CARTOGRAPHIC VISUALIZATION OF RELIEF IMPACT ON TRANSPORT DURING CRISIS SITUATIONS

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ABSTRACT: The goal of this paper is to identify the critical relief factors in terrain, which are important for the transportation analyses and cartographic visualization, especially for the rescue operations management during the crises situations and disasters such as floods, fires, storms, military operations and so on. Both of the relief parameters and technical vehicles parameters are important for the cross-country movement analyses procedures focussed on the shortest, fastest, or securest path in terrain finding and displaying.
In paper are included the results of the cross-country mobility analyses using mathematical and statistic methods. There were laboratory and terrain testes and measurements provided in the research to verify that methods. For the testes we used the basic military (wheel and tracked) vehicles and common ARC GIS Software (included CCM extension) for the evaluation and cartographic displaying of the research results.

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 procedures are mostly focussed on the shortest, fastest, or securest path finding and displaying.
Since 1999 we have provided plenty of the terrain research testes in the military training area near Vyskov (Czech Republic) to verify the vehicles obstacles overcome ability (across some relief slopes and micro relief formations) and to verify the relief data accuracy demands corresponding with the dimensions and other technical vehicles parameters. That research was very important for another cartographic research focussed on some microrelief forms which are not engaged in relief data bases and in

topographic map 1:25 000. Beside topographic map 1:25 000 we had to use the old military map1:10 000, where are displayed more microrelief forms and then we had to realise the terrain surveying to compare the data base, maps and reality. The bypasses of the micro relief forms were very important for the mathematical and cartographic simulation and cross-country mobility modelling and visualization.
The particular results of that research was a cross-country mobility relief maps 1:25 000 for main special vehicles which are able to go across terrain (tanks, heavy wheeled and tracked vehicles, personal vehicles and so on. Second result was the shortest, fastest, or securest path in terrain finding and displaying using mentioned methodology
The new more precise cross-country mobility analyses based on the mathematical and statistic methods verified and evoked the need of relief elevation data accuracy approximately 1 meter (0,5 m in flat terrain) and the needs of micro relief surveying. The floods which hit large areas of the Czech Republic in 1997, 2002 (damages were about 10 billion USD) evoked corresponding demands too.
The new prepared laser scanning in the Czech Republic has calculated with this accuracy, which could support our research and precise the cartographic cross-country mobility modelling and the shortest, fastest, or securest path in terrain finding and displaying.

2. TERRAIN CROSS-COUNTRY MOBILITY GEOGRAPHICAL FACTORS

The cross-country mobility has a significant impact on the rescue operations and military operations both in time and costs. Rescue and military standards identify three basic levels of terrain when considering the cross-country movement:

- GO terrain (transport without problem);
- SLOW GO terrain (transport is limited);
- NO GO terrain (transport is not able).

Geographical factors affecting the cross-country mobility

The factors affecting the cross-country mobility and selection of approach routes (in positive and also negative standpoints) are especially:

- Slopes of terrain relief;
- Vegetation;
- Surface water features;
- Soil conditions;
- Weather conditions;
- Urban / built-up areas;
- Lines of communication;
- Other natural and man-made features.

Fore mentioned factors interrelate and have common impact on cross-country mobility expressed by speed deceleration (or by interruption) of movement of certain vehicle phrased by multiple coefficient of deceleration „c" or by value 0 - 100 % with regard to hypothetically determined optimal conditions of transport - see too Rybansky (2002).

3. THE IMPACT OF RELIEF GRADIENT AND MICRORELIEF FORMS TO CROSS-COUNTRY MOBILITY

A relief gradient and micro relief forms are ranked among fundamental factors implicating cross-country mobility of an area by reason that each (with regard to dimensions and technical specifications of vehicles) significant elementary surface has certain **relief gradient** and in broad terms also several **microrelief form**.
The calculation of total resulting coefficient of vehicle deceleration by relief and microrelief impact is given for determinate surface by relation as follows:

$$C_1 = C_{11} \cdot C_{12} \tag{1}$$

where

C_{11} - deceleration coefficient by impact of **gradient factor**
C_{12} - deceleration coefficient by impact of **microrelief factor**

A cross-country mobility and attained terrain speed will be affected beside of relief gradient and terrain micro relief also by under mentioned limiting technical parameters of vehicles - see Rybansky (2002) and references [4] - [8].

3.1 The impact of relief gradient to cross-country mobility

In common sense, a relief gradient is determinable from topographic (finite and per partes plain) surfaces, that are the generalized morphologic picture of Earth surface and that can be implied by use of various models of terrain relief.

It is necessary to know, for purposes of vehicle running characteristics calculation on the subject of terrain relief impact, following parameters:

- profile section traversed by a vehicle and interpolation function to calculation of points of detailing of profile section;
- vehicle deceleration coefficients of relief gradient impact;
- critical values of slope gradients (for vehicle climbing, swerving motion and rollover);
- other fundamental characteristics of surface (coefficient of rolling resistance, coefficient of static friction etc.) – see also Vala – Rybansky (2001).

Profile section description of vehicle route

Running conditions of vehicles are versatile to a great extent. The impact of minor surface road roughness is frequently implicated in coefficient of rolling resistance which further depends on dimension, frequency and shape of these roughness. If we will presuppose the constant transversal terrain profile section at vehicle route, than we can describe that route at space by use of length, height and angle dimensions of terrain Vala – Rybansky (2001), as it is schematically depicted on Figure 1.

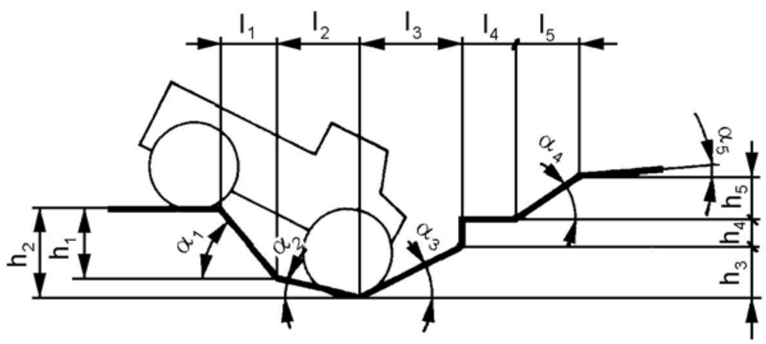


Figure 1. Vehicle route description by use of length, height and angle dimensions of terrain

This way is fully satisfying only at description of man-made obstacles made in general by plane surfaces considering the fact that in general the profile of terrain section changes also transversally.

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 - α, β, coefficient of rolling resistance – (f) and coefficient of static friction – (φ). The less these areas will be, the more accurate calculations from the point of view of vehicle movement can be made *(Fig. 2)*

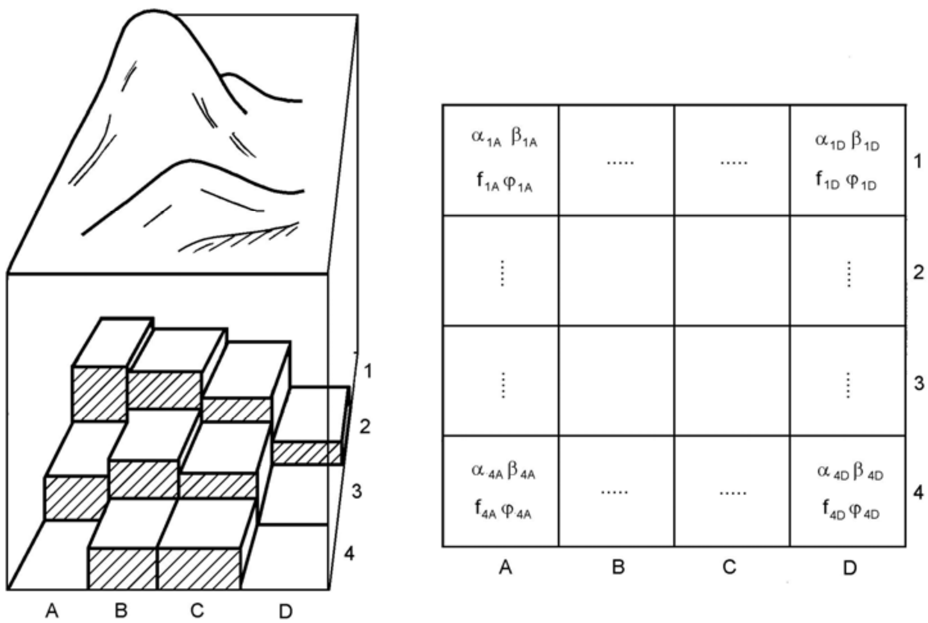


Figure 2. Terrain relief description by use of partial areas

At these elementary areas we can calculate their longitudinal gradient (α) in the direction of vehicle route and also their transversal inclination (β) (Figure 3).

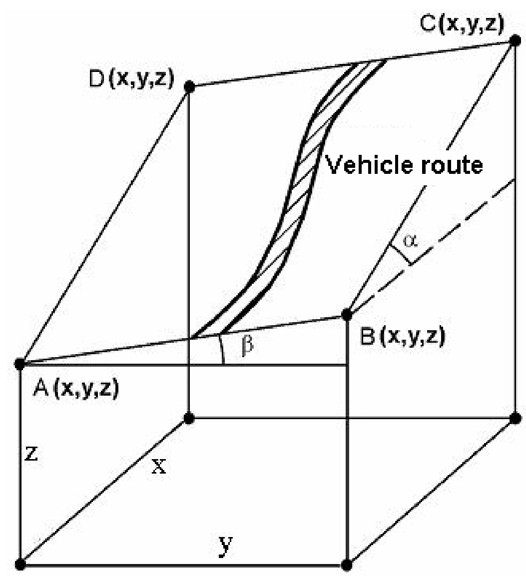


Figure 3. Calculation of longitudinal and transversal gradient in vehicle route direction

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 3:

$$\alpha = arc\ tg\left(\frac{z_C - z_B}{x_C - x_B}\right) \tag{2}$$

or

$$\alpha = arc\ sin\left(\frac{z_C - z_B}{BC}\right) \tag{3}$$

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 3:

$$\beta = arc\ tg\left(\frac{z_B - z_A}{y_B - y_A}\right) \tag{4}$$

or

$$\beta = arc\ \sin\left(\frac{z_B - z_A}{AB}\right) \tag{5}$$

at the calculation of transversal inclination by use of slant range between points A a B.

Relief gradient impact on the vehicle deceleration coefficient C_{11}

The coefficient of deceleration of impact of gradient factor $\mathbf{C_{11}}$ is determinable on the basis of tractive charts of particular vehicles. **A tractive chart** (fig. 4) is the formulation of tractive force dependence on vehicle driving speed. The driving speed is plotted on the horizontal axis of the chart, tractive force and forces of resistance are plotted on the vertical axis of fore mentioned chart. Coefficient of deceleration $\mathbf{C_{11}}$ is equal to proportion between the reduced gradient speed and the maximal road speed.
The sample of the tractive chart of road vehicle is demonstrated on Figure 4.

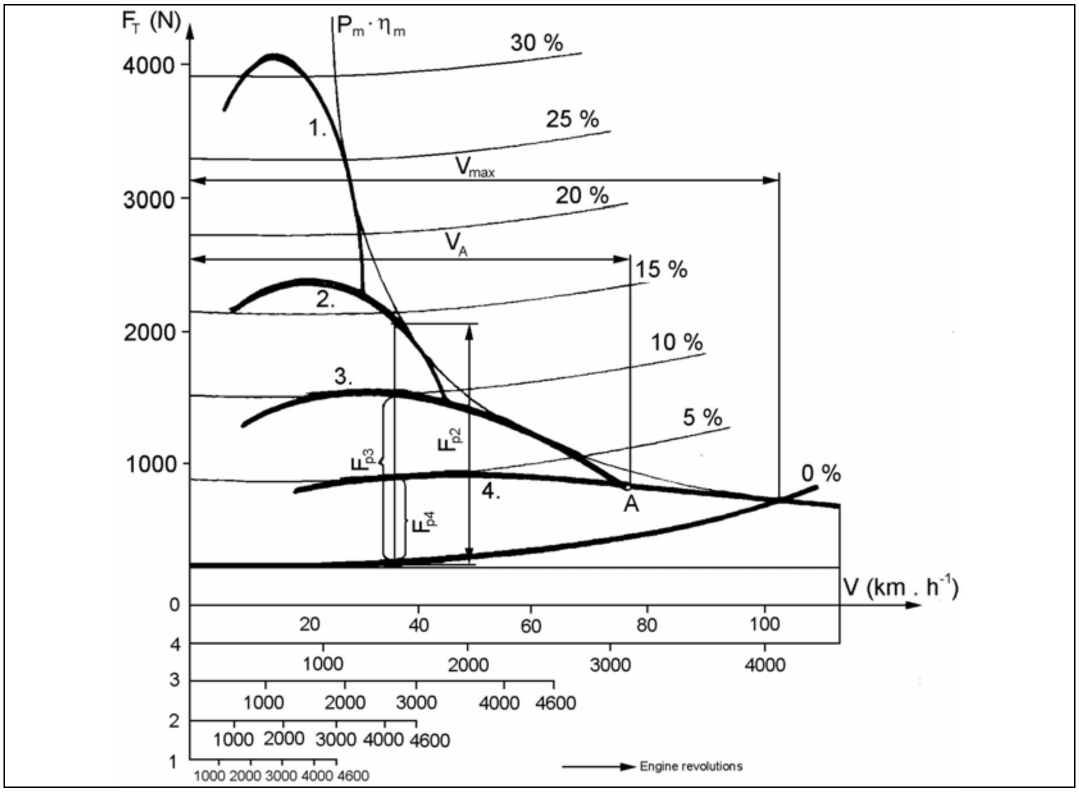


Figure 4. Tractive chart of a road vehicle with four-speed gearbox

3.2 The impact of microrelief to cross-country mobility

The terrain microrelief can be defined as man-made and natural both elevated and recessed topographic forms that cannot be expressed with regard to it´s relative height differences by use of contour lines or by the means of other principal method of terrain representation. Amongst microrelief forms are in particular:

- slopes (terrain stairs), i.e. rock cliffs, landslides, terraces, embankments and earthworks alongside communications, watercourses and the like;
- ravines, erosion rills and scoured holes of watercourses and storm water, karstic lowlands, sink holes;
- rock groups, boulders, talus and stone fields and rows of stones, hillock relief;
- delves, dumps and other forms created by impact of natural forces (external ones in particular) and by anthropogenic activity of human society.

Calculation of coefficient of deceleration by impact of microrelief (C_{12})

Two subjects are viewed by the determination of C_{12}:

– limit parameters to assessment of overcoming of microrelief form together with technical parameters of vehicle traffic ability
– length and orientation of microrelief form with regard to vehicle route axis to assess a by-pass trajectory

Determination of the coefficient of vehicle deceleration at microrelief overcoming

The essential parameters to the assessment of microrelief forms impact to cross-country mobility are as follows (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.

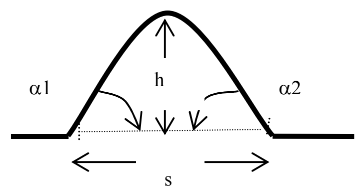
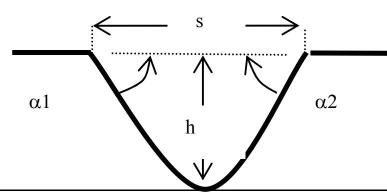
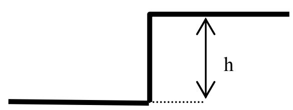
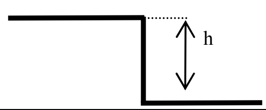
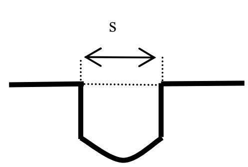
N.	Name	Form design	Evaluating parameters
1	embankment		- slope gradients ($\alpha 1$,$\alpha 2$) - embankment height (*h*) - embankment width (*s*)
2	Excavation, delve, crater		- slope gradients ($\alpha 1$,$\alpha 2$) - excavation depth (*h*) - excavation width (*s*)
3	Terrain stair (climbing)		- stair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

Table 1. Parameters of evaluation of the essential microrelief forms

The value estimation of C_{12} is to be determined on the basis of abovementioned parameters. The estimation proceeds in this way:

- At the microrelief forms No. 1 and 2 (name according to Table 1*)* we have to know at least two evaluation parameters: h, s or $\alpha 1(\alpha 2)$, s or $\alpha 1(\alpha 2)$, h. The third evaluation parameter is easy deducible by use of the under mentioned functions (*see 6*).

$$\alpha_i° = arctg \frac{h}{(s/2)} \; ; \qquad \alpha_i\% = \frac{h}{(s/2)} 100 \tag{6}$$

  In doing so we result from the presupposition that for the event of microrelief form traffic ability, the value of gradient $\alpha 1(\alpha 2)$ must not exceed definite top limit inferred from vehicle parameters.
  It results from the abovementioned facts that for particular vehicles and gradients of microrelief forms the values α_{mez} are determinable and these values will indicate specific limits of traffic ability of microrelief form by a vehicle and thus also values of coefficient C_{12} on the basis of under mentioned conditions:

  1) $\alpha_i < \alpha_{mez}$ then $C_{12} = 1$;
  2) $\alpha_i > \alpha_{mez}$ then $C_{12} = 0$

  The first condition and value $C_{12} = 1$ is valid providing that a microrelief form has not from the point of view of ratio of its size and total length of vehicle route the significant impact to the overall time needed for passing through the total length of vehicle route, i.e. a vehicle will pass over this mini microrelief in a relatively little time.

- At the microrelief forms No. 3, 4, 5, it is sufficient to compare evaluating parameter h (s) with parameters of vehicle traffic ability and this similar way to determine the value C_{12}.

If the microrelief form has indispensable dimensions and the time for its overcoming is with regard to overall time of vehicle movement indispensable, we have to compute the coefficient of vehicle deceleration in compliance with methods described at Chapter 3.1 (The impact of microrelief gradients to cross-country mobility).

4. CARTOGRAPHIC VISUALIZATION OF RELIEF IMPACT ON TRANSPORT

For the cartographic visualization of relief and microrelief impact on transport is possible to use relief (elevation) models as follows:

- raster model – GRID (quadrate pixel of terrain relief has assigned just one height);
- matrix model (each corner point of square or rectangle has defined height, it is possible to interpolate heights of the intermediate points between points given);
- triangular model – TIN;
- contour line model has heights at relation to the defining point incumbent on points of intersection of contour surface and terrain relief (height coordinates change parametrically pursuant to contour line equidistantion);
- other models (profile model, hachure model etc).

For the relief impact evaluation we used Digital Terrain Model 1:25 000 (DTM 25) and matrix elevation model of the Czech Military Geographical Service with the elevation data accuracy from 3 to 15 meters.

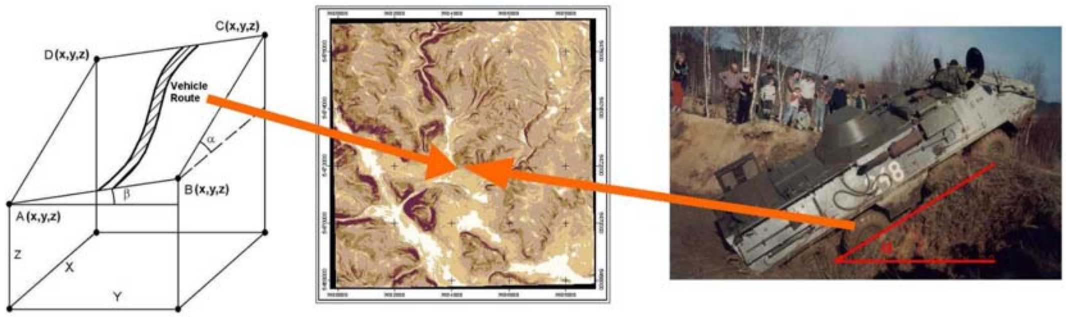
Our cartographic research was also limited and focussed on some microrelief forms which are not engaged in relief data bases and in topographic map 1:25 000. Beside topographic map 1:25 000 we had to use the old military maps 1:10 000, where are displayed more microrelief forms and then we had to realise the terrain surveying to compare the data base, maps and reality. The bypasses of the micro relief forms were very important for the mathematical and cartographic simulation and cross-country mobility modelling and visualization.

The new more precise cross-country mobility analyses based on the mathematical and statistic methods verified and evoked the need of relief elevation data accuracy approximately 1 meter (0,5 m in flat terrain) and the needs of micro relief surveying.

We have prepared the new laser scanning focussed on the new digital elevation models of the Czech Republic. First 4. generation GRID model (max. elevation error 1 m) and followed 5. generation TIN model (supposed standard elevation deviation 0,18 m in uncovered and 0,30 m in covered terrain) will better correspond with the above mentioned needs and the rescue vehicle dimensions for the more precise analyses and cartographic visualisation.

As a result of our particular research we created a cross-country mobility relief maps 1:25 000 for main special vehicles which are able to go across terrain (tanks, heavy wheeled and tracked vehicles, personal vehicles and so on. Second result was finding and displaying of the shortest, fastest, or securest path in terrain using mentioned methodology.

Using above mentioned methodology, ARC GIS SW and digital relief model we created the relief coverage of the cross-country mobility map 1:25 000 – CCM 25 (Figure 5).



Symbol	C11	Průchodnost	Legenda
	0	NO GO	nad 35°
	0-0.1	NO GO	28°-35°
	0.1-0.2	SLOW GO	21°- 28°
	0.2-0.5	SLOW GO	10°- 21°
	0.5-0.7	SLOW GO	6°- 10°
	0.7-1	GO	0°- 6°

Figure 5. Testing and GIS modeling of the slope angle influence on the vehicle speed

5. CONCLUSIONS

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 to optimize the rescue procedure. The cross-country mobility methodology is possible to exploit for terrain rescue vehicle navigation adapting the procedure for the 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. 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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