MODELLING AND CARTOGRAPHIC VISUALISATION OF TRANSPORT DURING CRISIS SITUATIONS AND MILITARY OPERATIONS

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ABSTRACT: The goal of this paper is to identify the critical spots on the roads and in terrain, which are important for transportation control, traffic accident analyses and especially for the rescue operations management during the crisis situations and disasters such as floods, fires, storms, military operations and so on.
In paper are included: technical parameters of the critical spots on the roads, their attributes and specifications; critical technical parameters of the transportation vehicles; common criterions for the road critical spots determination, place (coordinates) determination and description of the critical spots.
In the cases when we are not able to use the road net (due to damaged or destroyed segments and objects) we must provide the complete cross-country mobility analyses using the terrain futures also and we have to consider the influence of the relief slopes, micro relief forms, soils, vegetation, hydrography, roads, build-up areas, meteorological factors and so on. 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 our research to verify that methods. For the testes we used the basic military (wheel and tracked) vehicles and common ESRI SW for the evaluation and cartographic displaying of the research results.

1. INTRODUCTION

Geographical support is very important and indispensable element in solution of prediction system and resolution of elimination of a crisis situation impact.
The parts of traffic infrastructure especially the roads are the most critical objects of the landscape, with condition formation of crisis situation and are important for rapid service of rescue teams for elimination of crisis state as well.
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.
For cartographic support during solution of crisis state is necessary to determine the critical spots on the roads and in terrain, which are able to endanger transport or are able to reduce the secondary impacts (logistic, ecology impacts, security and so on). For modelling and cartographic visualization of transport is necessary to evaluate the

cartographic data sources which correspond with the methodology of the shortest, fastest or securest path finding using the road net or terrain. The rescue teams have mostly used the paper maps or navigation systems to reach the crisis places, but in many cases the maps does not correspond with real time situations or navigation systems are not supported with some data sources like damaged roads or bridges, bypasses, traffic jams, soils characteristics, angles of relief slopes, real hydrographical attributes (e.g. during floods), meteorological data (temperatures, precipitations), vegetation features, etc. The rescue operations are often not successful due to lack of precise data and lack of transport evaluation methodology which has to be implemented in navigation rescue systems. The goal of this paper is to present not only the limited road spots but also the geographical factors which have to be considered in transport analyses and their cartographic visualization. There are also examples of the cartographic visualization results in paper using tested geographical features and their characteristics.

2. CRITICAL SPOTS ON THE ROADS

For determination of the critical spots on the roads we have to consider the technical parameters of the critical spots on the roads, the transport vehicles technical parameters and the general criterions.

Technical parameters of critical spots (stages, objects) on the roads determining the formation of crisis state were forecasted on the basis of the expert evaluation, especially with the traffic and crisis management departments using the Czech Army topographic maps – see table 1.

Technical parameters of transport vehicles used for transportation (which are evaluated at the same time as the technical parameters of critical sport)
are especially:

- maximum rod speed;
- vehicle length (including trailer);
- vehicle width, vehicle weight including cargo;
- vehicle height;
- turning radius,
- maximum gradability,
- off-road transport ability .

Common criterions see too Cleric (2006), Fuchs (2006) - which are not analysed using general geographic data - are especially:

- sectors with abnormal traffic density;
- sectors of frequent road traffic accidents;
- maximum traffic carrying capability of sector;
- sector with limited bypass ability (length and parameters of bypass);
- sectors with limited parking areas;
- speed limit of the sectors;
- sectors with uneven surface;

- importance of road sector (highway, road of international importance...);
- time of the road sectors repair;
- importance of sector for the urban conglomerations transport connection;
- the importance of the sector for the strategic connection (e.g. important institutions, traffic services locations, important military objects etc.);
- area risks (flood area, traffic ability in winter, closeness to chemical object, accident frequency and so on).

Technical parameters of critical spots	**Specifications**
Unsatisfactory parameters of roads sectors i. e. width of lines, number of lines, loading limit of roadway including lengths of this sectors	Especially ride in convoy
Limitary pass ability of roads sectors due to weather	Roads passable: 1) all weather 2) all weather with limitation 3) good weather
Sectors of highways modified like runways	
Narrowed down spots on the roads	Sectors longer or shorter than 250 meters
Sectors of roads with limit curve radius (sharp curve)	< 25 meters
Sectors of roads with critical gradient (downhill grade)	> 7 %
Limit parameters of tunnels	Height, width, length
Scaffold bridge	Road, street
Road galleries	
Parking areas and parking spaces – limit technical parameters	If they are necessary for the transport.
Dividing line of surface materials	
No-go sectors of roads and streets	
Technical parameters of track (same like roads)	If they will be used
Limit parameters of bridges	Width of roads, length, load capability, surface material
Critical spots of under crossing	Minimum clearance height and clearance width
Limit parameters of aqueducts	Minimum clearance height and clearance width
Technical parameters of roads and railways crossing	Different control co-operation
Technical parameters of roads and highway crossing	Unsatisfactory parameters of road sectors and limit bridge parameters

Table 1. Technical parameters of critical spots and their specifications

Exactly localization of accident or crises situation is very important during resolve of prediction system and resolve elimination of impact the crisis situation. The place we can locate by someway:

- grid coordinates (x,y,z) in geodetic datum e.g. WGS 84,
- geographic coordinates φ,λ
- description.

3. TERRAIN CRITICAL SPOTS

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

- GO terrain (transport without problems);
- SLOW GO terrain (transport is limited or reduced);
- NO GO terrain (transport is very dangerous or not possible).

From the viewpoint of used transport means for movement and from the respect of the cross-country mobility, we identify the following basic types of terrain:

- Terrain suitable for tracked vehicles;
- Terrain suitable for wheeled vehicles;
- Terrain suitable for other types of transport means;

Geographical factors affecting the cross-country mobility

The factors $\mathbf{F_i}$ affecting the cross-country mobility and selection of approach routes (in positive and also negative standpoints) are especially:

$\mathbf{F_1}$ **Relief:** F_{11} - slope gradient, F_{12} - micro relief forms;

$\mathbf{F_2}$ **Vegetation:** F_{21} - spacing between stems, F_{22} - stem diameter, F_{23} - tree height, F_{24} - kind of tree, F_{25} - nature of root system;

$\mathbf{F_3}$ **Soils:** F_{31} - kind of soil, soil type, F_{32} - ground cover (kind of plants), F_{33} - skid resistance;

$\mathbf{F_4}$ **Climatic conditions:** F_{41} - dry season, F_{42} - moist season, F_{43} - wet season;

$\mathbf{F_5}$ **Hydrology:** F_{51} - kind of waters, F_{52} - depth, F_{53} - width, F_{54} - flow speed, F_{55} - characteristics of bottom, F_{56} - characteristics of bank (bank slope);

$\mathbf{F_6}$ **Settlements:** F_{61} - block build-up area, F_{62} - uptown, F_{63} - cottages;

$\mathbf{F_7}$ **Communications:** F_{71} - highways, F_{72} - 1st category road, F_{73} - 2nd category road,

F_{74} 3rd category road, F_{75} - hardened ways, forest and cart ways;

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).
It is possible, for purposes of cross-country mobility simulation, i.e. dependability of travel speed of rescue vehicles on geographic factors, to use various material (natural, artificial) and intellectual (describing, graphic, mathematical) models, see also **¡Error! No se encuentra el origen de la referencia. - ¡Error! No se encuentra el origen de la referencia.**.
For purpose of cross-country mobility simulation, the methods of mathematical simulation (statistic, analytic and statistic-analytic models) appear as the most exact ones.
Analytic models consist of the systems of mathematic equations (algebraic, differential, partial and other) and can be deterministic (when only mean values of monitored parameters of cross-country mobility are used) or stochastic ones (when probability distribution of values of monitored parameters are used).
Statistic models have the stochastic character (they are based on generating of events by mechanism of random events). These models are not factual indeed by reasons of rare possibility to make practical tests for verification of cross-country mobility simulation.
Common impact of geographic factors on deceleration (or interruption) of vehicle movement at given section of route can be expressed by following relation:

$$v_j = f(v_{\max}, c_1, c_2, ... c_n), \quad j = 1...k \qquad (3.1)$$

where

v_j - vehicle speed at j-section of vehicle path *[km/h]*
v_{max} - maximum vehicle speed at communications [km/h]
c_i - i-coefficient of deceleration due to factor F_i computed for j-section with invariable values c_i.
n - number of geographic factors effecting at given section of terrain
k - number of sections on vehicle path

The determination of resultant value of vehicle speed according to relation (3.1) is not factual because of impossibility of determination of mutual relation between the set of coefficients c_i and mentioned speed namely from the point of view of, as the infinity of relationship number between abovementioned geographic factors given by the time and space variability of landscape, as from the point of view of unreality of testing of cross-country mobility at the entire known specific forms of terrain.
The relation (3.1) is reducible indeed to formula (see relation (3.2) and also 8), where is determined the cross-country mobility differential dependence (vehicle running speed) on the partial geographic factors (coefficients of deceleration) or on the aggregate coefficient of deceleration „$\mathbf{c_j}$“ at given j-section of vehicle path .

$$v_j = v_{max} \cdot \prod_{i=1}^{n} c_i, \quad i = 1...n, \quad j = 1...k \; ; \qquad \text{where} \qquad \prod_{i=1}^{n} c_i = c_j \;\; \text{pro } i = 1,\dots n \qquad (3.2)$$

Furthermore, it is possible to calculate resulting impact of all the geographic factors on vehicle running speed (deceleration) on the entire path at a terrain expressed by formula:

$$v = \frac{1}{\sum_{1}^{k} w_j} \sum_{1}^{k} w_j v_j, \quad j = 1...k, \qquad\qquad w_j = \frac{s_j}{\sum_{1}^{k} s_j}, \qquad (3.3)$$

where

v [km/h]	- average vehicle speed on the entire path at a terrain;
w_j	- weight subsidiary to value vj in dependence on the section length sj;
s_j [km]	- length of j-section;
k	- number of sections on vehicle path.

While an impassable section on vehicle path occurs at the terrain, then such a section is not included into calculation of overall speed. If that case occurs, speed „v“ of the entire path (determined by start and end of a path) is not calculated, but partial speeds v_p (determined by start of a path, impassable sections and the end of a path). It is necessary to select a detour for abovementioned impassable sections.

Particular coefficients of speed deceleration can be determined (with regard to other geographic factors) relatively independently (e.g. deceleration coefficient of relief slope impact) or dependently (e.g. deceleration change caused by impact of soil parameters and by waters in dependence on climatic conditions).
Particular deceleration coefficients adherent to specific geographic factors can be dependable on a number of partial factors (e.g. dependance of deceleration coefficient of the impact of vegetation on spacing between stems, stem diameters, parameters of vehicle etc.) .
Synthetic character of impact of mentioned factors on cross-country mobility can be simulated (on the assumption that an adequate quantity of practical tests can be made) by use of the method of discrimination analysis referred-to Rybansky (2002).
Following chapters describe the classification of particular geographic factors abovementioned and method of determination of it´s impact on cross-country mobility.

Slope of terrain relief

In general, slopes of relief are most important for transport analyses and can be established from the topographical (final and plain) elementary areas that are generalized morphological picture of the earth surface that can be expressed by a continuous function

$$z = P_n(x, y) = \sum_{r=0}^{n} \sum_{s=0}^{n-r} a_{rs} x^r y^s \quad , \tag{3.4}$$

that is a polynomial of n-th level of variable coordinates x,y with coefficients a_{rs} determined by heights z .

According to the research results and generalization we classify terrain by angles of slopes (moving upwards the slope) for heavy wheeled vehicle movement as follows:

- GO terrain slope < 30%;
- SLOW GO terrain 30% < slope < 50%;
- NO GO terrain slope > 50%.

Using ARC GIS SW and digital terrain model 1:25 000 we could create the relief coverage of the cross-country mobility map 1:25 000 – CCM 25 (figure 1).

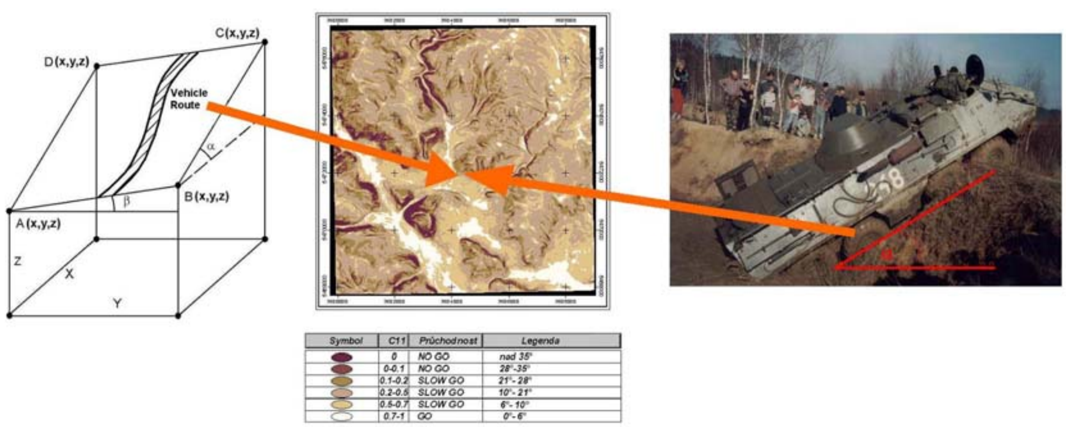

Figure 1. Testing and GIS modeling of the slope angle influence on the vehicle speed

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 digital terrain models 1:25 000 is not corresponding with the required elevation accuracy for more precise analyses especially apart from flat terrain.

Vegetation

According to the research results and generalization we classify terrain by vegetation for heavy wheeled vehicle movement as follows:
Tree stem diameter (see testes – figure 2) measured at a height of 1.5 m above a terrain:

- GO terrain diameter < 5cm,
- SLOW GO terrain 5cm < diameter < 15cm,
- NO GO terrain diameter > 15cm,

Tree spacing (average distances between tree stems):

- GO terrain 5m < spacing,
- SLOW GO terrain 3m < spacing < 5m,
- NO GO terrain spacing < 3m.

Figure 2: Vegetation overcoming testing and CCM 25 coverage visualization

For more precise analysis we used digital forestry map with the guaranty of the frequent data up-dating and the relevant tree stem diameters and spacing attributes. The topographic map 1:25 000 with the map up-dating period from 6 to 8 years were not appropriate due to trees growth and also above mentioned attributes changing.

Hydrology

The cross-country mobility is affected especially by the following main factors:
Width of surface water features:

- GO width < 1.5m,

– SLOW GO 1.5m <width < 18.0m,
– NO GO width > 18.0m;

Depth of surface water features:

– GO depth < 0.6m,
– SLOW GO 0.6 < depth < 1.2m,
– NO GO depth > 1.2m;

Stream velocity, where we identify the flowing water:

– GO velocity < 1.5m/s
– SLOW GO 1.5m/s < velocity < 2.5m/s
– NO GO velocity > 2.5m/s.

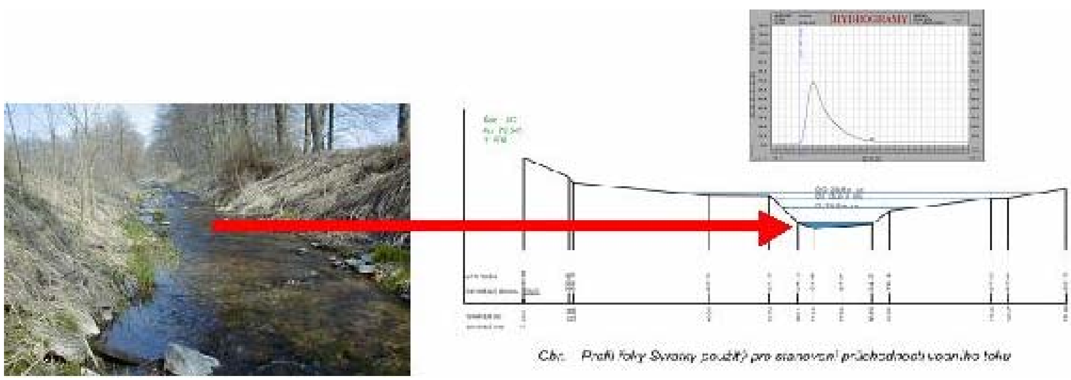

Figure 3: GIS modeling of the water features influence on the vehicle speed

For more precise analysis we used river profile characteristics (water depth, velocity) from Czech Hydro-Meteorological Institute with the data refreshing guaranty with the guaranty of the frequent data up-dating during day. The topographic map 1:25 000 and digital terrain model 1: 25 000 with the map up-dating period from 6 to 8 years contain only average long time profile attributes.

Soil conditions

According to percentage content of clay particles in size less than 0.01 mm and the penetrometer measuring testes , the soil can be divided into the following groups:
- **GO soils** (sandy clay and clay sand on a firm ground and clayish soil with higher thickness during dry weather);
- **SLOW GO soils** (clayish soil during wet weather or silty clay, marl and powdered soil during dry weather);

- **NO GO soils** or soils with marginal traffic ability during dry weather (mud, turf, gravel, rocky, stony).

For analysis we used soil characteristics (soil type, granularity) from Czech soil synthetic maps 1:200 000 and vehicle carry ability we determined according to the penetrometer measuring. The digital terrain model 1: 25 000 of the Czech geographical service does not contain some soil attributes.

We also had to provide the research procedure to determine the influence of micro relief, climate conditions, urban areas, roads to determine the deceleration (or interruption) of movement of certain rescue vehicle in terrain.

4. 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 when we know the procedure for each type of vehicle knowing its technical parameters.
For more precise analyses is usually not possible to use only basic topographical (geographical) databases, but also another data sources with the guaranty of the frequent data up-dating. The topographic maps or DTM 1:25 000 with the map up-dating period from 6 to 8 years are usually not appropriate.
We usually have used the road net for the rescue vehicles transport and we have searched the shortest, fastest or securest way using road maps or navigation, but in many cases we must use the complete net analyses when the road are crowded, or some road segments can be dangerous.
In some cases (floods, forest fires, etc.) we cannot use only road net but also terrain to get the places of crisis situations or natural disasters. In these cases we have to exploit many geographic data sources. 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 which correspondent with the vehicles dimensions and technical parameters. Radar or laser scanning methods are appropriate to reach that data accuracy. Soil data is better to exploit from soil types maps or databases, terrain verification and practical testing is necessary. Hydrological data have changed very much in real time. For example tested Svratka river in the Czech republic had discharge amount 1 m^3 / sec. in morning and 30 m^3 / sec. in evening in one day after precipitation and we usually cannot use GIS data for exact analysis without the on line connection with hydrological service and data transferring. The actual real time cooperation with hydro-meteorological service is necessary due to soil characteristics hangings during wet and cold period of year, especially in winter season when are rimes or snow falls predicted.

Knowing the methodology, having real time accurate data we could navigate rescue vehicles using roads or terrain. The focus of our research is to create methodology and GPS navigation system not only for the rescue vehicle drivers and transport managers, but also for some unmanned vehicles navigation in some very dangerous situations (radioactive, chemical pollution, etc.) where driver lives are endangered.

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