International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:8, No:11, 2014

The Effect of Land Cover on Movement of Vehicles in the Terrain

Dana Kristalova, Jan Mazal

Abstract**—**This article deals with geographical conditions in terrain and their effect on the movement of vehicles, their effect on speed and safety of movement of people and vehicles. Finding of the optimal routes outside the communication is studied in the Army environment, but it occur in civilian as well, primarily in crisis situation, or by the provision of assistance when natural disasters such as floods, fires, storms etc., have happened. These movements require the optimization of routes when effects of geographical factors should be included. The most important factor is the surface of a terrain. It is based on several geographical factors as are slopes, soil conditions, micro-relief, a type of surface and meteorological conditions. Their mutual impact has been given by coefficient of deceleration. This coefficient can be used for the commander`s decision. New approaches and methods of terrain testing, mathematical computing, mathematical statistics or cartometric investigation are necessary parts of this evaluation.

Keywords**—**Movement in a terrain, geographical factors, surface of a field, mathematical evaluation, optimization and searching paths.

I. Introduction

WAR conflicts in the last twenty years have shown the need for digitization of area, when the Commander needs a lot of input data for the correct decision. This data is becoming an essential part of the decision-making process when planning of a successful movement (for peace and for war) is one of the fundamental questions. For its creation it is necessary to know the impact of geographical factors on the maneuver, and if it is possible to use algorithms to find optimal routes. The algorithms of the route optimization (for communication and outside of them) may not be intended only for the war purposes because finding optimal routes outside the communication may be relevant also in civilian crisis situations, or the provision of assistance when natural disasters such as floods, fires, storms etc. "The optimization of the routes" means not only finding the shortest route, but also to ensuring the safety of movement, or at least limitation of risk factors and so the compliance with time limits or acceptance of the economic aspects of the movement can play an important role [1].

II. Cross-Country Movement

The issue of capability of the terrain (Cross-Country Movement, Traffic Ability of a Terrain) is still a current topic, despite the fact that for a long time the new approaches are developed. These approaches could contribute to optimizing the search paths [2]. Finding of the relevant algorithms is not a trivial matter, because the selection of the most appropriate routes and the estimate of the time that is needed for the move is a function of the quantity various factors: geographical, tactical, technical and the influences that are predetermined by the human behaviour.

Analysis of the Cross-Country Movement (trafficability, capability) means the assessment of several geographical and tactical factors together, i.e. that it is complex multi-field analysis [3]-[6].

Apart from these *geographical factors and their parameters* that affect the choice of routes, it includes:

- Relief (a parameter is a gradient);
- Micro-relief – i.e. embankments, excavations, holes, terrain steps, rock cliffs, terraces, rock groups, boulders, stone fields or rows of stones, etc. (parameters are height or depth, length, slope gradient, width);
- Vegetation – structure of partial forests, vineyards or hop-gardens (dimension, shape, orientation), structure and specific characteristic of woody plants (spacing between trunks, thickness of trunks measured at height 1,3 m over terrain, vegetation height, sort of plants);
- Soils - a sort of soil (depends on soil granulation), a type of soil at factual weather conditions, a vegetation cover of soils, a roughness of terrain surface;
- Waters – rivers, streams, lakes, dams, etc. (their parameters are width, depth, water flow rate and flow speed, characteristics of banks and of bottom, overall covering of terrain by drainage and mutual position of drainage and other geographical subjects);
- Weather conditions – precipitation, fogs, temperatures, humidity, wind speed, light conditions;
- Settlements - built-up of given territory by settlements, location, structure, shape and orientation in regard of troop movement, construction material, height of buildings, Fire behaviour of buildings;
- Communications- railways (number of tracks, traction – the kind of drive, track gauge, transportation significance) and roads (width or number of traffic lanes, quality of roadway wear course, transportation significance).

The impact of all factors is expressed by „*Coefficient of the deceleration*„ (abrev. CoD).

These factors and their parameters determine 3 levels of Cross-Country Movement – GO, SLOW GO and NO GO. The level called "GO" means the movement without a loss of speed the level "SLOW GO" means partial deceleration of the speed of the movement and the last level "NO GO" signifies

Dana Kristalova is with the University of Defence, Faculty of military leadership, Kounicova street 65, ZIP 662 10, Czech Republic (corresponding author to provide e-mail: dana.kristalova@unob.cz).

that the movement is not possible. These terms are given in [3]-[6].

From the point of view of means of transport (used for movement) following basic types of terrain are determined:

- Terrain passable for full track vehicles;
- Terrain passable for wheeled vehicles;
- Terrain passable for other means of transport;
- Terrain passable for infantry troops.

III. What about Factors, Data and Methodologies?

A. Factors

The goal of the research is the elaboration of the issue of the influence of the surface of the terrain on the movement of vehicles in terms of appropriate data and methods of evaluation. The following factors were examined: the surface of the terrain – this means the soil to a depth of layer influencing the driving characteristics of the vehicle, the elemental slopes, the frequency, size and shapes of the micro-relief and the specific material of surface routes (grass, sand, clay, gravel, concrete, asphalt and more). Properties of the surface were also changed due to climatic and meteorological conditions.

B. Data

The scheduling of movement routes may take place in an office, often far from the real battlefield. At this point we can use all the available sources as maps, plans, aerial photos, scenes (obtained by RS – Remote sensing of Earth). In real time the soldier often has only an analogue map or evaluation of the supporting documents, which thanks to the devastating effects of war need not be current. The determining of the correct routes of a movement or suitable visible or hidden areas may not be easy.

That is why it is calculated with the introduction of the "System of the 21thcentury Soldier" in the future. This system is developing, verifying and applying in similar versions in many advanced armies all of the world.

C. Methodologies

Thanks to the joint consideration of these factors and their standards indicating the degree of continuity, it would be possible to determine the correct route transfers and calculate the time estimates for the movements of various military or ambulance units. Speeds are relevant not only to the type of terrain, but also the type of (military) equipment. To devise a methodology for estimating the speed of movement of the influence of the terrain surface is necessary to establish a method of obtaining the relevant data (inclination of slopes, the frequency of the micro-relief shapes, types of surface soil conditions, terrain and weather conditions), to analyze data, identify ways to evaluate the data and build the algorithms for the calculation of time limits movements. It would be possible to modify the algorithms and other aspects (in terms of security, economic, or the shortest distance).

Several methodologies (in particular assessing the impact of geographical factors on the movement) were created at the Department of Military geography and Meteorology in the course of carrying out the tasks relevant to the specific research [7], [8]. Several effects, which had a majority influence on the ride of vehicles in the terrain, and which were still relatively neglected were evaluated during the research. Influence of micro-relief on the movement of military vehicles was the first [9], the influence of human reactions and of the surrounding environment was the second. New approaches for a comprehensive evaluation of the operating factors and their parameters, it has also been described in some articles [10], [11].

IV. New Approaches and Methods of Terrain Testing

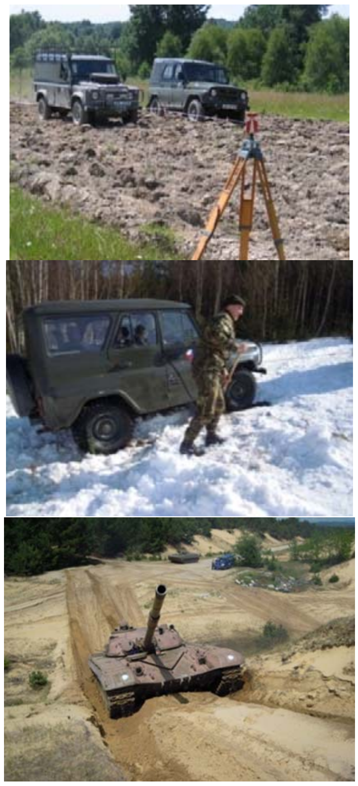

Fig. 1 On the first picture there is a ploughed field (in summer) as one of the typical terrain in the Czech Republic
In the middle frame there is vehicle UAZ 469 on the snowy slope of 6.4 degrees inclination. It was not able to overcome a combination of road resistances and had to be pulled up by the second vehicle.
At the bottom there is a tank that is trying to overcome the 15 degrees slope on sandy terrain. Slope went only with difficulty, unlike the same slope on the clay surface, which came without the problem. Source: own

Some earlier models (Micro-relief – Matlab and 3D Terrain) have not been tested in the field, because they were based on the cartometric investigation, mathematical modelling of the terrain and the subsequent simulation of rides in it. The tests directly in the field are necessary for verifying the methodologies referred to above. Times passes of different types of vehicles on different surfaces were measured, profiles of routes were targeted and other characteristics of the individual spaces by different methods (penetro-metric measurement, sampling the soil samples,...) were detected. [12], [13]

The use of environmental variability and the typical characteristics of each type of terrain with regard to the availability of these spaces, as well as on the available types of military vehicles is most important when testing the polygons are drawn. Straight and sloping spaces, flat and rough were tested. The surfaces of a grassy, rocky, sandy, clay, asphalt and snowy were investigated. For the preparation and implementation of these tests a large number of calls with the appropriate personnel is necessary and ensuring these areas is not easy. It is possible to use different methods for obtaining and evaluating these data, it is the right to choose the most practical.

V. New Approaches and Methods of Evaluation of Data

The result of the research, which takes place in the present, should be used to design a digital interface for collecting, managing, and redistribution of geographic data relevant to a given issue. Documents containing database tactical-technical data of vehicles and their traction diagrams (on whose basis it is possible to define the maximum possible speed attainable on exit or descent of the concrete slopes), detailed geographic data, algorithms for the determination of the coefficient of the slowdown on the basis of the frequency and the size of the micro-relief shapes, the coefficients of a deceleration defined on the basis of adhesive factors for the main types of surfaces and the coefficients of deceleration determined on the basis of meteorological characteristics would have been necessary for the new information system. These coefficients slowdown associated with each field types, however, interact and, therefore, it is not easy to quantify the impact of elementary.

Below an overview of the models for determining the speed of the vehicles is given.

A. The Definition of the Impact of Geographical Factors Using the Basic Formula

One way for calculating of the total CoD depends on the partial CoD of the different GF and is given by [3]-[6]:

$$C = \prod_{i=1}^{8} c_i \quad , \tag{1}$$

where C = total CoD and c_i = partial CoD due to geographical factors (C_1 is CoD of the relief, C_2 CoD of the soils, C_3 CoD of the vegetation,..).

B. The Assembly of the Various Models of Optimization Paths

1) The Model of Micro-Relief

Micro-relief is a neglected factor in optimizing route. There are several reasons:

- the absence of country-wide mapping of this factor (the maps, which provided the input data, are TM in scale 1 : 10 000, these maps are not in using today (the date of editing was between 1958-1964). Unfortunately, other map resources for these measurements were not available at the time of the creation of models. Today, it is possible to use civilian product ZABAGED in scale 1: 10 000, or watt for one of the products of ALS (aerial laser scanning), especially DSM 1G (Digital Surface Model the 1st generation) [14];
- the apparent "small size" of these shapes, and thus, in the context of generalization of maps, totally inaccurate data on maps.

The input data were obtained by the cartometric investigation (the length of the micro-relief shapes, their numbers in the squares of 10 by 10 km and the average height of these shapes).

The route optimization model due to micro-relief can be solved by different ways. The model was created and the values of the average length, numbers and height of the micro-relief shapes were accepted.

a) Model Matlab

The coefficients of the vehicle deceleration due to one obstacle and due to the influence of a probable number of obstacles in real morphometric type of total length of a route have been obtained by calculation of many simulations transits. The average elongation of route, then the average size of an obstacle and the fact that a driver sees the obstacle in distance d/2 and bypasses it by angle 45° is accepted and the probability that the obstacle is met in ¼ of size is accepted too, for one obstacle it is given by coefficient ρ = 1.0155 (see [5], pp 68).

b) Model 3D terrain

The model of routes optimization of the vehicle in the field is based on the knowledge of the programming environment, programming language C^{++}. As input values for a model of the micro-relief has been accepted the table, that was created based on the values of the cartometric investigation;

For the calculation of the elongation of the route it is appropriate to consider, for which vehicle the simulation is created. It is assumed that ambulances or other operational vehicles are equipped with GPS devices. The total elongation for a vehicle equipped with GPS devices searching the direct route is **about 5-8 % (**depending on the morphometric type).

This model can be optimized by modifying the algorithm, where the route leads only over the apexes of the obstacles that occur on the route. The vehicle is still oriented by using GPS to the target point. Here the value of the elongation of the route is **1-1.4 %, compared to 5-8 %.**

Unfortunately, not all vehicles have a GPS or other navigation instruments. The crew knows only the coordinates of the starting and destination point and a bypassing of obstacles leads to change of the azimuth to the target point. Here the average value of the elongation of the route is **12-15 %.**

The next models of optimization (see Fig. 2) were created similarly. Input data were gathered using digitalization of layers of micro-relief, waters and railways from the TM 1:10 000. The obstacles were selected carefully, the limits for CCM were considered. The first simulation model was for influence of micro-relief only but the second was for an influence of micro-relief, waters and railways together. The values of elongation of routes are stated in Table I (see [5], pp 78).

TABLE I
THE VALUES OF ELONGATION OF ROUTES

Type of model	An elongation of route (non-optimized) [%]	An elongation of route (optimized) [%]
Model of „microrelief“	7,40	1,19
Model of „microrelief + waters + railways“	14,91	3,79

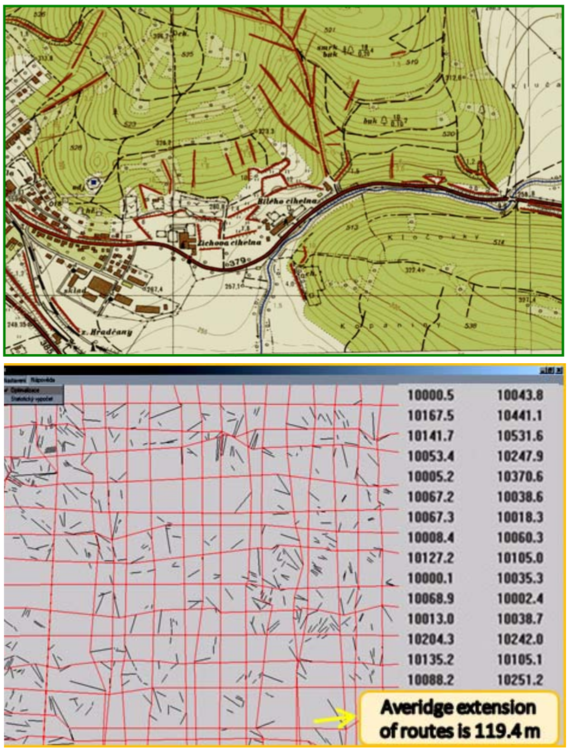

Fig 2 A new layer of „NO GO obstacles“ is created from topographic map 1: 10 000 as brown lines (up);
There is the illustration of solutions of simulation models of optimization of routes in C^{++} code and the value of average extension - the real routes as red lines, the obstacles as black shapes (down).
Source: [5], [14], [16]

2) Model of Optimization of Routes

This model offers a solution to the optimization of routes generally valid for any terrain or for influence of any geographical factor. Some of other ideas, how to optimize routes are quoted from [1], [5], [14], [16]. *The **general solution** for this issue (optimizing routes for communication or outside of them) can be expressed as two processing stage:*

- **to construct a graph**, the emphasis is on the correct determination of values of weight coefficients for links of individual nodes. The starting model is represented by a mathematical chart of a traffic network, which represents initiatory data model for solving given tasks. During the solution, the initial data model is being gradually modified based on influence of individual elements and their anticipated (calculated) path, where the time of appearance in individual (calculated) segments of optimum path is extrapolated;
- **to implement the algorithm** for searching of the shortest, fastest, safest or cheapest route. Another separate part is effective searching for optimum path of individual element. The key element in this part is effectiveness of the algorithm finding optimum (usually the shortest) path in a large not-oriented weighted chart (millions of nodes and dozens of millions of links). A searching has to be quickly enough to enable the solution "in the real time" for a large number of moving elements. A solution for each element depends on previous calculation of the optimum path (for the previous element).

Solution of both problems has the same basic principles, but with different data models and process of its construction. More detailed information on this issue you can see in this publication (see [5], str.20-65).

C. Model "Variation of the Function"

Mathematical evaluation of macro-relief and micro-relief and of the type of surface of the measured profiles using the mathematical formula called "variation of the function" (see [15]).

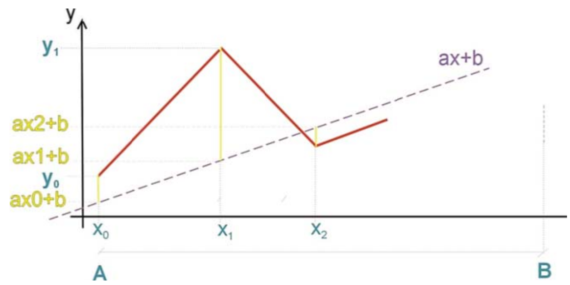

Fig. 3 (a) The first modification of the formula expresses the change in the timeline, to which there shall be deducted the value of acquisitions of coordinate difference. A new reference value in this case is violet marked connector profile

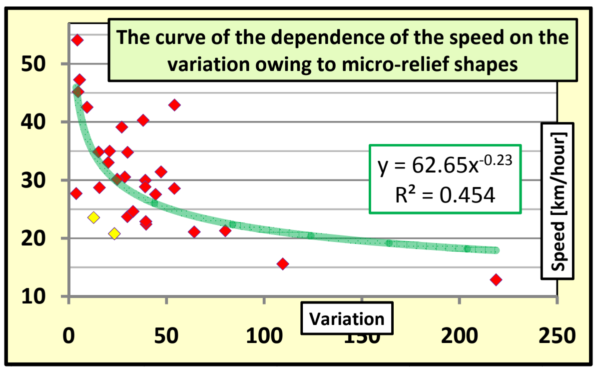

Fig. 3 (b) The curve of the dependence of the speed on the variation owing to micro-relief shapes. Variation is on the axis x, speed of vehicle is on the axis y [14]

The calculation of the curve that defines the estimate this dependency can be divided into three steps:

- How to calculate the "roughness of routes" (x axis)? The principle of variation is the expression of roughness of terrain on the basis of summarizing of the products of values of Directives of the tangents and lengths of elementary sections.
- How to calculate vehicle speed (y values)? The measured values of speed relevant to the types of surfaces have been used and a comprehensive table of speed from the huge number of rides in terrain was drawn up.
- How to establish a curve? An example of the calculation of the variation is based on the use of tabular data relevant to the length of elementary sections and elevation coordinates of the beginning and end of the connector, see Fig. 3.

D. Regression Model

One of the way, how to evaluate the speed of vehicles in terrain, is the use of mathematical-statistical calculations in a form of a regression model. [14], [15] The Program "R" (the sophistic software for regression analysis) was used to evaluate the speed of vehicles depending on many factors. A simple regression model was built, which describes the dependence of the speed of the drive based on the numerical representation of categorical variables. The input data was compiled into a table about 1872 records with 13 parameters and then the regression equation, which approximately describes the real speed of the vehicles, was established. On the basis of the carried out calculations the equation of regression was established. The regression equation has the form:

$$The\ speed\ of\ drive = 5{,}9170 + 1{,}2999 * num.of\ vehicle + 4{,}8573 * level\ of\ driver + 4{,}9551 * primarilly\ vehicle + 1{,}1451 * surface + 2{,}7789 * category\ of\ ride - 0{,}1066 * variation\ due\ to\ roughness - 0{,}0270 * variation\ due\ to\ inclination\ of\ slope - 0{,}2917 * inclination\ of\ slope + 0{,}9476 * meteorological\ condition - 5{,}4804 * direction\ of\ sunlight \quad (2)$$

E. Evaluation of the Influence of the Surface Using a Programming Environment in the Language "C^{++}" in Vector Format

Model simulating the ride vehicles in the field has been created in the programming language C^{++}. [14]

Input data defining the profile field curve was obtained by two methods – by terrestrial laser scanning or (measurement of the coordinates of the profile was targeted with step 10 cm) and by total station Leica (characteristic fracture points of terrain shapes in the same profile were targeted on the basis of a subjective selection of meters). Length and height coordinates were used.

Several algorithms have been built. Their purpose was: to retrieve data, to display the off-road curve, refining the methodology of the rolling wheel after the terrain and the final output was the determination of the value of the time needed to complete the profile.

Other input data were maximum vehicle speed, wheel diameter, the maximum speed of the vibrations the wheels – always relevant to a given type of vehicle. These data were calculated in models at the software ADAMS.

The author recommends this model and in particular in conjunction with the air laser scanning and use of UAV (Unmanned Aerial Vehicle).

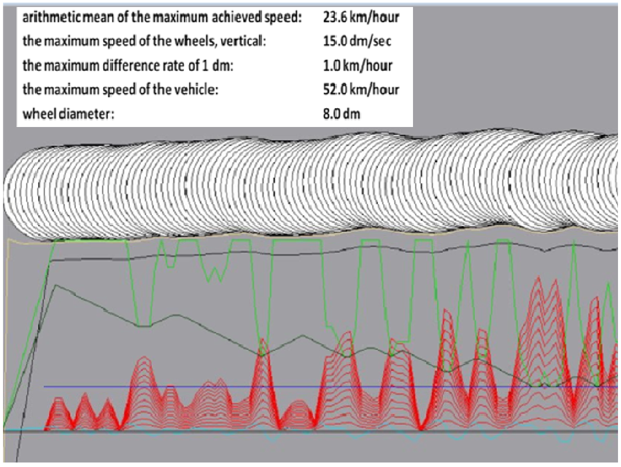

Fig. 4 Sample of an estimate of a calculation of time moving in the model in a programming language C^{++}

On the picture the issue of the rolling wheel on real terrain (the black curve under the wheel) and on the substitute terrain (the yellow curve under the wheel) is illustrate. The results of the calculation algorithms for actual speed are the red curve, the maximum speed of oscillation wheels as the dark blue curve, the maximum actually speed as a green and the maximum possible speed profile limited convolution filter is rendered dark green (it is a pyramid-shaped).

VI. Map Outcomes

The potential graphic outputs should be maps of optimal paths from the source to the destination points (with a time calculation for the move), secondary data could be used for the creation of the current flow maps of the terrain, which would have been over existing products as well as from the standpoint of the methodology of determining how the terrain, so from the standpoint of data bases (especially during the use of products produced by the method of laser scanning).

Aspect of the database data bases were open to question, however, is given to the development of methods and means for the collection of data, it is assumed that in the future the current ignorance of the field will not be a problem.

VII. Conclusion

The optimization of the route may be useful for ambulances or other operational vehicles for a solution of crises or natural disasters. These vehicles are equipped with GPS devices, which can maintain the direction to the target point in the current time and the issue of optimization of a movement can be calculated and used for a movement over the communication or outside of them.

The solution of the route optimization according tactical and geographical aspects of the combat operations planning process should be conditioned by a constructed graph, the emphasis is on the correct determination of values of weight coefficients for links of individual nodes as a parameter of the task was fulfilled. The second step is implementation of the algorithm for searching of the shortest, fastest, safest or cheapest route.

Another solution is the use of math-static models and model based on simulations of rides in terrain. The database, which is used for calculations, is created from the vast amount of data measured in the field. Capture the dependencies between individual factors is not a trivial matter, and therefore, the implementation of field tests is very beneficial. The scientific team is gradually getting to still more specific conclusions.

References

[1] Mazal, J., Algoritmy vlivu geografických faktorů na optimální pohyb vojenských vozidel po komunikacích i v terénu (in Czech) , projekt obranného výzkumu METEOR, UO Brno, 2009, 87 pp.
[2] Mazal, J., Real time manoeuvre optimization in general environment. Berlin: Springer Berlin Heidelberg, 2010, p. 191-196, Recent Advances in Mechatronics. ISBN 978-3-642-05021-3.
[3] Without the main author. Procedural Guide for Preparation of DMA Cross-Country Movement (CCM) Overlays. Defence Mapping School. Fort Belvoir, Virginia, 1993.
[4] Stanag 3992 – AgeoP-1 Terrain Analyses Field Manual No.5-33.Headquarters Department of the Army. Washington, DC., 2005. 302 pp.
[5] Zelinková, D.: The analysis of the obtaining and using of the information for evaluation of CCM, Analýza získávání a využitelnosti informací pro vyhodnocení průchodnosti území, DP, VA Brno, 2002 (in Czech).
[6] Rybansky, M.: Cross-Country Movement, The Impact and Evaluation of Geograhical Factors, Brno, Nakladatelství CERM, s.r.o., 2009. 114 pp. ISBN 978-80-7204-661-4.
[7] Rybanský, M., Křišťálová, D. Rýdel, J., Zikmund J.: Metodika vyhodnocování vlivu mikroreliéfu a terénních překážek na průchodnost kolových vozidel“ se zaměřením na různé specifické povrchy území a různé meteorologické podmínky. Methodology of Evaluating of Cross-Country Movement across the variable Surfaces and in Variable Meteorological Conditions, Vyškov 2011, 32 s, Ident. číslo: J-4-720/74. (in Czech).
[8] Sobotková, Š.: Metodika diagnostiky únosnosti terénu pro stanovení míry průjezdnosti kolovou technikou pomocí kuželového penetrometru. 2012. (in Czech)
[9] Rybanský, M., Mazal, J., Zelinkova, D. Vliv mikroreliéfu na průchodnost terénu – Evaluation of the Effect of Micro-relief Shapes, VA Brno, 2002 (in Czech), 65 pp.
[10] Kristalova, D.: The contribution of the methods of terrestrial laser scanning to the evaluation of the impact on movement of military vehicles (Conference paper). IDEB Bratislava, 2012a. ISBN 978-80-8075-525-6, 8 pp.
[11] Kristalova, D., Rybanský, M.: The methods used for creating a new system of Cross-Country Movement and determination of possible movements in the terrain. (Conference paper). Romenia, 2012b, ISSN 1843-6722, 8 pp.
[12] Kristalova, D., Mazal, J., Neubauer, J.: *The Effect of Geographical Environmental on Speed and Safety of Movement on Vehicles*, the Conference paper, The Czech Republic, 2012, ISBN 978-80-7231-871-1, 8 pp.
[13] Kristalova, D., Rybanský, M.: *The Methods Used for Creating a New System of Cross-Country Movement and Detrmination of Possible Movemnts in the terrain*. The conference paper. Romenia, 2012, ISSN 1843-6722, 8 pp.
[14] Brázdil, K. a kol. *Realizační projekt zpracování výškopisných dat*. Praha, ZÚ/VGHMÚř. 2009, 44 pp.
[15] Kristalova, D.: *Vliv povrchu terénu na pohyb vojenských vozidel* (The Effect of the Terrain Cover on the Movement of Military Vehicles), The Ph.D. Thesis (in Czech). The Czech Republic, Brno: The Univerzity of Defence, 2013, 318 pp.
[16] Kristalová, D.: An Evaluation of methods of optimization of movement routes according to tactical aspects of the combat operation planning process, ICMT 2010, ISBN: 978-80-7231-787-5, 8 pp.