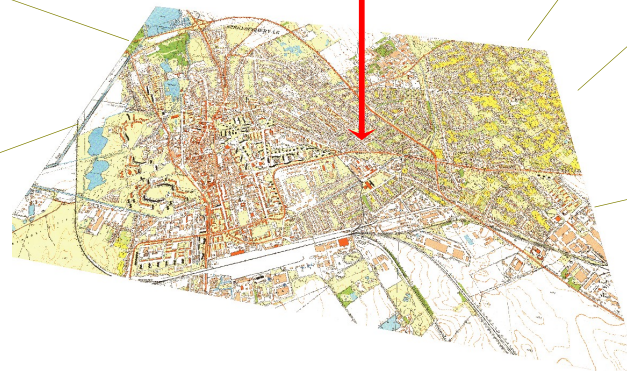
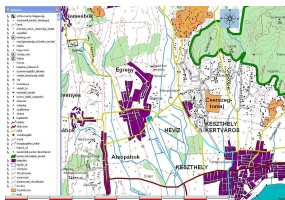
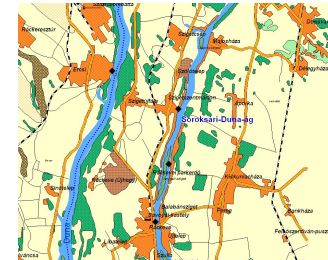
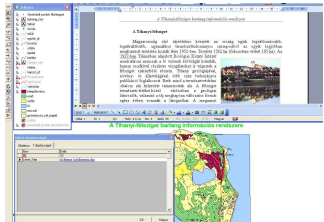
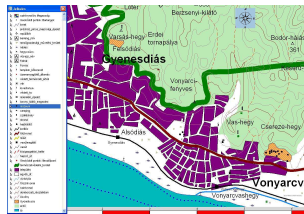
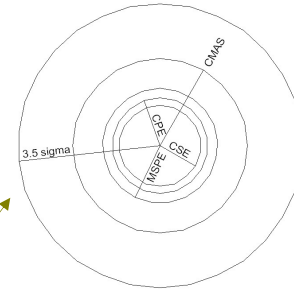
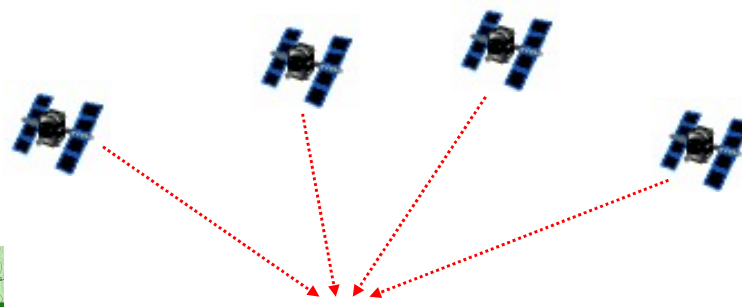


Digital topographical maps –positional accuracy



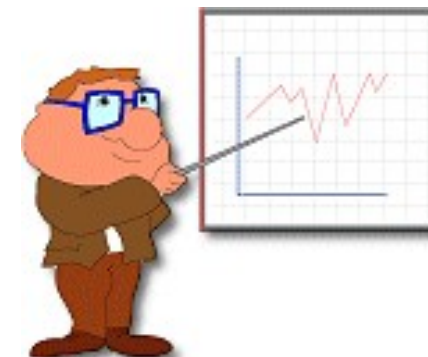
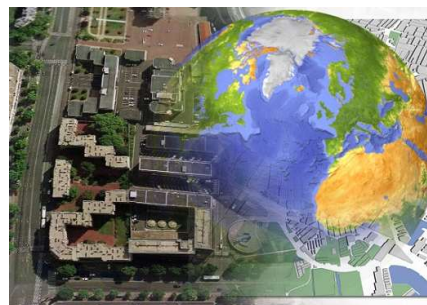
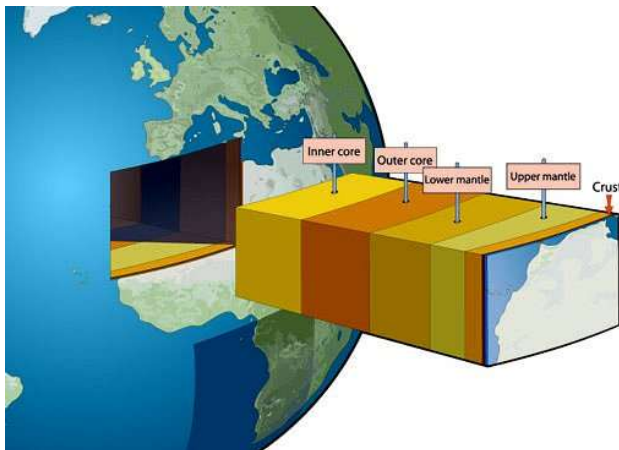
TS 7B – Mapping, Aerial Survey and Remote Sensing
Peter Tarsoly

Digital topographical maps – positional accuracy
7th FIG Regional Conference

Spatial Data Serving People: Land Governance and the Environment – Building the Capacity
Hanoi, Vietnam, 19-22 October 2009



1. Hypothesis and aims
2. The equation for calculating the quantitative accuracy
3. Preliminary works – digitalization
4. Preliminary works – testing the data collecting instrument
5. The sampling strategy
6. Testing quantitative accuracy
7. Geospatial positioning accuracy standards
8. Metadata
9. Final conclusions



Hypothesis and aims

- **Hypothesis**

- My presentation intends to answer the following specific question: Can quantitative accuracy of digital topographical maps be determined by using spatial sampling and adjustment methods, and applying the measurement method of DGPS?

- **Aims**

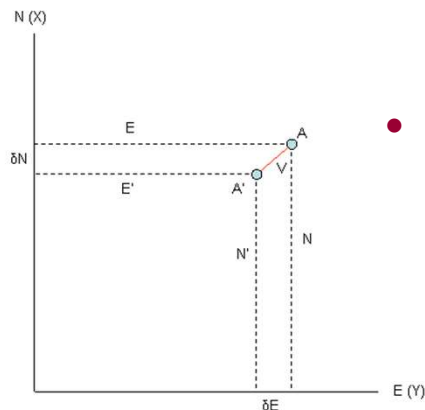
- Shows the basics of cartometry to highlight the problem of accuracy in the vector and raster environment,
- Apply an interesting and useful methods, to express the accuracy of the digital map (CMAS), the data-collecting instrument and the sampling strategy and method (stratified random sampling),
- Shows, how real-time DGPS works on the field,
- Compares map qualifying methods (NMAS, NSSDA and ASPRS),
- Shows the importance and place of the map accuracy documentation in different metadata-descriptions. (Hungarian Standard 7772-1, FGDC Digital Geospatial Metadata Standard, INSPIRE Draft Implementing Rules for Metadata 2007).



The equation for calculating the quantitative accuracy I.



- In quantitative accuracy evaluation we compare the two or three dimensional surface of the ground with another surface mapped in two dimensions with height represented by means of spot heights and contour lines.
- Let see a point $A(E, N)$ on the ground which is shown on the map by the point $A'(E', N')$.



$\delta E, \delta N$	Simple distinction
V	Vectorial distance
s_E, s_N, s_V	Root mean square error
$\overline{\delta E}, \overline{\delta N}$	Average discrepancy
σ_E, σ_N	Standard error
σ_c	Parameters of Circular Map Accuracy Standard

$$V = \sqrt{(\delta E^2 + \delta N^2)}$$

$$\delta E = E - E'$$

$$\delta N = N - N'$$

$$V = \sqrt{(\delta E^2 + \delta N^2)}$$

$$s_E = \pm \sqrt{\left(\frac{\sum \delta E^2}{n-1}\right)}$$

$$s_N = \pm \sqrt{\left(\frac{\sum \delta N^2}{n-1}\right)}$$

$$\overline{\delta E} = \frac{\sum \delta E}{n}$$

$$\overline{\delta N} = \frac{\sum \delta N}{n}$$

$$\sigma_E = (s_E^2 - \overline{\delta E}^2)^{1/2} = \left[\frac{\sum (\delta E - \overline{\delta E})^2}{n} \right]^{1/2}$$

$$\sigma_N = (s_N^2 - \overline{\delta N}^2)^{1/2} = \left[\frac{\sum (\delta N - \overline{\delta N})^2}{n} \right]^{1/2}$$

$$s_V = \sqrt{(s_E^2 + s_N^2)}$$

$$\sigma_c = \frac{s_V}{\sqrt{2}}$$

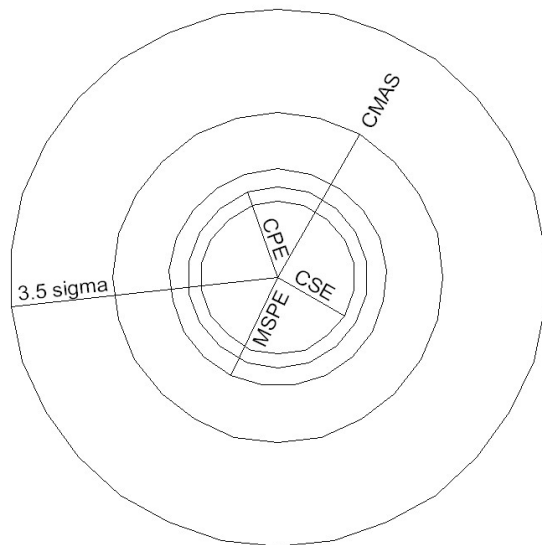




The equation for calculating the quantitative accuracy II.

- **Visualize the accuracy**

- Circular probability means that may imagine a point on the map, corresponding a series of concentric circles (if δE is equal to δN); the radius of each circle corresponding to a different probability value. The likelihood that the true position lie within one of these circles is measured by the probability which is corresponding to each circle.



Name	Symbol	P_c	Derivation
Circular standard error	σ_c	0.3935	$1.0 \sigma_c$
Circular probable error	CPE or CEP	0.5	$1.1774 \sigma_c$
Circular mean square positional error	MSPE	0.6321	$1.4142 \sigma_c$
Circular map accuracy standard	CMAS	0.9	$2.1460 \sigma_c$
Three-five sigma error	3.5σ	0.9978	$3.5 \sigma_c$





Preliminary works – digitalization I.

- On-screen digitalization-digital topographical map (number 54-411, 8-bit-tiff, 159 Mb, pixel size 0.846 meter) in a raster format from the FÖMI (Institute for Geodesy and Remote Sensing)
- Different GIS software packages: DigiTerra Explorer v4., DigiTerra Map v.2.3., GeoMedia Professional 5.1., ArcMap 9.1., AutoCad Map 2004, ITR4
- Digitalize: single points, straight lines, curved lines, simple geometrical figures (triangle) and for closed curve. Sampling ratio: 100. For eliminate systematic errors I digitalize straight lines and curved lines fifty times from North-West to South-East, and than fifty times from South-East to North-West; single geometrical figures and closed curves fifty times clockwise and fifty times counter clockwise.
- Adjustment: The mean square error of a measurement whose weight is unity.

$$A = L_1, L_2, \dots, L_{n-1}, L_n$$

$$a = \frac{\sum_{i=1}^n L_i}{n}$$

$$L'_i = L_i - a$$

$$X' = \frac{\sum_{i=1}^n (p_i \cdot L'_i)}{\sum_{i=1}^n p_i}$$

$$L^a = a + X'$$

$$v = L^a - L'$$

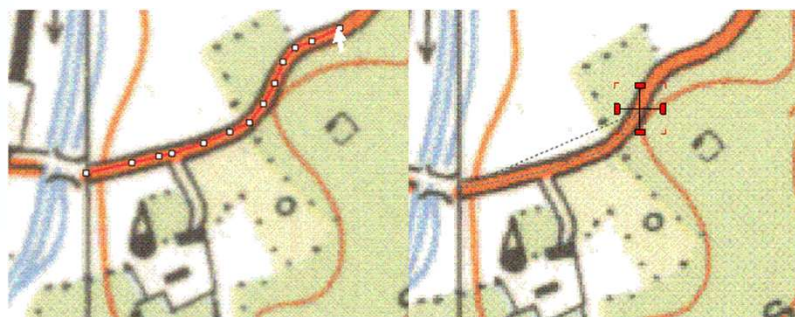
$$m_0 = \sqrt{\frac{\sum_{i=1}^n (p_i \cdot v_i \cdot v_i)}{n-1}}$$

$$m_x = \frac{m_0}{\sqrt{\sum_{i=1}^n p_i}}$$

$$m_i = \frac{m_0}{\sqrt{p_i}}$$

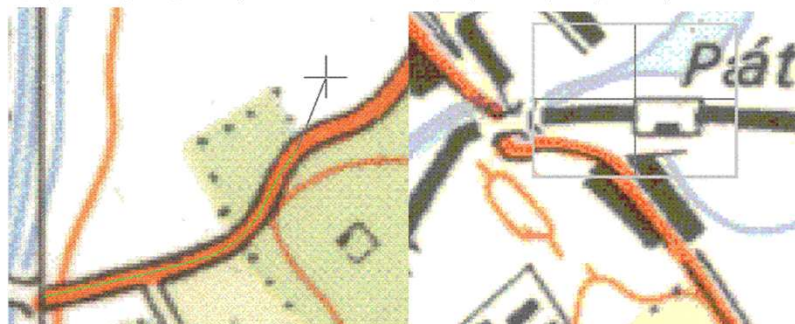


Preliminary works – the results of digitalization



a, Single arrow by the DigiTerra Explorer v4.

b, Multiple cursor by the DigiTerra Map v2.3



c, Single cross-hair by the AutoCad Map 2004

d, Free-scaling window by ITR4

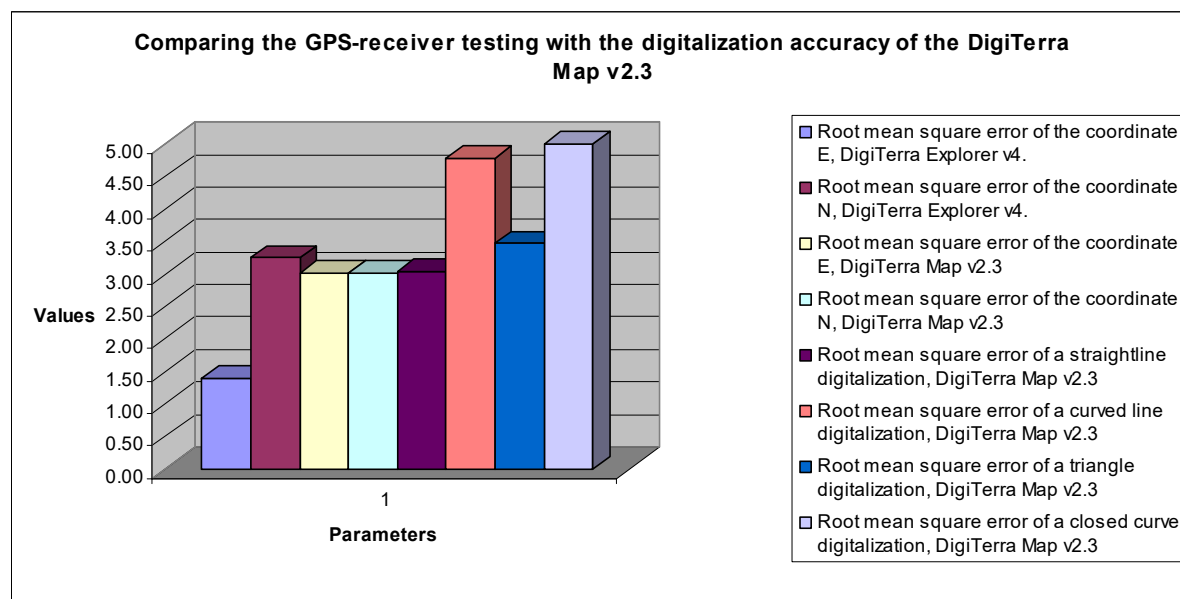
- The used GIS-environment does not influence the accuracy of digitalization. Only the accuracy of the DigiTerra Explorer v4 was not sufficient; this software was not made for drawing and editing, but for field data collecting. The less accurate was the digitalization of a curved line and a closed curve; much better was the accuracy by a point, straight line and simple geometrical feature digitalization.
- The cursors shape indicates and influences the accuracy of digitalization. Digitalization with a simple cross hair cursor (AutoCad Map 2004, ITR4) or with a multiple cursor (DigiTerra Map v2.3., ArcMap 9.1.) is more accurate, as digitalization with some other pointer.

	Root mean square error (m)					
	DigiTerra Explorer v4.	DigiTerra Map v2.3.	GeoMedia 5.1	ArcMap 9.1.	AutoCad-Map 2004	ITR4
Coordinate E	0.07	0.01	0	0	0.02	0
Coordinate N	0.05	0.02	0	0	0.01	0.01
Straightline	0.05	0.05	0	0	0.04	0.01
Curved line	1.71	1.79	0	0	0.14	0.05
Triangle	0.31	0.47	0	0	0.09	0.00
Closed curve	3.7	2.00	0	0	0.48	0.03

Preliminary works – testing the data collecting instrument

- using the GPS- and EGNOS satellite system (receiver DigiTerra Explorer v4)
- testing the receiver at the roof of the faculty
- ideal circumstances, there are not any obstacles in any direction
- measure the position on the pillar 100 times
- recorded 3D coordinates, but used for the further investigations only 2D coordinates

Root mean square error in the Eastern direction (Y-axis)	1.39m
Root mean square error in the Northern direction (X-axis)	3.25m
The root mean square error in height	4.90m
Average discrepancy without height	3.53m
Average discrepancy using height	6.04m

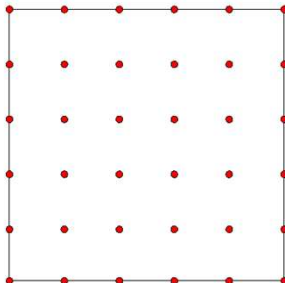
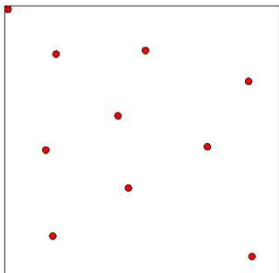


The sampling strategy I.

- **Good sampling is based upon good sampling frame, sampling units and sampling strategy.**

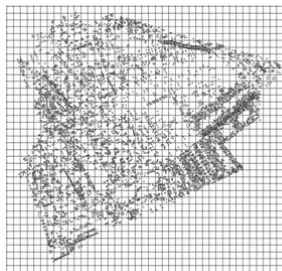
- Sampling frame: list, map, database or other specification (f.e. grid cell)
- Sampling unit: unit, which is a part of an aggregate data (f.e. coordinate)
- Sampling strategy: stratified random sampling
 - the advantages of both systematic and random sampling
 - often used when accuracy needs for an entire map or digital database

<u>Stratified random sampling</u>	
<u>Advantages</u>	<u>Disadvantages</u>
focuses on important subpopulations and ignores irrelevant ones	can be difficult to select relevant stratification variables
improve the accuracy of estimation	not useful when there are no homogenous subgroups
efficient	require accurate information about the population, or introduces bias, expensive
sampling equal numbers from strata varying widely in size may be used to equate the statistical power of tests of differences between strata	look randomly within specific sub headings

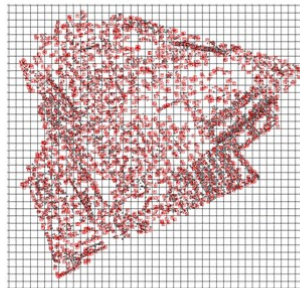


The sampling strategy II.

- All point were digitalized with the same method (on-screen digitalization)
- the points do not contains spatial variations
- All points had got the same root mean square error value
- **Sampling:**
 - Sampling frame: grid cell (50*50m, 2500m²)
 - Sampling unit: coordinate
 - Sampling strategy: stratified random sampling
 - Every cell contains on average 15-20 points, but among these points only 5-6 were eligible to make GPS-measuring on them (GPS and EGNOS signals)
 - Sampling from every cell two well-defined point randomly using the software DigiTerra Explorer v4
 - the total point number was 8973 pieces, the sample 1669 pieces



1. Defining the grid-cells



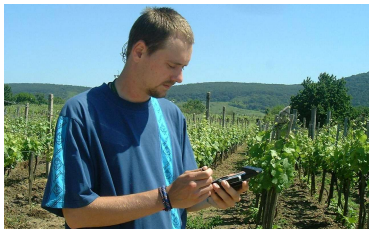
2. Random sampling

3. Sampling points in the digital database



Testing quantitative accuracy I.

- **Data collecting on the field: DigiTerra Explorer v4.**
- **Three different layers: topographical map (raster), sampling points (dxf-format), actual DigiTerra Explorer measuring file (map-format)**
- **Navigate to the sampling points, measure them**
 - Use the auxiliary measuring functions of the receiver, e.g. outside measuring
 - Use other, auxiliary measuring methods, e.g. taping





Testing quantitative accuracy II.

- Using real-time code measuring (DGPS) is feasible for the field data collecting, except there, where is not free the receiving-window for the southern horizon.
- Real-time DGPS is not the best method for the field data collecting, better would be a combined method: using GPS-technique and traditional technique, like total station and taping.

Topographical map Scale: 1:10 000 Number: 54-411	Root mean square error
Root mean square error (sE^*) in the eastern direction on the ground in meters (+/-):	0.449
Root mean square error (sN^*) in the northern direction on the ground in meters (+/-):	0.395
Root mean square error (sE') in the eastern direction on the map in millimeters (+/-):	0.045
Root mean square error (sN') in the northern direction on the map in millimeters (+/-):	0.039
Average discrepancy for the points in the eastern direction on the ground in meters (δE^*):	0.208
Average discrepancy for the points in the northern direction on the ground in meters (δN^*):	-0.021
Average discrepancy for the points in the eastern direction on the map in millimeters ($\delta E'$):	0.021
Average discrepancy for the points in the northern direction on the map in millimeters ($\delta N'$):	-0.002
	Standard error
Standard error in the eastern direction on the ground (σEg):	0.398
Standard error in the northern direction on the ground (σNg):	0.394
Standard error in the eastern direction on the map (σEm):	0.040
Standard error in the northern direction on the map (σNm):	0.039



Testing quantitative accuracy III.

The circular probability values:

Ground (m)						Probability
Circular standard error (σ_c^*):			0.423			0.3935
Circular probable error (CPE):			0.498			0.5
Circular mean square positional error (MSPE):			0.598			0.6321
Circular map accuracy standard (CMAS):			0.907			0.90
Three-five sigma error (3.5σ):			1.480			0.9978

Map (mm)						Probability
Circular standard error (σ_c'):			0.042			0.3935
Circular probable error (CPE):			0.050			0.5
Circular mean square positional error (MSPE):			0.060			0.6321
Circular map accuracy standard (CMAS):			0.091			0.90
Three-five sigma error (3.5σ):			0.148			0.9978





Geospatial positioning accuracy standards I.

- **The FGDC-NSSDA standard:**
 - The National Standard for Spatial Data Accuracy (NSSDA) implements a statistical and testing methodology for estimating the positional accuracy of points on maps and in digital geospatial data, with respect to georeferenced ground positions of higher accuracy.
- The NSSDA was developed by the FGDC working group on spatial data accuracy, with the intent to update the United States National Map Accuracy Standards (NMAS).
 - Testing methodology and reporting:
 - Use RMSE to estimate positional accuracy
 - Accuracy is reported in ground distances at the 95% confidence level (NMAS - 90%)
 - independent source of higher accuracy is the preferred test for positional accuracy
 - Accuracy would be: 1.04 meters, and this means, that at 95% confidence level 93% of my check points have got good quality and only 7% of my check points failed on this statistical probe.

$$\text{RMSE}_x = \sqrt{\sum (x_{\text{data}, i} - x_{\text{check}, i})^2 / n}$$
$$\text{RMSE}_y = \sqrt{\sum (y_{\text{data}, i} - y_{\text{check}, i})^2 / n}$$

$x_{\text{data}, i}$, $y_{\text{data}, i}$ are the coordinates of the i -th check point in the dataset,
 $x_{\text{check}, i}$, $y_{\text{check}, i}$ are the coordinates of the i -th point in the independent source of higher accuracy,
 n is the number of check points tested,
 i is an integer ranging from 1 to n .

Horizontal error at point i is defined as:

$$\sqrt{(x_{\text{data}, i} - x_{\text{check}, i})^2 + (y_{\text{data}, i} - y_{\text{check}, i})^2}$$

Horizontal RMSE is:

$$\text{RMSE}_r = \sqrt{\sum ((x_{\text{data}, i} - x_{\text{check}, i})^2 + (y_{\text{data}, i} - y_{\text{check}, i})^2) / n} = \sqrt{\text{RMSE}_x^2 + \text{RMSE}_y^2}$$

Computing accuracy according to the NSSDA when $\text{RMSE}_x = \text{RMSE}_y$:

$$\text{RMSE}_r = \sqrt{2 * \text{RMSE}_x^2} = \sqrt{2 * \text{RMSE}_y^2} = 1.4142 * \text{RMSE}_x = 1.4142 * \text{RMSE}_y$$

$$\text{Accuracy}_r = 2.4477 * \text{RMSE}_x = 2.4477 * \text{RMSE}_y = 2.4477 * \text{RMSE}_r / 1.4142 = 1.7308 * \text{RMSE}_r$$





Geospatial positioning accuracy standards II.

- **Approximating circular standard error when $RMSE_x \neq RMSE_y$**
- **$RMSE_{min}/RMSE_{max}$ is between 0.6 and 1.0**
 - $CSE = 0.5 * (RMSE_x + RMSE_y)$, (at 39.35% confidence level)
 - $Accuracy_r = 2.4477 * 0.5 * (RMSE_x + RMSE_y)$
- **Relationship between NSSDA (horizontal) and RMSE (x or y)**
- **$RMSE_x = RMSE_y$**
 - $RMSE_x = RMSE_y = RMSE_r / 1.4142$
 - $RMSE_x = RMSE_y = Accuracy_r / 2.4477$
- **Relationship between NSSDA and NMAS (horizontal)**
- **NMAS is using 90 % probability value**
 - $CMAS = 2.1460 * RMSE_x = 2.1460 * RMSE_y = 2.1460 * RMSE_r / 1.4142 = 1.5175 * RMSE_r$
 - $Accuracy_r = 2.4477 / 2.1460 * CMAS = 1.1406 * CMAS$

	$RMSE_r (m)$	$Accuracy_r (m)$	$CMAS (m)$
<i>NSSDA</i>	0.60	1.04	
<i>NMAS</i>	0.60	1.04	0.91
<i>CMAS</i>			0.91

Different accuracy calculating methods, same results



Geospatial positioning accuracy standards

III.

- ***American Society for Photogrammetry and remote Sensing Accuracy Standards for Large-Scale Maps (ASPRS)***
 - ASPRS Accuracy Standards for Large Scale Maps provides accuracy tolerances for maps at 1:20000-scale or larger prepared for special purposes or engineering applications.
 - RMSE is the statistic used by the ASPRS standards.
 - Accuracy is reported as Class 1, Class 2, or Class 3.(see Table)
 - Positional accuracy is reported at ground scale. (feet or meter).
 - The limiting RMSE number for scale 1:10 000 is 2.50 meters, every check point of my investigation is within this limit.

<i>Class 1 Planimetric Accuracy limiting RMSE (meters)</i>	<i>Map scale</i>
<i>0.0125</i>	1:50
<i>0.025</i>	1:100
<i>0.050</i>	1:200
<i>0.125</i>	1:500
<i>0.25</i>	1:1000
<i>0.50</i>	1:2000
<i>1.00</i>	1:4000
<i>1.25</i>	1:5000
<i>2.50</i>	1:10000
<i>5.00</i>	1:20000





Metadata I.

- **Metadata is structured information, describes, explains, locates, manage an information resource.**
- **Metadata is often called data about data or information about information.**
 - Descriptive metadata: describes a resource.
 - Structural metadata: indicates how compound objects are put together.
 - Administrative metadata: provides information to help manage a resource.
- **The Hungarian Standard 7772-1**
 - based on structural standardization results of CEN TC-287
 - model formulated in 6 DAT-Instructions (DAT1., DAT1-M1., DAT1-M2., DAT1-M3., DAT2. and DAT2-M1.)
 - it does not express horizontal accuracy in numbers
- **FGDC Content Standard for Digital Geospatial Metadata**
 - First version in 1994, than revised in 1998 by the Federal Geographic Data Committee
 - Data elements: Identification Information, Data Quality Information, Spatial Data Organization Information, Spatial Reference Information, Entity and Attribute Information, Distribution Information, Multi-use Sections
- **INSPIRE Draft Implementing Rules for Metadata 2007**
 - INSPIRE is a Directive (2007/2/EC) of the European Parliament and of the Council establishing an Infrastructure for Spatial Information in the European Community⁴
 - assist policy-making in relation to policies and activities that may have a direct or indirect impact on the environment
 - handling spatial information created by the Member States (Hungary 2004)
 - Implementing Rules (IRs): information must be compatible, usable and trans-boundary
 - IRs on metadata must be adopted within one year of the entry in force of the Directive, i.e. by May 15, 2008





Metadata II.

	Vector maps: approximately 2-5Mb/digital database
Quantity	Raster databases: 15 db Vector databases: 15 db 2D-databases, hydrological layers: 15 db
Planimetric accuracy (CMAS)	0.907 m
Cost	Colour raster maps: 8000Ft (30 Euro)/digital database or 6Ft (0.024 Euro)/km ² 2D digital databases (1 bit): 3000Ft (12 Euro)/digital database vagy 3Ft (0.012 Euro)/km ² DTM and hydrological layer (1 bit) 2500Ft (10 Euro)/digital database or 3Ft (0.012 Euro)/km ² Vector maps: Hydrological layer: 20300Ft (78 Euro)/ digital database or 22Ft (0.085 Euro)/km ² DTM (TIN): 20300Ft (78 Euro)/ digital database or 22Ft (0.085 Euro)/km ²

Positional accuracy-Hungarian Standard 7772-

1

<i>Data quality</i>	
Attribute accuracy report	Field checks, cross-checks, statistical analysis of values, parallel independent measures.
Logical consistency report	Topological checks, logical checks.
Completeness report	Completeness checks, fields checks.
Positional accuracy report	Use of the National Standard for Spatial Data Accuracy. The Accuracy limit is $1.7308 \cdot \text{RMSEr}$, 1.04 meter. 93% of the points were good, and 7% of the points were failed at 95% confidence level. The value of the Circular Map Accuracy Standard (90% confidence level) is 90.7 centimeter.
Process step	1. Analysis of the generalization methods 2. Analysis of the measurements errors 3. Analysis of the digital database accuracy, calculating and drawing methods 4. Analysis of the digitalization, different methods and GIS-environments 5. Testing the data field collecting instrument 6. Sampling, frame, unit and strategy 7. Metadata standards
Process contact	Peter Tarsoly, p.tarsoly@geo.info.hu

Positional accuracy- FGDC Content Standard for Digital Geospatial Metadata

<i>Quality and validity</i>	
Lineage	Use of the National Standard for Spatial Data Accuracy. The Accuracy limit is $1.7308 \cdot \text{RMSEr}$, 1.04 meter. 93% of the points were good, and 7% of the points were failed at 95% confidence level (NSSDA). The value of the Circular Map Accuracy Standard (90% confidence level, NMAS) is 90.7 centimeter.
Spatial resolution	An equivalent scale, 1:10 000

Positional accuracy- INSPIRE Draft Implementing Rules for Metadata 2007

Final conclusions

- The used GIS-environment has not got influence for the accuracy of digitalization. Less accurate: closed curve, curved line; the most accurate: point, straight line.
- The cursors shape indicates and influences the accuracy of digitalization. The best: multiple cursor, single cross hair; the worst: simple pointer (such as arrow).
- Real-time DGPS is not the best method to collect data in the field.
- For determination map or digital database accuracy stratified random sampling is an adequate method.
- CMAS is a responsible parameter to express in numbers positional accuracy, and circular probability diagram could visualize positional accuracy.
- The efficiency of the different map qualifying methods were the same: NMAS, NSSDA and ASPRS were equally good-working.
- The Hungarian Standard 7772-1/DAT1 instruction is dealing with the metadata-base for maps and digital databases, but it does not store positional accuracy in numbers. FGDC and INSPIRE-standards are more efficient and detailed.

