The Impact of Microrelief Forms on Mobility of Terrain Vehicles

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Abstract. When deploying off-road vehicles in military and rescue operations, it is necessary to analyse the characteristics of the terrain, its segmentation and obstacles, that can significantly eliminate the movement of this technique. The mobility of off-road vehicles depends on many factors such as terrain relief, soil, vegetation, water, road network, settlement unit structure, meteorological conditions, etc. The goal of this paper is to identify the critical micro-relief forms in the selected test area, which can be important for the transportation analyses and cartographic visualization, especially for the military and rescue operations management during the crisis situations and natural disasters such as floods, fires, storms, military operations, etc. Both of the relief parameters and technical vehicles parameters were considered for the cross-country movement analysis to predict the GO, SLOW GO and NO GO areas as a part of crisis management support.

1. Introduction
Geographical support and cartographic visualization is very important and indispensable element in solution of prediction system and resolution of elimination of a crisis situation impact. In the case when we are not able to use some segments on the roads (damaged or destroyed objects, traffic jam, etc.) we must to provide the complete cross-country mobility analyses to solve the transportation problems.

The main terrain elements, which determine the cross-country movement, are relief slopes and microrelief forms. Both of the relief parameters and technical vehicles parameters are important for the cross-country pass ability analyses. These analyses are often concentrated on predicting the obstacles to support the safe movement of terrain vehicles. There is a large body of literature describing the general methodologies of the cross-country movement evaluation using terrain data [1-23].

Microrelief forms are very important for the movement of off-road vehicles. Often, they cannot be detected from digital terrain models if the density of elevation points is 10 m or more.

The essential forms and parameters to the assessment of microrelief forms impact to cross-country mobility are as follows (see table 1): slope gradient of microrelief form; height of terrain stair; width of microrelief form, e.g. of scarp, trench, watercourse; selected technical parameters of vehicle.
Table 1. Parameters of evaluation of the essential microrelief forms.

| N. | Name               | Form design | Evaluating parameters                                                                 |
|----|--------------------|-------------|---------------------------------------------------------------------------------------|
| 1  | embankment         | ![embankment diagram] | - slope gradients ($\alpha_1, \alpha_2$)  
- embankment height ($h$)  
- embankment width ($s$) |
| 2  | Excavation, delve, crater | ![excavation diagram] | - slope gradients ($\alpha_1, \alpha_2$)  
- excavation depth ($h$)  
- excavation width ($s$) |
| 3  | Terrain stair (climbing) | ![stair diagram] | - stair height ($h$) |
| 4  | Terrain stair (descent) | ![stair diagram] | - stair height ($h$) |
| 5  | trench, scarp (passing) | ![trench diagram] | - trench width ($s$) |

Figure 1. This figure shows one of the basic terrain profile – bank (causeway).

Figure 2. This figure shows a watercourse trench.

Figure 3 shows the basic terrain profile parameters of a microrelief form expressed by the length elements $l_i$, height segments $h_i$ and longitudinal slope $\alpha_i$. 
We can describe terrain segments using the relief profiles, which may be continuously, randomly rough, may consist solely of a single discrete obstacle, uniformly spaced obstacles of a specific height or may be anything in between.

The other possibility is to divide a terrain area into partial areas and to describe each of them by an assignment of value characterizing it (longitudinal and transversal gradient $\alpha, \beta$, coefficient of rolling resistance – $f$ and coefficient of static friction – $\phi$). The less these areas will be, the more accurate calculations from the point of view of vehicle movement can be made, see figure 4.

At these elementary areas we can calculate their longitudinal gradient ($\alpha$) in the direction of vehicle route and also their transversal (side) inclination ($\beta$), see figure 5.
Figure 5. Calculation of longitudinal and transversal gradient in vehicle route direction.

If we will ponder the general orientation of plane in fixed grid system, then the longitudinal gradient in direction of vehicle route determined from the nearest utmost points of matrix model will be according to figure 5.

\[ \alpha = \arctan\left( \frac{z_C - z_B}{x_C - x_B} \right) \]  

(1)

or

\[ \alpha = \arcsin\left( \frac{z_C - z_B}{BC} \right) \]  

(2)

at the calculation of transversal inclination by use of the slant range of vehicle route in terrain and the truncation of terrain relief roughness between points \( B \) and \( C \).

The transversal inclination will be according to figure 4:

\[ \beta = \arctan\left( \frac{z_B - z_A}{y_B - y_A} \right) \]  

(3)

or

\[ \beta = \arcsin\left( \frac{z_B - z_A}{AB} \right) \]  

(4)

at the calculation of transversal inclination by use of slant range between points \( A \) and \( B \).

2. Data and Methods

Different geographical data sources can be used to carry out terrain analyses and identify the terrain obstacles and microrelief forms as well. One method, which can be used during operation for terrain
analyses, is using a topographic map. This type of maps is intended for assessment of landscape in relation to planning, commanding and controlling the military or rescue operations, for orientation and navigation in the terrain or for study of military-geographical characteristics of territory in generally.

Members of the Army of the Czech Republic (ACR) can use the most detailed map product - the Topographic Map in a scale 1:25000 (TM 25), see figure 6, for the purpose of terrain analyses on the tactical level. The terrain relief is represented on this map by contour lines, elevation points and other objects that represent microrelief forms. The content of the map is subject of the cartographic generalization and this data source is not suitable for a detailed terrain analysis such as the identification of microrelief objects. Nowadays, it is more efficient to use modern information technologies for a terrain analysis, process digital geographic data and creating the thematic map products. The source digital database for creating the topographic maps in ACR is Digital Landscape Model 25 (DMU 25), see figure 7. This data creates a cartographic model at a scale of 1:25000. For this reason, this data is already generalized – the position of microrelief objects on the map may differ in the actual position or some microrelief objects are not displayed in the map.

Information about relief and local elevation conditions can be obtained from the digital elevation models. In the Czech Republic, there is an elevation model - Digital Terrain Model of the Czech Republic of the 5th generation (DMR 5), which by its declared total mean height error 0.18 meters can capture effectively the detailed diversity of terrain relief.

To evaluate the terrain relief features and identify microrelief objects can be used DMR 5 because this model cover whole territory of the Czech Republic and it is the most accurate from available elevation models. Based on the previous study [24], the DMR 5 was converted from the heights of discrete points format to a raster format of pixel size 0.5 meter. SW ArcGIS and its tools for spatial analyses Arc Toolbox Spatial Analysis were used to identify microrelief terrain obstacles. The Slope tool calculates the first derivative value of the input surface on a cell-by-cell basis (see figure 8 and figure 9). The Curvature tool calculates the second derivative value of the input surface on a cell-by-cell basis. For the microrelief objects identification was used profile curvature (horizontal curvature), see figure 10 and figure 11. For the verification of above-mentioned method, the part of military training area was chosen (1.46 square kilometre), where natural and artificial microrelief objects occur.

![Figure 6. Cut-out of TM 25.](image1)

![Figure 7. Cut-out of TM 25 with microrelief forms from DMU 25 (embankment – green line and terrain stair – violet line).](image2)
In the figure 8, it is possible to identify the terrain forms in places of rapid change of slope value. Figure 9 shows that not all microrelief object are included in DMU 25.

In the figure 10, it is possible to identify the terrain forms in places, where profile curvature reaches the local minima (convex curvature) and maxima (concave curvature). Figure 11 shows that not all microrelief objects are included in DMU 25 as well as in figure 9.

Another task of the analysis is to express influence of microrelief objects on their overcoming by military vehicles. The parameters of terrain shapes were compared with technical parameters of two selected wheeled vehicle types (table 2) – rate of climbing ability versus terrain inclination value and wheelbase and ground clearance versus profile curvature, see [5].

| Table 2. Technical parameters of selected wheeled military vehicles. |
|---------------------------------------------------------------|
| Rate of climbing (°) | Wheelbase (m) | Ground clearance (m) |
|----------------------|--------------|----------------------|
| Land Rover Defender 110 | 30           | 2.79                 | 0.23                 |
| Tatra 815 8x8         | 29           | 2.97                 | 0.37                 |

Based on the previous research, knowledge of the DMR 5 accuracy and on vehicle field tests, a possible error corresponding to 10% of the output value has to be included in the calculation. The calculated values of rate of climbing (RC) are classified as follows:

- impassable microrelief forms \( S \geq RC + 0.1RC \)
probably impassable microrelief forms \( (RC + 0.1RC < S > RC - 0.1RC) \)

- passable microrelief forms \( (S \leq RC - 0.1RC) \)

where \( S \) is a slope value, see figures 12, 13.

The research and field tests show the dependence of the terrain profile curvature value on the angle defined by the wheelbase and the ground clearance. The limit values of terrain profile curvature (LC) for both vehicles were calculated with reliability of 0.992. Limit values of profile curvature cannot be public due to confidentiality. The calculated values of profile curvature (PC) are classified as follows:

- impassable microrelief forms \( (PC \geq LC + 0.1LC) \)
- probably impassable microrelief forms \( (LC + 0.1LC < PC > LC - 0.1LC) \)
- passable microrelief forms \( (PC \leq LC - 0.1LC) \)

The follows figures 14 and 15 show classified terrain profile curvature.

3. Results
Using the above-mentioned methodology, ARC GIS SW and digital relief model DMR 5, we created the relief slope coverage of the cross-country mobility map 1:25 000 – CCM 25, see figure 16.
In the next phase of the research, we searched for such microrelief objects, which can cause by their profile curvature and slope characteristics the vehicle to get stuck, see figure 17 and figure 18.

We found that DMR 5 captures microlief shapes more accurately than topographic maps, see figure 19 and figure 20.
4. Conclusion

The cross-country mobility research as a part of the terrain analyses is very important, especially during natural disasters and crises situations, when some road segments and objects can be damaged, destroyed or crowded. In these cases, we must use the special rescue vehicles and know which terrain areas are passable and which not to ensure the rescue personnel, vehicles and optimize the rescue procedure. The cross-country mobility methodology is possible to exploit for terrain rescue vehicle navigation adapting the procedure for each type of vehicle knowing its technical parameters. For the future research approach it will be necessary to create more accurate databases, especially elevation databases with the precision corresponding with the dimensions and other vehicle technical parameters – see also [23]. Another problem is effectively to link up the cross-country movement digital map with the GPS navigation vehicle system and to train the vehicle crews to effectively use these systems.

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