Point Z	2	15	15	642172,31	5466553	476,7	TRASA	K5	Pandur	17:37:43	233	34,4	233	34,4	304	43,044632	642172	546655
16	Point Z	2	16	16	642159,06	5466567,5	475,21	TRASA	K5	Pandur	17:37:45	252	35,4	253	35,5	302	45,398098	642159	546656
17	Point Z	1	17	17	642146	5466583,5	474,8	TRASA	K5	Pandur	17:37:47	273	37,2	273	37,2	301	54,728764	642146	546658
18	Point Z	1	18	18	642134,63	5466597,5	474,64	TRASA	K5	Pandur	17:37:49	291	32,5	291	32,5	299	57,916969	642135	546659
19	Point Z	1	19	19	642122,13	5466610,5	474,39	TRASA	K5	Pandur	17:37:51	309	32,5	309	32,5	297	57,65844	642122	546661
20	Point Z	1	20	20	642108.63	5466625	474.07	TRASA	K5	Pandur	17:37:53	329	35.7	329	35.7	295	56.196995	642109	546662

Figure 7. Attribute table structure

From the statistical point of view is interesting the histogram of differences between modelled and real vehicle speed. Next picture shows a histogram of such differences of off-road vehicle PANDUR II.

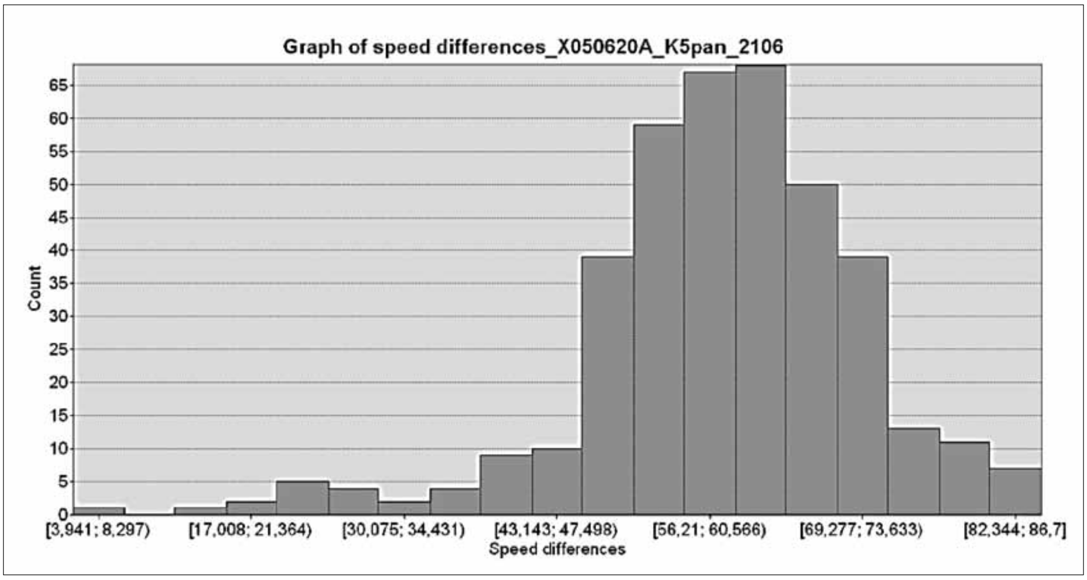

Figure 8. Histogram of differences between modelled and real vehicle speed (PANDUR II, time 6. 5. UTC 19:06)

4. Discussion

As already mentioned in the preceding text, the individual deceleration coefficients were derived on the basis of field testing. Furthermore, a comprehensive physical, mathematical, and information model for the system of evaluation of possibility of a vehicle free movement through the open terrain. Described field tests were the first comprehensive examining of the functioning of the entire system on a relatively large area. It is therefore obvious, that not all the expectations regarding to the models we had, were met. The following text presents major problems that were encountered.

4.1. Creating cost maps and their accuracy

Our goal was to create cost maps with the highest possible resolution using standard geographic data that are commonly used in the Czech Army. Therefore it was decided to use a pixel size of 1 m. This resolution worked well in the areas without any roads. However, the problems occurred when for example a track without the attribute of the feature width was present in the forest that was evaluated as not passable feature. Resulting cost map then showed a line of 1 m pixels having a favorable coefficient of deceleration, but all the adjacent pixels had the coefficient of deceleration equal 1, i.e. the vicinity of the track was evaluated as not passable. The similar visualization can be seen in (Kubíček & Šašinka, 2011). In fact, the track had a width of 4 m (see Figure 9) and the vehicle was able to pass easily even in these locations. (Svatonova, 2015)

Figure 9. Superposition of the cost map (gray scale), measured vehicle position (PANDUR II, red dots), and ortogonalised aerial image

For this reason, there are also negative values of differences in speed in the histogram (Figure 8). The solution to this problem lies in another setting of fuzzification when calculating the cost maps. Due to the real width of roads, the interval of fuzzification was chosen two meters on each side of the axis of the road. Thanks to this, the coefficient of deceleration was changed in such a way that and the coefficient C_7 was really equal to 1 only out of the road. The recalculated cost map is on the following figure and the next figure (Figure 10) is again superposition of the cost map (gray scale) and measured vehicle position (PANDUR II, red dots) (Hoskova-Mayerova & Hofmann, 2016).

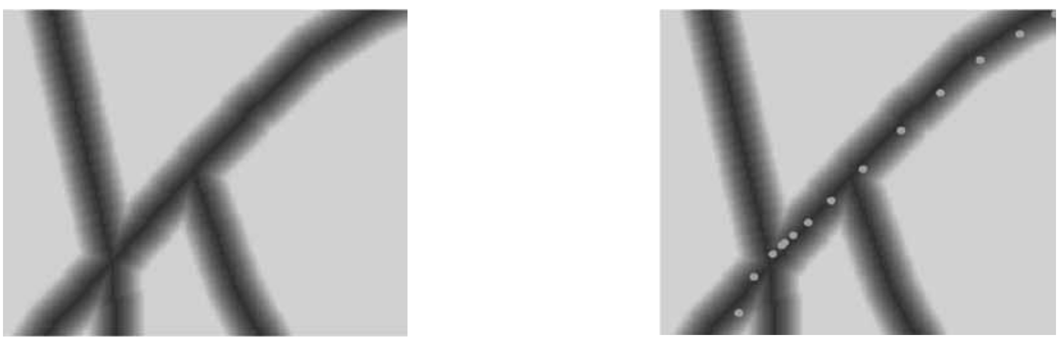

Figure 10. Recalculated cost map and superposition with the recorded track log

4.2. Overestimation of the model

Another problem is the overestimation of speed calculations. As is evident from the next table (Table 4) validated model is significantly more optimistic compared to the reality. The overestimation of the model occurred in spite of the fact that the climatic conditions at the time of tests allow drivers to go fairly high speed, and that we had an experienced driver who knows the area perfectly. The standard deviations of the individual vehicles are similar. From this fact we can conclude that there will be a systematic effect that it would be appropriate to incorporate into existing models.

After discussions within the research team and with the drivers, we have reached the conclusion that it is necessary to also work with the psyche of the driver, in addition to more accurate modeling, calculation of the deceleration coefficients, and including the coefficient of the surface roughness.If the driver is convinced that even in a slightly covered terrain (tall grass, low self-seeded trees), there will be no small micro relief obstacles, he can drive relatively fast, even though he can’t see the road completely.

However, if the surface is grooved by the micro relief obstacles as in the test area, the driver will have psychological barriers to go with the maximum speed of the vehicle. Tilt of the vehicle and its aftershocks will force him to slow down.

The mental obstacle mentioned above can be expressed by another slowdown coefficient, whose derivation we are presently starting to work on.

4.3. Modelling and reality

Designed and tested model gives only an idea about the conditions in which the specific vehicle is located and whether it is in terms of landscape surface configuration and landscape cover under the given climatic and meteorological conditions passable.

On the basis of verification tests and thorough analyzes it can be expected that it will be possible – fairly reliably –to determine whether the vehicle or group of vehicles can move in such a terrain.

Further progress in the development of models can be expected on the basis of its application in specific tasks solved within the command and control process. For example, it can be the deployment of troops in given area and given time, assessment of the possibility of fast and hidden movement, etc. In this case it will not be only an expression of the ability of a vehicle to pass through given section, but also direct involvement of the proposed model into command and control system.

Conclusion

The performed tests proved that each model is functional and together they will enable to partially, yet objectively, evaluate the passability of the terrain by different vehicles. They also proved the applicability of standard geographic data for evaluating this passability. Simultaneously, however, they detected the weaknesses of the solution. Nevertheless, they indicated how to deal with these weaknesses.

In 2015, the research team carried out similar tests of more specified model under the same scenario and bigger area of military district Libavá. Received data are now being evaluated.Based on the detailed analyses of influence of the individual factors on the resulting deceleration coefficient, it is necessary to precise especially:
- Expression of roughness of the terrain surface;
- Expression of terrain surface type (clay, grass, leaves, stones, etc.);
- Expression of influence of drivers` skills;
- Expression of influence of meteorological conditions;
- Expression of light conditions.

When calculating cost maps for stable linear objects that do not have attributes of width specified in the database, it is necessary to calculate with a broader zone for fuzzification that corresponds to the presumed character of the object (field and forest roads, tank routes).
In the following phases, especially analyses of data from the route records will be done. It is presumed:
- Analysis of speed deviations in homogenous parts of routes (the same character from the point of view of surface roughness, its cover, surrounding space, etc.);
- Creation of CM variants with variously set deceleration coefficients and analysis of speed deviations according to variant coefficients;
- Detailed evaluation of the influence of the quality of underlying data on the resulting speed deviations.

It will also be tested in real conditions in a larger area with more vehicles. See (Hoskova-Mayerova & Talhofer, 2016).Complex conception of tests of CCM model is only a starting point of the whole system of verification of the system of deceleration coefficients, as well as their values. The research team is fully aware that the used models (physical, mathematical and information) currently contain a lot of drawbacks. Also there appeared some problems with recording the driven routes by GNSS receivers. The stated problems, however, are now being solved and they will be responded to in the upcoming experiments.

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References

Ahmad, B., & Kharal, K. (2009). Fuzzy Sets, FuzzyS-OpenandS-Closed Mappings. *Adv. Fuzzy Systems*, p. 5.

D´Amico, P., Di Martino, F., & Sessa, S. (2013). A GIS as a Decision Support System for Planning Sustainabel Mobility in a Case-Study. In A. Ventre, A. Maturo, S. Hoskova-Mayerova, & J. Kacprzyk (Eds.), *Multicriteria and Multiagend Decision Making with Applications to Economics and Social Sciences* (Studies in Fuzziness and Soft Computing ed., pp. 115-128). Berlin Heidelberg, Germany: Springer Verlag.

Dejmal, K., & Repal, V. (2010). Influence on a mission due to the weather. *New Aspects of Fluid Mechanics, Heat Transfer and Environment.WSEAS Mechanical Engineering Series*, pp. 287-290. World Scientific and Engineering Acad and Soc,, Athens, Greece.

Dejmal, K., Hudec, F., Novotny, J., & Repal, V. (2010). Minimum temperature forecasting - adjustment of McKenzies technique on Czech territory. In A. Stefek, & R. Jalovecky (Ed.), *ICMT'09: International Conference on Military Technologies* (pp. 547-550). Brno: Univ Defence, Brno, Czech Republic.

Di Martino, F., & Sessa, S. (2011). Spatial Analysis and Fuzzy Relation Equations. *Advances in Fuzzy Systems, 2011*, p. 14.

ESRI. (2013). User documentation. Copyright © 1995–2013 Esri.

Hofmann, A., Hoskova-Mayerova, S., Talhofer, V., & Kovarik, V. (2014, July). Creation of models for calculation of coefficients of terrain passability. *Quality & Quantity, 49*(4), pp. 1679-1691.

Hoskova, S., & Cristea, I. (2010). Fuzzy pseudotopological hypergroupoids. *Iranian Journal of fuzzy sets, 4*(6), pp. 11-19.

Hoskova-Mayerova, S., & Hofmann, A. (2016) Development of Applications in the Analysis of the Natural Environment. *Aplimat - 15th Conference on Applied Mathematics 2016 Proceedings*. Bratislava, Slovakia: STU Bratislava, 2016, p. 467-481.

Hoskova-Mayerova, S., & Talhofer, V. (2016). Verification Tests of Mathematical Models of Passage throug Terrain. *Aplimat - 15th Conference on Applied Mathematics 2016 Proceedings.* (pp. 1010-1025). Bratislava, Slovakia: STU Bratislava.

Hošková-Mayerová, Š., Talhofer, V., & Hofmann, A. (2013). Decision-Making Process with Respect to the Reliability of Geo-Database. In A. G. Ventre, A. Maturo, Š. Hošková-Mayerová, & J. Kacprzyk, *Multicriteria and Multiagent decision Making with Applications to Economics and Social Sciences.* (Studies in Fuzziness and Soft Computing ed., pp. 179-195). Berlin Heidelberg, Germany: Springer-Verlag.

Kainz, W. (2007). *Fuzzy Logic and GIS.* Vienna, Austria: University of Vienna.

Kubíček, P., & Šašinka, Č. (2011). Thematic uncertainty visualization usability – comparison of basic methods. *Annals of GIS, 17 (4)*, pp. 253-263.

Mason, G. L., Gates, B. Q., & Moore, V. D. (2012). Determining forces required to override obstacles for ground vehicles. *Journal of Terramechanics, 49*(3-4), pp. 191-196.

Raudeliūnienė, J.; Stadnik, B.; Kindarytė, R. 2016. Knowledge appliance process: theoretical and practical evaluation aspects, *Entrepreneurship and Sustainability Issues* 3(4): 368-379. <http://dx.doi.org/10.9770/jesi.2016.3.4 (5)>.

Rezk, M. A.; Ibrahim, H. H.; Tvaronavičienė, M.; Sakr, M. M.; Piccinetti, L. 2015. Measuring innovations in Egypt: case of industry, *Entrepreneurship and Sustainability Issues* 3(1): 47-55.<http://dx.doi.org/10.9770/jesi.2015.3.1(4)>.

Rezk, M. A.; Ibrahim, H. H.; Radwan, A.; Sakr, M. M.; Tvaronavičienė, M.; Piccinetti, L. 2016. Innovation magnitude of manufacturing industry in Egypt with particular focus on SMEs, *Entrepreneurship and Sustainability Issues* 3(4): 306-318. <http://dx.doi.org/10.9770/

jesi.2016.3.4(1)>.

Rybansky, M. (2009). *Cross-Country Movement, The Imapct and Evaluation of Geographic Factors* (First ed.). Brno, Czech Republic: Akademické nakladatelství CERM, s.r.o. Brno.

Rybansky, M,(2013) Modelling of the optimal vehicle route in terrain in emergency situations using GIS data, *8th International Symposium of the Digital Earth (ISDE8) 2013, Kuching, Sarawak, Malaysia 2014 IOP Conf. Series.: Earth Environmental Science 18*, 012071

Rybansky, M., Hofmann, A., Hubáček, M., Kovařík, V., Talhofer, V.(2015). Modelling of cross-country transport in raster format. *Environmental Earth Sciences*, 2015, 74(10), p. 7049-7058.

Rybansky, M, & Vala, M. (2009). Analysis of relief impact on transport during crisis situations. *Moravian Geographical Reports, 17*(3), pp. 19-26.

Rybansky, M., & Vala, M. (2010). Relief impact on transport. *ICMT'09: International Conference on Military Technologies* (pp. 551-559). Brno: University of Defence.

Shoop, S., Knuth, M., & Wieder, W. (2013). Measuring vehicle impacts on snow roads. *Journal of Terramechanics, 50*(1), pp. 63-71.

STANAG 2999. (2012). *Use of Helicopters in Land Operations Doctrine* (9 ed.). Brussels: NATO Standardization Agency (MAS).

Sunila, R., & Hottanainen, P. (2004). Fuzzy Model for Soil Polygons for Mapping the Imprecision. *Proceedings of the StartGIS 2003*, (p. 8). Pörtschach.

Svatonova, H. (2015) Aerial and satellite images in crisis management: Use and visual interpretation. In Krivanek V.. *ICMT 2015 - International Conference on Military Technologies 2015*. 1. vyd. Brno: Institute of Electrical and Electronics Engineers Inc., 2015. pp. 1-5,. doi:10.1109/MILTECHS. 2015.7153705.

Svatonova, H., & Rybansky, M. (2014). Visualization of landscape changes and threatening environmental processes using a digital landscape model. *IOP Conf. Ser.: Earth Environ. Sci.18*, pp. 12-18. IOP science.

Talhofer, V., Hoskova-Mayerova, S., & Hofmann, A. (2012). Improvement of digital geographic data quality. *International Journal of Production Research, 50*(17), pp. 4846-4859.

Zadeh, I. (1965). Fuzy Sets. *Information and Control, 8*, pp. 338 - 353.