Cross country movement - theory, practice, field tests

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1.

Introduction

Natural Environment

- ***Natural environment*** has a big ***impact on*** military or non-military ***activities of armed forces***
- ***Good knowledge of natural environment*** in the Area of Responsibility is an assumption of a mission success
- It is necessary to ***evaluate the impact of natural environment*** on the given activity
- Classical and digital models of territory (maps, charts and digital spatial data) help to understand given territory
- ***The advance methods of analysis*** of main military geographic and hydro-meteorological properties of natural environment are used only particularly in the areas of responsibility

Natural Environment

- ***Presentation*** of geographical, meteorological and hydrological information and results of spatial data analyses ***in Command and Control Systems*** (C2S) are in a form of a ***Recognized Environmental Picture (REP)*** as a part of a ***Common Operational Picture (COP)***
- ***Present visualization is*** often ***static*** in the classical and electronic forms and ***limited*** by amount of graphical items which can be visualized in a picture
- Some ***information loses*** its ***value*** because of rapid changes of given object or phenomena unless on-line up-dating system is applied

Process of Terrain Analysis for Armed Forces

- ***Definition of requirements*** for analysis
- ***Definition of goals*** of analysis
- Creation of ***physical models*** of analysis - sources:
  - technical properties of used weapon or weapon systems
  - used command and control system
  - definition of interaction of landscape, used weapon and used command and control system
  - creation of physical model of given activity and given environment
- Creation of ***mathematical models***:
  - formalisation of physical models – derivation of mathematical relations and equations
  - discussion of reliability of calculations and created models
- Creation of ***processing models*** in GIS
- ***Models verification*** and their corrections
- ***Incorporation models*** into practice

CCM and Geographic Factors

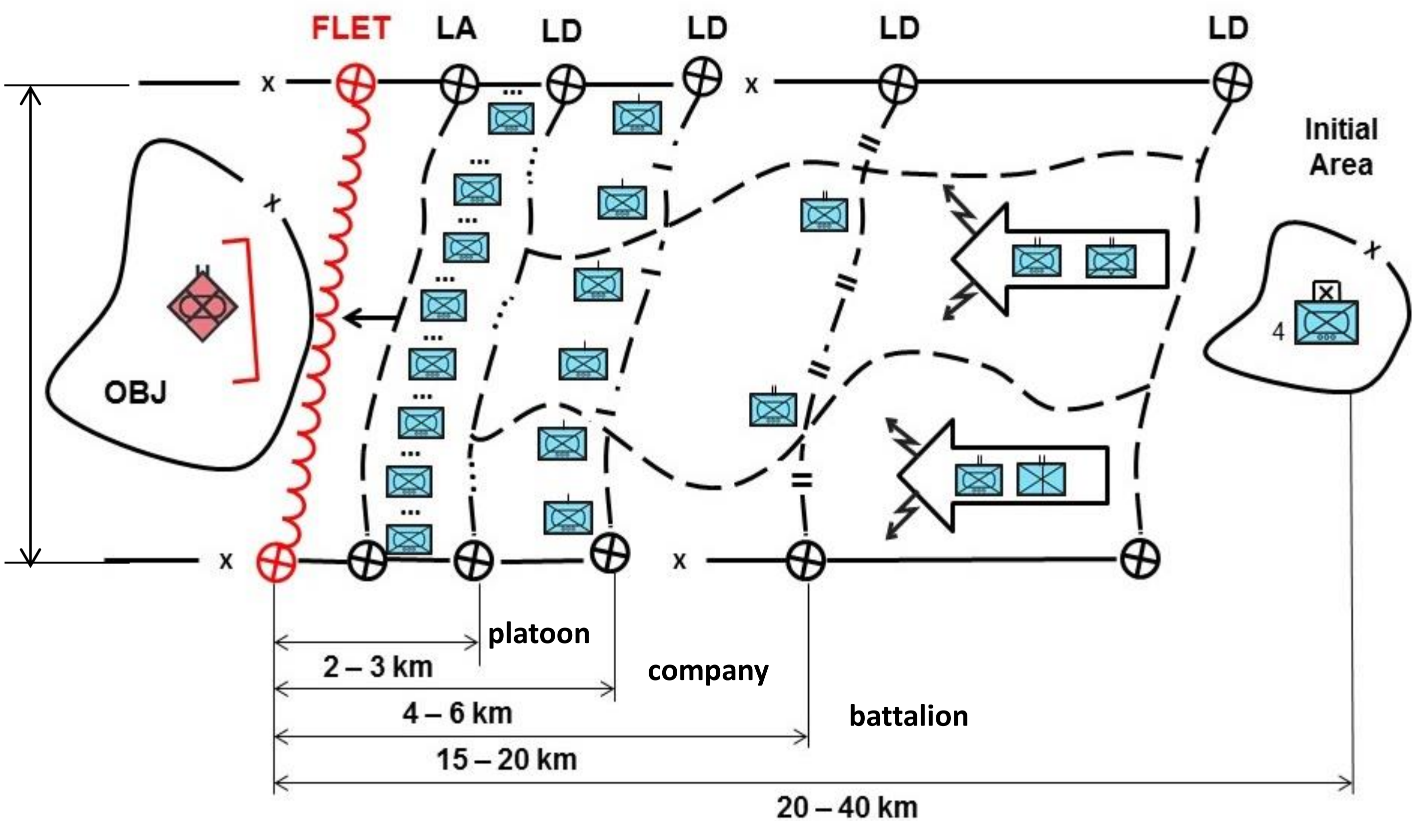
- ***Main goal of CCM theory*** is to evaluate the impact of geographic conditions on of movement of certain vehicles in terrain
- ***Mobility of*** given ***unit*** is given by the movement of individual vehicles in the unit
- For the ***purpose of classification and qualification*** of geographic factors of vehicle movement, it is necessary to determine:
  - particular degrees of CCM
  - typology of terrain practicability by kind of military (civilian) vehicles
  - geographic factors and features with significant impact on CCM
- Three ***degrees of CCM*** are usually as a final results of impact evaluation:
  - ***GO*** - passable terrain
  - ***SLOW GO*** - passable terrain with restrictions
  - ***NO GO*** – impassable terrain

CCM and Geographic Factors

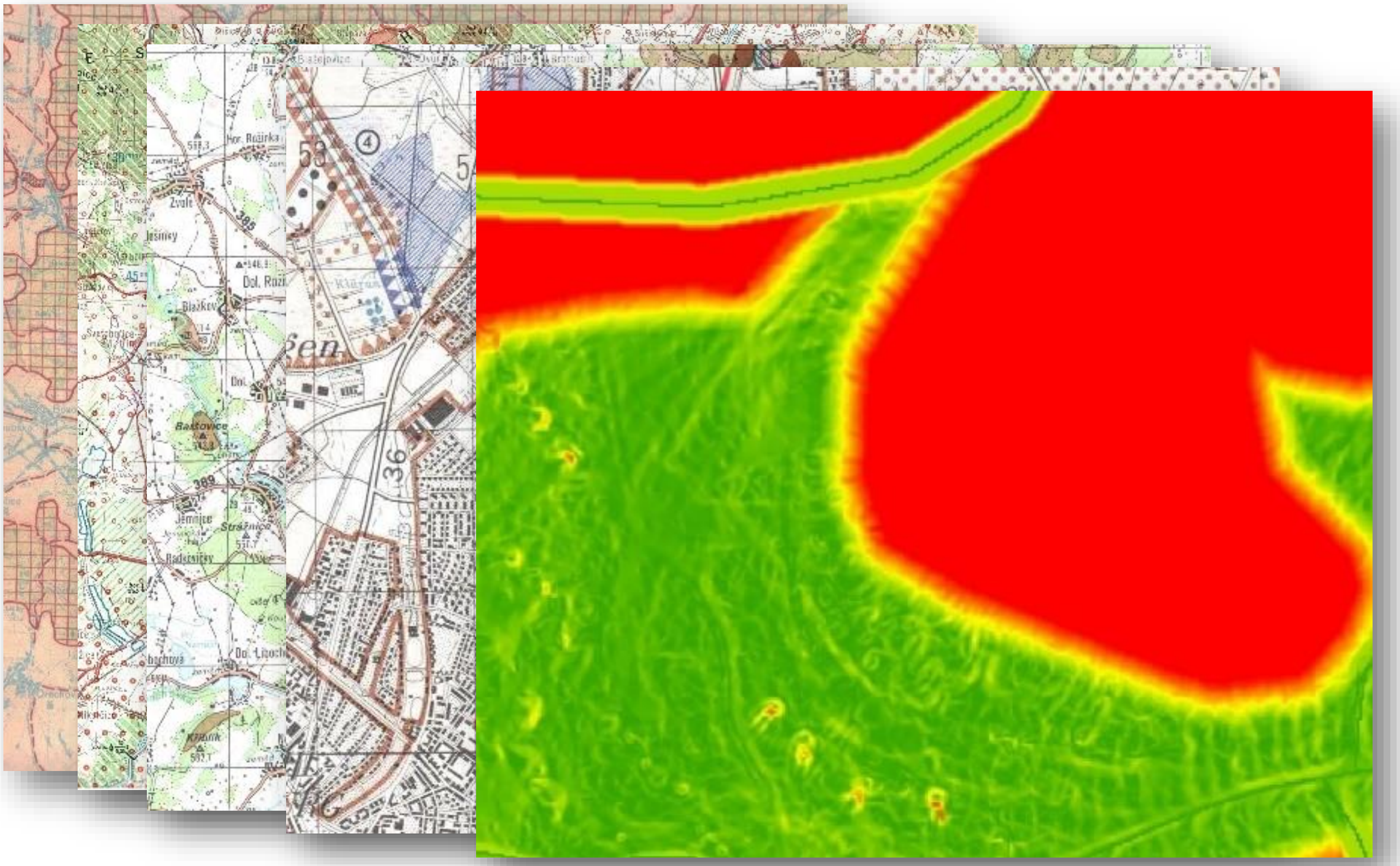
Geographic factors determining CCM and the selection of the access routes are following:

- gradient of terrain relief and micro relief shapes
- vegetation cover
- soil conditions
- meteorological conditions
- water sheets, water courses
- settlements
- communications
- other natural and man made objects

AOI for CCM modelling



Development of CCM evaluation



Why is it important?

Tasks

- Transpoirt of soldiers to given place and on time
- Protect their life and health
- Prevent material damage
- Protect nature

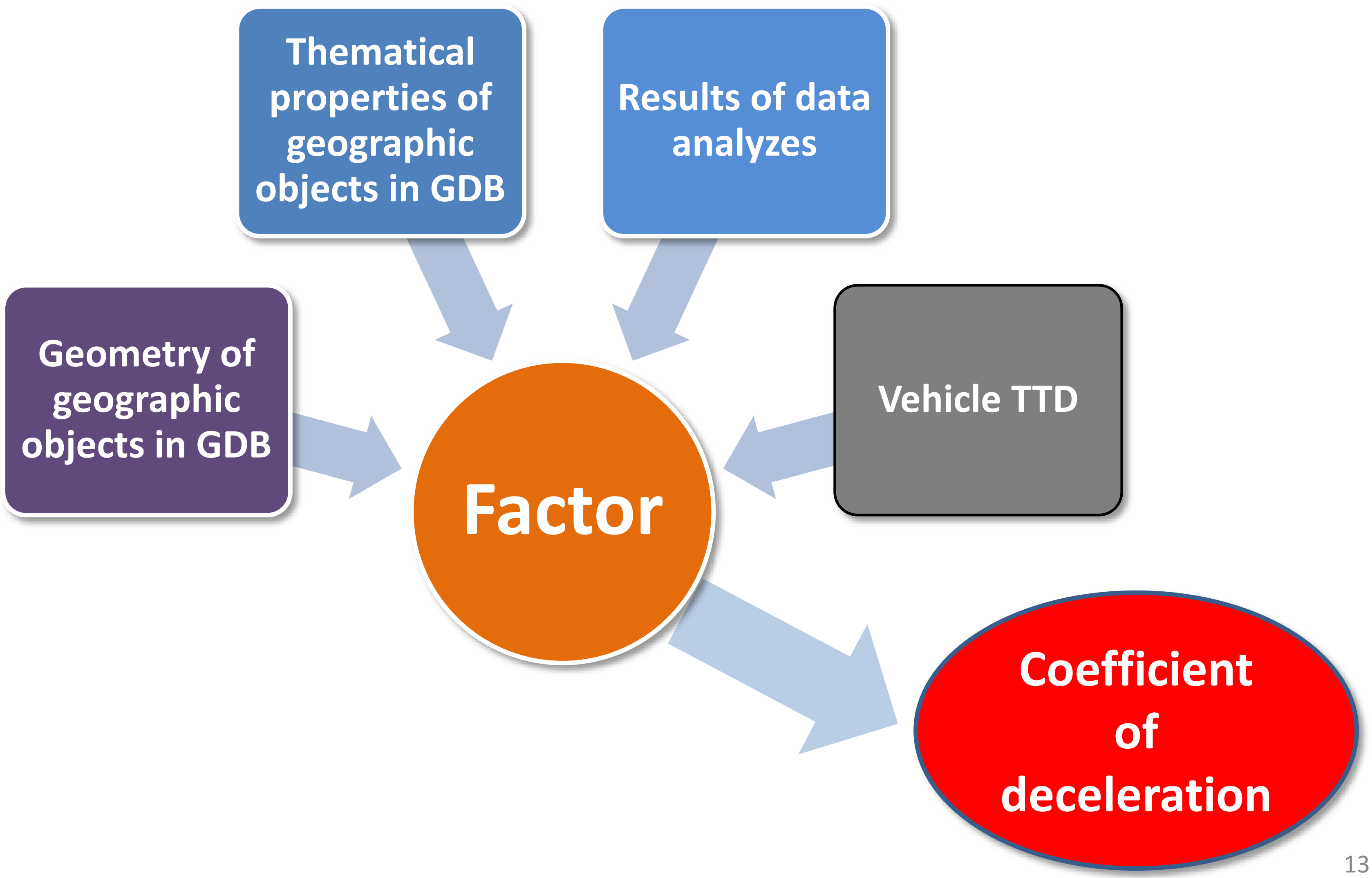
Main questions of CCM

- Is it possible to overtaken the area?
- If yes – where?
- How quick is it possible to drive?

CCM modeling

- Main goal of CCM – impact of given part of terrain on given vehicles
- Inputs:
  - Geographic factors
  - Vehicle technical properties (TTD)
  - Driver abilities and condition
- Classification of geographic factors – determination:
  - separate degree of CCM
  - typology of terrain according to given vehicle
  - determination of the most important factors for CCM
- Final results of CCM – three degrees:
  - GO – passable terrain
  - SLOW GO – passable terrain with some restrictions
  - NO GO – impassable terrain

CCM modelling



2.

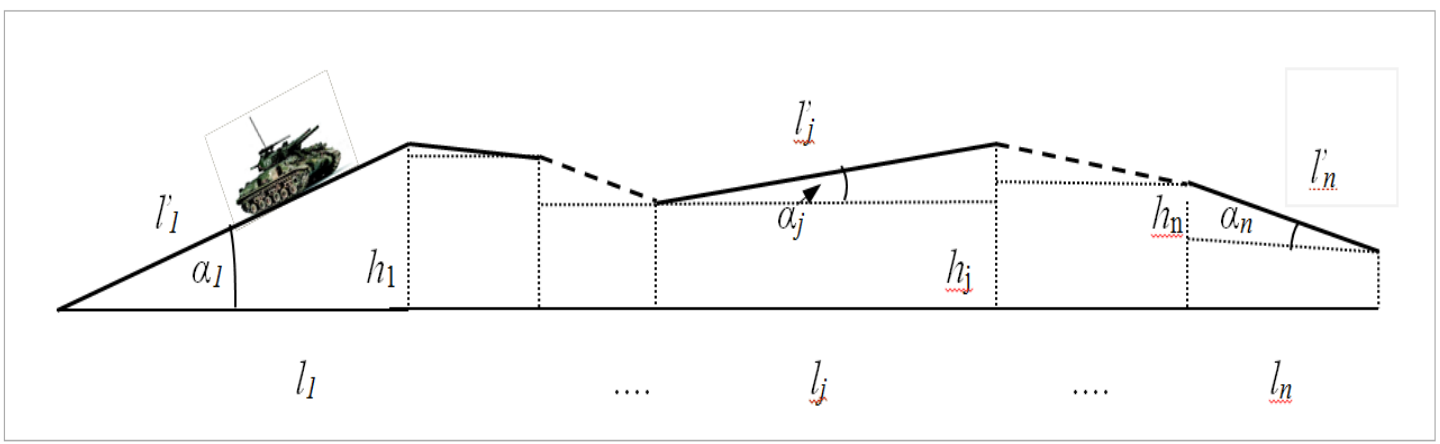
PHYSICAL MODELS CREATION

Physical Models Creation

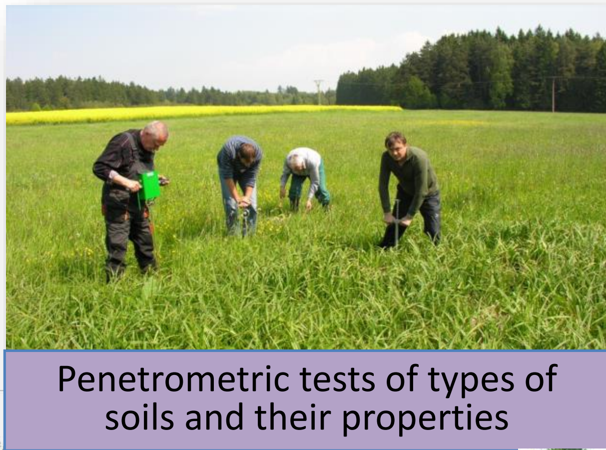
- Two possibilities:
  - the ***parameters of models*** are determined by ***regulations*** or ***instructions*** created usually on the base of previous measurements or experience – example Helicopter Landing Sites (HLS)
  - the ***parameters*** are ***developed*** on the base of ***field measurements*** – example – Cross-Country Mobility (CCM) – next example

Geographic Factors Evaluation

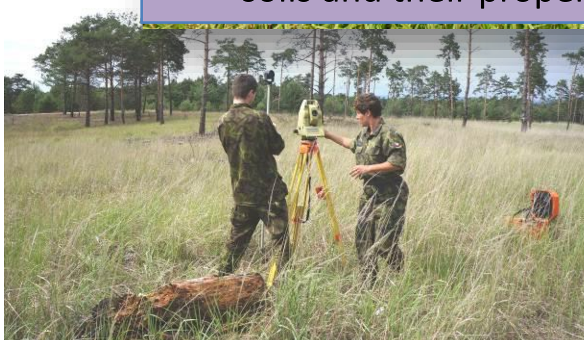
- ***Impact of*** given ***geographic factor*** can be evaluated as a ***coefficient of deceleration 'C_i'*** from the scale from 0 to 1
- Coefficient of deceleration shows ***the real (simulated) velocity of vehicle v_j*** in the landscape in the confrontation with the maximum velocity of given vehicle ***v_{max}***
- The ***impact*** of all ***n*** geographic factors can be expressed as a ***„real velocity“***:



Coefficients Determination – Field Measurements



Penetrometric tests of types of soils and their properties



Surveying of support´s values

Tests of military vehicles traficability

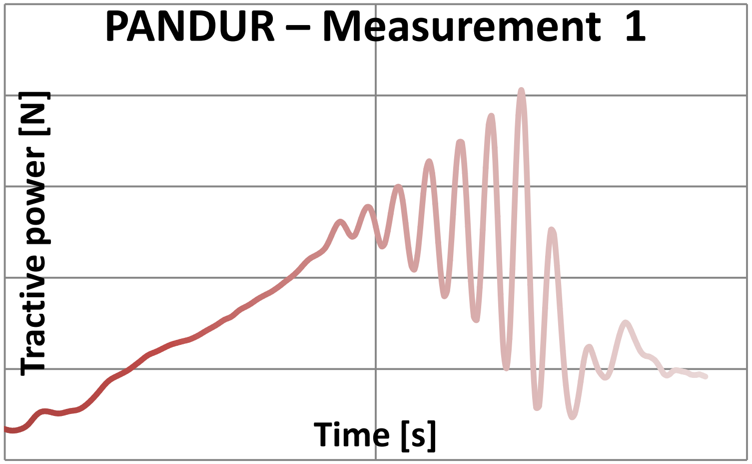
Coefficients Determination – Field Measurements

Přehled lokalit měření penetrometrických charakteristik půd na území ČR (24.5 – 25.5 2010)

č.	místo	x [m]	y [m]	h [m]	map. list	Δhoriz [cm]	Δvert [cm]	druh půdy	typ půdy	čas měření	vlhkost %	t °C
1.	Vatín	5485782	570029	542	C4	12,5	25,1	HP - PH	kambizem	8:00	34,5	+11,5
2.	Gajer	5519638	601484	526	B4	27,4	3,3	H	pseudoglej	10:00	36,5	+15,0
3.	Podrážek	5536097	586631	515	B4	20,1	11,1	JH - JV	pararendzina	12:00	41,2	+18,5
4.	Zivanice	5545279	545229	382	B4	1,7	16,6	P	kambiem arenická	15:30	17,1	+21,5
5.	Veltruby	5546714	512372	202	B3	26,5	16,5	PH - H	fluvizem	17:00	35,6	+23,0
6.	z. St. Splavy- u parkoviště	5605215	471834	257	A3	9,6?	5,3?	P	podzol arenický	19:00	25,3	+14,0
7.	Strašín (z. Říčany)	5539093	478476	390	B3	10,6	13,2	H	hnědozem	9:00	34,5	+15,5
8.	Turoveç (v. Sezim.Ústí)	5469953	483030	415				JP	pseudoglej	10:30	45,5	+18,0
9.	Horní Bolikov v. Studená	5448238	522407	657				PH - HP	kambiem modální-kámen	13:00	22,2	+20,5
10.	z. Olšany (v. Telč)	5449207	539634	620				?	glej	15:30	69,1	+18,5
11.	j. Branišovice	5422990	602432	215	D4	31,1	29,3	H	černozem na spraši	17:30	41,3	+20,5
A	2 km v. Svitavy	5512077	603520	452					zaplavené	9:00	-	+14,0
B	v. Kostice	5401100	646015						zaplavené	19:00	-	+19,0

Penetrometric tests of types of soils and their properties in various meteorological conditions

Dynamometric Testing of Vehicle Power



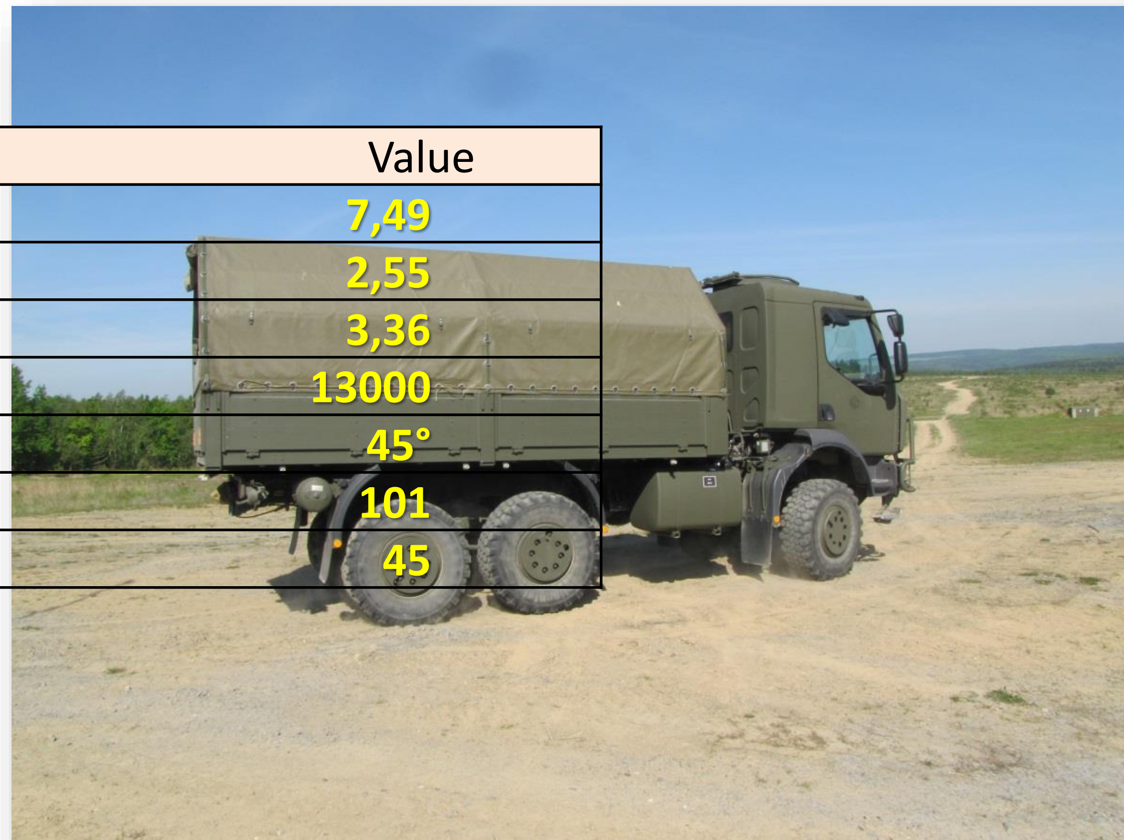
Tactical-Technical Data of BMP 2

Parameter	Value
Length [m]	6,73
Width [m]	3,15
High [m]	2,45
Weight [kg]	14000
Maximum climbing capability [°]	35°
Maximum road speed [kmph]	65
Maximum speed on dry soil [kmph]	40

BMP 2 ability

Tactical-Technical Data of Tatra T810

Parameter	Value
Length [m]	7,49
Width [m]	2,55
High [m]	3,36
Weight [kg]	13000
Maximum climbing capability[°]	45°
Maximum road speed [kmph]	101
Maximum speed on dry soil [kmph]	45



Tactical-Technical Data of Pandur II

Parameter	Value
Length [m]	7,84
Width [m]	2,77
High [m]	3,77
Weight [kg]	20800
Maximum climbing capability [°]	30°
Maximum road speed [kmph]	95
Maximum speed on dry soil [kmph]	60

3.

MATHEMATICAL MODELS

Set-up Conditions

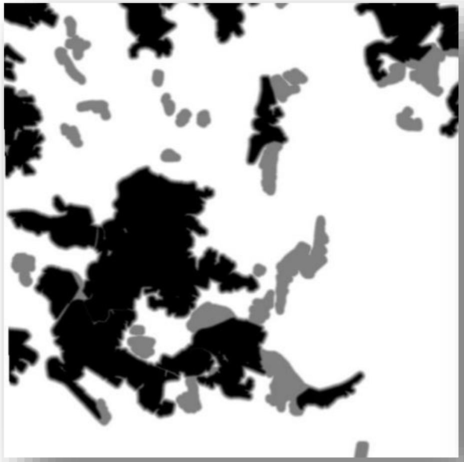
- ***Determination the conditions*** for each group of features coming into analysis
- Two ***ways*** are generally ***possible***:
  - ***no uncertaint***y is considered – crisp set analysis
  - ***uncertainty*** is considered:
    - data quality is entering into the calculations
    - fuzzy logic analysis is possible to apply

$$C_{21} = \begin{cases} 1, & for \quad sp \geq 5m \\ 0{,}5 & for \quad sp = (3{,}5)m \\ 0, & for \quad sp \leq 3m \end{cases}$$

C_{21} calculation for tree trunks spacing (TSC) - crips set

$$\mu(x) = \begin{cases} 0, & for \quad x > 0{,}5 \\ \dfrac{0{,}5 - x}{0{,}5 - 0{,}3}, & for \quad 0{,}3 \leq x \leq 0{,}5 \\ 1, & for \quad x > 0{,}3 \end{cases}$$

C_{21} calculation for tree trunks spacing (TSC) – fuzzy set



Mathematical equations

- Calculation of conditions include ***more variables*** - some are independent, some are dependent
- ***Deterministic and statistical procedures*** for equations determining
- Example (C_{11} coefficient)

$$C_{11} = \frac{G_{rad}T_{\max} - SH}{G_{rad}K_{\max}}$$

  - Where:
  - $G_{rad}T_{max}$ is maximum climbing capability of a vehicle on a terrain
  - $G_{rad}K_{max}$ is maximum climbing capability of a vehicle on a road
  - SH is mean value of slope gradient i given pixel
- ***Final calculation*** of modelled ‚real’ speed in a given pixel

$$v_j = v_{\max} \prod_{i=1}^{n} C_i, n = 1, \ldots, \mathrm{N}$$

- ***Reclassification*** speed value into given scale from 0 to 1
- ***Crisp set or fuzzy logic*** is possible to use

4.

SPATIAL (GEOGRAPHIC) DATA

Types of spatial data

Spatial data and data quality

- Technical quality - technical properties evaluation
- User value – evaluation of user properties
- Reliability – functionality in place and in time
- Examples:
  - DMÚ25 – LoD 5/15, specification using ACC
  - Digital elevation models – Mean square error of high

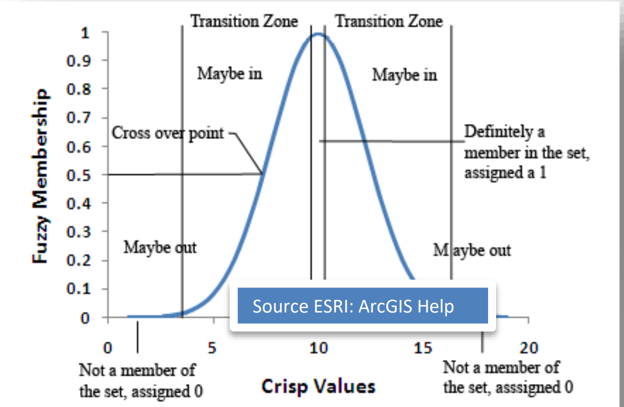
Code	Name	List of values	Remarks
ACC	Horizontal position quality	001 accurate	Adequate to product criterion
		002 approximate	Overtakes product tolerance
		003 uncertain	Position is estimated
		007 precise	Position is more precise then required

DEM	Structure	Mean square error		
		Open terrain	Settlements	Forests
SRTM	Points in grid 3 x 3″	16 m	16 m	16 m
DMR3	Points in grid 10 x 10 m	1-2 m	1-2 m	3-7 m
DMR4	Points in grid 5 x 5 m	0,3 m	No information	1 m
DMR5	TIN	0,18 m	No information	0,3 m

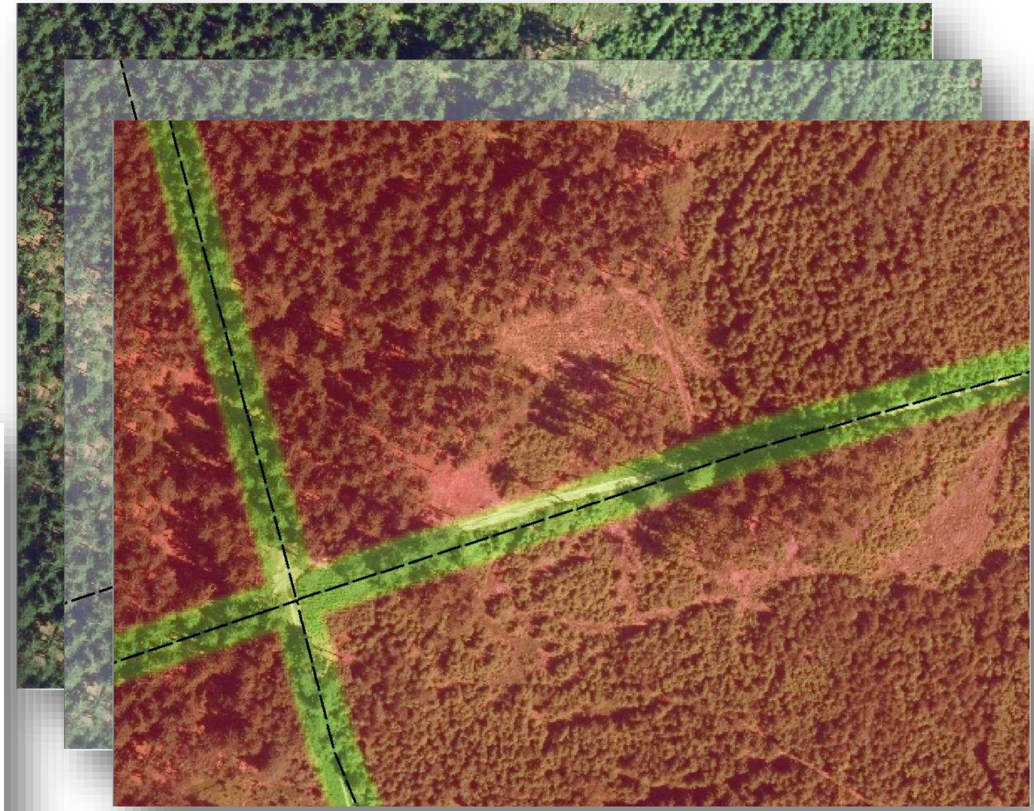
Data quality - examples

Uncertainty of data - solution

- Data quality – uncertainty in position and thematic properties
- Solution – fuzzy sets



Fuzzy membership function diagram



5.

PROCESSING MODELS

Data Sources and Programme System

- CCM – standard national databases:
  - DMU25 – vector data (MoD)
  - DMR3, DMR4, DMR5 – digital elevation models (MoD & CUZK)
  - Aerial images (WMS CUZK)
  - Synthetic Soil Database (MoD)
  - TTD given vehicles
- ArcGIS 10.x – programme system (Esri)

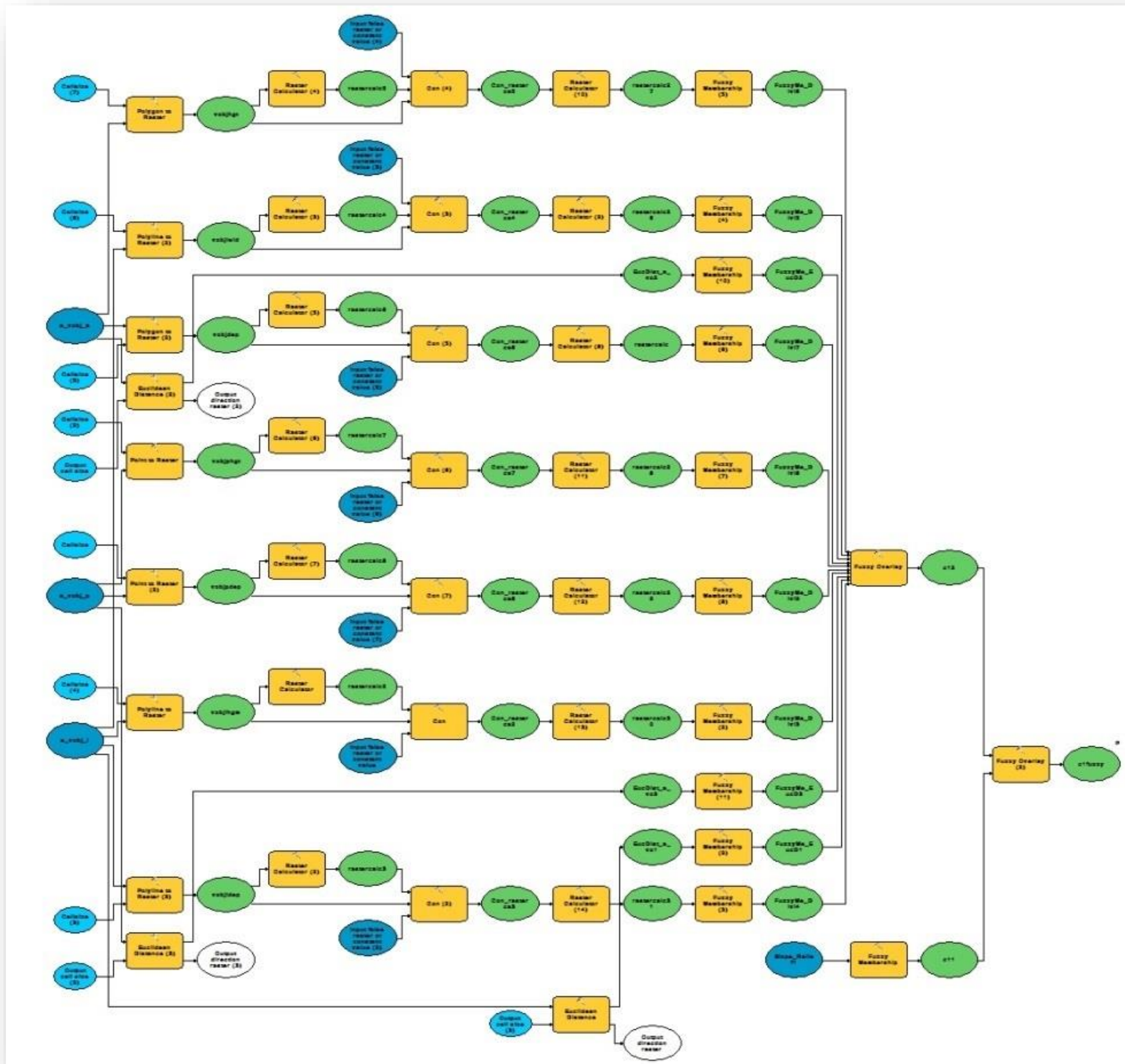
CCM – Fuzzy Logic Analyses

- Input ***data quality*** is considered:
  - different position accuracy
  - different data completeness
  - etc.
- Fuzzy Membership function and Fuzzy Overlay are used
- All coefficients are evaluated separately

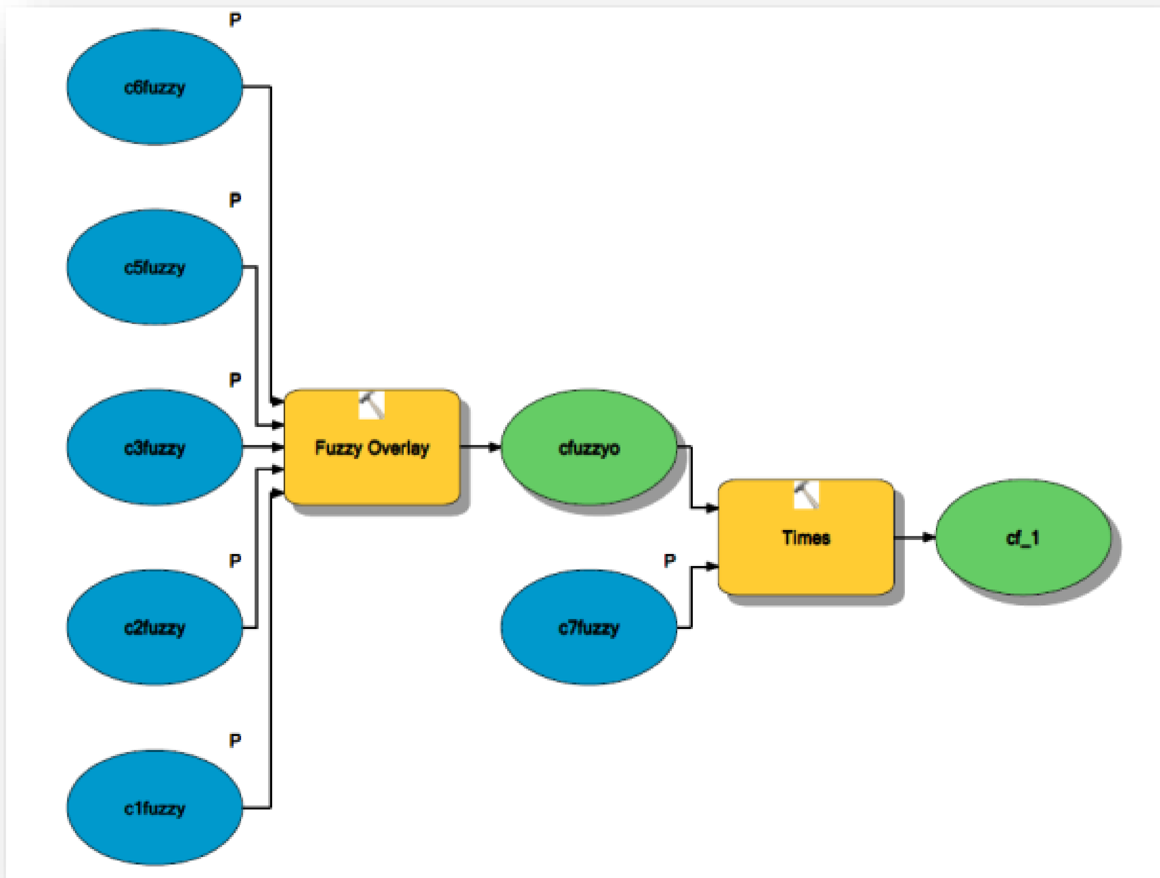
CCM – Fuzzy Logic Analyses

- ***Fuzzyfication*** for ***all particular coefficients*** on the base of data properties
- ***Euclidean distances*** are generally calculated with respect to the positional accuracy for each feature coming into evaluation
- Final deceleration is calculated from individual coefficients with the help of the tool ***Fuzzy Overlay***
- Result – ***cost map***
- Cost map can be used e.g. as an input for searching of an optimal route in a decision-making process in CCM

Processing Model of Coefficient C_1 Evaluation – First Variant



Processing Model of Final Coefficient of Deceleration Evaluation – First Variant



Processing Model of Coefficient C_1 Evaluation – Second Variant

Example of analysis of recorded trips - LOV IVECO

F1: $y = -0{,}0733x^2 - 0{,}2165x + 74{,}6$

F2: $y = -1{,}91x + 74{,}434$

F3: $y = -0{,}1499x^2 + 0{,}6234x + 70{,}949$

F4: $y = -2{,}0625x + 74{,}246$

F5: $y = -1{,}2023x + 62{,}232$

F6: $y = 5{,}604x + 36{,}325$

F7: $y = -0{,}0428x^2 - 0{,}1762x + 71{,}977$

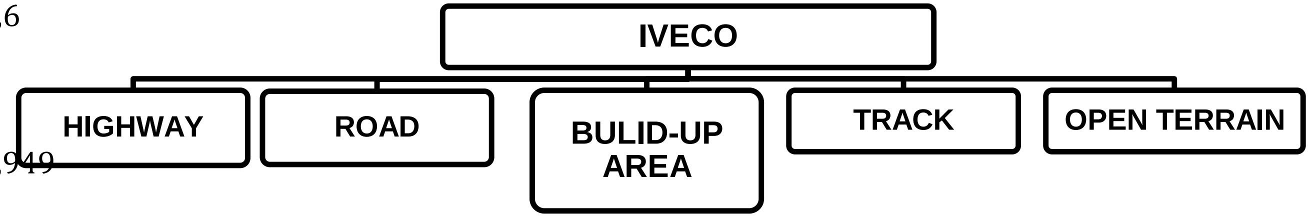
F8: $y = -1{,}9155x + 73{,}007$

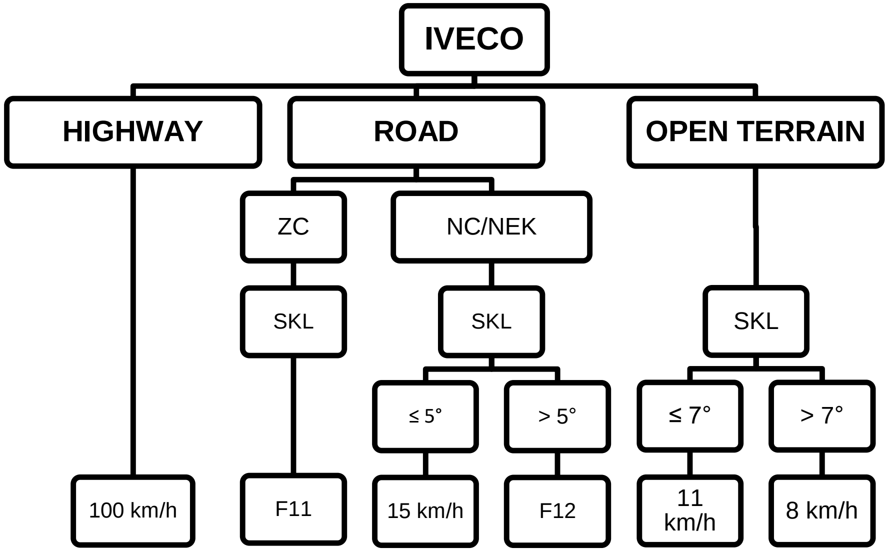
F9: $y = 1{,}4067x + 35{,}763$

F10: $y = -1{,}3067x + 41{,}325$

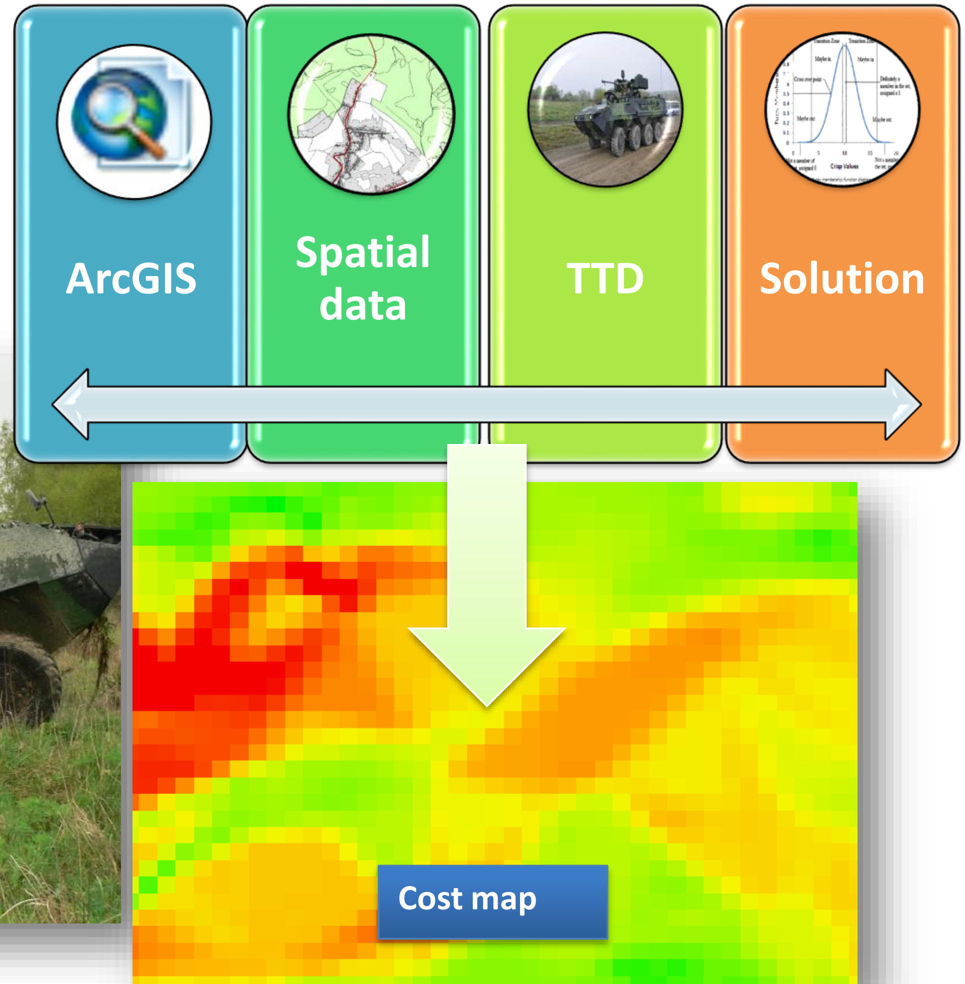
F11: $y = -0{,}1194x^2 + 2{,}6998x + 22{,}408$

F12: $y = -0{,}6418x + 18{,}707$





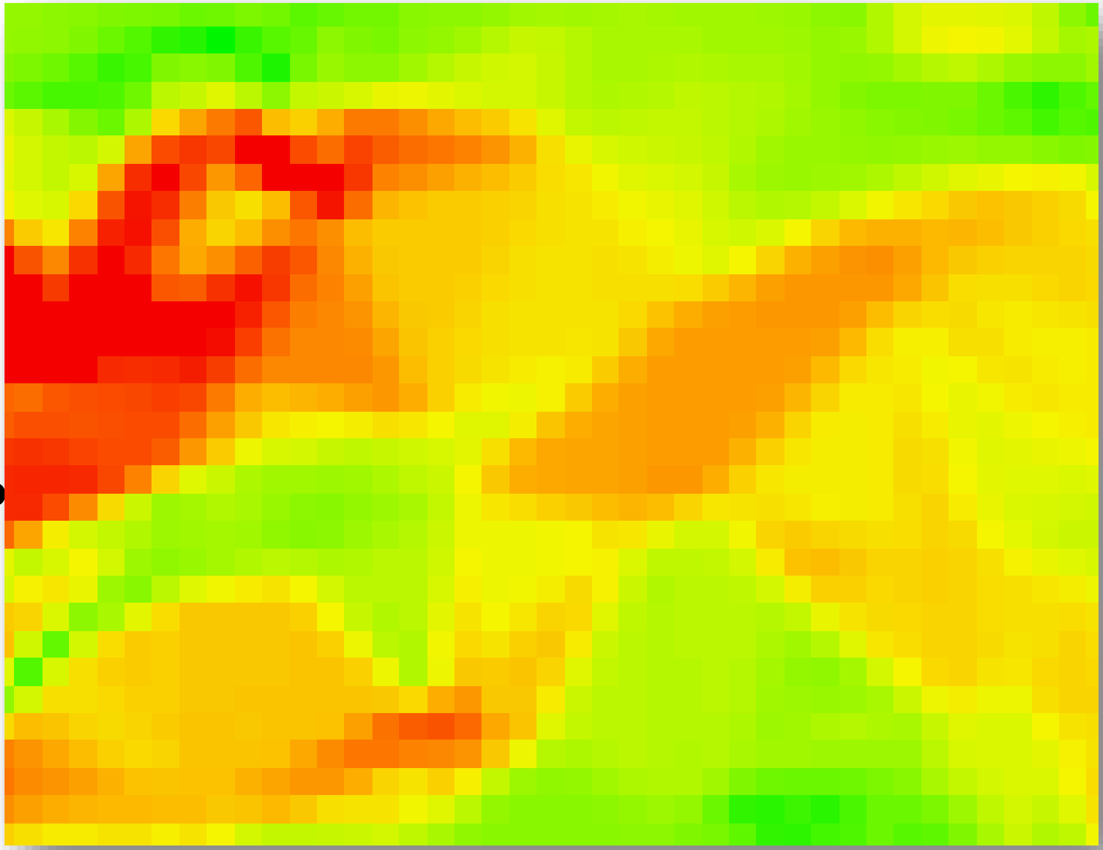
CCM model



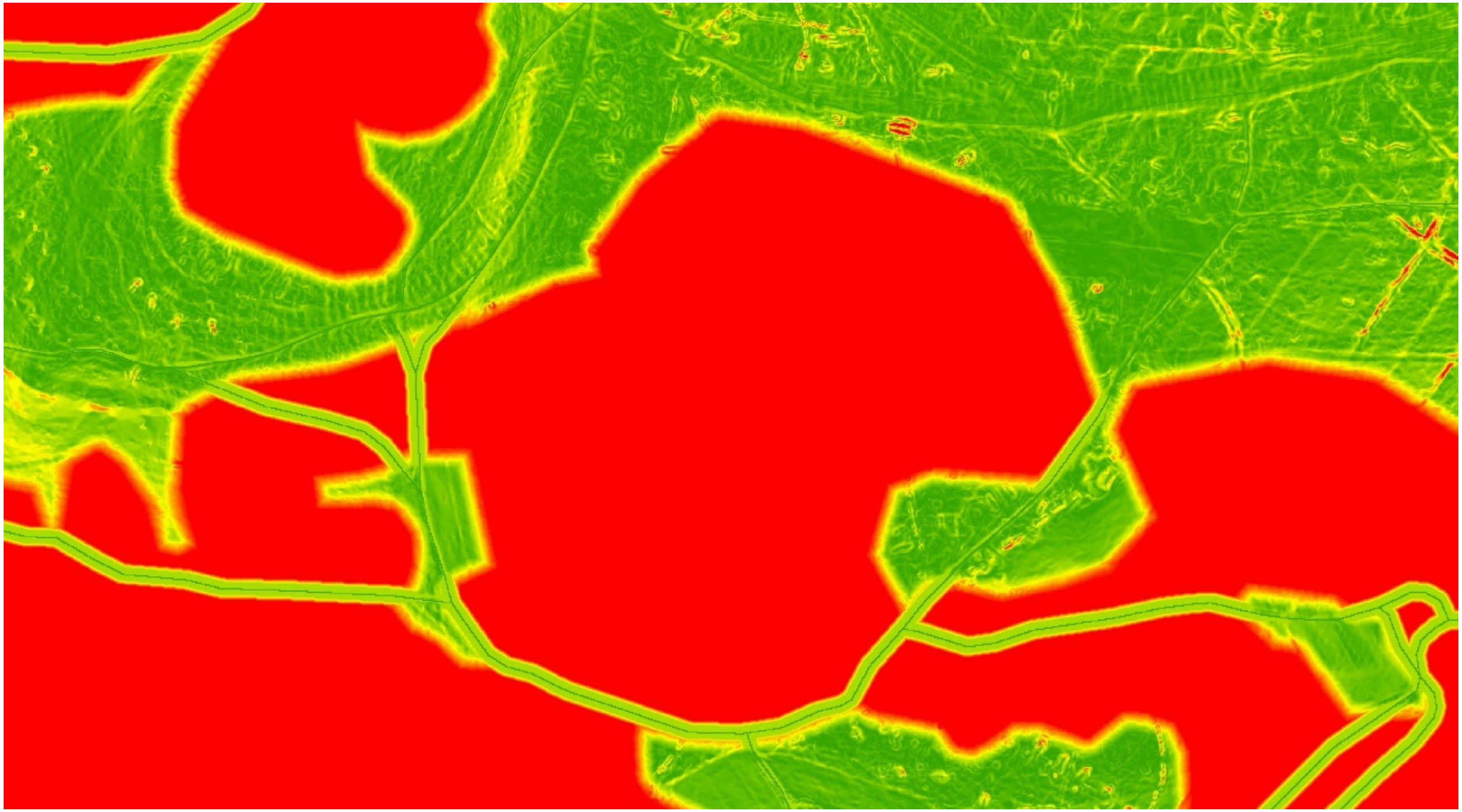
Cost map importance

- Answers:
  - Is it possible to overtaken?
  - Where is it possible?
  - How fast is it possible to drive?

GO
SLOW GO
NO GO



Result of complex model



Impact of data quality on final result

DEM	Structure	Mean square error		
		Open terrain	Settlements	Forests
SRTM	Points in grid 3 x 3″	16 m	16 m	16 m
DMR3	Points in grid 10 x 10 m	1-2 m	1-2 m	3-7 m
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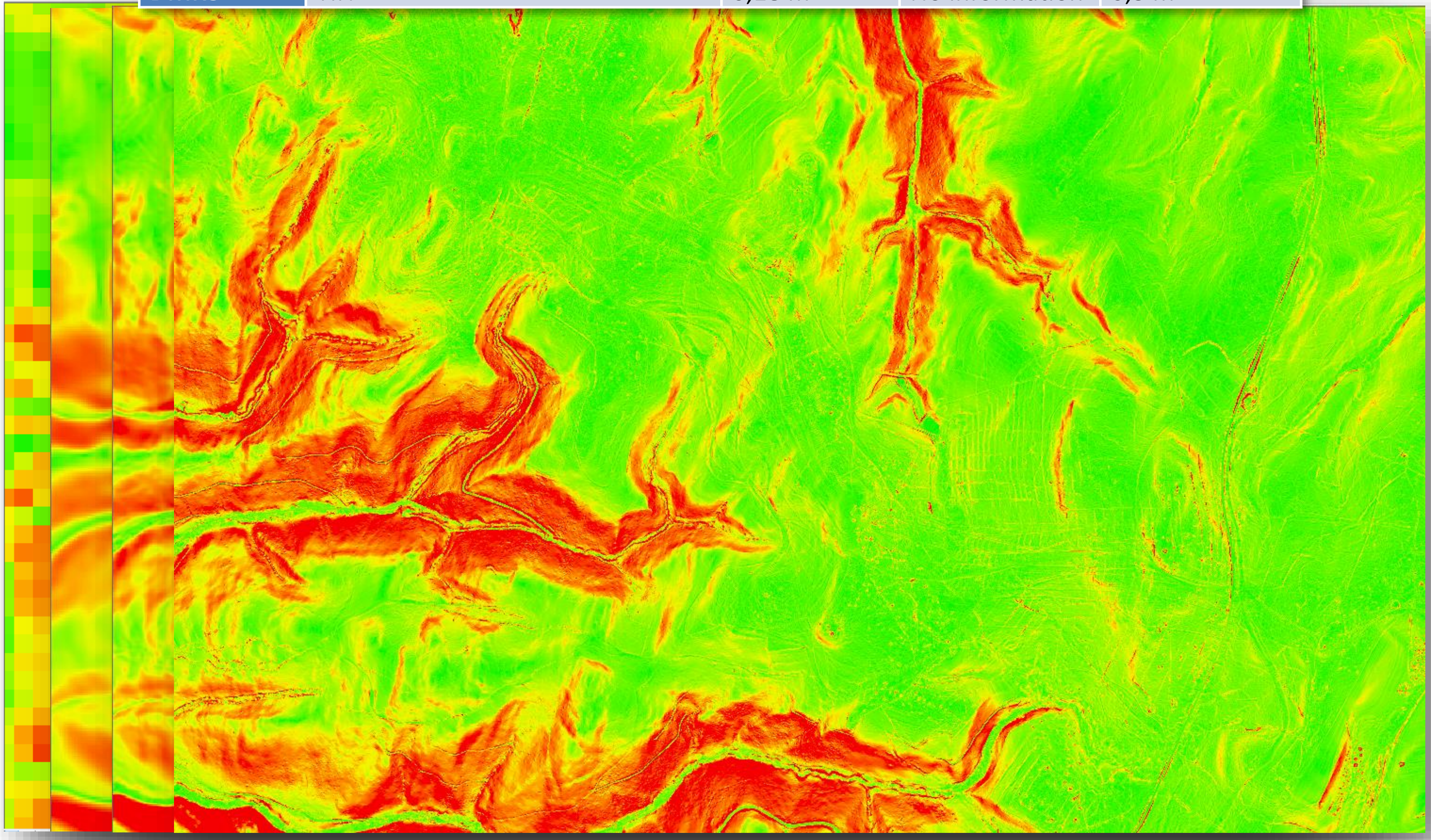
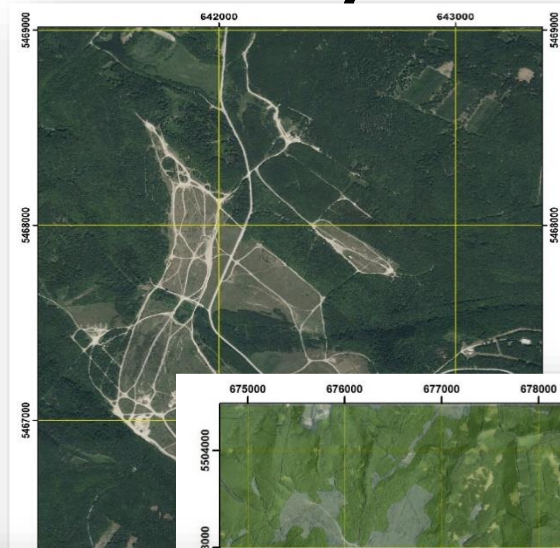


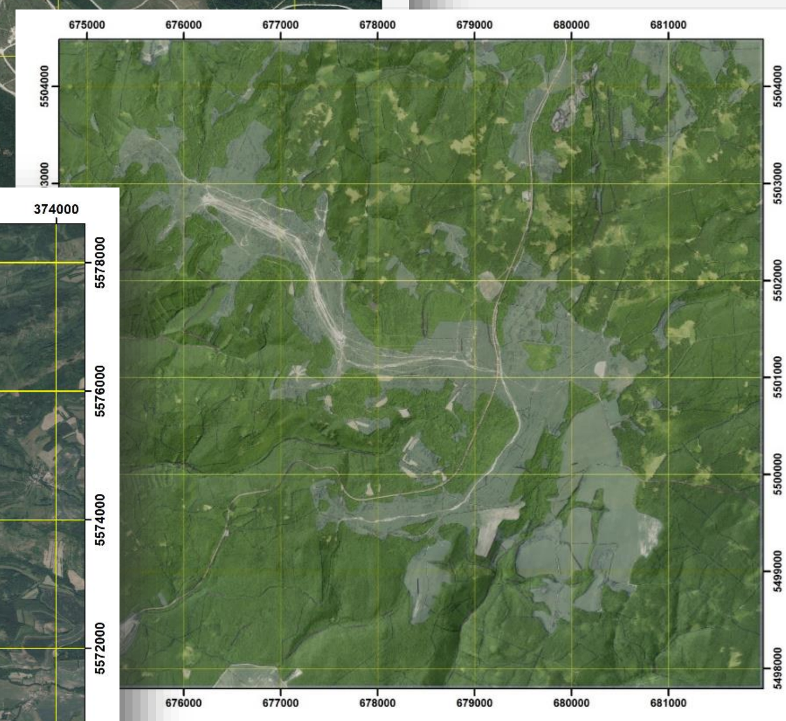
6.

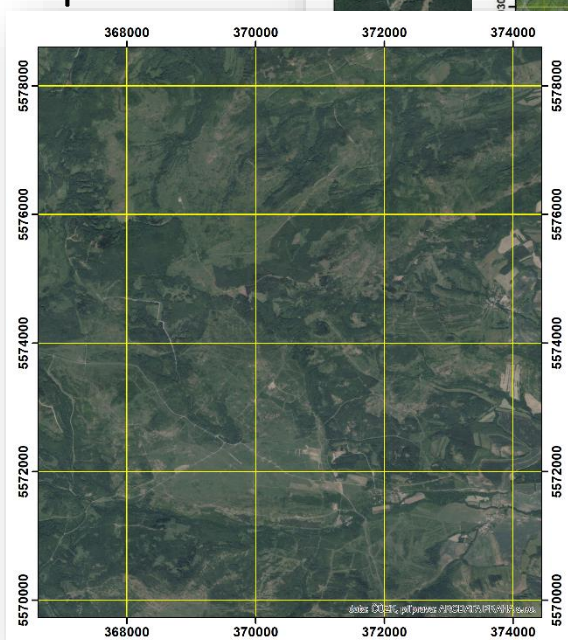
MODEL VERIFICATION

Field Tests with Military Vehicles

- Four multi-days field tests with military vehcles(MTA Brezina, MTA Libava, MTA Doupov)
- May 2014, 2015, 2017, March 2018
- ***Goal of tests*** – verification of coefficients, mathematical and processing models, models refinement, dynamic power testing
- ***Used vehicles:***
  - UAZ 469
  - LR 110
  - T815
  - T810
  - Pandur II
  - BMP 2
  - IVECO
  - T72







Source data

- Data models
  - DMÚ25, ed. 2010
  - DMR3
  - DMR4
  - DMR5
  - Synthetic Soil Database (SSD)
- Data combinations for CM evaluation:
  - K3 – DMÚ25, DMR3, SSD
  - K4– DMÚ25, DMR4, SSD
  - K5 – DMÚ25, DMR5, SSD

Test scenario

- the first pass of a vehicle using the assigned route and recording of the actually passed route in GPS - ***recognition pass***
- ***repeated passes*** of a vehicle using the assigned route and recording of the actually passed route in GPS - pass at maximum speed possible, the same driver
- ***pass*** of a vehicle using the assigned route ***at degraded visibility conditions*** (dark) and recording of the actually passed route in GPS - pass at maximum speed possible, the same driver

Weather conditions

Tire condition of PANDUR II - detail

NO GO flat terrain – very wet soil

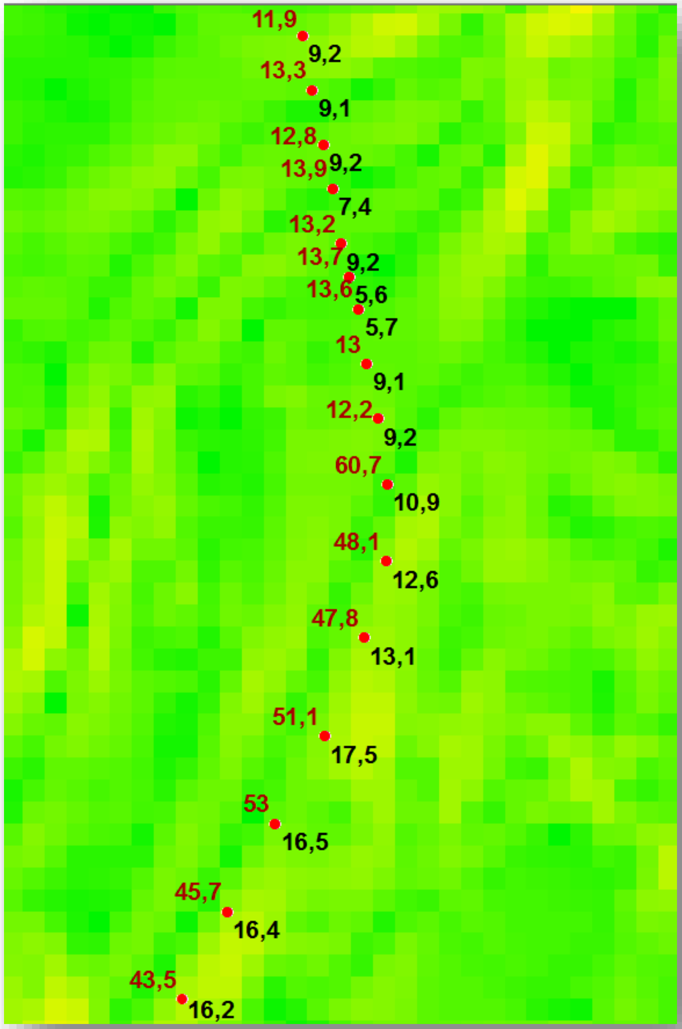
SLOW GO terrain – damaged track

Final drive of skilful driver

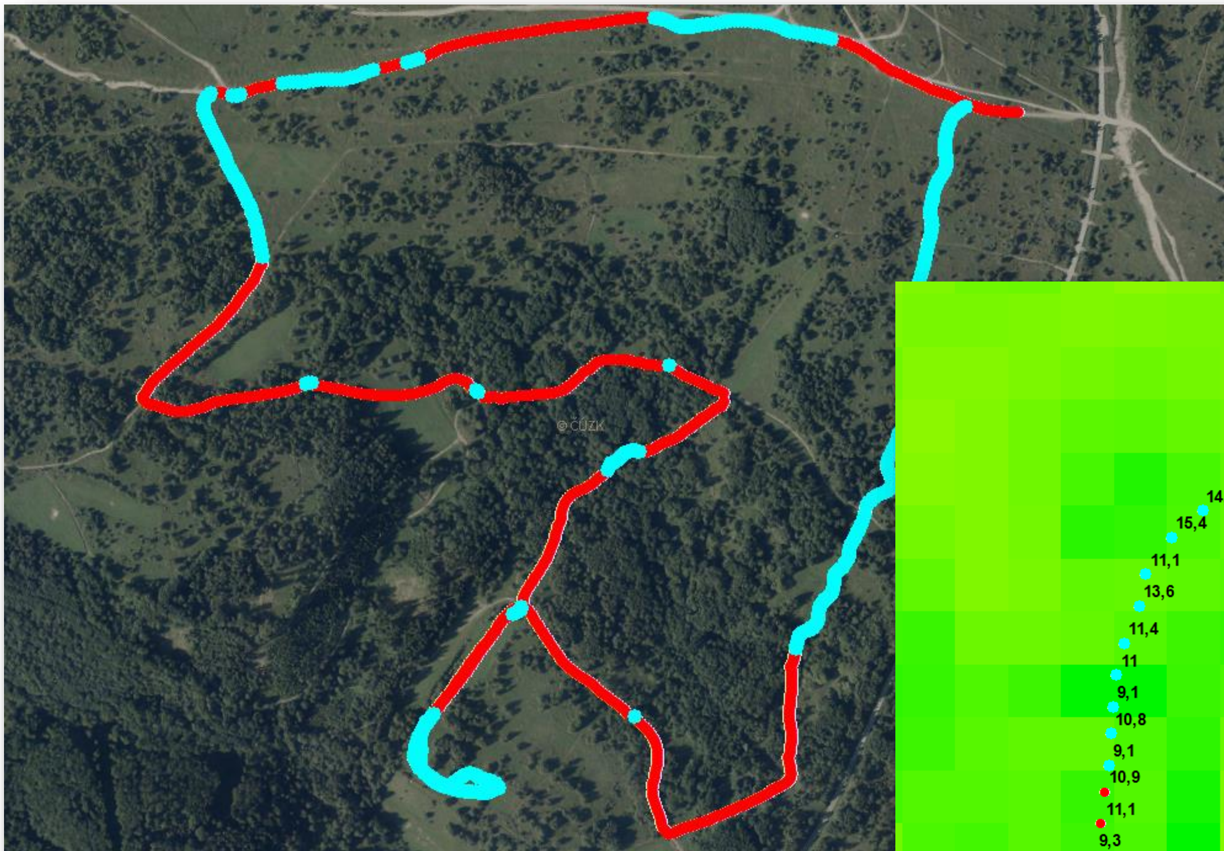
Typical field track in the MTA

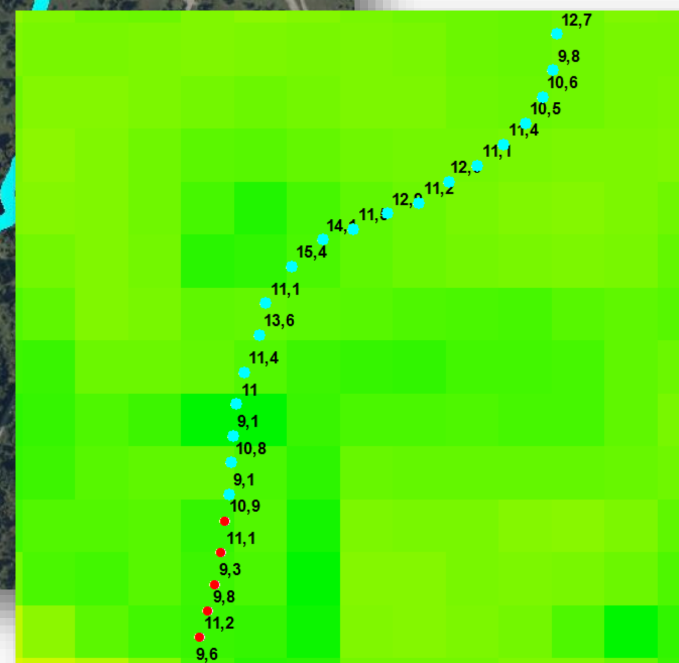
Analyses of recorded tracks and data quality

- Calculation of differences modelled and real velocity of vehicle
- Analyses of differences
- Analyses of sources of differences
- Influence of data quality on results determination

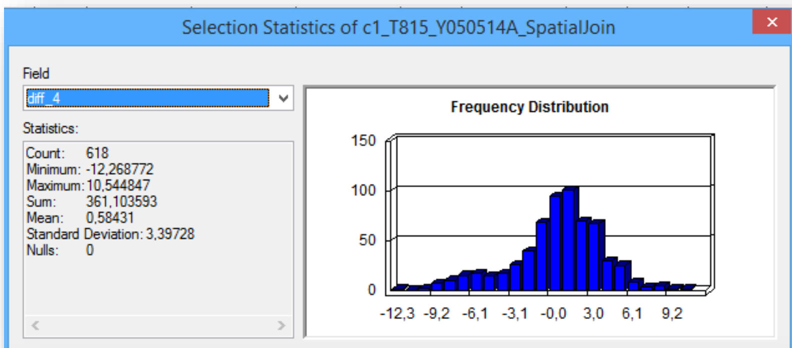


Parts of track on gravel road and off road

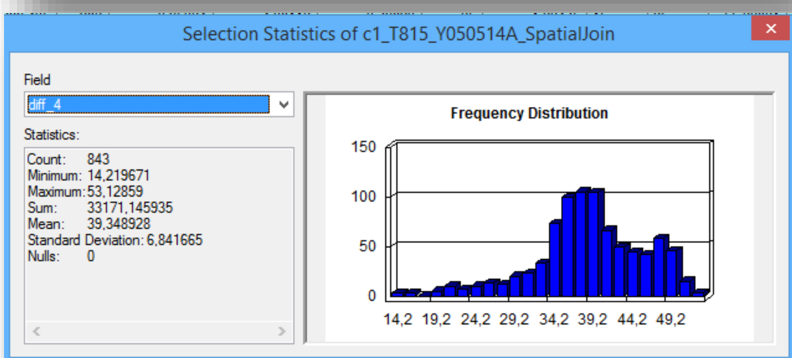




Statistical distribution of differences between modelled and real velocity (T815 8x8)



Off road parts – average coefficient of deceleration *C*=0,28

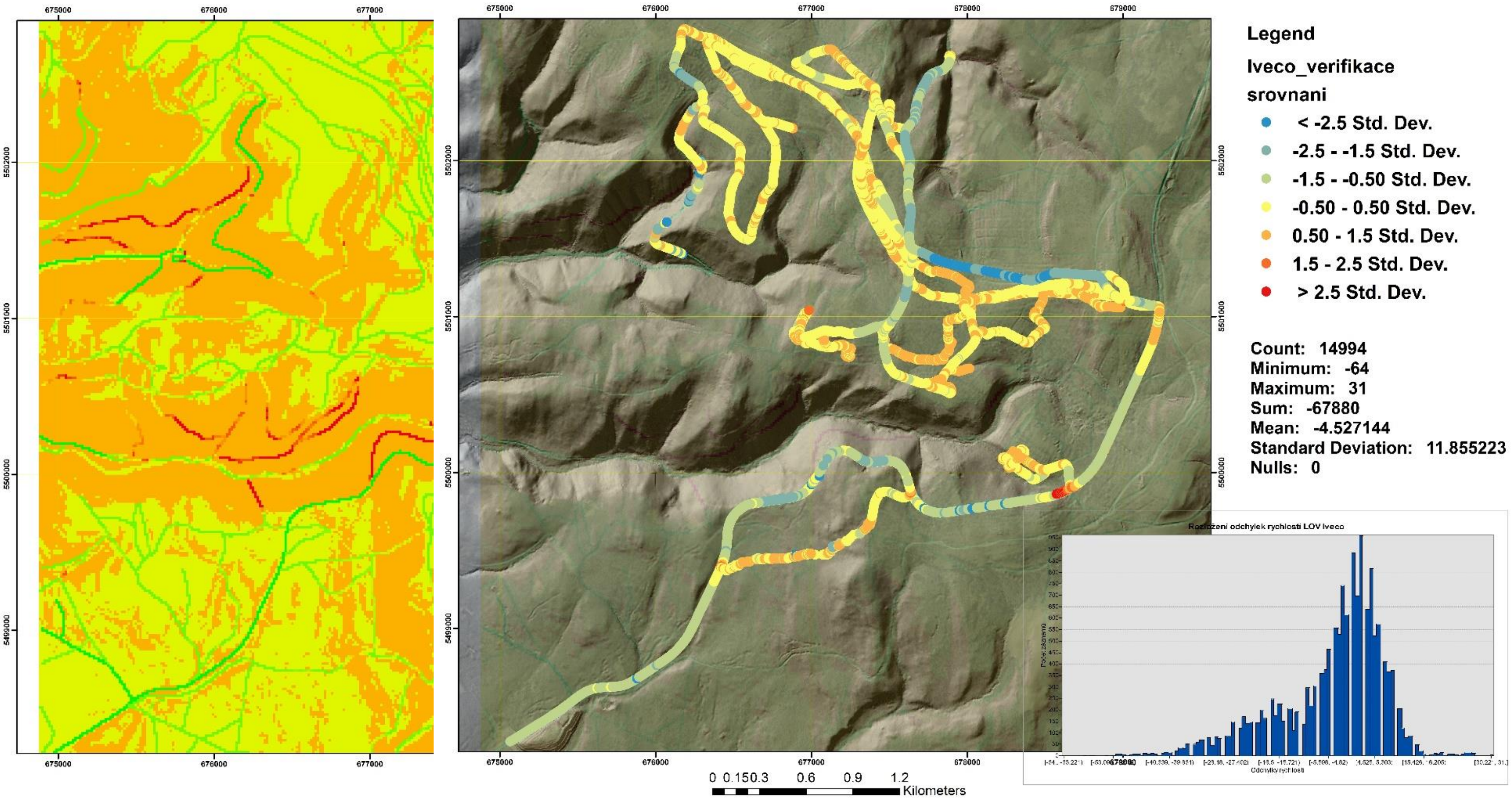


Gravel road parts - average coefficient of deceleration *C*=0,52

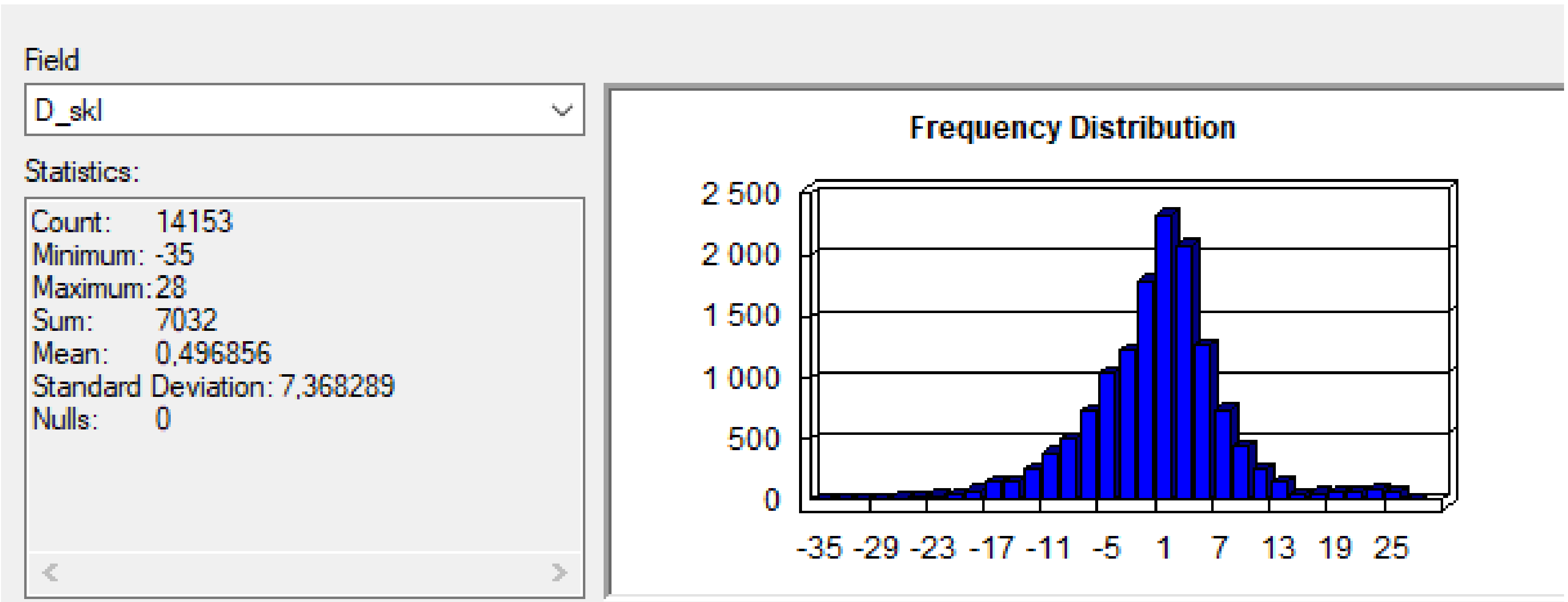
Second model of CCM

- Impact of terrain relief
- Impact of type of surface
- Impact of road geometry
- possibility of "generalizing" the type of vehicles (lorry, passenger vehicle - off-road, tracked vehicle)
- transition from deterministic modeling to statistical
- authentication data series – MTA Doupov, 7. a 8. 3. 2018

Processing Model of Coefficient C_1 Evaluation – Second Variant



Tatra 815 8x8 in MTA Libava



7.

CONCLUSION

Particular project conclusions

- There is a ***strong relationship*** between ***quality of data*** and the ***results of*** spatial ***analysis***
- It is appropriate to ***assess*** the ***technical properties*** of the spatial database, and also to consider the ***quality*** of the ***whole complex of data usage***
- Visible differences between crisp set and fuzzy logic in spatial analyses
- ***Advantage of Fuzzy Logic*** – better information for decision making process
- ***Disadvantage of Fuzzy Logic*** – worst interpretation of results from user point of view and time for calculation

Particular project conclusion

- Particular ***coefficients must be deeply specified*** according to real conditions
- ***Missing information have to be added*** (weather conditions, drivers abilities, real soil conditions etc.)
- ***CCM model*** have to be ***connected with given operational tasks*** to help commanders to make appropriate decision
- ***No general usage*** can be considered
- To precise model is ***never-ending story*** – new vehicles, new geographic data, new possibilities of data up-dating