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DETERMINATION OF TERRAIN SERVICEABILITY OF MILITARY VEHICLES BY GIS RELIEF ANALYSIS

ABSTRACT

This paper analyses capabilities of terrain serviceability of vehicles in regards to the ground features. Two key relief attributes related to the slope inclination are defined, as well as relief forms quantitatively defined as deviations of height above sea-level. As the secondary attribute, the topographic wetness index is estimated, which, in correlation with the drainage coefficient yields the wetness value index as an essential factor of passableness in the conditions of harder and more intensive precipitations, that is to say, sudden snow melting. By application of GIS analysis, based on the digital model of space heights along the Kupa River from Pisarovina to Šišinec, the values of primary and secondary relief attributes have been calculated, and the analysis of Landsat satellite images has been used to define the values of vegetation cover. Based on these values and data on the soil type, the layer of ground wetness has been estimated. Cross Country Mobility Program of ESRI company, within GIS program package Arc View 3.3. has been used to set the marginal values of the defined relief parameters and to estimate the levels of mobility for single vehicles in different terrain conditions. The comparison of the obtained results clearly indicates a possible application of the defined data in the analysis of terrain serviceability of military vehicles, with regard to the relief features of the terrain. For full applicability of the model it is also necessary to define other attributes of mobility related to hydrographical, vegetation, pedological, anthropogenic and other ground features.

KEY WORDS

terrain mobility, GIS, relief, military geography

1. INTRODUCTION

Obstructions are any natural or manmade objects that stop, hinder or divert the movement of military units. Roads, river valleys and lowlands represent routes of approach which provide spaces for fast development of battles. Movement may be slowed down, i. e. made impossible by natural obstructions such as swamps, big rivers, dense forests, soft and sandy soil, and ground with large vertical division of relief (hilly and mountainous landscape). Major urban areas represent a significant manmade obstruction to the movement of military units. The passableness of certain areas may be distinguished within different seasons, i. e. periods of time. Snow and ice in mountainous regions may significantly slow down the movement of vehicles, whereas fast snow melting or lengthy rains may convert passable lowlands into impassable areas. Fires, fallen trees and soil contamination due to the use of chemical weapons may suddenly change the movement conditions.

Knowing the ground characteristics regarding the general passableness represents a very important element of standardized military analysis of the scope of action of the military units since the ground that directs the movement allows the defenders easier organization of the defence and focusing on the dangerous routes of approach. In such areas the attacker has to either secure the area before the defender has time to occupy it, or start bypassing on land or in the air, i. e. by dropping. In prevailingly open areas, the attacker will be able to choose among different routes of approach, and the defender may be forced to conduct elastic defence in depth. Natural or manmade obstructions can protect the sides of the units performing the attack or counter-attack. The estimate of obstructions results in the identification of possible mobility corridors within a certain ground. The estimate of obstructions includes identification of obstructions, and determining of the effect of each obstruction to the mobility of the estimated forces. The defined effects of individual obstructions to mobility have to be integrated into a unique display. Because of the unique display of mobility maps, there are some standards regarding their generation. The basic parameters of NATO standard in generating the mobility maps (CCM – Cross Country Movement) will be mentioned as part of military geographic terrain analysis. [11]. The final product of serviceability analysis is represented by a layer of combined obstructions, which, as thematic content, is presented on topographic charts in the scale of 1:50,000 and 1:250,000 depending on the military and geographic analysis of space within individual warfare levels[1]. The ground factors that affect the mobility of military forces are organized in the following groups:

- ground,
- slope inclination,
- inclines, cuts, etc.,
- surface drainage system,
- other obstructions (vegetation, urbanized areas, etc.).

Individual categories of obstructions are represented by adequate symbols on the thematic chart, and the mobility classes with the respective CCM index values are defined based on all the parameters.

The automated analyses of the serviceability by GIS system application represent specific analysis, usually within the standardized military procedure of the intelligence preparation of the battlefield [3,7], i. e. within these, for the analysis of the military aspects of the terrain [4]. Such GIS analyses include three basic elements, data stored in the organized military space database, specific GIS software, and adequately educated people for the system maintenance and data analysis.

2. METHODS

The introduction has already shown that the analysis of the terrain serviceability of military vehicles includes an entire series of natural and manmade serviceability factors. They should be included in the analysis as separate obstructions and in turn combined in the mutual analysis with the aim of obtaining a unique serviceability display. Considering in more detail the issues themselves, the fact may also be noticed that certain parameters need to be observed also in the interdependence of actions on the possibility of mobility. Thus, e. g. the analyses of soil wetness concentrations need to take into account the relief configuration as well, i. e. the concave relief forms in which the wetness concentration will be greater should be singled out, etc. Because of this fact, the analysis of mobility parameters was approached from the principle of studying individual parameters as separate elements, and in interdependence with other parameters. Thus, the thematic layers of single basic mobility parameters related to geo-morphological, pedological, hydrological, vegetation and manmade obstructions whose mutual space analysis leads to the creation of a single mobility layer are defined for the GIS analysis requirements. Since mobility differs for single types of military vehicles, the parameters used in the definition of the marginal mobility values of single basic parameters will refer to the tactical and technical characteristics of single military combat and non-combat vehicles. The article will present in detail the algorithms for defining the relief parameters as the limiting factors of terrain mobility.

The analysis of the relief as a two-dimensional surface regarding the mobility of vehicles is used to single out the morphometric characteristics of relief in the sense of slope inclinations and basic relief forms as primary factors, and horizontal and vertical curvature of the slopes as secondary factors of terrain serviceability. The value categories of primary factors affect directly the possibility of movement, i. e. represent one of the parameters of defining individual optimal tactical (operational) directions where the forces need to be grouped, whereas the values of secondary factors are integrated with the data on the type of soil and volume of precipitation with the aim of producing the soil wetness intensity layer. The main source of information for the analyses of relief is the digital model relief (DMR), where the level of serviceability analysis is directly related to the accuracy and resolution of DMR. [5]. Most of the system for generating DMR generates the relief surface in 2.5D space. This means that only those surfaces can be presented that can be expressed in the form of a function:

$$f(Z) = Z(X, Y), \quad (1)$$

where Z is the height above sea-level of the point in given coordinates (X, Y)

In order to obtain a true model that describes the Earth surface or some part of it, random errors should be avoided in the model generation process, and geo-morphological information should be also taken into consideration, such as the breaking lines in the relief, single dominant relief forms, etc. In order to reduce the amount of information in the computer memory, the present relief models allow variable density of dots, i. e. variable size of surface sections that are described.

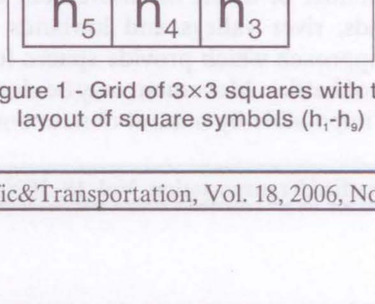

Figure 1 - Grid of 3×3 squares with the layout of square symbols (h_1-h_9)

Determining of the slope inclination based on the DMR altitude data has been defined by maximal change in the altitude value between the central cell and the surrounding adjacent cells [1]. Although there is a large number of algorithms for determining the slope inclinations [2,6] the majority is based on calculating the derivations of the first order of the value within the square 3×3 (Figure 1).

The differences refer primarily to the number of cells per single directions included in the calculation. The simplest method includes the computing of the "marginal difference" in the direction of X axis and Y axis (east – west, north – south):

$$h_x = \frac{\partial h}{\partial x} \approx \frac{h_2 - h_6}{2d}$$

$$h_y = \frac{\partial h}{\partial y} \approx \frac{h_8 - h_4}{2d} \quad (2)$$

The method included in the ARC/INFO algorithm of calculating the slope inclination includes all the eight values of 3×3 square:

$$h_x = \frac{\partial h}{\partial x} \approx \frac{(h_1 + 2h_2 + h_3) - (h_7 + 2h_6 + h_5)}{8d}$$

$$h_y = \frac{\partial h}{\partial y} \approx \frac{(h_1 + 2h_8 + h_7) - (h_5 + 2h_4 + h_3)}{8d} \quad (3)$$

Based on the computed derivations the inclination is determined by the method of marginal differences:

$$N = \sqrt{h_x^2 + h_y^2} \quad (36)$$

$$\beta(^\circ) = \arctan(N) \quad (4)$$

Based on the described calculation, the layer of slope inclinations is defined whose marginal values of serviceability are defined according to the tactical and technical characteristics of military vehicles, i. e. the possibility of their overcoming the slope inclination.

The second relief primary factor of terrain serviceability of vehicles is related to the relief forms of the observed space. This refers to the spatial distribution of individual steep elevations or larger concave relief forms as obstructions to mobility, i. e. larger plateaus and wider valley bottoms as significant mobility corridors. The problem occurs in quantitative evaluation of both positive and negative values of this parameter, which requires the definition of the regions of levelled relief, in relation to the dynamic relief area characterized by variations in altitude on a small surface. The solution has been found in computing the values of deviations of arithmetic means as the difference of arithmetic mean of altitude divided by the value of altitude standard deviation (σ) within the unit area:

$$dev = \frac{h_i - \bar{h}}{\sigma} \quad (5)$$

The attribute of deviation from the altitude arithmetic mean represents the measure of relative topographic position as part of the local relief and as such is determined by the intensity of altitude relief variations. The values of this attribute in the range from –1 to +1 represent levelled area sections, without relief obstructions to the passage of military vehicles. The indicators of relief obstructions are related to the values outside the mentioned range, where greater deviations either of positive or negative sign characterize single "irregularities" within the topographic surface, where the height above sea-level values deviate from the typical hypsometric classes within unit area and indicate the possible relief obstructions in the terms of difficult- or impossible-to-pass elevations or recesses.

The analysis of secondary relief parameters, related to the analysis of slope wetness concentrations, is based on the computation of the convergent and divergent direction of the flow down the slope in the form of topographic slope wetness index [12]. The topographic wetness index (ω) establishes a relation between the specific catchment area (A_s) and the slope inclination angle (β) according to relations:

$$\omega = \ln \frac{A_5}{\tan \beta} \quad (7)$$

The specific catchment area (A_s) in single point is defined as the catchment area that represents the hydraulic connection with the observed cell drained through the width unit of this part of the catchment area (m^2/m).

If one takes into consideration that the values of topographic wetness index are proportional with the catchment area in the given point, i. e. inversely proportional with the slope inclination, the relations of the relief and the computed index values is clear as well. Thus, the computed values indicate the influence of relief (topographic area) on the wetness intensity of the pedological horizon, and the levelled spaces with larger areas of possible water inflow will also have higher values of the observed index, i. e. the terrains with large slope inclination very low index values since they represent free-flowing slope sections where water is not detained. It is to be assumed that the locations with same wetness index values will also have the same relation between the local depth and the average depth of the underground water level [12].

Based on the described methods the algorithms for computing of primary and secondary relief parameters in the analysis of the terrain serviceability of military vehicles have been set, and built into the GIS application "Mobilnost" (Mobility).

3. PRESENTATION OF RESULTS

The relief analysis for the sake of defining the terrain serviceability of military vehicles was carried out on the basis of DMR of a wider region of the Kupa valley from Pokupsko to Šišinec covering a total area of

30.2km^2. For the analysis requirements, the tactical and technical data of the tank M-84AB and BoV 8×8. (Table 1) have been used.

Table 1 - Tactical and technical characteristics of military vehicles

Characteristics		BoV 8×8	tank M-84AB
Ascent	[%]	60	58
	[°]	31	30
Lateral inclination	[%]	30	47
	[°]	15,5	25
Crossing the ditch [m]		2	2.80
Vertical obstruction [m]		0,6	0,85
Deep ford (no preparation) [m]		1,5	1,20
Deep ford (with preparation) [m]		1,5	1,.80
Maximal diving depth [m]		–	5
Maximal navigation speed [km/h]		10 +/- 2.0	–

Based on the digital relief model the grid layers of primary and secondary relief serviceability parameters have been computed with regard to the slope inclination, height above sea-level deviation and the topographic wetness index (Figure 2).

From the computed values the proportional relation of the slope inclination values and the altitude deviations may be clearly observed, as well as the inversely proportional relation of the topographic wetness index to the primary attributes. Studying the connection between the height above sea-level and the altitude deviation value it may be noted that the desired objective of singling out and quantitative defining of individual relief forms has been achieved. The levelled relief sections (alluvial plain and terrace lowlands of the Kupa river, valleys of minor tributaries, and wide plateau elevations) adopt the values between -1 and 1 whereas the dynamic relief in the terms of positive forms is defined by the values ranging from 1 to 9. Thus, synonymous quantitative evaluation of the relief forms has been achieved, regardless of the height above sea-level at which it is located. The connection between the digital altitudes model and altitude deviations in 3D display can be observed in Figure 3.

By computing the topographic wetness index, the quantitative evaluation of the relief regarding the wetness intensity has been achieved, where the lowest values of the slope index represent parts of the terrain with divergent flows (crests), i. e. spaces where no larger volumes of atmospheric water are detained. High values of the topographic wetness index represent terrains with concentrated, divergent flows, i. e. plateaus and recesses with significant wetness concentration of pedological horizon. Such areas in the conditions of intense, i. e. long-lasting rains may represent a significant obstruction to the mobility. It has already been mentioned that the value of the topographic wetness index is the secondary relief attribute, and that it is considered in correlation with other terrain mobility parameters. This refers primarily to the correlation with the type of soil and vegetation cover, and the drainage coefficients need to be determined in different environmental conditions (Table 2).

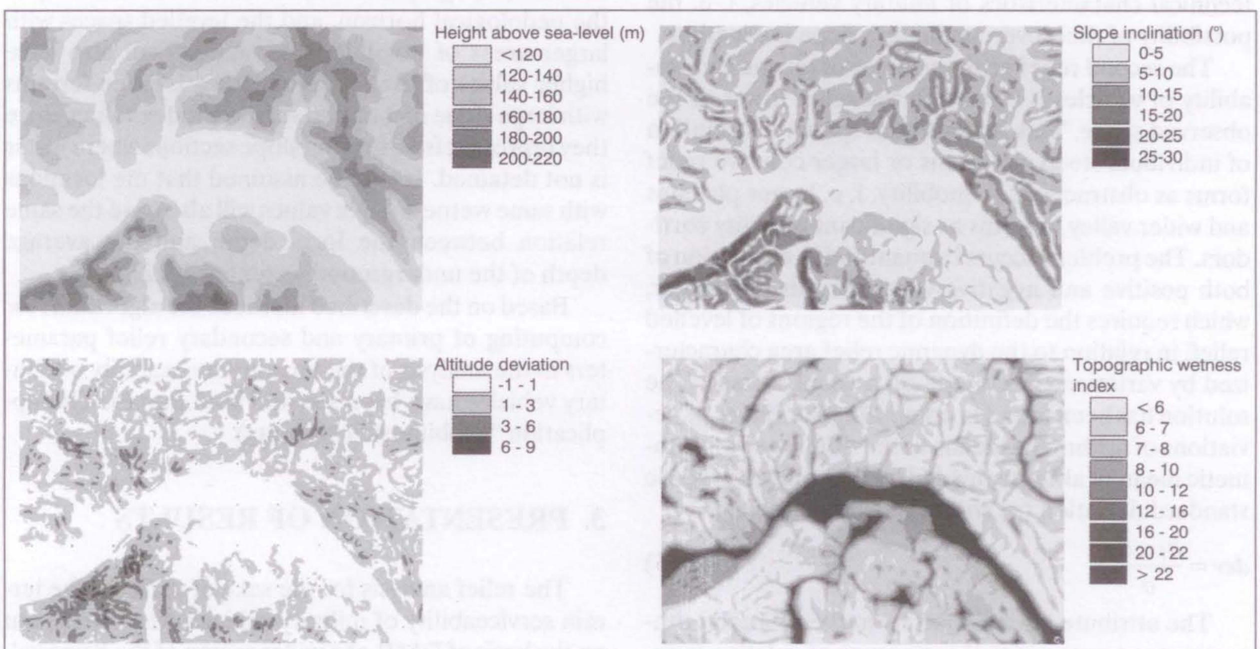

Figure 2 - Defined relief parameters as part of the analysis of the terrain serviceability of military vehicles

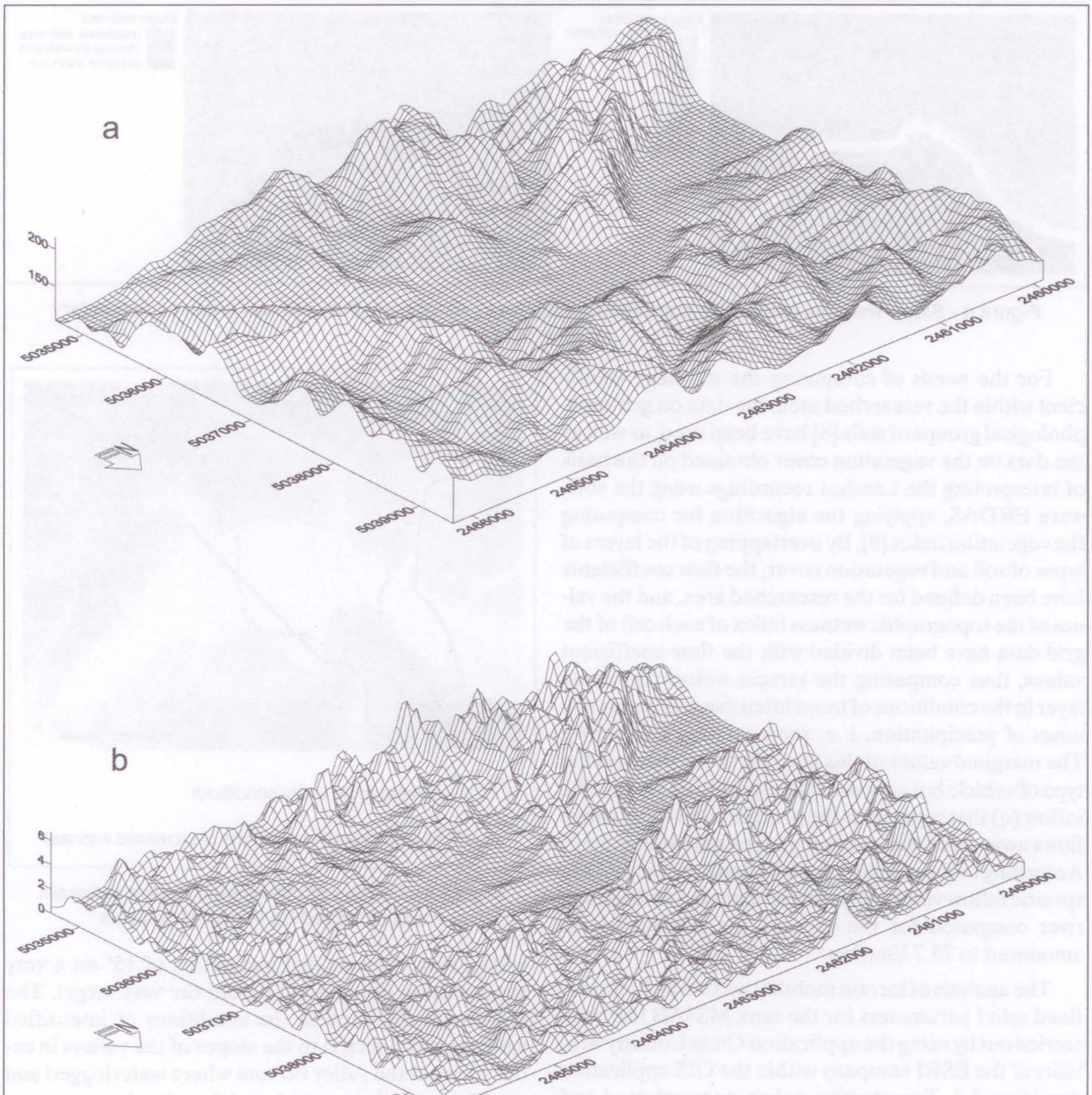

Figure 3 - 3D display of altitude relations (a) and altitude deviations (b) within the researched area

Table 2 - Drainage coefficients in different environmental conditions

Type of soil	vegetation cover		
	cultivated	natural	forrest
Soils with above-average filtration. Sandy or gravel soils	0.2	0.15	0.1
Soil with average volume of filtration	0.4	0.35	0.3
Soil with above-average filtration. Clayey soils or shallow soils on impermeable base.	0.3	0.45	0.4

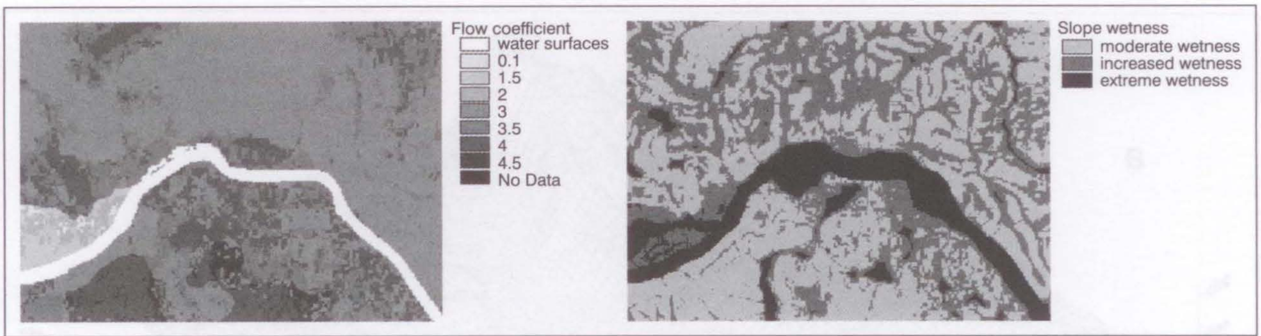

Figure 4 - Slope wetness categories computed on the basis of topographic wetness index as secondary relief attribute

For the needs of computing the drainage coefficient within the researched area, the data on geo-morphological groups of soils [8] have been used, as well as the data on the vegetation cover obtained on the basis of interpreting the Landsat recordings using the software ERDAS, applying the algorithm for computing the vegetation index [9]. By overlapping of the layers of types of soil and vegetation cover, the flow coefficients have been defined for the researched area, and the values of the topographic wetness index of each cell of the grid data have been divided with the flow coefficient values, thus computing the terrain wetness intensity layer in the conditions of more intensive and larger volumes of precipitation, i. e. snow melting (Figure 4). The marginal values of this layer do not depend on the type of vehicle but vary with the intensity of the specific inflow (q) that represents the precipitation value which flows away from the catchment area unit at l/sec/km^2. According to the research done by Srebrenović [10] the specific inflow value in the catchment area of the Kupa river computed for the area of the station Šišinec amounted to 25.7 l/sec/km^2.

The analysis of terrain mobility according to the defined relief parameters for the tank M84AB has been carried out by using the application Cross Country Mobility of the ESRI company within the GIS application Arc View 3.3. Two starting points were selected and the common target point, and the mobility directions have been analyzed in three cases: for dry ground, under the conditions of intensified wetness and under the conditions of extreme wetness (Figure 5).

It should be noted that under the conditions of extreme wetness the alluvial plain and the terrace lowlands of the Kupa river become impossible to pass without additional engineering works. Already a rough analysis of the mobility routes from the starting point 1 (PT 1) gives a clear difference between the selection of the optimal mobility route regarding the relief in the conditions of dry weather and in the conditions of moderate wetness. In dry conditions the shortest way to the valley is defined, along which the movement continues southwards, a wider alluvial plain is crossed and the target is reached by climbing a smaller

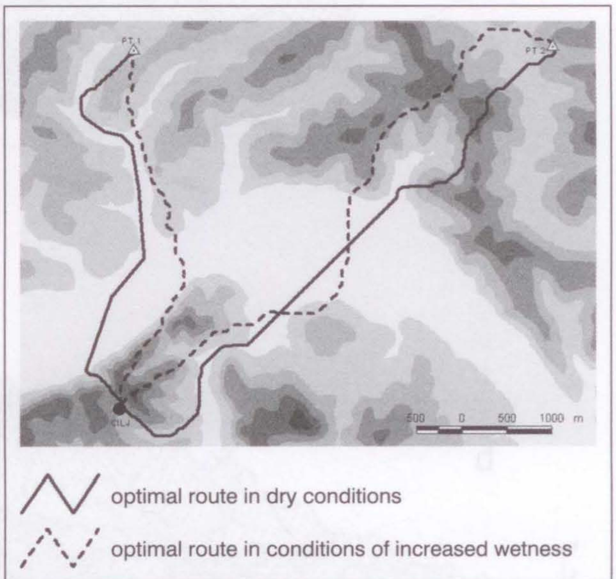

Figure 5 - Display of determined routes of terrain mobility based on the relief analysis

valley, with the maximal inclination of 15° on a very short section (45 metres) before the very target. The movement direction in the conditions of intensified wetness is connected to the slopes of the valleys in order to avoid the valley bottom where waterlogged and muddy terrain is expected, and then the shortest crossing of the alluvial plain of the Kupa river. Since emphasis in this part of analysis is on the wetness index parameter, larger slope inclinations have been selected in marginal cases for the direction of movement compared to the milder slopes and lowlands prone to flooding. Thus the maximal inclination on this route is 20°, and the lateral inclination 15°. The described relations are identical also for the selection of the direction of movement from the starting point 2 (PT 2) towards the target.

4. CONCLUSION

The work presents the basic applications of the GIS analyses of relief as the parameter of terrain serviceability of military vehicles. The GIS analysis of the relief as support to modelling of the military traffic system has the objective of providing the answer regarding the movement of the armed units. This includes the selection of the optimal route of terrain mobility of military vehicles regarding the relief in different weather conditions, and in correlation with the pedological base and vegetation cover. Based on the analyses of digital relief model the basic algorithms of computing the primary and secondary relief parameters in the analysis of terrain serviceability of military vehicles have been set, and have been built into the GIS application entitled mobility. Regarding the relief characteristics as the possible limiting factor of terrain mobility the primary relief parameters have been defined as slope inclination and average altitude derivation. Whereas the application of the slope inclination categories is clear, it should be noted that the average altitude derivations quantitatively define individual elements and relief forms based on their morpho-metric and morpho-graphic characteristics. Thus, the individual relief units (valleys, wide plateaus of mountain elevations) have been singled out, which define the general terrain serviceability of the landscape. The secondary relief parameters affect certain processes, which are directly connected with the general terrain serviceability. Based on the Topographic Wetness Index the drained sections of land have been quantitatively classified compared to those parts where the precipitation water accumulation occurs. Establishing a connection between the flow index as the result of a type of pedological base and vegetation cover with the topographic wetness index, it is possible on the basis of the volume of precipitation to define the intensity of pedological horizon flooding, i. e. the possibility of terrain serviceability in different weather conditions (precipitation volumes).

The relief analysis in order to define the terrain mobility of military combat and non-combat vehicles was carried out in the wider area of the Kupa valley from Pokupsko to Šišinec covering a total area of 30.2km^2. The analysis was done on the basis of the tactical and technical characteristics of military vehicle the tank M-84 AB and vehicle BoV 8x8. The terrain mobility analysis according to the defined relief parameters for the mentioned vehicles was carried out by using the application Cross Country Mobility by the ESRI company within the program package Arc View 3.3. Based on the selected starting points (PT 1 and 2), and a joint target point, the mobility routes were analyzed under three weather conditions; for dry ground, under the conditions of more intense wetness and under the conditions of extreme wetness. The application of the model defines the passage route in dry conditions where the optimal route is defined by the direction of valleys in the direction of the target, with maximum inclination of 15° on a very short section before the very target. The direction of movement in conditions of more intense wetness is related to the valley slopes in order to avoid valley bottoms where extreme wet ground is expected. Regarding this part of analysis, with focus on the wetness index parameter, for the direction of movement greater slope inclinations have been selected in marginal cases compared to the milder slopes and lowlands prone to flooding. The maximal inclination on this route amounts to 20°, and the lateral inclination is 15°. The analysis results have given the answer that in the conditions of extreme wetness the alluvial plain and terrace lowlands of the Kupa river become impassable unless engineering works are applied. The described relations are identical also for the selection of the route from the starting point 2 (PT2) towards the given target.

Based on the carried out analysis it may be concluded that the set model of the GIS analysis of the relief as the parameter of terrain serviceability of military vehicles yields reliable information as essential support to the decision-making process at all military levels ranging from the strategic, operational to the tactical level regarding mobility i. e. movement of the units in all ground conditions. GIS analysis of relief gives further answers to the creation of better-quality and more efficient conditions of military vehicle movement while performing various types of both war and non-war tasks in variable terrain conditions, thus insuring a high level of readiness and giving an answer to the set task in solving the transport problem of vehicle mobility.

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SAŽETAK

ODREĐIVANJE TERENSKE PROHODNOSTI VOJNIH VOZILA POMOĆU GIS ANALIZE RELJEFA

U radu se analizira mogućnost terenske prohodnosti vozila s obzirom na reljefna obilježja zemljišta. Definirana su dva primarna atributa reljefa vezana za nagib padina, te reljefne oblike kvantitativno definiranih kao devijacije nadmorskih visina. Kao sekundarni atribut izračunat je topografski indeks vlaženja koji u korelaciji sa koeficijentom otjecanja daje vrijednosti indeksa vlaženja kao bitnog čimbenika prohodnosti u uvjetima većih i intenzivnijih padalina, odnosno naglog topljenja snijega. Primjenom GIS analiza, na temelju digitalnog modela visina prostora uz rijeku Kupu od Pisarovine do Šišinca, izračunate su vrijednosti primarnih i sekundarnih atributa reljefa, a analizom Landsat satelitskih snimaka definirane su *vrijednosti biljnog pokrivača. Na temelju tih vrijednosti i podataka o vrsti tla izračunat je i sloj vlaženje zemljišta. Korištenjem programa Cross Country Mobility tvrtke ESRI unutar programskog GIS paketa Arc View 3.3. postavljene su granične vrijednosti definiranih parametara reljefa i izračunati slojevi mobilnosti za pojedina vozila u različitim terenskim uvjetima. Usporedba dobivenih rezultata jasno ukazuje na moguću primjenu definiranih podataka u analizi terenske prohodnosti vojnih vozila, s obzirom na reljefna obilježja zemljišta. Za potpunu primjenu modela potrebno je definirati i ostale atribute mobilnosti vezane za hidrografska, vegetacijska, pedološka, antropogena i dr. obilježja zemljišta.*

KLJUČNE RIJEČI

terenska mobilnost, GIS, reljef, vojna geografija

REFERENCE

1. The three basic levels of modern warfare are tactical, operational and strategic level.

LITERATURE

[1] **Burrough, P. A.** (1986): *Principles of Geographical Information Systems for Land Resources Assessment*. Clarendon Press, Oxford.

[2] **Engelen, G. & Huybrechts, W.** (1981). *A Comparison of Manual and Automated Slope Maps*. Catena, Vol. 8, 239-249.

[3] FIELD MANUAL 34-130, (1994): *Intelligence preparation of the battlefield*, Headquarters Department of the Army, Washington.

[4] **Grindle, C., Lewis, M., Glinton, R., Giampapa, J., Owens, S.** and **Sycara, Katia** (2004): *Automating Terrain Analysis: Algorithms for Intelligence Preparation of the Battlefield*, Proceedings of the Human Factors and Ergonomics Society, 533 – 537.

[5] **Guth, P.** (2005): *Challenges for Military Application of High Resolution DEMs*, Sixth International Conference on Military Geology and Geography, June 2005, Nottingham

[6] **Hickey, R., Smith, A., Jankowski, P.** (1994): *Slope Length Calculations from a DEM within Arc/Info Grid*. Comput., Environ., and Urban Systems, Vol. 18, no. 5, 365-380.

[7] JOINT PUBLICATION 2-01.3, (2001): *Joint Tactics, Techniques, and Procedures for Joint Intelligence Preparation of the Battlespace*, Department of the Army, Washington. 185.

[8] **Kovačević**, (1995): *Područja i podpodručja geomorfoloških grupa tala i osvrt na način njihovog iskorištavanja u Hrvatskoj*, Agronomski glasnik 3, Zagreb, 139 – 211.

[9] **Lampak, I.** (1997): *Primjena daljinskih istraživanja u GIS projektima, GIS u Hrvatskoj* (Ed. Kereković, D.), INA, 327-347.

[10] **Srebrenović, D.** (1986): *Primijenjena hidrologija*, Tehnička knjiga, Zagreb

[11] STANAG 2259, (1975): *Military Geographic Documentation - Terrain*

[12] **Wilson, J. P. & Gallant, J, C.** (2001): *Terrain Analysis, Principles and Applications*, J. Wiley & Sons.