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CARTOEVALUATION METHOD FOR ASSESSMENT OF GIS SOFTWARE

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Abstract. The article offers proposals for a new approach to evaluating GIS programs in cartographic functions. The newly proposed CartoEvaluation method is a comprehensive guide in monitoring all cartographic features and in subsequent selection of the program. The CartoEvaluation method is based on Gold-Question-Metric method. CartoEvaluation method was applied for assessment of some desktop GIS software. The result of assessment brings the rank of software. Method can help a user in the choice of GIS program when a user requires a higher cartographic functionality.

Keywords: cartography, GIS, assessment, CartoEvaluation, open source software.

Introduction

The comparing GIS software is not easy task. GIS software differs very often in native formats. It causes different processing of spatial data and set of GIS functions. The structure of data is often under the influence of the cartographic requests (Dobesova 2012). The amount of cartographic functionality is also at different levels.

The reason for cartography evaluation is to help future users of programs to select the most suitable and appropriate program focusing on cartographic outputs from GIS programs. Therefore, the user does not need to conduct its own survey and random testing of programs in order to determine an appropriate program. Evaluation is an early step in the decision making process. Insufficiencies and errors in software bring more manual work during map creation and at finishing of digital output map.

The quotation by Galileo Galilei is "What is not measurable make measurable". The CartoEvaluation method tries measure GIS software from the point of cartography.

1. Methodology for evaluation

The proposed CartoEvaluation method is part of the methodology, which consists of four steps:

1. step: Learning to work with selected GIS program by studying the documentation and practical activities in creating maps.

2. step: Creation of a series of test maps.

3. step: Application of CartoEvaluation method.

4. step: Evaluation of results obtained using CartoEvaluation method.

Expert who evaluates GIS software must be familiar with the software. The practical experiences with the creation of maps are necessary in that software. Important is the utilization of various cartographic methods (choropleth method, chart maps), labelling, creation of legend etc. The theoretical cartographical knowledge is precondition for evaluation (Vozenilek, Kaňok *et al.* 2011; Brewer 2005, 2008).

2. The CartoEvaluation method

The new CartoEvaluation method is applied in the third step of the methodology. CartoEvaluation method is based on multi criteria evaluation and on Goal-Question-Metric method.

2.1. Multi criteria evaluation

The first decision was to choose the evaluation method. It is possible to use only a simple verbal evaluation or yes/no evaluation or multi criterion evaluation or fuzzy evaluation (Dobesova 2009b). Fuzzy evaluation is deeply described by J. Talasova (2003). Multi criteria evaluation is used very often in multi criteria decision making. Various criteria are considered to choose the best variant from the set of potential variants. In that case, the variant is the best software from the point of cartography.

The result of the overall evaluation is based on the weighted sum of the criteria (1). A key step in a multi criteria evaluation is to determine the weights of criteria. Different groups of assessors prefer different criteria with different weights, so it can be a significant conflict of opinions. Determination of weights is very difficult, and therefore there are methods based on simple subjective information from users to finally construct estimation of the weights.

All the different methods for estimating weights are based on the principle that the sum of the weights over all criteria is one (2).

$$S = \sum_{i=1}^{n} w_i * c_i, \qquad (1)$$

$$\sum_{i=1}^{n} w_i = 1, \qquad (2)$$

where w is weight, c is criterion, S is final sum.

2.2. Weights and Saaty matrix

Individual weighting factors of metrics were designed by expert estimation which arose from debates of cartographers. The weights of goals and weight of sub-goals arose from expert estimation of international group of cartographers. Previous discussions were performed among them. Finally, the method of quantitative pair wise comparison of criteria (Saaty matrix) was used. The set of weights is objective cartographer's consensus.

Method of quantitative pair wise comparisons (Saaty matrix) is based on a subjective evaluation which expresses preference between criteria. It is done by pair wise comparisons. There are no direct input weights and the weights are not set directly. The method is suitable in case when evaluators or experts can not afford direct determination of weights. Ratios are express the importance for every pair of criteria. The pair wise comparison of the use-weighing scales are set to 1 (equal criteria i and j), 3 (i criterion weakly

prefers j criterion), ..., 9 (i criterion absolute prefers j criterion), and a reciprocal value. Ratings are stored in the Saatyho matrix $S = (s_{ij})$ according to the following schedule:

$$S = \begin{bmatrix} 1 & s_{12} & \dots & s_{1n} \\ \dfrac{1}{s_{12}} & 1 & \dots & s_{2n} \\ \dots & \dots & \dots & \dots \\ \dfrac{1}{s_{1n}} & \dfrac{1}{s_{2n}} & \dots & 1 \end{bmatrix}. \qquad (3)$$

The calculation of weights is a normalize geometrical average of rows in Saaty matrix (Brozova *et al.* 2007).

Cartographer pair wise compares the importance of the setting of coordinate system of software with the library of point, line and area symbols or with the possibilities to create choropleth map or an automatic function of generation of legend.

One form of multi criteria evaluation is goal-question metric method. The metric means the suggestion of weights for each criterion in that method.

2.3. Goal-Question-Metric method

The Goal-Question-Metric method (Basili *et al.* 1994) was chosen as the theoretical basis for the evaluation method. Goal-Question-Metric method (GQM) is designed by Victor Basili at University of Maryland, College Park and in Software Engineering Laboratory in Goddard Space Flight Centre NASA. This is a system of questions and simple answers for evaluation of properties.

Goal – Question – Metric method was developed for multi-purpose evaluation of software. Principle of the method consists of identifying the main goals that the program should perform (Dumke 2009). In this case, these goals reflect key tasks to be performed during the creation of map output. The main goals, which are the form the highest levels, are distributed to sub-goals (the second level) and to partial goals (the third level). This method was also for evaluation open source GIS software under CASCADOSS project (Orlitova, Vobora 2008).

Division of main goals to the sub-goals and partial correspond to the Analytic Hierarchy Process (AHP). The AHP first decomposes the problem into a hierarchy of sub problems. Then the decision-maker evaluates the relative importance of its various elements by pairwise comparisons. The AHP converts these evaluations to numerical values

Table 1. The contribution of main goals

Goal	Maximal score [%]
A – Map construction	15
B – Map symbols	35
C – Cartographic methods	35
D – Map syntax	15
Total score	**100**

Table 2. The list of goals and sub-goals in CartoEvaluation method

Main goal Sub-goal	Sub-goal weight [%]	Goal weight [%]
A – Map construction		15
1. Base of the map	3	
2. Reference system of map face	4	
3. Transformation of map outline	4	
4. Metadata about map construction	2	
5. Cartometry	2	
B – Map symbols		35
1. Pattern book of symbols	1,5	
2. Point symbols	8	
3. Line symbols	8	
4. Area symbols	8	
5. Localization of map symbols	3	
6. Color setting	6	
7. Metadata about symbols	0,5	
C – Cartographic methods		35
1. Basic methods	8	
2. Diagram methods	8	
3. Scale of values	3	
4. Label	10	
5. Specific methods	6	
D - Map syntax		15
1. Intra-composition	1,5	
2. Map layers	2	
3. Extra-composition	2	
4. Basic elements: title, colophon	0,5	
5. Legend	5	
6. Map scale	1	
7. Additional composition elements	2	
Total score	**100**	**100**

Fig. 1. The point symbol library in Quantum GIS

(weights or priorities), which are used to calculate a score for each alternative.

GQM method defines a measurement model on three levels:

– *Conceptual level (goal)* – a goal is defined for an object for a variety of reasons, with respect to various models of quality, from various points of view and relative to a particular environment.

– *Operational level (question)* – a set of questions is used to define models of the object of study and then focuses on that object to characterize the assessment or achievement of a specific goal.

– *Quantitative level (metric)* – a set of metrics, based on the models, is associated with every question in order to answer it in a measurable way.

2.4. Goals of CartoEvaluation method

According to the GQM method the main goals were suggested. The main goals of CartoEvaluation methods are:

– *A – Map construction;*
– *B – Map symbols;*
– *C – Cartographic methods* – types of cartographic expression method;
– *D – Map syntax* – stratigraphical, componental and compositional.

Sets of questions and answers to these questions determine the fulfilment of partial goals. Resulting numerical rating is calculated using the metrics.

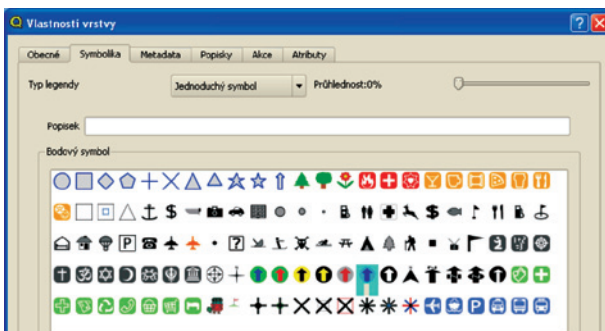Maximum total sum is 100%. The contribution of main goals is in Table 1.

Contribution can be converted to multi criteria equation (4):

$$\text{Score} = 15 * A + 35 * B + 35 * C + 15 * D, \qquad (4)$$

where *A*, *B*, *C*, *D* are main goals.

All the main goals are divided to sub-goals. The number differs in each goal. The list of sub-goals is in Table 2. The sub-goals represent second level of goals. Each sub-goal consists of partial goals at the third level.

E.g. evaluation of library of point symbol belongs to the goal B – Maps symbol, sub-goal "2. Point symbols". The goal "B – 1. Basic methods" evaluates cartographic mapping methods as choropleth, areals, iso-lines methods.

2.5. Operational level of CartoEvaluation method

The set of question and possible answers is arranged in Microsoft Excel table (Figs 2, 3). A numeric score is obtained by answering questions concerning the accomplishment of individual cartographic goals. The cells contain predefined formulas for automatic calculation.

2.6. Implementation of CartoEvaluation method

The evaluation method is implemented in Microsoft Excel 2003 file because of a simple recording of answers and automatic calculation of the total numerical score.

This Excel file contains five sheets. The four sheets are for four main goals. The names of sheets correspond to the name of goals (A – Map construction, B – Map symbols, …). The fifths sheet contains the table with the partial sum and calculates final score from the previous sheets. For automatic calculation of column

D, all answers are set to the default maximum value (1 or 2). User can change the answer to 0 in the case of a negative response when the functionality is missing.

Any user can very easy perform an evaluation of any GIS program according to the CartoEvaluation method. CartoEvaluation method is freely available on the information project website (*http://www.geoinformatics.upol.cz/app/visegrad*) (Fig. 4) as a downloadable Microsoft Excel file. It is possible to download Czech or English version.

Application of this methodology can be time-consuming as well as knowledge-demanding task. Second possible use is to explore the results of evaluations made by others earlier reviewers. The evaluations of some software are also downloadable. Therefore, it is not always necessary to perform new testing of the program and following evaluation according Carto-Evaluation method.
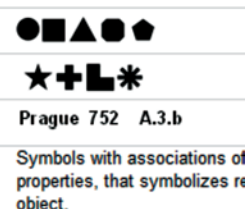

Fig. 2. Example of questions, answer and explanation in Excel sheet for goal B – map symbols, sub-goal 2. Point symbols

Fig. 3. Example of questions, answer and explanation in excel sheet for goal C – cartographic methods, sub-goal 2. Diagram map
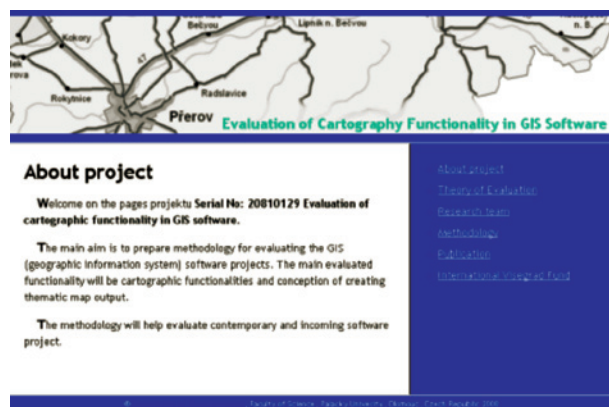
Fig. 4. Internet web pages of CartoEvaluation method

3. Results of assessment

Method CartoEvaluation was practically used for assessment. Therefore, it is applied methodology. Several experienced users and producers of programs from the Czech and Slovak Republic were asked to work out evaluations. Evaluation of the same GIS program was usually carried out by multiple evaluators to eliminate minor inaccuracies in answers. In total, 13 GIS programs were evaluated, both commercial and Open Source Software, including free viewers. The evaluated programs and results are shown in Table 3.

The results of the evaluation confirm that most of the programs achieved good basic cartographic functions. Nine programs achieved more than 50% from the maximum possible score (100%). Tested programs were: ArcGIS, MapInfo, Geomedia,

GRASS, TopoL, AutoCAD Map, Kristýna GIS, MISYS and OCAD. Commercial programs are among the best because they have been developed for a long time, and thus have the chance to meet the requirements of expert cartographic outputs (Dobesova 2009a, b).

Programs GRASS, Kristýna GIS and MISYS also reached good ranking. When program reaches a score between 40% and 50%, it is appropriate to use the GIS program only for simple cartographic outputs. Such a program can be expected to miss some cartographic functions. Manual editing by graphic and text tools is likely to be necessary in finalisation of the map.
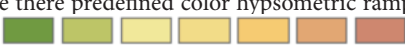
Evaluation of programs also revealed some weak or missing cartographic functions. Whereas the possibilities of setting a projections and reference coordinate system, including the choice of national coordinate systems are without problems, other functions were revealed to insufficient. The possibility of transformation of mapping face is missing in some programs. Programs often do not have the ability to generate metadata about the map construction and metadata about construction of symbols.

Some cartometric and geodetic tools are missing (cartographic distortion etc.). Included pattern books for point, line and areal symbols are numerous, but often one-sidedly oriented. Symbol editor is rarely available to let the user create and re-use new symbols, especially problematic are composite line symbols.

Table 3. Results of eval uated GIS programs

GIS software	A Map construction (15%)	B Map symbols (35%)	C Cartographic methods (35%)	D Map syntax (15%)	Total score 100%
JANITOR J/2	4,32	18,95	6,68	1,60	31,75
IDRISI Taiga	3,17	14,50	7,82	7,48	33,50
Kristýna GIS view.	2,16	17,70	12,31	4,88	37,05
Quantum GIS	9,4	18,95	6,95	8,55	43,85
Geomedia Viewer	9,32	25,45	3,88	4,55	43,20
uDig	10,80	17,50	12,13	7,7	48,13
OCAD	8,12	25,85	9,13	7,88	50,98
MISYS	11,90	21,10	10,58	7,47	51,05
Kristýna GIS	7,32	19,55	16,53	8,67	52,06
AutoCAD Map 3D	9,30	20,35	16,21	10,10	55,96
TopoL xT DMT	10,80	17,65	16,00	12,97	57,42
GRASS	10,60	17,05	21,03	11,20	59,88
Geomedia Professional	12,60	25,45	12,13	11,73	63,58
MapInfo Professional	10,10	25,80	22,59	11,97	70,45
ArcGIS – ArcMap	11,62	30,10	27,50	13,03	82,25

Table 4. Comparison of results for the color ramps libraries

GIS Software	ArcGIS	AutoCAD Map	Geomedia Prof.	Geomedia V.	GRASS	IDRISI Taiga	JANITOR	Kristýna GIS V.	Kristýna GIS	MapInfo Prof.	MISYS	OCAD	Quantum GIS	TopoL xT	uDig
Q1: Are there predefined qualitative (categorical) color schemes (various colors)?	**1**	1	1	1	1	**1**	1	0	0	1	1	**0**	1	**1**	1
Q2: Are there predefined sequential color schemes?	**1**	1	1	1	0	**1**	1	0	0	1	1	**0**	0	**1**	1
Q3: Are there predefined bipolar color schemes?	**1**	0	0	0	1	**1**	1	0	0	0	0	**0**	0	**1**	1
Q4: Are there predefined color hypsometric ramps (tint)?	**1**	1	0	0	1	**1**	1	0	0	0	0	**0**	0	**1**	0
Q5: Can you create your own color schemes and save them for reuse?	**1**	0	1	1	1	**1**	0	0	0	1	1	**0**	1	**1**	1
Total	**2,4**	1,5	1,4	1,4	1,9	**2,4**	2.0	**0**	**0**	1,4	1,4	**0**	0,9	**2,4**	1,9

Functionality of setting colors is good. It is possible to interactively select the color from a palette in the different color models (RGB, HSV). Some color schemes (ramps) are, however, missing, in particular bipolar, gradation or hypsometric color schemes. Possibility to create, save and reuse custom color schemes is very rare. The advantage of the method is that is possible to compare software in sub-goal or partial goals. Example of comparing in partial goal "Color ramps libraries" is in Table 4.

The line vector method (line motion) and its variants are missing in the cartographic expression methods. Programs also have insufficiencies in creating point and area diagram map (chart diagrams). Multi-parameters totalizing diagrams, comparative diagrams and dynamic diagrams are missing. Similar situation occurs with line diagrams (ribbon). Totalizing line diagram, compound structural line diagram and two-direction line diagram are missing. Diagram scales in the legend are incomplete. This insufficiency solves external custom extension "Diagram map creator" for ArcGIS (Dobesova, Valent 2011).

Cartograms methods (anamorphosis) are very seldom implemented. Only program MapInfo has cartograms method and an extension for ArcGIS exists. Programs have the lack of options in the definition of the functional scale for determining the parameters of symbols. On the contrary, options of classification (setting of interval scales of values) are well-implemented. Some insufficiencies are also in the automatic creation of a legend. It is not possible to create a hierarchy in a legend or divide legend to segments. Some symbols in map do not correspond to the symbols in the legend.

It is not possible to create animated symbols and animated maps (except for program ArcGIS). The only other frequent lack of programs in the map syntax is a possibility to create templates for repeated map composition, which is often used in compiling a series of maps with an identical composition. For detailed finding of implemented and the missing functions it is possible to look directly into the resulting evaluation tables at web pages (CartoEvaluation). Additional notes and comments in tables from evaluators are also interesting and helpful.

4. Discussions

The proposed methodology and CartoEvaluation method was designed for desktop GIS programs. The method could be modified and with certain changes and additions applied to applications that are used to create web map applications. Further utilization of method could also be used for evaluation of programs for mobile computing devices designed for field work. The newest research is finishing modification of method to the CartoEvaluationM method for assessment software for mobile computers (ArcPAD, QGIS etc.). Programs for mobile devices are generally characterized by a small number of functions in comparison to desktop programs, including restrictions of cartographic functions (limited pattern book of symbols etc.). The modification of method reduces the number of question.

There is also expectation to support the cartographic design by intelligent systems. These systems follow cartographic rules to avoid mistakes and errors by users (Brus *et al.* 2009, 2010; Brus, Dobesova 2011).

The utilisation of CartoEvaluation method is not limited. It is possible to test the new version of the software. The method predicts the evolution of cartographic function and the tables contain questions about new cartographic methods: animated maps with animated symbols, visualization of 3D surfaces, visualization of spatio-temporal data (Popelka, Vozenilek 2012) etc.

Conclusions

In conclusion, it is impossible to create the best simple single evaluation method. A simple evaluation method is not sufficient because software systems and cartography have many different properties. Depending on objectives, environment and processes, evaluations will vary from complex assessment method as CartoEvaluation. Just one single measurement is not sufficient to express software quality. Software quality has many aspects and needs different measurements, such as reliability, maintainability, error-rate, etc. There are also values that cannot be measure, such as user satisfaction.

The valuable effect of CartoEvaluation method is a wide list of aspect (goals) in the area cartographical function. The method concerns very deep and detailed cartographic functions and this complex evaluation has not been existed yet. The weight and final score is not the most important. The proposed CartoEvaluation method will help users to select from a wide variety of GIS programs and subsequently to use it in the maximum extent for the fast, comfortable and correct digital map output making.

Acknowledgment

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