Modelling and Simulation of Microrelief Impact on Ground Path Extension

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Abstract. Geographic data are essential input parameters in the decision support systems for the evaluation of whether the planned routes of territory are passable or not. Micro-relief is one of the most notable geographical factors and although its influence is crucial, the micro-relief shapes are as the obstacles often neglected. These obstacles are existed almost in all types of terrain and their quantity and distribution in each specific type of terrain for evaluation of the mathematic model were determined on the bases of carto-metric investigation. Subsequently such system can serve for the optimization of routes of movements, calculating of a coefficient of the deceleration and next parameters and finally for an evaluation of the best solution for manoeuvre of military units according the commander‘s requirements. The object of this paper is to point out that the calculated route extensions can help in the planning and decision-making process on the "just in time" concept, which should be commonly used in an operational environment.

Keywords: Geographic factors · Micro-relief · Terrain feature modelling · Optimization of routes · Tactical decision support systems; cross-country movement · Off-road vehicle · Off-road navigation · Contemporary operational environment

1 Introduction

The presence of micro-relief objects is the factor, which is very significant for movement of off-road vehicles or UGV to make decision within the purview of decision support system and to a certain extent the considering of this geographic factor appertains to tasks and challenges of the contemporary operational environment [1–3]. Micro-relief shapes influence and limit particular manoeuvre and fall into multi-spectral terrain analyses called Cross-Country Movement [4, 8]. The results of this terrain analyses may be very dissimilar to each other and it depend on a specific determination of military assignment. That means to set a type of terrain, type of unit, a type of vehicle and its technical data, attainable time, length and costs limits and the target for every task [5, 6].

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Within the contemporary warfare, it is more than convenient to use various methods of modelling and simulation and to estimate scenarios of possible situations as accurately as possible before a given manoeuvre. Appropriately compiled algorithms can predict the so-called "operational coefficient" according to the parameters assessed. The parameters can be individual terrain components, technical vehicle data or economic or logistical requirements. Basically, it is a point of view, where the right algorithm answers the appropriate question. Without modelling and simulation, these answers would often remain hidden, and sometimes would manifest themselves directly in a given situation. In most of the time, these facts would be negative, and therefore it is greatly important to evaluate the operational coefficient in advance [21–23].

The problem dealing with an absence of mapping of micro-relief shapes is a question of time. Nowadays it is possible to obtain the 3D data of a territory with very high resolution but many systems for off-road navigation do not have these mapping service at its disposal [7]. They have to depend on analogue maps and on some navigator‘s help or they can apply the 3D map model without high accuracy only. Such situation relates especially on high level operation planning and the results of route planning are unresponsive of this geographic factor.

2 Object of the Research

This paper deals with a modelling of a terrain to determine optimal route for off-road vehicles or UGV. In order to make up commander‘s mind and settle on a solution the object of a research has to be examined. That means to study the presence of microrelief shapes in different types of terrain and establish the standards of Cross-Country Movement.

The object of a research mentioned below are the targets of a military study and know-how about their mutual impact could serve for determining of the key effect to conducting of military tasks [21–23].

Microrelief

The terrain forms of the "microrelief" can be defined as man-made and natural both elevated and depressed topographic forms that cannot be expressed with regard to its relatively small height differences by use of contour lines or by the means of other principal method of terrain representation [4, 8].

Micro-relief shapes such as: small slopes (terrain steps), rock cliffs, landslides, terraces, erosion forms of watercourses, gullies, craters, holes, embankments, rock groups, boulders and other relief forms created by impact of natural forces and anthropogenic activity can have an important influence on any operations [4, 8].

Within the microrelief, parameters of microrelief forms of watersheds (eventually of profiles of drainage systems) and erosion rills were also identified as impassable obstacles, i.e. those that cannot be overcome in a given place and which need to be bypassed.

Terrain and its Types

The "*terrain*" is defined as any part of the earth's surface with all the unevenness (created by natural forces or artificially) and with all objects and phenomena found on the earth's surface [8].

The *"types of terrain"* are divided according to terrain objects (forests, settlements, watersheds, etc.) and terrain shapes (given by ruggedness). In terms of tactical characteristics and operational significance, the terrain is evaluated either by morphogenetic properties (types resulting from the action of endogenous and exogenous forces and process of inception) and by morphometric properties (types are determined by relative ruggedness, relative slope ratios, relative elevation, absolute heights and other quantitative indicators).

From a military point of view, relative elevation difference is of the greatest importance. The degrees of height breakdown of the territory (in advance defined by extreme values) are characterised by specified indicators [8].

Dividing by terrain objects:

- *open* - without any terrain objects, or only with unique objects (tree, mast, monument,..);
- *semi-covered* - scattered occurrence of terrain objects;
- *covered* - covered with terrain objects more than half.

Dividing by terrain shapes:

- *Flat* - the area is flat or only slightly undulating;
- *Wavy* - the terrain already has more striking shapes with height differences up to 100 m. The off-road shapes are round, the slopes are gentle, and the angle of the slope is less than 5°;
- *Hilly* - already has distinctive shapes with height differences up to 500 m. As a rule, the ridges follow the direction of the mountain massif, the slopes are steeper, and the valleys are deeper;
- *Mountainous* - includes areas with significant elevation of the earth's surface, usually situated at higher altitudes (i.e. above 1000 m).

Terrain objects and shapes are interrelated and the terrain types mentioned above form different combinations. These combinations have to be embraced in determining the Cross-Country Movement.

Dividing by morphogenetic properties:

- *lowlands;*
- *plains;*
- *basin;*
- *ridges;*
- *mountains, etc.*

Dividing by morphometric properties:

- *plains* - flat areas at any altitude, where relative terrain elevation differences up to a distance of 2 km are less than 30 m, slope slopes up to 1°;

- *uplands* - hills with relative differences from 30 to 150m, slopes are mostly mild, their slopes usually do not exceed 3°;
- *highlands* – area with a relative height difference from 150 to 300 m, slope slopes usually 5° to 10°;
- *mountains* - rocks with height differences of 300 to 600 m, form significant ridges between marked valleys (the ridges usually form a watershed), the slopes are already considerable and range between 10° and 25°;
- *high mountainous* - terrain, often formed by rocky peaks and distinctive ridges between steep valleys, height differences over a distance of 2 km exceed 600 m, slope slopes are greater than 25°.

Analysis of the Cross-Country Movement (CCM)

CCM means the assessment of several geographical factors (GF) and tactical factors together (TF), i.e. that it is global analysis.

These factors and their standards determine 3 levels of Cross-Country Movement:

- *GO;*
- *SLOW GO;*
- *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 that the movement is not possible. These terms are given. [4, 8].

From the point of view of means of transport (used for a 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.*

The impact of all factors is expressed by, “**Coefficient of the deceleration**” (abr. CoD). This multiple coefficient gives degree of deceleration from full speed owing to constituent factors.

The total CoD depends on the partial CoD of the different GF and is given by this formula [4, 8]:

$$C = \prod\nolimits_{i=1}^{8} c_i \tag{1}$$

where C *is the total CoD,*
c_i *is partial CoD.*

3 State of the Art

Terrain analysis and route planning and their optimization are still topical theme despite of the fact that a number of mathematical models and terrain tests have been drawn up and conducted [9, 10].

Lot of articles or studies for searching of a right corridor devoted to Air Unmanned Vehicles (UAV) were created [11, 12]. The more complex situation is for off-road vehicles or Unmanned Ground Vehicles (UGV) where the effect of soil condition, vegetation, relief and micro-relief and other factors is more significant and a multiple analysis for a passability of a territory were applicable. The research papers [13, 14] are dedicated to this topic. Traveling salesman problem (TSP) or methods of collision avoidance are elaborated [15–17] but this is an extension of a route searching and optimizing process, nevertheless it could serve as an example of using [21–23].

4 Occurrence of Microrelief and Other Obstacles

The current solutions offer the use of existing data and experimental measurement of the missing variables. Micro-relief, a type of surface, a slope, waters (rivers or lakes), soil conditions and the weather conditions are the main factors, whose reciprocal influence has not been evaluated yet and these factors are of fundamental importance for the movement of vehicles in the field. To create the input dataset, it was necessary to define the type of terrain and perform a carto-metric investigation.

4.1 Assessed Factors

The first assessed factor was microrelief. Embankments, excavations, delves or craters, terrain steps (ascent or descent) and trenches are the most frequent shapes at the territory of the Czech Republic. These shapes have very important parameters for CCM, that are subject of interest, for example slope gradients, height or width.

The target was to obtain the average value of lengths, numbers and heights of shapes separately for each type of terrain. The shapes were divided into 4 categories – according to length interval in the following way:

- 0 m < Category A < 100 m
- 100 m < Category B < 500 m
- 500 m < Category C < 1000 m
- 1000 m < Category D

The hollowed microrelief erosion rills, wathesheds (rivers, lakes), railways and slopes have been measured too, but for methods of searching and optimizing of routes of off-road vehicles these factors do not express the primary aim of algorithms. For the added factors - as profiles of drainage systems, erosion rills and railways - the other advanced models and algorithms were created. The data mentioned above were obtained by digitalization and using of ArcGIS from another data sources – from TM in scale 1:25 000. The data about micro-relief were the major subject of an interest in [8].

4.2 Types of Terrain

Types of terrain" are very significant input parameter what was established by carto-metric investigation. The distribution and frequency of microrelief shapes as obstacles are determined by the type of terrain and the set of input values could be determined from a large number of statistical pronunciations [8].

The most important types of terrain (in the Czech Republic) are: plains (4,5%), uplands (50,1%), highlands (33,8%), mountains (10,8%) and high mountains (0,8%). Due to the low incidence of high mountains, this factor was omitted in further modelling. The frequency and parameters of obstacles within each terrain type are given in the following chapter. See Fig. 1.

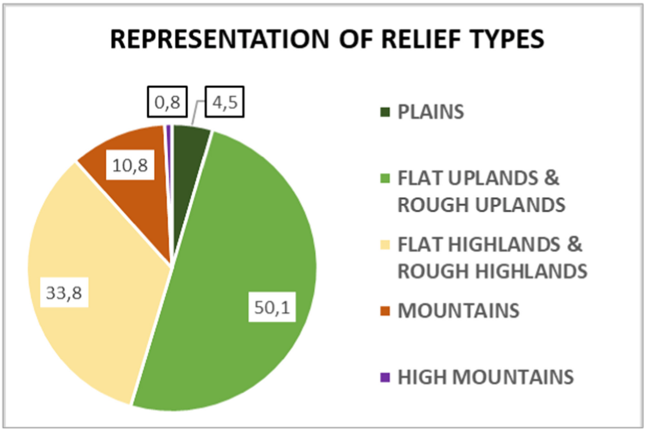


Fig. 1. Percentage representation of terrain types

5 Carto-Metric Investigation and Formation of Data Set

The input data was evaluated on the basis of mathematics and statistical methods which are used in cartography. The basic file was formed as a selection from all the maps of the Czech Republic. The presence of microrelief forms on area of movement was determined by use of the basic topographic maps (TM) in scale 1:10 000 (depicted forms as a rule of height difference over 0.5 m). These TMs 1:10 000 are not in using today (the editorial deadline was in 1958–1964), but they have been evaluated as the best source of this factor. See Fig. 2.

Substitute source, which is able to obtain data from, is the Digital Terrain Model (DTM) in scale 1:25 000 (depicted forms of height difference over 2 m). This base was used to create the input data file of microrelief, watersheds and communication (railways). The accuracy of microrelief shapes from this data source was not detailed - microrelief data on maps are very generalized due to their small sizes, so the occurrence of this factor is very inaccurate, but it served for a comparison of both models.

The task of the carto-metric investigation was to obtain the length of the microrelief shapes, their numbers in the squares of 10 by 10 km and the average height of these shapes.

Fig. 2. The special tool “opisometer” was used to measure the lengths of microrelief shapes on maps in scale 1: 10 000.

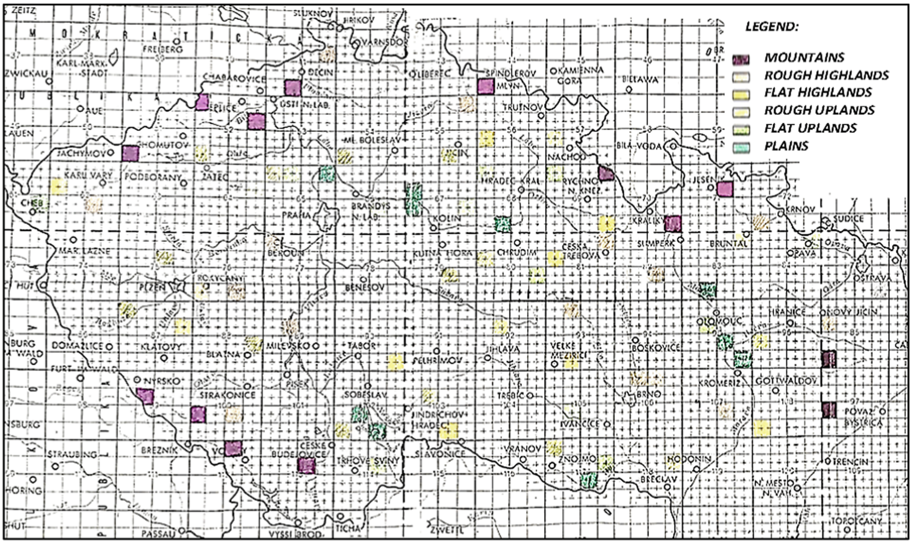


Fig. 3. Selection of maps sheets in scale 1:10 000 for the creation of input data file

The measurement of all the statistical units and statistical characters of basic file, however, is not tolerable and so there is chosen a sufficiently representative file (= set of maps). The whole area can be assessed according to the quantitative and spatial characteristics. See Fig. 3.

The first selection input file was composed of 320 pieces of tm 1:10 000. A square of 2 * 2 km was measured on each map, i.e. 1280 km^2.

The second set consisted of 102 sheets of these maps and each territory was examined for at least five representative maps of 1:25 000 for each type of relief. (Four map sheets of 1:10 000 record 4 * 5 km^2 and this is equal to the space of one map of 1:25 000. For 5 sample maps 1: 25 000, it is a total of 100 km^2 for each individual type of relief. In total, more than 600 km^2 were measured.)

As a result of carto-metric investigation the input parameters of data set were quantified. See Table 1.

Table 1. Input data file as a result of carto-metric investigation

TYPE OF RELIEF	PARAMETERS	CATEGORY OF MICRORELIEF SHAPES				LENGTH OF WATERSHEDS km/1km^2
		within 100 m	within 500 m	within 1 km	over 1 km	
MOUNTAINS	Number	312	247	22	15	1,1
	Length /m/	55	213	714	1648	
	Height /m/	1,5	1,5	2,2	2,0	
ROUGH HIGHLANDS	Number	707	482	40	10	1,34
	Length /m/	62	213	779	1074	
	Height /m/	1,6	1,8	2,0	2,2	
FLAT HIGHLANDS	Number	387	329	25	6	0,67
	Length /m/	63	170	620	1148	
	Height /m/	1,4	1,3	1,8	1,6	
ROUGH UPLANDS	Number	382	316	36	12	0,89
	Length /m/	60	214	629	1366	
	Height /m/	1,5	1,5	1,8	1,6	
FLAT UPLANDS	Number	272	205	17	9	0,7
	Length /m/	56	209	664	1622	
	Height /m/	1,5	1,7	2,1	2,4	
PLAINS	Number	65	85	27	19	0,95
	Length /m/	85	175	580	1343	
	Height /m/	1,7	1,5	1,7	1,7	

6 Approach to the Solution

6.1 The Key Idea

The main idea of a movement is formed as follows: If a vehicle cannot overcome a microrelief form, it has to by-pass it and the vehicle route then lengthens. Even if such an event should not mean a vehicle deceleration on every occasion, the resulting effect on overall time of movement will be similar to the situation that a vehicle overcomes obstacles on direct route but with decreased speed by impact of relief gradient or of the other geographic factor. On the vehicle particular movement (lengthened), caused by obstruction by-passing, the following parameters of impassable microrelief forms have the impact:

- number of microrelief forms;
- length of microrelief forms;
- orientation of microrelief forms with regard to vehicle path axis;
- overall structure (space distribution of microrelief forms).

Several models (mentioned bellow) were created on the basis of values gathered by a carto-metric investigation. Different interconnections were sought and different criteria were applied.

6.2 Establishment of a Basic Simulation Model

It is necessary to convert the obtained values into a vector format (for example if the optimization is solved in program language C++) or into a bitmap format, which is the search of optimized routes performed using instruments of ArcGIS.

Table 1 as input values for a model of the microrelief has been accepted. However, this database can be read from any other source, if needed.

The computational algorithm of the route works on the principle of iterative search of minimal anti-collision junctions on the destination line (from the current point) approximated by 2D vectors. and algorithm to prevent possible intersect of microrelief units was resolved;

Gaussian normal distribution was used for the representation of shapes and basic train area is the square of the size 10 by 10 km;

The program saves each microrelief shapes and their coordinates (each shape is characterised by four values - these are the coordinates of two points in the plane – $[\mathbf{x_i}, \mathbf{y_i}]$ and $[\mathbf{x_j}, \mathbf{y_j}]$, where the set of all points that lie on their shortest connector defines an approximation to the theoretical microrelief) in the field (which is a sequence of consecutive variables of that type) with an accuracy of one meter.

7 Models and Their Resulting Effect on a Movement

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, which can maintain the direction to the target point in the current time.

7.1 The Model Nr. 1 – Non-optimized

The Model Nr. 1 is for a vehicle equipped with GPS devices. This vehicle searches the direct route, if it is intersected by a certain shape, it starts bypassing along the edge of the shape (the shorter end), and after finding that it is at the end of the obstacle, it again will orient to the target point. It continues in the same way.

The Description of Model Calculation

1. From the starting point (**Z**) (**Z = S** if the algorithm is at the beginning) the shortest connection is led to the destination point (**C**), (in our case always 10 km away from S).
2. Determining the nearest $\mathbf{m_i}$ that intersects this shortest line (the nearest mi is found by searching the whole field, while detecting the intersections $\mathbf{P_i}$ [x_p,y_p] of the vector $\mathbf{d_i} = \mathbf{SC}$ with $\mathbf{m_i}$.

Collision (intersection) detection of 2 random **vectors with indices i, j** is given by this formula [8, 21]:

$$\begin{aligned}
c_1 &= (y_{i1} - y_{i2})x_{j1} + (x_{i2} - x_{i1})y_{j1} - (y_{i1} - y_{i2})x_{i1} - (x_{i2} - x_{i1})y_{i1} \\
c_2 &= (y_{i1} - y_{i2})x_{j2} + (x_{i2} - x_{i1})y_{j2} - (y_{i1} - y_{i2})x_{j1} - (x_{i2} - x_{i1})y_{j1} \\
c_3 &= \left(y_{j1} - y_{j2}\right)x_{i1} + \left(x_{j2} - x_{j1}\right)y_{i2} - \left(y_{j1} - y_{j2}\right)x_{j1} - \left(x_{j2} - x_{j1}\right)y_{j1} \\
c_4 &= \left(y_{j1} - y_{j2}\right)x_{i2} + \left(x_{j2} - x_{j1}\right)y_{i2} - (y_{i1} - y_{i2})x_{j1} - \left(x_{j2} - x_{j1}\right)y_{j1}
\end{aligned} \tag{2}$$

where c_i – *parameters of collision.*

x_i, y_i – *components of I vector*

x_j, y_j – *components of J vector.*

If c1 and c2 have different signs and at the same time c3 and c4 have different signs as well, then vectors with i,j indices (defined by their entry points) intersect. In such cases, the parameter of this **vector (t)** is calculated.

The calculation of the **parameter $\mathbf{t_i}$** (the parametr t_i appertains to vector d_i) and coordinates of the intersection P of both vectors i,j is this:

$$\begin{gathered}
t_i = \frac{(y_{j2}-y_{j1})(x_{i1}-x_{j1})+(x_{j2}-x_{j1})(y_{j1}-y_{i1})}{(x_{j2}-x_{j1})(y_{i2}-y_{i1})-(y_{j2}-y_{j1})(x_{i2}-x_{i1})} \\
x_p = (x_{i2} - x_{i1})t_i + x_{i1} \\
y_p = \left(y_{i2} - xy_{i1}\right)t_i + y_{i1}
\end{gathered} \tag{3}$$

The obstacle $\mathbf{m_i}$ that is in collision with the $\mathbf{d_i} = \mathbf{SC}$ vector with the lowest parameter value (t) is sought, if any. If no $\mathbf{m_i}$ intersects this connector (ZC), the algorithm ends, which means the final path finding from point S to point C. If not, the algorithm continues with step 3.

3. If the path is crossed by a microrelief shape, the algorithm determines the "diversion" of the obstacle by this way:

- by calculating the distance from the starting point **Z** (Z - is meant here as the starting point from which the path is led towards point $\mathbf{C_i}$);
- it is determined the route through the individual vertices $\mathbf{V_i}$ of the microrelief shape $\mathbf{m_i}$ (of this one, that intersects the vector **ZC** with the lowest parameter value **t**) to **C.** The shorter path that leads over the vertex $\mathbf{V_i}$ continues. This means that the **Z** point in the next step is assigned the coordinate of the definite vertex ($\mathbf{V_{i1}}$ **or** $\mathbf{V_{i2}}$) through which this distance is shorter. See Fig. 4.

4. In this step, the algorithm goes back to step 1, where the shortest connector from point Z (in this case, it will be one of the vertices of some mi shape) to C (destination point) is determined again, and the path search procedure is repeated until we are at the destination.

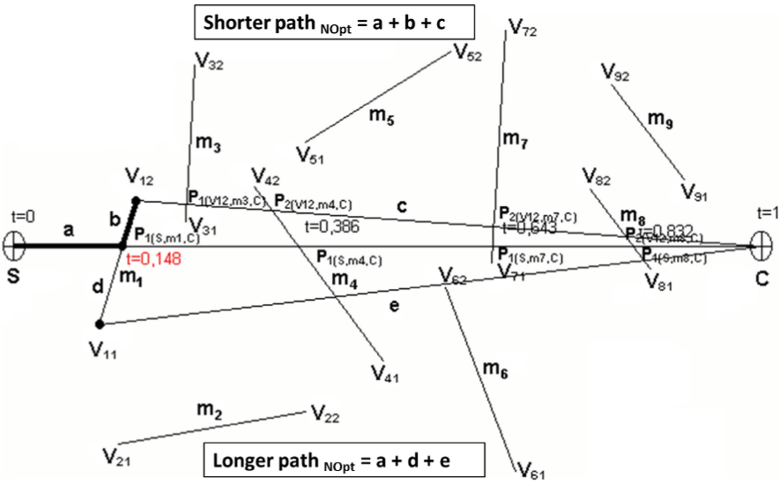


Fig. 4. Criterion for selecting the vertex of a microrelief shape in a non-optimized process

Six thousand attempts for each of the six types of terrain were carried out. The obstacles were newly (randomly) placed on the basis of a table of input values for each passage. The extension of the vehicle’s movement route due to microrelief was implemented.

The total elongation is **about 5–8 c/o, it is** depending on the morphometric type. See Table 2.

This algorithm for simplicity calculates that once it encounters an obstacle, in this case $\mathbf{m_i}$, it proceeds along this obstacle to one of its peaks (edges) and from there directly to the destination point, this of course prolongs the path. However, depending on his visual effects, the driver of the vehicle would probably change direction to a certain peak in advance in order to shorten the journey as much as possible. This model can therefore be optimized.

Table 2. Percentage route extension for non-optimalized model (average, maximum and minimum)

Type of relief	Path elongation		
	Mean value	Maximal value	Minimal value
Plains	7,9	10,9	3,6
Flat uplands	7,0	12,7	3,7
Rough uplands	7,4	11,2	4,6
Flat highlands	6,9	9,1	3,7
Rough highlands	5,4	6,6	4,6
Mountains	7,6	9,3	5,6

7.2 The Model Nr. 2 - Optimized

The Model Nr. 2 is for the same type of vehicles (the vehicle is still oriented by using GPS to the target point), but the input algorithms used in Model Nr. 1 are optimized. This model consists in modifying the algorithms, where the route leads only over the apexes of the obstacles that occur on the route. The assumption is that - depending on its visual capabilities - the driver would probably not go around the whole obstacle just along its edge, but would change direction in advance to certain vertices in order to shorten the journey as much as possible. See Fig. 5.

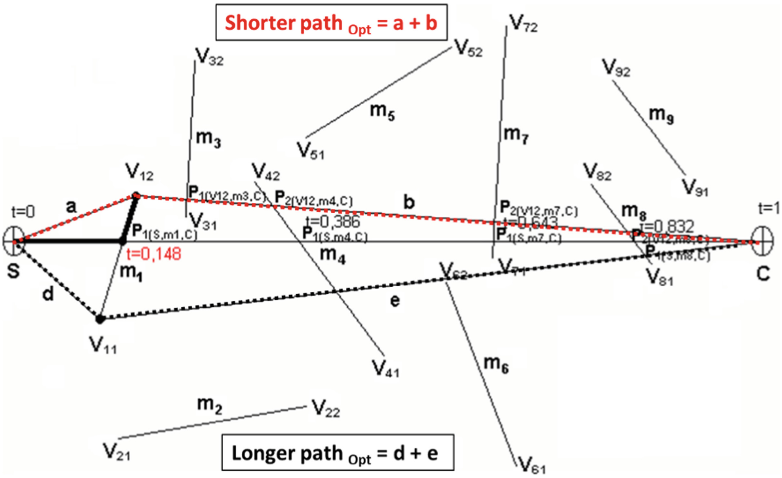


Fig. 5. Criterion for selecting the vertex of a microrelief shape in an optimized process

To Find an Optimized Path

Steps 1–4 remain the same as for process in Model Nr.1.

5. The algorithm examines whether the path intersects at least one shape $\mathbf{m_i}$ (otherwise it ends – the path is optimal and at the same time the shortest possible).

6. If so, it will check whether it is possible to connect any two found vertices directly so that they do not intersect with obstacle $\mathbf{m_i}$ (the number of these combinations is equal to a two-element combination of N)

$$\binom{N}{2} = \frac{\mathrm{N!}}{(N-2)!2!} \tag{4}$$

where *N – the number of vertices.*

If it finds two vertices that meet this condition, it discards all points (mi) that lie between this connector (vertexes linked by the path). See Fig. 6.

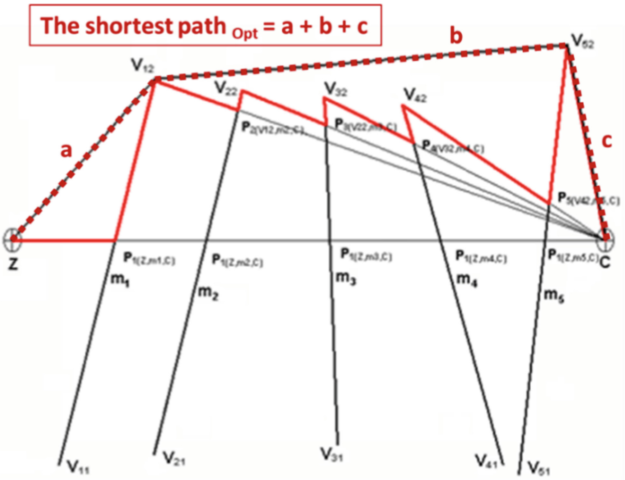


Fig. 6. The optimization principle is demonstrated on the following figure (dashed line)

As a final step, the length of the entire route, is calculated along edge points. The calculation of the length of the path along the edge points (s - is the number of edge points) is given by the relationship:

$$D_c = \sum_{n=1}^{S-1} \sqrt{(x_{n+1} - x_n)^2 + (y_{n+1} - y_n)^2} \tag{5}$$

where D_c *– path length,*

S – the number of vertices in the path,

x,y – x,y axes of the particular vertex,

n – index within the set of vertices.

This **optimized** process is characterized by shortening the default path on average up to an extension of **1–1.4** percent due to the shortest possible path (this depends on the number and type of micro-relief shapes), compared to the **5 to 8** percent extension that is characteristic of the default **non-optimized path** (the extension again depends on the type of relief). See Table 3.

Table 3. Route extension for the optimized model (average, maximum and minimum)

Type of relief	Path elongation [%]		
	Mean value	Maximal value	Minimal value
Plains	1,4	1,8	1,0
Flat uplands	1,3	1,8	1,1
Rough uplands	1,4	1,7	1,2
Flat Highlands	1,2	1,5	0,9
Rough highlands	1,1	1,3	0,9
Mountains	1,3	1,6	1,0

7.3 Model Nr. 3 -Without GPS Navigation

Unfortunately, not all vehicles have a GPS or other navigation instruments, if they are equipped only with instruments such as a gyroscope, or gyrocompass the length of the distance-size detour depends on the ability of the crew to keep moving. 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%** (Table 4).

Table 4. Percentage route extension for non-optimized model without navigation device (average, maximum and minimum)

Type of relief	Path elongation		
	Mean value	Maximal value	Minimal value
Plains	14,3	22,5	10,3
Flat uplands	14,1	21,2	10,9
Rough uplands	15,1	19,8	10,3
Flat highlands	12,1	18,1	9,9
Rough highlands	14,1	19,0	9,2
Mountains	13,7	17,4	10,0

7.4 Model Nr. 4 – Joint Factors

The advanced models of optimization were created similarly. Input data were gathered using digitalization of layers of microrelief, waters and railways from the TM 1:25 000. The obstacles were selected carefully, the limits of CCM and NO GO obstacles for the Tank T-72 were considered.

The area of an interest was surrounding of Tišnov town (TM M-3393-D-d) and it was a part of the defence research project. The first simulation model was for influence of microrelief only but the second was for an influence of microrelief, waters and railways together. It is obvious that path optimization has very satisfactory results.

The values of elongation of routes are stated in Table 5.

Table 5. Values of elongation of routes

Type of model	Elongation of route (non-optimized) [%]	Elongation of route (optimized) [%]
Model of "Microrelief"	7,40	1,19
Model of "Microrelief + Watershed + Railways"	14,91	3,79

8 Analysis and Discussion

8.1 Interdependence of the Parameters Evaluated

The carto-metric survey shows the density of microrelief shapes occurrence – this is evaluated in km/km^2. The definition of types of relief is given by morphometric parameters like the size of elevation or value of inclination of slopes and it was supposed that the density of microrelief shapes would be the crucial parameter.

See Table 6.

Table 6. The table shows the density of obstacles

Type of relief	Density of microrelief shapes
Plains	0,71
Flat uplands	0,70
Rough uplands	1,50
Flat highlands	1,17
Rough highlands	1,75
Mountains	1,14

However, the density of microrelief obstacles is not a very definite indicator for calculating of route extensions, as was found by simulation models. It has been evaluated that the length of individual shapes has the most significant influence.

Longer shapes have the greatest effect on CCM. Impact of obstacle size on route extensions indicate the Table 7.

Table 7. Impact of obstacle size on route extensions for an optimized and non-optimized model

Length of obstacle [m]	Number of shapes			
	1000	2000	1000	2000
	Elongation of route (Optimized) [%]		Elongation of route (Non-Optimized) [%]	
100	3,7	19,8	15,6	45,8
200	7,7	36,0	20,5	58,2
300	13,5	47,0	28,0	73,3
400	19,5	56,2	37,1	80,3

The 2D and 3D charts (located below, see Figs. 7 and 8) are a final example of a statistical calculations and they show how the length of microrelief shapes and their number affects the overall elongation of the route. The 2D graph also indicates a comparison of the effectiveness of the optimized and non-optimized calculation process as a percentage.

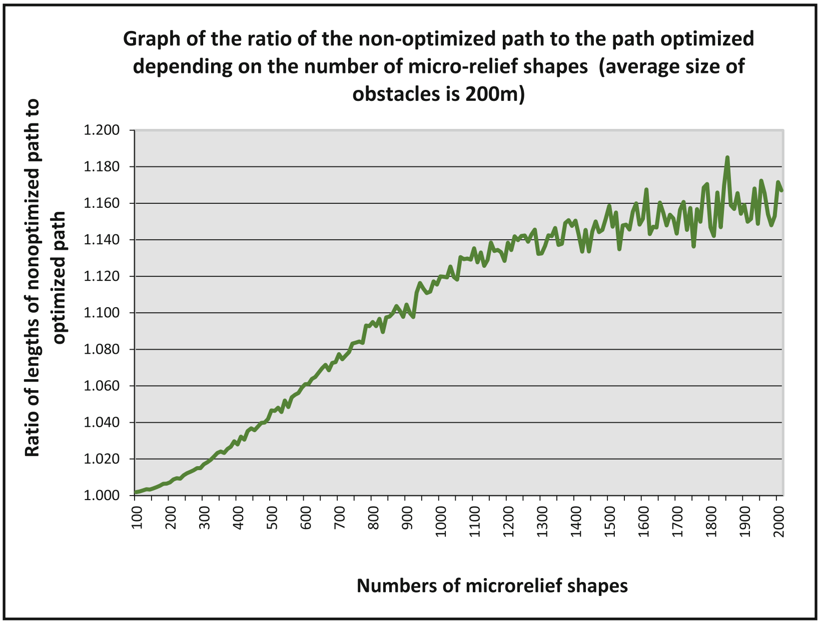
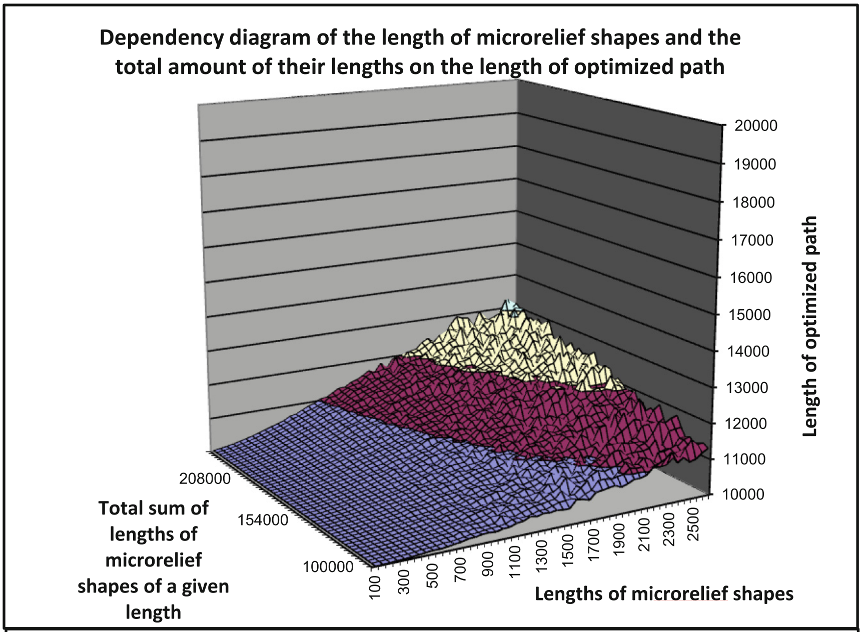


Fig. 7. The 2D graph shows the comparison of the effectiveness of the non-optimized and optimized calculation procedure in finding a path complicated by obstacles. (An average length of obstacles is 200 m. The area of the test area is 10 × 10 km.)



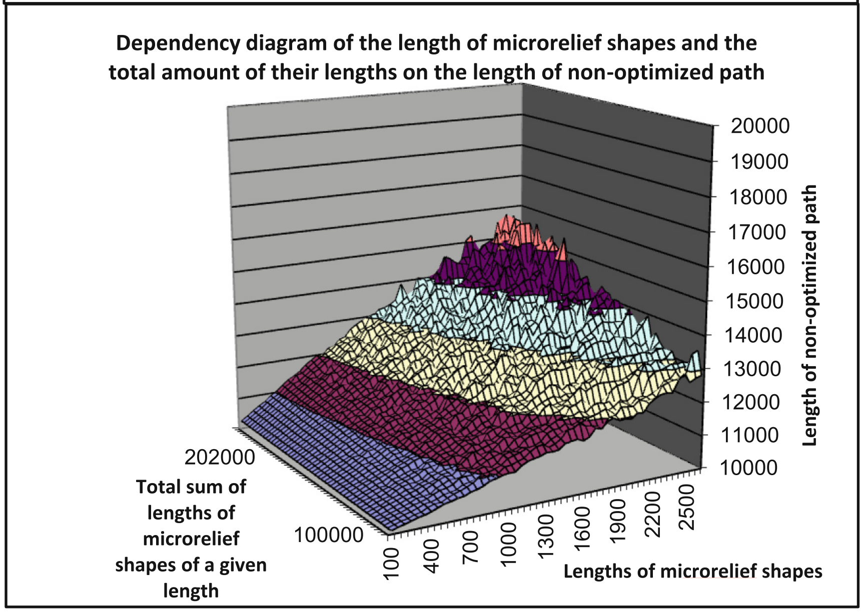


Fig. 8. The 3D graphs of the mutual effect of the number of obstacles, their sizes and the length of the distance travelled. These charts illustrate the dependence of path length (optimized – above and non-optimized - below) on the length of microrelief shapes whose total (sum) does not exceed a given value.

This statistical investigation is based on a large number of generated models and their calculations. As part of this task, 1,536,000 microrelief models were generated to which the calculations of 52,224,000 different paths were applied.

9 Conclusion

As it is obvious, the significance of effective automation of operational planning aspects in different areas (as a decision support component) increases constantly. It is necessary to say, that automation and optimization include a great potential in of operational tasks. These procedures are closer to the human high-level reasoning instead of low-level engineering problems and it seems Modelling and Simulation methods could be successfully applied [18, 21].

Much projects, studies and other work has already been done to build a system that would have different algorithms available to evaluate the influence of particular - specific input parameters, whether tactical, technical, economic, logistical or otherwise, but the research is definitely not finished yet. The variability of interactions of the factors (mentioned above) is large, and the creation of a system that would, moreover, predict the common influence of selected parameters is a very demanding task. A decision-making system in a military operational environment would certainly gladly accept such a solution. However, any step that makes it possible to get close to this complex system is certainly worthy.

It is possible to say that a crucial aspect to evaluate an operational planning dealing with OPFOR and other players (e.g. civilians, neutral units, suspect ones) is tightly related to the ability to evaluate their behaviours. Owing to this assertion to create some effective models and behaviour that reproduce the actions/reactions based on the different boundary conditions is necessary.

It is certain that use of Intelligent Agents driving objects during simulation magnify largely the effectiveness of simulation approach in this context as well as in other joint scenarios [19].

Presented solution shows the possible approach in operational problem solution dedicated to the air manoeuvre optimization in operational conditions [20] with undefined starting and destination point, what means new dimension of options and calculations leading to a higher decision area then problems with selected constraints and known initial inputs.

The aim of the article is to describe the methodology of evaluation of the influence of microrelief shapes on the mobility of military vehicles. The article is based on the statistical determination of the extent of microrelief shapes in the territory of the Czech Republic. These shapes were detected in various geomorphological relief types using topographic maps of 1:10 000 and the Digital Elevation Model (DEM 5) with the density of 1 × 1 m.

The article describes both the methodology of calculations of possible collisions of the vehicle chassis with the terrain, as well as the calculation of the optimal route of the vehicle avoiding micro-relief obstacles. These models are closely correlated with the factors under assessed and their parameters, and in the field of the use of non-manned equipment, they are a necessary step leading to a successful outcome of the military task, but also in crisis management operations. 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.

Micro-relief shapes, types of surface, slopes, soil conditions and the weather conditions are the main factors, whose reciprocal influence has not been evaluated yet and these factors are of fundamental importance for the movement of vehicles in the field. Therefore, the current state of the supporting documents, which contain these data was assessed. The data about micro-relief were the subject of an interest in [8]. Several models were created on the basis of values gathered by a carto-metric investigation.

Further research will look for the correlation between synthetic model and real terrain in terms of validation of some previous assumptions about terrain categories and also it will look for the high-level generic model for operational purposes to upgrade the estimated total sum of the particular paths for logistic planning and preparation.

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