Digital Geographical Data: Potential Evaluation

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GENERAL

Geoinformation has infiltrated every day life of most people more and more. The users of geographic information systems have spread in many areas and their user requirements of area range data, data content and update rate has been growing constantly. The number of users is growing but the number of geoinformation staff is usually constant or even reduced. The trend is particularly obvious in the government administration, as most European governments have tried to save some budget funds.

The increased number of users is accompanied with increased requirements. The production organisations have made effort in meeting the demand as much as possible. However, all can never be hundred per cent satisfied nor in future may be expected so. Therefore, a compromise acceptable for most users must be searched. This paper intends to sort the users' requirements into a system and project their assessment without prejudice. The assessment uses the value analysis method.

KEYWORDS: digital geoinformation, evaluation, benefit cost evaluation

FUNCTIONS OF LAND DIGITAL MODELS

Digital geoinformation (DGI) is used in finding solutions of a number of projects of various natures. The project nature is determined by the way and manner of its usage. DGI is applicable similarly to classical analogue data – maps. However, they are applicable also in digital form directly, e.g. as source data for analyses of different types, control etc. Certain level of generality allows definition of common features of all actions and thus to make s list of functions desired for DGI, as follows:

1. *Information function* expresses DGI's ability of fast and reliable provision of information on position and basic features of the entered topographic subjects and phenomena in the area of interest.
2. *Model function* expresses DGI's applicability in model role for derivation of geometric or other relations of the topographic and other subjects and phenomena and their characteristics.
3. *Source function for mathematical modelling, designing and planning*, applicable to the cases that use DGI to make future action intent or to design a work to be done.
4. *Automation function* in implementation process control of designed and planned projects. This function applies to position finding on move (ground or air), co-ordination or surveillance of a large number of moving objects (air traffic control, air surveillance in a sector region, vehicle movement tracking, and so on), traffic or other construction control and monitor.
5. *Illustration function* expresses DGI's ability to illustrate situation, communication traffic such as in the HQ intranet, and others.
6. *Source function for derivation* of other types of GIS and maps and for cartographic purposes.

The above mentioned functions are uneasy assessable for meeting users' demand, though. It means, it is impossible to determine their level of satisfaction. However, to carry out the functions as listed, DGI needs certain features. Then, assessment of those features (criteria) shall replace assessment of function level of satisfaction and thus it shall be determinable what level the criteria meet the defined standards, regulations, etc.

Function conditioned qualities of land digital models, assessment criteria

Determination of criteria of useful value measurement issues from the list of features and characteristics most often required as essential for both the producers and their customers.

Five essential criteria imply from DGI quality review. Their assessment gives the baseline for relatively reliable determination of each product utility value:

1. *Database content* expresses mostly compliance of its definition and users' needs, i.e. concord of the "real modelled world" and its model represented by objects and phenomena stored in the database.
2. *Database quality* defines the quality of stored data.
3. *Database timeliness* tells how much are the entire database or its elements updated.
4. *Area importance* is determined by users' needs so that it meets the requirements of processed or supported area range.
5. *User friendliness.* This criterion defines data usability in various software environment types of GIS nature reflected mostly in compliance to standard principles. This criterion further reviews data independence and security.

Each of the criteria is mathematically assessable through independent tests.

Database content

The *database content* criterion expresses mostly compliance of the defined content and users' needs. The users' requirements should be accepted already in the intended database model concept design. The model should define all required objects and phenomena of the modelled reality providing also the adequate position and thematic resolution level determined particularly by the abstraction and generalisation procedures and tools used in modelling the "real world".

The criterion reviews concord of particular directives and instructions of database making and users' requirements and their compliance in database processing. The criterion subdivides into two 1st group sub-criteria and two 2nd group sub-criteria.

The first group includes the *real world model integrity* criterion to assess the concord of the built model and the users' requirements summary for a model based on their needs and user applications requirements. The criterion value is defined by the following equation:

$$k_{11} = 100 - \alpha_{11} \qquad (4)$$

The α_{11} value ranges in the scale 1-100 to express the user requirements disaccord level being determinable basically as drawn from users research.

The other criteria group consists of *required data resolution level compliance* criteria. Resolution stands for the least accountable distinguished detail. Regarding that the objects and phenomena have got their own geometric and thematic elements, the criterion must subdivide into two sub-criteria of the second group - *geometric resolution level compliance* and *thematic resolution level compliance*.

Both criteria may be expressed in the form of complying objects and phenomena percentage out of the total number of all modelled objects and phenomena defined in the database concerned:

$$k_{12i} = 100 \frac{n_{12i}}{n_d}, i = 1,2 \qquad (5)$$

In which

n_d is for the number of all objects and phenomena defined in the database,

n_{121} is for the number of objects and phenomena in the database compliant to the users' requirements as long as the geometric resolution level concerned,

n_{122} is for the number of objects and phenomena in the database compliant to the users' requirements as long as the thematic resolution level concerned.

The total value of the *data base content* criterion may be expressed in the following equation:

$$k_1 = \frac{p_{11}k_{11} + \sum_{i=1}^{2} p_{12i}k_{12i}}{p_{11} + \sum_{i=1}^{2} p_{12i}} \qquad (6)$$

The criterion weights of p_{11} and p_{12i} are determined from the expert estimates, such as paired comparison method, direct estimate in defined classification scale and so on.

Database quality

The *quality of the database* and data entered therein is an important criterion of a strong influence on utility value and quality of digital geoinformation. Many publications from the geoinformation branch involve the data quality definition issue (e.g. DIGEST, 1994 , Geospatial Positioning Accuracy Standards, 1998, STANAG 2215, 1989).

This criterion is again quite difficult, but has got its elements – 1st group sub-criteria that comprise source data and its transformation methods assessment along with data location and attribute accuracy, logic consistence and completely entered objects and phenomena. Some criteria subdivide into the second group sub-criteria for methodical purposes. The total data base quality assessment needs, therefore assessing of all individual elements.

Transparent source data origin and methods used for secondary data derivation

The first part of the mentioned sub-criterion is the *transparent origin of source information for primary data collection*. It is necessary to assess whether the database designers know the origin and characteristics of all sources used in its loading. Provided that the database designers know exactly the mentioned characteristics this criterion value equals 100. If the exact characteristics are unknown, the value is decreased by the percentage of the unknown or incomplete information expressed as number α_{211}. The *technically correct use of secondary data derivation methods and models* make the sub-criterion other part. The methods and mathematic models used in secondary data derivation may considerably affect data output accuracy. Similar to the previous criterion, its value equals 100 if the database designer and administrator provide complete information. If the exact information of employed methods or models is unknown, the value is decreased by the percentage of the unknown or incomplete information expressed as number α_{212}. Then the following applies:

$$k_{21i} = 100 - \alpha_{21i}, i = 1,2 \qquad (7)$$

The k_{21} sub-criterion aggregated value is defined in the following equation:

$$k_{21} = \frac{\sum_{i=1}^{2} p_{21i}k_{21i}}{\sum_{i=1}^{2} p_{21i}} \qquad (8)$$

in which p_{21i} is for k_{21i} sub-criterion weights. Again, those are available from direct estimate or paired comparison method.

Location accuracy

The second sub-criterion - *location accuracy* – is to assess the accuracy of objects and phenomena locations in the questioned geodetic reference co-ordinate system in both *horizontal* and *altitude accuracy* of the objects and phenomena. The *horizontal and altitude accuracy* values are determined by location of elements proved to definition. The data provider classifies the product in particular category giving the user information of what data accuracy is expectable for project output. An independent test of location accuracy based on the same method may prove justice or injustice of the category classification and from this point of view, then k_{221} and k_{222} criterions evaluate the product utility as in the following equation:

$$k_{22i} = 100\frac{n_{22i}}{n} + h_s, i = 1,2 \qquad \textbf{(9)}$$

in which

n is for the total number of objects and phenomena in the database,
n_{22i} is for the number of objects and phenomena in the database that comply particular category horizontal or altitude accuracy, respectively,
h_s is for selected reliability level in per cent.

Note: The k_{221} and k_{222} coefficients cannot exceed 100 even if their values calculated from the equation (9) went beyond the limit.

Then, the k_{22} sub-criterion aggregate value is:

$$k_{22} = \frac{\sum_{i=1}^{2} p_{22i}k_{22i}}{\sum_{i=1}^{2} p_{22i}} \qquad \textbf{(10)}$$

Similar to the previous criterion k_{21} the weights p_{22i} are determined by some of the expert estimate methods.

Attribute accuracy

The third sub-criterion is *attribute accuracy*. The terms of *accuracy* and *resolution level of the thematic data* should also diversify, though. The desired resolution level of thematic data is predetermined by land model project technology to inform the user of the amount and size of the least recognised thematic detail. The data attribute accuracy is thus a criterion to evaluate the technical quality of model made.

The product function ability is assessable from the mentioned independent test results with k_{23} criterion as the correct (to the particular class) thematic attributes objects and phenomena percentage of all objects and phenomena in the database. The following applies:

$$k_{23} = 100\frac{n_{23}}{n} + h_s \qquad \textbf{(11)}$$

in which
n is for the total number of all the objects and phenomena in the database,
n_{23} is for the objects and phenomena in the database compliant to the attribute accuracy class,
h_s is for the chosen reliability level in per cent.

Again, the criterion value can't exceed 100.

Data base logic consistency

The fourth sub-criterion is the *data base logic consistency*. Logic consistency means that the database establishes and maintains all necessary affiliations among the objects and phenomena and their characteristics to analyse relation and links among those objects. This criterion evaluates presence of obvious conflicts within the whole database that might occur at the first entry and particularly at its update. The evaluated features include primarily *topologic consistency* for the most applications basic qualification, then *thematic consistency* and *time consistency*.

To express the level of *topologic consistency* provisions, criterion k_{241} is useful as the percentage of the topologically consistent objects out of the all database objects.

Thematic consistency means the database contains no redundant occurrence of thematic domains of identical names and unequal data. Again, criterion k_{242} is useful to express the level of thematic consistency provisions as the percentage of the thematically consistent objects out of the all database objects.

The last component of the logic consistency is the *time consistency* applicable to data in the time storing domains. If the database is time consistent no two different events may occur in a single time instant. It level is expressible with k_{243} criterion once independent tests made.

The following equation applies to all logic consistency elements:

$$k_{24i} = 100\frac{n_{24i}}{n}, i = 1,2,3 \qquad (12)$$

in which

n is for the total number of the objects and phenomena in the database,

n_{24i} is for the number of topologic, thematic or time consistent objects and phenomena in the database, respectively.

The aggregate value of k_{24} sub-criterion is calculated in the same way as for the preceding criteria, thus:

$$k_{24} = \frac{\sum_{i=1}^{3} p_{24i} k_{24i}}{\sum_{i=1}^{3} p_{24i}} \qquad (13)$$

The k_{24i} criteria weights of p_{24i} are determined similarly to those of the preceding sub-criteria.

Data integrity

Data integrity is the last sub-criterion to evaluate integrity rate of all specified objects and phenomena and their characteristics. However, a number of objects may enter the database without thematic attributes included. This is a quite frequent practice the users meet. Therefore, it is practically useful to assess *integrity* of individual *objects and phenomena* and *integrity* of their *thematic attributes*. Both the criteria are evaluated in per cent as follows:

$$k_{25i} = 100\frac{n_{25i}}{n}, i = 1,2 \qquad (14)$$

in which

n is for the specified number of all objects and phenomena in the database from questioned location,

n_{251} is for the actually loaded objects and phenomena,

n_{252} is for the objects and phenomena in the database of all specified thematic attributes completely entered .

The aggregate value of k_{25} sub-criterion is calculated with the same equation as the previous ones:

$$k_{25} = \frac{\sum_{i=1}^{2} p_{25i} k_{25i}}{\sum_{i=1}^{2} p_{25i}} \qquad (15)$$

Again, the weights p_{25i} of k_{25i} criteria are determined with the expert estimate methods.

The aggregate value of k_2 criterion to evaluate the data base quality is calculated with the following equation:

$$k_2 = \frac{\sum_{i=1}^{5} p_{2i} k_{2i}}{\sum_{i=1}^{5} p_{2i}} \qquad (16)$$

The weights of each first group sub-criterion are determinable using paired comparison or direct estimate within the chosen classification scale.

Database timeliness

Database timeliness tells the entire database is as updates as possible.

The database timeliness is to express the level of concord of its content and the modelled reality at certain time that is the obsolescence rate. The database timeliness level changes relatively fast in dependence on various factors. Its value is principally expressible as percentage of changes occurred in all the geometry, topology and/or attributes of the objects and phenomena. Nevertheless, it seems useful to assess the timeliness rate as a cumulative time function measured since the last database update.

Database timeliness function

The function that expresses the overall change in the database content timeliness is a function of time. The database content is in full concert with the modelled reality at time T_0 however the ideal status is unattainable in reality for the time gap between the data loading commence and provision to the users is omnipresent. Therefore, the assessment baseline thereinafter is time T^*_{vm} at which the desired concert applies of the modelled reality and database content. Time T_{vm} is deducible for each part of the database that is the baseline time and determined by the actually used technology and time capacity of the administrator.

If the database content is not updated, it will get lost in timeliness until utility limit level (at time T_{mez}) after which it is useless for the purpose it was made. The obsolescence limit value has been observed quite often for the classical maps review as these loose their utility at already 15 to 25 per cent map content changed (Miklošík, 1987) that it is possible to use it for digital data too. The function f_i *(T)* to express time obsolescence of the database content at time *T* is applicable for various qualifications.

A qualification may be the base of linear time function of content timeliness. The desired function then takes the following form:

$$f_1(T) = \frac{(1-C)(T_{mez} - T)}{T_{mez} - T^*_{vm}} + C \qquad (17)$$

The letter *C* is for constant limit utility value of the database in time. As the previous analysis showed the database is useful only for time $T <= T_{mez}$, then the following applies for $T > T_{mez}$:

$$f_1(T) = C \qquad (18)$$

Provided the drop rate of the database content timeliness level in a time unit decreases as time *T* continues the exponential form of the function equation applies:

$$f_2(T) = e^{-b(T - T^*_{vm})} \qquad (19)$$

in which *b* is for a constant dependent on obsolescence limit time from the following:

$$b = \frac{d}{T_{mez}} \qquad (20)$$

The *d* constant is chosen from interval <1, 2> depending on relative abundance of various time stability objects and phenomena. A database containing objects and phenomena of equal modification rate would be the ideal case and *d* constant would equal 1. A database containing objects and phenomena of considerably inhomogeneous modification rate would be the worst case and *d* constant would equal 2.

The assessment of database timeliness for value analysis expressed with k_3 coefficient is applicable to the following equation:

$$k_3 = 100 f_i(T) \qquad \textbf{(21)}$$

in which f_i is one of the above mentioned functions.

Area importance

The criterion of *area importance* issues from user needs so that their processed or supported area range requirements are met. The significance of the criterion considers different importance of the same area for different users, such as military, political, economic and others.

Evaluation criteria and weights

The area importance assessing criteria express the characteristics of the area and events that have been, are or will be occurring in it related to the area causing or having raised either directly or implicitly interest in the area. When digital geoinformation use for military purposes is considered the following structure of sub-criteria is highly expectable:

1. geographic location of the evaluated area,
2. access corridors to the area of interest,
3. amount and nature of obstacles,
4. industrial centres,
5. population density,
6. highly national/religious minority populated regions,
7. garrison deployment and size,
8. military training areas,
9. emergency, operation and other supply sites,
10. area defence systems/equipment deployment.

The mentioned criteria are far from complete the list, still represent the wide scope of issues to consider while evaluate area importance. They can be later amended, reduced, combined etc. each of the criteria has its own weight being mostly determined on user survey basis, such as paired comparison method.

Area importance aggregate evaluation

The final importance level of an area through sub-criteria assessment may be determined using the following aggregation function:

$$v_j = p_1 v_1 \sum_{i=2}^{n} p_i v_{ij} \qquad \textbf{(22)}$$

in which

v_j	… is for aggregate evaluation of j-th area unit,
v_{ij}	… is for partial evaluation of j-th area unit by i-th criterion,
p_i	… is for i-th sub-criterion's weight,
n	… is for total number of sub-criteria used.

The first criterion – geographic location of evaluated area – is of specific significance. Considering the data provider is able to provide also area beyond user's interest, it is necessary to choose the mentioned multiple function to express area importance value of the intended area units. The sub-criteria weights used in the equation should be in advance with coefficient D calculated using:

$$D = \left[p_1 \sum_{i=2}^{n} p_i \right]^{-\frac{1}{2}} \qquad \textbf{(23)}$$

The criterion resultant value of area importance k_4 is calculated using the following equation:

$$k_3 = 100 v_j \qquad \textbf{(24)}$$

Data standards, independence and security

The criterion *standards, independence and security of data* means data usability in different GIS-nature software environment, independence of data of particular software environment and, last data security system against damage or misuse.

This criterion divides also into three sub-criteria – data standards, data independence of software environment and data security against damage or misuse.

Data standards

Digital geodata standards are a subject of many discussions on these days. The standards principally consist in the agreement of involved parties on providing data to each other in standard exchange formats to avoid troubles in the systems hat support the standards. However, important for the users is whether the data are or are not provided in standard format. The standard will of course always specific for particular data that either will or will not fully respect the standard. Therefore, the value of k_{51} criterion is

$k_{51} = 0$ for disrespected the specific standard,
$k_{51} = 100$ for respected the specific standard.

Software independent data

The data software independence means primarily the data are usable in different software environments without any modification necessary for the full utility value. Basically, it is considerably linked with data standards, nevertheless its separate assessment proves useful. The assessment of k_{52} criterion consists only in decision whether data are or are not software dependent, thus:

$k_{52} = 0$ for provided data dependent on data producer's software,
$k_{52} = 100$ for data independent of data producer's software.

Data security against damage or misuse

Data security is a system of measures to prevent data from incidental or malicious damage, misuse or loss. The criterion framework assessment should cover individual components of the system related, though to the digital data utility features for the process purposes. The components of data security for production technology are excluded from this assessment.

The user main data security consists of the following:

1. user access rights to the databases,
2. copyright system,
3. data security while handled or transported to the users, mostly via communication lines.

Each of the sub-components is evaluated with security grade within a hundred point scale, in which the value 100 means complete security and coefficient α is for a criterion breach deduction; the i-th sub-component assessment is then as follows:

$$k_{53i} = 100 - \alpha_{53i} \qquad (25)$$

Provided that all the sub-components have equal weight in aggregate data security, this is expressed as:

$$k_{53} = \frac{\sum_{i=1}^{n} k_{53i}}{n} \qquad (26)$$

in which n is for the number of all criterion sub-components.

The aggregate value of the criterion k_5 - standards, independence and security of data may be written as the following function:

$$k_5 = \frac{\sum_{i=1}^{3} p_{5i} k_{5i}}{\sum_{i=1}^{3} p_{5i}} \qquad \textbf{(27)}$$

General assessment of digital geoinformation utility

The product or a part of the product resultant function utility degree may be assessed based on the above mentioned criteria using a suitable aggregation function:

$$°F = p_3\, k_3 . p_4\, k_4\, (p_1\, k_1 + p_2\, k_2 + p_5\, k_5) \qquad \textbf{(28)}$$

The chosen form of the aggregation function concerns also the case the user gets data on an area beyond his interest or data obsolete so that their use could seriously affect or even disable the DGI functions.

The weights of each criterion p_i are determined as the sub-criteria weights with the expert estimate methods. However, similar to the "area importance" criterion and regarding the aggregation function form, the sub-criteria weights need first multiplication by coefficient D calculated in the following equation:

$$D = \left[p_3 p_4 (\sum_{i=1}^{2} p_i + p_5) \right]^{-\frac{1}{3}}$$

The mentioned aggregation function proves the product status at the questioned instant and its utility rate. It is applicable also to experiments to find the ways of how to increase product utility at minimum cost increment.

Individual DGI benefit cost assessment structure

The DGI are usually developed and maintained by individual partial components of the complete database, such as measurement units, loading units, map sheets etc. Therefore, it is quite a good idea to assess their utility value in the above-described system within the established loading units introducing *individual benefit cost value*.

When assessing database utility, it is useful to define *ideal quality level* at first. The ideal level is used as a *comparison standard* to express each criterion compliance level. Using the comparison standard the individual criteria compliance level and consequently aggregate utility may be assessed.

Individual criteria compliance level general equation is as follows:

$$u_s^x = \frac{k_s}{k_s^*} \qquad \textbf{(29)}$$

in which

k_s is for the value of *s-th* sub-criterion compliance,

k_s^* is for the level of compliance of *s-th* sub-criterion or its sub-group criterion of the comparison standard.

The aggregate individual benefit cost value (*individual functionality)* of the *x-th* measurement unit is defined by the aggregation function of the same type as (28). Therefore:

$$U^x = °F^x = p_3 u_3^x p_4 u_4^x (p_1 u_1^x + p_2 u_2^x + p_5 u_5^x) \qquad \textbf{(30)}$$

The individual criteria weights are identical with the weights in database utility value calculation.

The equation to calculate the aggregate individual utility value is therefore a function of 29 variables that characterise the levels of compliance for the individual criteria. Provided individual variables are independent of each other the derivation of the stated function can model the changed utility values or individual utility values.

$$d°F^x = \frac{dU^x}{du_i} \qquad \textbf{(31)}$$

The principal criteria compliance levels are functions of more variables, though. Determination of du_i value is thus feasible in two ways regarding the desired information structure. When assessing *individual variables effects* on the aggregate individual utility value while the other variables keep constant values, it is necessary to derive *U* function as follows:

$$d°F^x = \frac{dU^x}{du_i^x}\frac{du_i^x}{dx} \qquad \textbf{(32)}$$

in which *x* is for one of the 29 mentioned variables.

However, practically multiple factors may change at the same time. An example would be the database technical quality changes all its parameters – secondary data derivation methods improve, location and attribute accuracy and data integrity increase and on top of it data are stored in a geodatabase accessible to all authorised users and handled well for all topologic, thematic and time relations. In such a case it is suitable to define du_i value as a total differential of all variables describing the modified factors.

Improved geographic service products utility using value analysis

Data base functionality degree is comparable to the cost necessary for provisions – direct material, direct wages, other direct expenditures (HW, SW, amortisation, costs for co-operations, tax and social payments etc.), research and development cost, overhead cost and others. Functionality and cost imply *relative cost efficiency (RCE)* calculated as follows:

$$RCE = \frac{°F}{\sum_{i=1}^{n} N_i} \qquad \textbf{(33)}$$

It is possible to find the most suitable option using RCE. The presented model functionality is shown in the following table and diagrams (Table 1, Figure 1).

In the initial stage, the database degree of functionality is 0.5238. In cases 1 to 5, there are various attitudes to improve its properties – more database update (case 1), increased stored features amount (case 2), completing all missing features (case 3), completing all missing thematic properties (case 4) and completing all missing features and thematic properties (case 5). The cases 4 and 5 proved as the most functional ones. But if expenses are calculated, case 3 is the most effective output.

The described model brings no absolute solution, but it can represent an useful tool for DGI utility value assessment as well as for finding economic ways how to increase this value even under personnel or financial restrictions.

Table 1: Model of RCE calculation

Case	**initial**	**1**	**2**	**3**	**4**	**5**
	T=5, a_{11}=20, n_{251} = 99, n_{252} = 50	**T=1, a_{11}=20, n_{251} = 99, n_{252} = 50, difficulty class 3**	**T=1, a_{11}=15, n_{251} = 99, n_{252} = 50, difficulty class 4**	**T=1, a_{11}=20, n_{251} = 100, n_{252} = 50, difficulty class 3**	**T=1, a_{11}=20, n_{251} = 99, n_{252} = 100, difficulty class 4**	**T=1, a_{11}=20, n_{251} = 100, n_{252} = 100, difficulty class 4**
°F	**0.5238**	**0.6734**	**0.6815**	**0.6737**	**0.6856**	**0.6859**
RCE (currency unit)		**2.8878**	**2.4965**	**2.8889**	**2.5116**	**2.5126**
□ RCE (currency unit)			**0.3913**	**-0.0011**	**0.3762**	**0.3752**

The presented process is applicable to evaluation of present products as well as planned products. When this model is used for a present product, it is possible to optimise its characteristics. In the case of a planned product, it is possible to assess various variants.

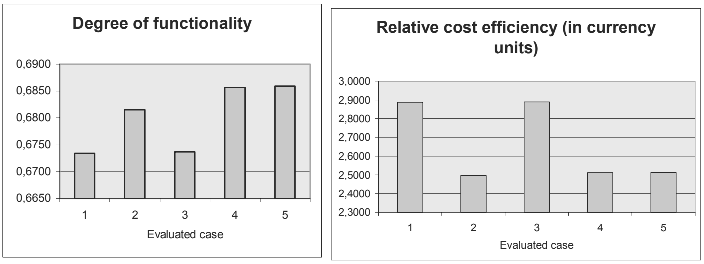

Figure 1: DGI functionality and RCE comaring

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