

Comparison with the Reference Value on the Example of GIS-Based Applications

Dalibor Bartoněk, Stanislava Dermeková and Ján Škurla

Abstract The article gives a new approach to the assessment of objects in terms of various criteria which by its nature belong to the issue of multi-criteria decision making and analysis. The proposed variant of multi-criteria decision-making is based on a comparison of the real considered object model that is created according to user's requirements with the reference value. The geographic object means a real object in this case the object is stored in digital geo-database in the geographic information system (GIS). The reference value represents optimal geographic object which is the most suitable for user's purposes. The comparison of the values of individual criteria is based on the theory of tolerance and metric spaces. Supplementary GIS-based application to calculate the weights of the criteria, which have served to comparison was used. The proposed procedure for the evaluation of various criteria has been validated on a pilot project "SMART Regions" in the city Brno district of Nový Lískovec neighbourhood in the Czech Republic. Around the city district known by its typical of prefabricated blocks of flats it is necessary to compare the different options for renewal urban housing development. Urbanization city prefabricated housing estates using GIS opportunities will be ready to quick respond to the call of various changes in the field of energy sustainability. Therefore, it is important to utilize the available environmental resources for energy sustainability.

D. Bartoněk (✉)

Faculty of Civil Engineering, Institute of Geodesy, Brno University of Technology,
Veveří 330/95, 602 00 Brno, Czech Republic
e-mail: bartonek.d@fce.vutbr.cz

D. Bartoněk

European Polytechnic Institute, Osvobození 899, 686 04 Kunovice, Czech Republic

S. Dermeková · J. Škurla

Faculty of Civil Engineering, AdMaS Center, Brno University of Technology,
Purkyňova 139, 602 00 Brno, Czech Republic
e-mail: dermekova.s@fce.vutbr.cz

J. Škurla

e-mail: skurla.j@fce.vutbr.cz

© Springer International Publishing AG 2018

I. Ivan et al. (eds.), *Dynamics in GIScience*, Lecture Notes in Geoinformation
and Cartography, DOI 10.1007/978-3-319-61297-3_1

Keywords Multi criteria analysis · GIS-based application · SMART regions

Introduction

Methods using multi-criteria analysis are applied in various areas of the real world that are valued in terms of various criteria. These methods are widely-used in regional economics and economic geography, and could lead to different predictions that help to determine the spatial component of economic activity. The article will focus on the use of GIS-based applications for spatial analyses of SMART Regions.

The concept of SMART Regions is now primarily associated with the Europe 2020 strategy and the objectives that are set out by 2020 in the European Union. This means in particular a reduction in energy consumption and CO₂ emissions. The result would be a better living environment and support for innovation related to it. SMART Regions make the same assumptions as SMART Cities, with the only difference being that the focus is on the broader context and takes more account of the environment of cities and their complexes in order to find the maximum amount of synergies usable for the stated goals (European Innovation Partnership on Smart Cities and Communities. Strategic Implementation Plan 2013).

SMART Regions solve the problem of deployment and the use of intelligent technology. This issue contains a huge potential for increase of the efficiency of the strategic development of cities, their functionality and interconnection in all areas of sustainable development (the development of transport infrastructure, alternative energy, public transport, energy efficiency in buildings and residential areas, increasing the share of renewable energy, waste management, achieved savings, improved service quality and operation of cities and regions) (Wawerka et al. 2015). Therefore it needs using multi-criteria method for this multidisciplinary method of decision for the SMART regions. The diversity of individual areas of interest require this approach. This paper aims to use a multi-criteria methods for the purposes of issue of SMART regions. SMART Regions idea implementation in the Czech Republic would address the issue of housing estates that are perceptible threat in connection with the huge consumption of energy in these prefab housing estates. Intelligent technologies incorporate greater transparency and accountability, efficient management of resources (energy consumption, production and waste disposal, reducing the consumption of various resources and the related costs).

The use of available environmental resources become less costly. This prevents degradation of the environment. Decision-making processes are important for understanding the environmental impacts associated with energy production from renewable sources such as wind, solar, geothermal, biomass or hydropower. Due to implementation of the decision-making processes in GIS it will be possible to measure and compare different scenarios planning stakeholders (urbanists, city leaders, citizens, etc.) according to defined indicators for the use of environment, transport, natural resources, employment, etc.

Until now, many methods have been developed to merge diverse parameters criteria into common categories and the results then assign the appropriate value. Overview of currently used methods is given in the publication (Wang et al. 2009). This article describes an alternative approach to multi-criteria analysis based on the comparison of the real considered object with an idealized model—called the reference value. The reference value is determined by the price the Bulletin valid according to the current Valuation Decree under which the property appreciate. The decree sets the prices, coefficients, price increases and reductions of prices and procedures for the application of principles of valuation assets, rights and other assets. It is an attempt for a new approach at the multi-criteria analysis, where the user pre-determined values of the criteria according to their intentions concerning the further exploitation of the assessed object. So far used methods of multi-criteria analysis are used in its calculation of the criteria weights (linear relationship). The proposed solution differs from current methods in that instead of the weighting coefficients are used functional relationships that transform diverse criteria to a single comparable platform. The proposed multi-criteria method is derived from the assumptions of AHP (Analytical Hierarchical Process) and OWA (Ordered Weighted Averaging) method. The main idea is a modelling of decision-making strategy for the localization of the smart activities in the space for the different options of renewal urban housing development. The proposed method has been validated on the pilot project SMART Regions in a selected city district Brno Nový Lískovec in the Czech Republic. Applications have been developed for academic and public organizations through GIS-based platform for data integration, system for geospatial analysis and collection models for visualization and decision making. The decision-making process is carried out using spatial analysis in the form of 3D analysis, modelling environment, multidimensional data, urban planning, geo-statistics, etc. This was created with financial support Technology Agency of the Czech Republic Competence Centres No. TE02000077 and under the project No. FAST-S-15-2723.

Related Works

Multi-criteria analysis is the topic of many research projects and scientific papers. They are given only the most important studies that are closely related to our article from an extensive list of publications. They can be divided into these groups in terms of application methods:

- The optimization methods in computer technology (Thiele et al. 2009; Popov 1999). These methods using multi-objective optimization problem for improving the response time in data warehouse or updates data quality. The article (Oliviera et al. 2013) is devoted issue which describes analysis of three versions of an evolutionary algorithm for determining preference using ELECTRE TRI method. Another article deals with the implementation decision analysis with

visual basic to check the validity and reliability flood-affected areas (Oztuk and Batuk 2011).

- Pre-processing of data in GIS projects which leads to the optimization of spatial analysis (Tirelli and Pessani 2011; Sureg and Vasselmann 2004; Nath et al. 2000; Lee 2004; Vahidnia et al. 2009). The method of pre-processing contributes to evaluation of effectiveness for inducing artificial neural networks and decision trees (Tirelli and Pessani 2011).
- Multi-criteria analysis as a supporting tool for the solution of general optimization problems such as knapsack problem. The DSS is aimed on supporting decision-making concerning bi-criteria location models which deal with current questions of environmental impacts (Mikhalevich et al. 1993).
- The use of multi-criteria analysis in the control and management level (Mikhalevich et al. 1993; Bryzgalin et al. 1983; Rabinabitch 1994; Avdagie and Karabegovic 2008). These studies develop information system for LandScape using different ways of managing urban landscape information and solution related to visual impacts of proposed development projects (Oh 2001). Another way is the possibility to identify and quantify alternatives at the level of managerial decision making, provide information to decision making of stakeholders (Avdagie and Karabegovic 2008). The article deals with the issue of decision making for areas in the watershed for rehabilitation and enhancement projects (Malchewski et al. 2003). Support Systems for environmental management (Massei et al. 2014). The paper describes methodology to evaluate the urban built space under different perspectives. It integrates a data base management module which consider heterogeneous criteria with the influence of various factors (Natividade et al. 2007).
- Special applications such as the use in computer support in the archaeology (Bartoněk and Bureš 2012), in the construction industry (Bureš and Bartoněk 2012) or in the CAD systems (Bartoněk and Opatřilová 2014), FuzzyCell system (Yanar and Akyurek 2006), criteria evaluation for land slide susceptibility mapping (Feizizadeh et al. 2014a), spatially-explicit sensitivity and uncertainty analysis (Feizizadeh et al. 2014b), multi-criteria spatial decision support system for planning urban infrastructures, land-use suitability assessment (Dermeková 2013; Joerin et al. 2001), analysis for the identification of spatial land-use conflicts (Ioja et al. 2014), integration of multi-criteria decision analysis in GIS to develop land suitability for agriculture (Mendas and Delali 2012). The purpose of this article is to improve uncertainty cases occurring in the decision-making process for a better interpretation of alternatives (Meng et al. 2011).
- The proposed method has the closest relationship to the methods of TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), OWA and ELECTRE (ELimination and Choice Expressing Reality) (Wang et al. 2009). The authors were inspired mainly of publication (Peters and Wasilewski 2012) where metric spaces and the theory of tolerance have been discussed. On this theoretical core is based the method for comparison of the criteria between geographic objects and optimally generated model.

Theoretical Foundations

The implementation itself preceded by determination of the mathematical model and determining the input parameters for the development and programming of the particular application.

Let the non-empty set $U \neq \emptyset$ be the universe of discourse and $A \subseteq U$. In our case represents the set U of the modelled area and the subset A is a geographic object (GO). GO can be structure, land, allotment and other object of our interest. It is defined the relation of tolerance $\tau \subseteq (A \times A)$ on the set A . This tolerance is a reflexive and symmetric relation. Then $\langle A, \tau \rangle$ is the space of tolerance. Let B denote set of relevant parameters of geographical objects and let $\varphi: B \rightarrow \mathfrak{R}$. For $x \in B$, $\varphi(x)$ is evaluation of given GO according to some multi-criterial method.

Consider the tolerance space $(B, \cong_{\varphi, \varepsilon})$ with the relation $(\cong_{\varphi, \varepsilon})$:

$$\cong_{\varphi, \varepsilon} = \{(x, y) \in B \times B \mid |\varphi(x) - \varphi(y)| \leq \varepsilon\} \quad (1)$$

In our case $y \in B$, $\varphi(y)$ is the reference value that means evaluation of optimal GO that is most suitable for the user's purposes.

Furthermore is defined a function p at the non-empty set A : $p: A \times A \rightarrow [0, +\infty) \subseteq \mathfrak{R}$ which is called pseudometric (it differs from the metrics by the launch requirement to close to zero distance between two different points) if it satisfies for an arbitrary $x, y, z \in A$ the following conditions:

$$p(x, x) = 0, p(x, y) = p(y, x), p(x, y) + p(y, z) \geq p(x, z) \quad (2)$$

Let $\langle p, A \rangle$ be a pseudometric space and $\varepsilon \in (0, +\infty)$. There is defined the relation of tolerance metrics $\tau_{p, \varepsilon}$ by relationship:

$$(x, y) \in \tau_{p, \varepsilon} \Leftrightarrow p(x, y) < \varepsilon \quad (3)$$

Each pseudometric space can actually be seen as a topological space which is a very important in GIS issue and spatial expression of the real object. Relations (1) and (2) are then used to compare of geographic objects (GO) in the area represented by a set A with the reference value.

Let us have a system $\langle B, F \rangle$ where O is the set GO and F is a non-empty set of real functions: $F := \{\varphi \mid \varphi: B \rightarrow \mathfrak{R}\}$. It is possible assessment GO to represent by the set of parameters from our point of view, $G \subseteq A$. Then for each parameter $g \in G$ is possible to assign function $\varphi(g) - \varphi \in F$, which transforms the given parameter for our needs i.e. to compare with another object (in our case the reference value). Each GO G can be described as a vector of real functions in the space \mathfrak{R}^n :

$$\vec{\varphi}(G) = (\varphi_1(g_1), \varphi_2(g_2), \dots, \varphi_n(g_n)) \quad (4)$$

If we apply a metric space into two different GO G, M and measurable distance d at the O between them, then you get the relationship:

$$p(G, M) := d(\vec{\varphi}(G), \vec{\varphi}(M)) = \sqrt{\sum_{i=1}^n (\varphi_i(g_i) - \varphi_i(m_i))^2} \quad (5)$$

for each $g_i \in G$ and $m_i \in M$.

When the Eq. (5) is substituted into Eq. (3) it gets:

$$(G, M) \in \tau_{p,\varepsilon} \Leftrightarrow \sqrt{\sum_{i=1}^n (\varphi_i(g_i) - \varphi_i(m_i))^2} \leq \varepsilon \quad (6)$$

This means that the pair GO (G, M) (M is in our case reference value) belongs to the pseudometric space with a tolerance metrics $\tau_{p,\varepsilon}$ just when it satisfies the condition (5). At this relationship is based comparison of criteria values for real GO with the reference value. Reference ranges are then defined by individual tables valuation decree. Reference ranges are designed for individual criteria arising out of conditions valuation areas.

Materials and Methods

SMART Regions solve the problem of deployment and use of intelligent technology. This issue contains a huge potential for increasing the efficiency of the strategic development of the cities, their functionality and interconnection in all areas of sustainable development (the development of transport infrastructure, alternative energy, public transport, energy efficiency in buildings and residential areas, increasing the share of renewable energy, waste management, and others), achieved savings, improved service quality and operation of cities and regions. Mentioned various areas have a great potential for mutual assessment, diversity requires a multi-criteria approach. For this reason we decided to use multi-criteria decision-making methods. The aim is to assess the various criteria that must be considered against the background with the issue of SMART Regions for housing estate.

The user selects criteria from the database according to the usage purpose of the object and determines the parameters of the model. This defines a model expressing the values belonging to the reference range or close to the reference value. It results in definition of the model (etalon). In case study will consider the criteria that describe the socio-economic determinants influencing the spatial location of areas of smart activities for sustainability and reduce energy consumption. Specifically,

the determinants of social (interaction of man and society, e.g. settlements), economic (e.g. Localization problems of industry, agriculture, services, tourism), communication problems (transport services, infrastructure, etc.), determinants of expressing complex problems studying determination of man's environment and vice versa (e.g. the problems of sustainable development, renewable sources, environmental protection, etc.). Potential GO in the given locality are analysed in GIS. Each GO is analysed and then quantified the relevant criteria according to user requirements. The values of these criteria are compared with the criteria of the etalon in comparative block which works on the basis of Eq. (5). For each criterion it is necessary to determine the appropriate function (Eq. 5), which transforms the criterion on a common platform and represents the user's accent due to this criterion. The result of comparison goes to the output block where it is decided whether a given geographic object meets or does not meet the requirements of users for a particular purpose. If that result does not satisfy the user's ideas then user has the possibility to correct the parameters of the etalon and the whole evaluation process can be repeated. Selection of functions for individual criteria is based on empirical knowledge.

Application “AHP-MCA”

Part of the activities related to the methodology of strategic decision making is a tool for strategic decision making. Implementation of tool is carried out by means add-on applications in an environment of ArcGIS software. The reason for choosing this software is the display of spatial information (both vector and raster data in a GIS environment) for the purpose of SMART region spatial modelling. This application leverages the capabilities of multi-criteria decision-making system. It was determined AHP method (Analytical Method hierarchical process). We can generate criteria matrix using Saaty method calculations where variants “divide” the weight of the relevant criteria. Value weights are called preferential indexes. AHP method is used for determining the size preferences for each pair of criteria. It is a method of criteria quantitative paired comparison.

Weights (preferential indexes) were calculated using add-on applications. It developed a desktop application (the plugin) for MCA (Multi-Criteria Analysis) in GIS—“AHP-MCA”. Plugin extends the functionality of ArcMap. It allows to create data in raster format. Plugin has extensions using the Add-In Manager—components without registration Specific applications of various multi-criteria methods for decision in a GIS environment have been developed in Java Desktop SDK ArcObjects. Plugin has been programmed in Java, in development environment Eclipse. The application is shown in Fig. 1. Applications in ArcGIS is able to process only raster data for now. The intention will be for the processing of both raster and vector data within the development of applications in ArcGIS.

Part of the spatial analytical functions was to determine the main factors which can be defined as criteria containing the socioeconomic determinants. It is possible

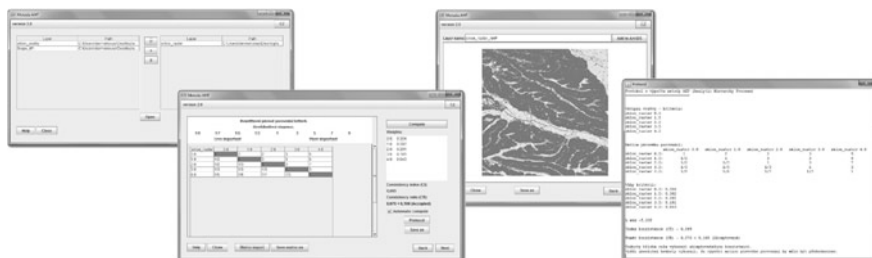


Fig. 1 Application of multi-criteria analysis—“AHP-MCA”

to determine the main determinants in strategic decision-making areas for the purpose of SMART Region spatial modelling: geographic, environmental, socio-economic and territorial administrative determinants. Determinants based on predetermined coefficients which are contained in the Valuation Decree. These are the values determined from the base price building plot where there are individual coefficients. These are coefficients of the size of the community, economic and administrative importance of the municipality, the municipality location, technical infrastructure in the municipality, transport needs or civic amenities in the municipality. SMART regions can be identified by the following main factors of sustainability: economic, social, environment, governance, services.

Furthermore, it is necessary to consider also the indexes by price comparing, through which it is also possible accurately determine the criteria for multi-criteria decision-making in relation to the areas for SMART management and intelligent planning of cities. Specifically, it represents the index of the real energy sustainability, the index of the renewable sources and the index of position. Another source for determining criteria from the Valuation Decree are qualitative zones (C1–C12) that are listed in the following text as specific criteria decision-making process.

Transport accessibility is one of the key criteria for the SMART region spatial modelling (transport network, such as highway, expressway and first class roads) and its associated transportation system and access to the lot. Within the territorial administrative determinant are crucial the urban and suburban studies, the characteristics of the surrounding objects and the areas typology. The following are important relationships of the locality to the surrounding infrastructure in relation to the availability of utility networks (electricity supply, gas, heating networks, sewerage, water supply and telecommunications).

Individual areas of criteria were determined according to the needs of the target users who were civil servants working in the process of strategic decision making for the regional development (urban development areas for the purposes of competitiveness in the region around the city of Brno. For the purpose of the functional definition of the criteria in locating areas were observed mainly these characteristics of the qualitative zones (environmental, social and economic objectives of cities).

Set intervals of the availability were solved by the method of metric spaces. It is assumed the maximized character of the criteria. Not all of the criteria were maximized therefore it was necessary to convert them to the maximization. It is assumed that higher value of the criterion is desired. All the values are normalized to the interval for easy comparison of specific parameters $\langle 0, 1 \rangle$.

Experimental Results

The proposed procedure for the evaluation of various criteria has been validated on a case study in the municipality of city district Brno—Nový Lískovec in the Czech Republic. Processing was carried out in software ArcGIS 10.2. according to the proposed mathematical methods. The aim was to select a suitable location in the specified area for the establishment of zones for the SMART region energy sustainability spatial modelling. First, was selected the appropriate criteria for analysis. For each criterion was determined reference range values and defined the corresponding function φ (Eq. 4). All criteria values were normalized (standardized) for better comparison, i.e. presented to the interval $\langle 0, 1 \rangle$. Calculation of the selected criteria was carried out according to the Eq. (5).

In the case study were compared the real assessed areas with reference established under the tabulated data of the Valuation Decree. They were assessed different alternative with consideration of all the criteria that influence the decision-making process. They were selected 4 alternatives cooperation with a panel of expert system (civil servant and experts important for strategic decision making in cities).

Individual alternatives incorporate all the values that are listed in the valuation decree. Table values represent different ranges of values that are listed in the tables for built-up areas or specified for buildings. These are mainly land and buildings used primarily for prefabricated housing estates. These areas and buildings are determined by the Classification CZ-CC which includes locally and spatially coherent civil engineering works to such equipment or device so that it can perform the functions for which they are intended (Figs. 2, 3, 4 and 5).

Alternatives were chosen according to the results shown in the Table 1. These signs then belonged qualitative range that voted by solved region. Then they were assigned to the recommended values for these qualitative ranges which represented for our model reference value. According to the reference values 4 different range of values represented alternatives are voted.

Alternatives are reference values—the appropriate allowable values (corresponding to the restriction on the Valuation Decree), which were derived from 4 different levels and were adjusted according to the FAO system. These levels are divided into: highly suitable (A1) relatively suitable (A2), slightly suitable (A3) and unsuitable and (A4).

Criteria values for the various alternatives were compared with a reference tabulated values and have been shown using a spider graph. Differences from the

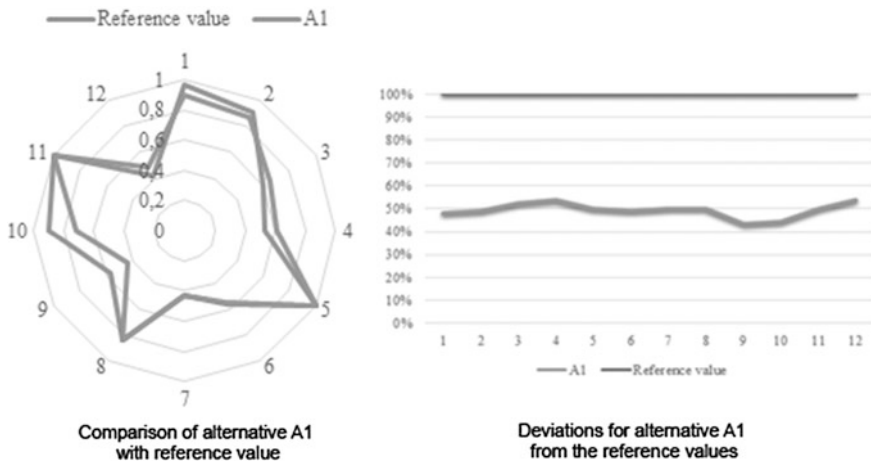


Fig. 2 Alternative A1 (highly suitable)

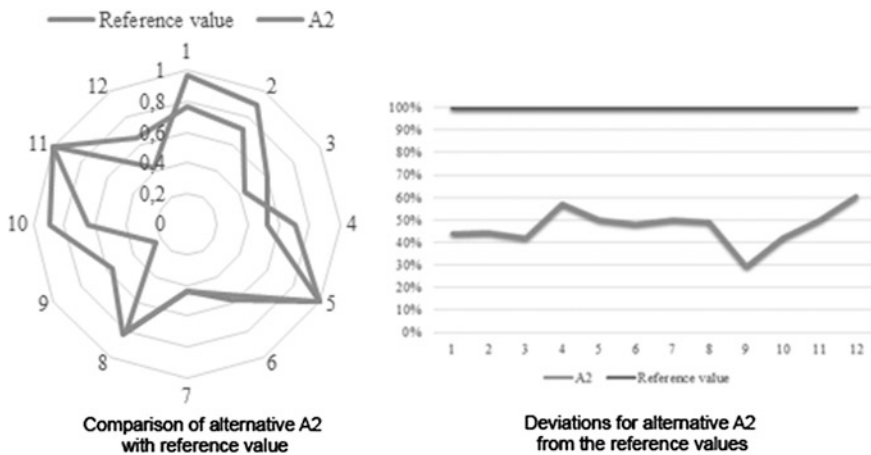


Fig. 3 Alternative A2 (relatively suitable)

reference values were reviewed and discussed with stakeholders. Alternative A1 was as expected, chosen it as the correct one. For the purposes of decision-making targets and strategies of the city it is always necessary to make several variants, which in itself include the risky variant. Management of the city needs to rethink as well as the unfavourable variants on the basis of which it is then degraded risk implications for positive alternatives. Further option appears to be admissible alternative A2, which allows certain deviations from the reference value. For this variant is necessary to develop risk analysis and impact considering the influence of the individual criteria.

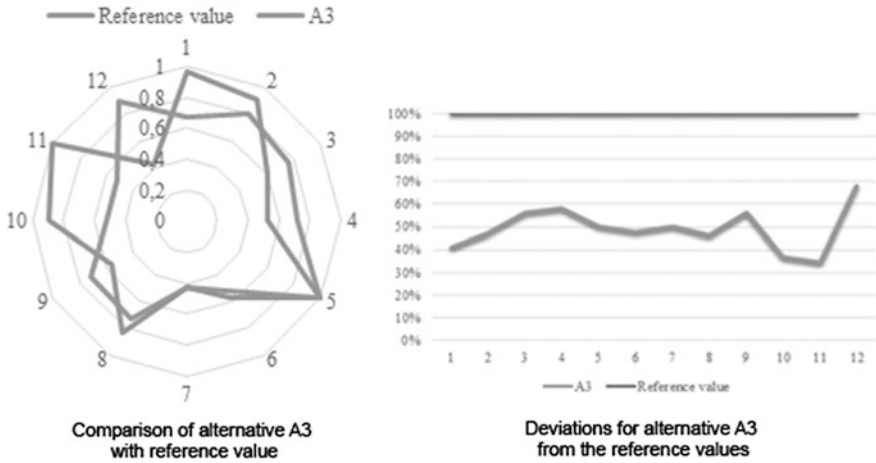


Fig. 4 Alternative A3 (slightly suitable)

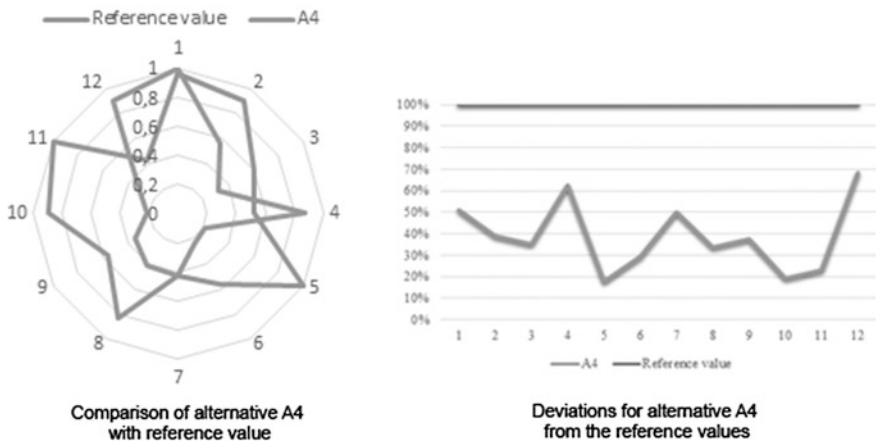


Fig. 5 Alternative A4 (unsuitable)

Alternatives A3 and A4 are examples of unsuitable placement of areas for SMART activities of energy sustainability. These alternatives are solved and submitted as areas for further assessment for land use within urban planning. Individual deviations from the reference values are shown in the following charts. As satisfactory alternatives were chosen alternative A1 and alternative A2 were chosen as substitute variants. The result of variant A1 is shown on Fig. 6.

Table 1 Mainly these characteristics of the qualitative zones

Zone signification	Characteristics of criteria
C1	Wider relations related to the development of the residential structure
C2	The concept of residential development functions
C3	Surrounding production and employment activities—investment, jobs, innovation
C4	Availability of transport infrastructure
C5	Healthcare and social care
C6	Public safety
C7	Availability of the research institutions and universities
C8	Geographical conditions
C9	The level of technical infrastructure
C10	Nature and landscape protection, pollution
C11	Energy efficiency
C12	Renewable resources

Fig. 6 Map of selected objects of alternative A1

Conclusions

This article describes a method for multi-criteria analysis the main difference of which, compared with the existing methods is that instead of weighting coefficients of the individual criteria there are used general functions. These functions transform various criteria on a common comparable platform. The aim is to assess the various criteria that must be compared with each other relative to the reference values in relation to the issue SMART regions for housing estate. The paper describes the use of multi-criteria method for determination of the evaluated criteria and for the comparison a sensitive method and reference values is used.

By combining the different results of multi-criteria analysis it was discovered the need to compare the real considered object or property (the available environmental resources for energy sustainability) with a model that is designed according to the requirements of the users who have decision-making power for strategy in the area of sustainable development and competitiveness of the region. This conclusion was confirmed by the spatial localization of areas for energy sustainability of a specific pilot project in the city district Nový Lískovec. After examining the socio-economic determinants, which resulted in the formation of spatial localization, a completely new approach, which allowed the comparison of the values of individual criteria based on the theory of tolerance and metric spaces was used.

The proposed multi-criteria analysis provided complete arrangement sets of all resulting variants and the possibility of choosing the best variant for purposes of strategic decision for localization of areas for sustainable development. The proposed method can be used for developers, for strategic planning of regional development or as a supporting method to compile the land use plan of the municipality.

Acknowledgements This was created with financial support Technology Agency of the Czech Republic Competence Centres No. TE02000077 and under the Project No. FAST-S-15-2723.

References

- Avdagic, Z., & Karabegovic, A. (2008). Fuzzy Logic and Genetic Algorithm Application for Multi Criteria Land Valorization in Spatial Planning. *Artificial Intelligence Techniques for Computer*, 175–198.
- Bartoněk, D., & Bureš, J. (2012). Expert GIS for locating of archaeological sites. In *4th International Conference on Cartography & GIS*. ISSN 1314-0604. Albena, Bulgaria: Bulgarian Cartographic Association.
- Bartoněk, D., & Opatřilová, I. (2014). Design of man-machine interface for mobile mapping. *Advanced Science Letters*, 20(2), 501–504(4).
- Bureš, J., & Bartoněk, D. (2012). Application of GIS in civil engineering. In *4th International Conference on Cartography & GIS*. ISSN 1314-0604. Albena, Bulgaria: Bulgarian Cartographic Association.

- Bryzgalin, G. I., Bagmutov, V. P., & Kopeikin, S. D. (1983). Analysis and optimization of laws governing composite media on the basis of the multi-criterial approach. *Mechanics of Composite Materials*, 19(2), 154–162.
- Dermekova, S. (2013). Evaluation of the criteria in real estate engineering using the GIS Support. *Geodetický a kartografický obzor*, 9(101), 235–244. ISSN: 1805-7446. (In Czech).
- European Innovation Partnership on Smart Cities and Communities. Strategic Implementation Plan. 2013. <http://ec.europa.eu/eip/smartcities/>
- Feizizadeh, B., Roodposhti, M. S., Jankowski, P., & Blaschke, T. (2014a). A GIS-based extended fuzzy multi-criteria evaluation for land slide susceptibility mapping. *Computers & Geosciences*, 73, 208–221.
- Feizizadeh, B., Jankowski, P., & Blaschke, T. (2014b). A GIS based spatially-explicit sensitivity and uncertainty analysis approach for multi-criteria decision analysis. *Computers & Geosciences*, 64, 81–95.
- Ioja, C. I., Razvan, Nita M., Vănuș, G. O., Onose, D. A., & Gavrilidis, A. A. (2014). Using multi-criteria analysis for the identification of spatial land-use conflicts in the Bucharest Metropolitan Area. *Ecological Indicators*, 42, 112–121.
- Joerin, F., Thériault, M., & Musy, A. (2001). Using GIS and outranking multi-criteria analysis for land-use suitability assessment. *Geographical Information Science*, 15(2), 153–174.
- Lee, I. (2004). Mining multivariate associations within GIS environments. *Innovations in Applied Artificial Intelligence*, 1062–1071
- Malczewski, J., Chapman, T., Flegel, C., Walters, D., Shrubsole, D., & Healy, M. (2003). GIS—multi-criteria evaluation with ordered weighted averaging (OWA): Case study of developing watershed management strategies. *Environment and Planning*, 35, 1769–1784.
- Massei, G., Rocchi, L., Paolotti, L., Greco, S., & Boggia, A. (2014). Decision Support Systems for environmental management: A case study on wastewater from agriculture. *Journal of Environmental Management*, 146, 491–504.
- Mendas, A., & Delali, A. (2012). Integration of multi-criteria decision analysis in GIS to develop land suitability for agriculture: Application to durum wheat cultivation in the region of Mleta in Algeria. *Computers and Electronics in Agriculture*, 83, 117–126.
- Meng, Y., Malczewski, J., & Boroushaki, S. (2011). A GIS-based multi-criteria decision analysis approach for mapping accessibility patterns of housing development sites: A case study in Canmore, Alberta. *Journal of Geographic Information System*, 3, 50–61.
- Mikhalevich, V. S., Volkovich, V. L., & Yatsenko, Y. P. (1993). Multi-criterial analysis of industry conversion rates using integral models. *Cybernetics and Systems Analysis*, 29(1), 26–34
- Nath, S. S., Bolte, J. P., Ross, L. G., & Aguilar-Manjarrez, J. (2000). Applications of geographical information systems (GIS) for spatial decision support in aquaculture. *Aquacultural Engineering*, 23, 233–278.
- Natividade-Jesus, E., Coutinho-Rodrigues, J., & Antunes, C. H. (2007). A multi-criteria decision support system for housing evaluation. *Decision Support Systems*, 43, 779–790.
- Oh, K. (2001). Landscape information system: A GIS approach to managing urban development. *Landscape and Urban Planning*, 54, 79–89.
- Oliviera, E., Antunes, C. H., & Gomes, A. (2013). A comparative study of different approaches using an outranking relation in a multi-objective evolutionary algorithm. *Computers & Operations Research*, 40, 1602–1615.
- Ozturk, D., & Batuk, F. (2011). Implementation of GIS-based multi-criteria decision analysis with VB in ArcGIS. *International Journal of Information Technology & Decision Making*, 10(6), 1023–1042.
- Peters, J. F., & Wasilewski, P. (2012). Tolerance spaces: Origins, theoretical aspects and applications. *Information Sciences*, 195, 211–225.
- Popov, N. M. (1999). On some optimality principles in multi-criterial problems. *Computational Mathematics and Modeling*, 10(2), 178–183.
- Rabinovitch, M. (1994). Multi-criterial optimization in production and management. *Operations Research '93*, 405–407.

- Suveg, I., & Vosselman, G. (2004). Reconstruction of 3D building models from aerial images and maps. *ISPRS Journal of Photogrammetry & Remote Sensing*, 58, 202–224.
- Thiele, M., Bader, A., & Lehner, W. (2009). *Multi-objective scheduling for real-time data warehouses* (pp. 137–151). Berlin: Springer.
- Tirelli, T., & Pessani, D. (2011). Importance of feature selection in decision-tree and artificial-neural-network ecological applications. *Alburnus alburnus alborella: A practical example. Ecological Informatics*, 6, 309–315 (Elsevier).
- Vahidnia, M. H., Alesheikh, A. A., & Alimohammadi, A. (2009). Hospital site selection using fuzzy AHP and its derivatives. *Journal of Environmental Management*, 90, 3048–3056.
- Wang, J., Jing, Y., Zhang, Ch., & Zhao, J. (2009). Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renewable and Sustainable Energy Reviews*, 13(9), 2263–2278.
- Wawetka, R., Volařík, T., & Dermeková, S. (2015). Smart housing estate: Implementation of ICT user friendly application to raise inhabitant' s sustainability awareness. In *15th International Multidisciplinary Scientific Geoconference SGEM 2015. International multidisciplinary geoconference SGEM. Informatics, Geoinformatics and Remote Sensing, Conference proceedings, Volume I*. Sofia, Bulgaria: STEF92 Technology Ltd., 51 “Alexander Malinov” Blvd., 1712 Sofia, Bulgaria, 2015. s. 793–799. ISBN: 978-619-7105-34- 6. ISSN: 1314- 2704.
- Yanar, T. A., & Akyurek, Z. (2006). The enhancement of the cell-based GIS analyses with fuzzy processing capabilities. *Information Sciences*, 176, 1067–1085.