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Measuring Congruence of Ranking Results Applying Particular MCDM Methods

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Abstract. The aim of the current research is to measure objective congruence (incongruence) of the results obtained in a process of multiple criteria analysis when applying different MCDM methods. The methodology for evaluation of ranking results is developed on the ground of a case study of the redevelopment of derelict buildings as well as on composed experimental tasks. Fuzzified COPRAS, TOPSIS and VIKOR methods are applied for ranking the alternatives. Calculation results are evaluated by applying mathematical statistics methods. A methodology for measuring the congruence (incongruence) of the relative significances of alternatives is proposed.

Keywords: MCDM, COPRAS, TOPSIS, VIKOR, congruence of ranking results.

1. Introduction

Multiple criteria decision making (MCDM) can be applied for complex decisions when a lot of criteria are involved. There is a variety of MCDM methods developed as well as case studies of their application presented. However, it was observed that different MCDM methods can produce diverse, not always coinciding ranking results. Therefore, in the current paper the authors suggest applying COPRAS (a method of multiple criteria COmplex PRoportional ASsessment of projects), TOPSIS (the Technique for Order Preference by Similarity to Ideal Solution) based on vector as well as linear normalization of initial criteria values and VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje; in Serbian) methods for ranking of alternatives as well as compare and analyze calculation results.

Zavadskas and Kaklauskas (1996) developed a method of multiple criteria complex proportional assessment of projects for determining the priority and the utility degree of alternatives. Lithuanian as well as foreign scientists have been applying the original or expanded method for solving different engineering and management multi-attribute problems in the period of 1996–2011 (Zavadskas *et al.*, 2009a; Mazumdar *et al.*, 2010; Podvezko *et al.*, 2010; Chatterjee *et al.*, 2011). Some other authors have been applying modified COPRAS method. Zavadskas and Antucheviciene (2007) applied fuzzified COPRAS method and performed a multiple criteria analysis of regeneration alternatives of derelict buildings in Lithuanian rural areas. Zavadskas *et al.* (2009b) considered the application of grey relations methodology for defining the utility of alternatives (COPRAS-G). The compromise ranking method with grey numbers was also used by Madhuri *et al.* (2010), Madhuri and Chandulal (2010).

Usual crisp TOPSIS as developed by Hwang and Yoon (1981) or fuzzy TOPSIS has been widely applied in construction management for ranking of construction-technological alternatives, selecting of resource-saving decisions, accepting other technological or facility management decisions (Zavadskas and Antucheviciene, 2006; Liu, 2009; Liaudanskiene *et al.*, 2009; Kucas, 2010; Kalibatas *et al.*, 2011). The above method was successfully applied for selecting of various projects (Amiri, 2010), suppliers (Boran *et al.*, 2009), partners or contractors (Marzouk, 2008; Ye, 2010), consultants (Saremi *et al.*, 2009), evaluating road design and transport systems (Jakimavicius and Burinskiene, 2009). In some papers the application of extended TOPSIS has been analyzed. In Zavadskas *et al.* (2006) the methodology for measuring the accuracy of determining the relative significance of alternatives as a function of the criteria values was developed. A new fuzzy multicriteria decision making approach for evaluating decision alternatives involving subjective judgments made by a group of decision makers was presented in Yeh and Chang (2009) paper. Attempts using extended TOPSIS method with different distance approaches were published (Antucheviciene *et al.*, 2010; Chang *et al.*, 2010).

Compromise ranking method (VIKOR) was developed and presented by Opricovic (1998) as well as VIKOR and TOPSIS methods were compared by Opricovic and Tzeng (2004). According to Opricovic and Tzeng, the values normalized by vector normalization and applied in TOPSIS may depend on the evaluation unit. Moreover, these two methods introduce different aggregating functions for ranking. Therefore, the authors of the current paper also applied the VIKOR method for ranking redevelopment alternatives of derelict buildings (Antucheviciene and Zavadskas, 2008). The VIKOR-F method has been developed to solve fuzzy multicriteria problem with conflicting and noncommensurable criteria (Opricovic, 2007).

However, combination of VIKOR with some other MCDM methods has been more often applied and handling of a proper MCDM technique has been discussed. Selection of proper methods considering their advantages and disadvantages in qualitative manner was analysed in Ginevicius and Zubrecovas (2009), Ginevicius and Podvezko (2009). TOPSIS and VIKOR were applied for evaluating of environment of enterprises (Ginevicius *et al.*, 2010). The Comparative Analysis of SAW and COPRAS was carried out by Podvezko (2011). Ic and Yurdakul (2010) compared results of decision support system based on fuzzy TOPSIS with experts' opinion. Spearman's correlation was used for that purpose. Hajkowicz and Higgins (2008) applied some other multiple criteria assessment methods to water management decision problems and showed that different methods were in strong agreement with high correlations amongst rankings.

The aim of the current research is to measure objective congruence (incongruence) of the results obtained in a process of multiple criteria analysis when applying different MCDM methods. The methodology for evaluating of ranking results is developed on the ground of a case study of redevelopment of derelict buildings as well as on composed experimental tasks. Calculation results are evaluated by applying mathematical statistics methods. The methodology for measuring the congruence (incongruence) of the relative significances of building redevelopment alternatives is proposed. The above methodology is applicable for analyzing the results of different multi-attribute tasks.

2. MCDM Methods Applied for Ranking of Building Redevelopment Alternatives

The methods evaluate the decision matrix F, which refers to n alternatives that are evaluated in terms of m criteria. The system of criteria and alternatives as well as the initial values and weights of criteria are determined.

Suppose, there is the initial decision-making matrix:

$$F = \begin{pmatrix} f_{11} & f_{12} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ f_{m1} & f_{m2} & \cdots & f_{mn} \end{pmatrix}, \tag{1}$$

where m is a number of criteria and n is a number of alternatives. The member f_{ij} denotes the performance measure of the jth alternative in terms of the ith criterion, $i = 1, \ldots, m$; $j = 1, \ldots, n$.

Then the weighted normalized decision-making matrix is formed and the relative significances as well as a priority order of alternatives is established applying a particular MCDM method as described in the following subsections.

2.1. *COPRAS*

According to the method of multiple criteria COmplex PRoportional ASsessment of projects, a generalized criterion determining the complex efficiency of the project is directly proportional to the relative effect of values and weights of the criteria considered in a project.

To eliminate the units of the criterion functions and to receive the weighted values, the method under discussion uses the following formula (Zavadskas and Kaklauskas, 1996):

$$w_{ij} = q_i \frac{f_{ij}}{\sum_{j=1}^{n} f_{ij}}, \tag{2}$$

where q_i is the weight of ith criterion, w_{ij} is the normalized weighted value of each criterion, $i = 1, \ldots, m$; $j = 1, \ldots, n$.

Then the sums of weighed normalized values of criteria describing the jth alternative are calculated. Following the (2), w_{ij}, $i = 1, \ldots, m$, $j = 1, \ldots, n$ is the normalized weighted value of each ith criterion, that belongs to benefit criteria or cost/loss criteria. Accordingly, the jth alternative is then described by maximizing indices $w_{ij}^{*},\ i = 1,\dots,m$, and i is associated with benefit criteria, and minimizing indices $w_{ij}^{-},\ i = 1,\dots,m$, and i is associated with cost/loss criteria.

Maximizing indices w_{ij}^{*} and minimizing indices w_{ij}^{-} are summed up separately for every jth alternative. The sums of weighted normalized maximizing and minimizing indices S_j^{*} and S_j^{-} , respectively, characterizing the jth alternative, are calculated as follows (Zavadskas and Kaklauskas, 1996):

$$
\begin{aligned}
S_j^{*} &= \sum_{i=1}^{m} w_{ij}^{*}, \\
S_j^{-} &= \sum_{i=1}^{m} w_{ij}^{-},
\end{aligned}
\tag{3}
$$

The relative significance Q_j of each alternative is determined according to positive S_j^{*} and negative S_j^{-} and is calculated by the formula (Zavadskas and Kaklauskas, 1996):

$$
Q_j = S_j^{*} + \frac{S_{\min}\cdot \sum_{j=1}^{n} S_j^{-}}{S_j^{-}\cdot \sum_{j=1}^{n} \frac{S_{\min}}{S_j^{-}}},
\tag{4}
$$

where $S_{\min} = \min_j S_j^{-},\ j = 1,\dots,n.$

Then the priorities of alternatives can be determined. Relative significance Q_j of the jth alternative indicates the satisfaction degree of demands and goals pursued by the interested parties. The greater the value of the generalizing criterion Q_j, the more effective is the alternative. In the case of $Q_{\max} = \max_j Q_j,\ j = 1,\dots,n$, the satisfaction degree as well as the priority (rank) of the alternative is the highest. The rank of the remaining variants is lower compared with the most rational alternative.

2.2. *TOPSIS Based on Two Criteria Values' Normalization Methods*

Considering the opinion, that there are normalization procedures with effects on the final MCDM result, two normalization methods were used in the TOPSIS technique. The classical TOPSIS uses vector normalization (Hwang and Yoon, 1981; Triantaphyllou, 2000):

$$
r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^{n} f_{ij}^{2}}},
\tag{5}
$$

where r_{ij} is the normalized value, $i = 1,\dots,m;\ j = 1,\dots,n.$

Lai and Hwang (1994) introduced linear normalization into the TOPSIS:

$$
r_{ij} = \frac{f_{ij}}{f_i^{*} - f_i^{-}},
\tag{6}
$$

where $f_i^{*} = \max_j f_{ij}, f_i^{-} = \min_j f_{ij},\ i = 1,\dots,m;\ j = 1,\dots,n.$

The weighted normalized value w_{ij} is calculated as

$$w_{ij} = q_i r_{ij}, \tag{7}$$

where q_i is the weight of ith criterion, $i = 1, \dots, m;\ j = 1, \dots, n.$

The ideal and the negative-ideal solutions denoted respectively as A^* and A^- are defined as follows (Hwang and Yoon, 1981; Triantaphyllou, 2000):

$$A^* = \{w_1^*, w_2^*, \dots, w_m^*\}, \tag{8}$$

$$A^- = \{w_1^-, w_2^-, \dots, w_m^-\}, \tag{9}$$

where $w_i^* = \max_j w_{ij},\ w_i^- = \min_j w_{ij},\ i = 1, \dots, m;\ j = 1, \dots, n$, if the ith criterion represents a benefit; $w_i^* = \min_j w_{ij},\ w_i^- = \max_j w_{ij},\ i = 1, \dots, m;\ j = 1, \dots, n$, if the ith criterion represents a cost/loss.

The Euclidean distance method is then applied to measure the distances of each alternative from the ideal solution and negative-ideal solution:

$$S_j^* = \sqrt{\sum_{i=1}^{m} \left(w_{ij} - w_i^*\right)^2}, \tag{10}$$

$$S_j^- = \sqrt{\sum_{i=1}^{m} \left(w_{ij} - w_i^-\right)^2}, \tag{11}$$

where S_j^* is the distance from the ideal solution and S_j^- is the distance from the negative-ideal solution, $i = 1, \dots, m;\ j = 1, \dots, n.$

The relative closeness of an alternative A_j to the ideal solution A^*, i.e., the relative significance of an alternative Q_j is defined as follows:

$$Q_j = \frac{S_j^-}{S_j^* + S_j^-}, \tag{12}$$

where $1 \geqslant Q_j \geqslant 0$ and $j = 1, \dots, n.$

The best alternative can be found according to the preference order of Q_j.

2.3. *VIKOR*

At first applying the compromise ranking algorithm one needs to determine the best x_i^* and the worst x_i^- values of all criterion functions, $i = 1, \dots, m$ and to calculate the weighted normalized values w_{ij}:

$$w_{ij} = q_i \frac{x_i^* - x_{ij}}{x_i^* - x_i^-}, \tag{13}$$

where $x_i^* = \max_j x_{ij},\ x_i^- = \min_j x_{ij}$ if the ith function represents a benefit and $x_i^* = \min_j x_{ij},\ x_i^- = \max_j x_{ij}$ if the ith function represents a cost/loss, q_i is the weight (or significance) of the ith criterion, $i = 1, \dots, m;\ j = 1, \dots, n$ (Opricovic and Tzeng, 2004).

The next step is the computation of the values S_j, R_j, and Q_j:

$$S_j = \sum_{i=1}^{m} w_{ij}, \tag{14}$$

$$R_j = \max_i w_{ij}, \tag{15}$$

$$Q_j = v(S_j - S^-)/(S^* - S^-) + (1 - v)(R_j - R^-)/(R^* - R^-), \tag{16}$$

where $S^* = \max_j S_j,\ S^- = \min_j S_j,\ R^* = \max_j R_j,\ R^- = \min_j R_j$, $i = 1, \dots, m$; $j = 1, \dots, n, \nu$ is introduced as the weight of the strategy of "the maximum group utility". Here, $\nu = 0.5$, meaning that a compromise solution is stable within the decision-making process by consensus. (When $\nu > 0.5$, 'voting by majority rule' is needed; when $\nu < 0.5$, the solution is stable within the decision-making process 'with veto'.)

Then, the alternatives should be sorted by values S, R and Q in the increasing order. The best alternative A' is the one with the minimum value Q, if two complementary conditions are satisfied (Opricovic and Tzeng, 2004):

C1. 'Acceptable advantage': $Q(A'') - Q(A') \geqslant DQ$, where A'' is the alternative having the second position in the ranking list by Q; $DQ = 1/(J - 1)$; J is the number of the alternatives.

C2. 'Acceptable stability in decision-making': A' must also be the best ranked by S or/and R.

If one of the conditions is not satisfied, then, a set of compromise solutions with the advantage rate is proposed instead of the only best alternative. This will consist of the alternatives A' and A'', if only condition C2 is not satisfied, or the alternatives $A', A'', \dots, A^{(N)}$, if condition C1 is not satisfied, while and $A^{(N)}$ is determined by the relation $Q(A^{(N)}) - Q(A') < DQ$ for the maximum N (the positions of these alternatives are 'in closeness').

2.4. *Some Items of Fuzzy Sets Theory, as Applied to MCDM*

Considering the fuzziness of the available data and the decision-making procedures, fuzzy numbers could be used to assess the values of all criteria and provide the relative significances of each alternative with respect to each criterion. Hereby, we can convert the decision making matrix (1) into a fuzzy decision making matrix.

Fuzzy Numbers

Fuzzy numbers are a fuzzy subset of real numbers, representing the expansion of the idea of a confidence interval. In this paper the triangular fuzzy numbers are used for fuzzy numbers. A triangular fuzzy number $\tilde{f}$ can be defined by a triplet (f_1, f_2, f_3).

The membership function $\mu_{\tilde{f}}$ of $\tilde{f}$ is defined as (Hwang and Yoon, 1981; Sanayei *et al.*, 2010):

$$\mu_{\tilde{f}}(x) = \begin{cases} 0, & x < f_1, \\ \frac{x-f_1}{f_2-f_1} & (f_1 \leqslant x \leqslant f_2), \\ \frac{x-f_3}{f_2-f_3} & (f_2 \leqslant x \leqslant f_3), \\ 0, & x > f_3. \end{cases} \tag{17}$$

The operations on fuzzy triangular numbers used in this research are defined as follows (Sanayei *et al.*, 2010):

Addition of a triangular fuzzy number

$$\tilde{f}(+)\tilde{f}' = (f_1, f_2, f_3)(+)\big(f_1', f_2', f_3'\big) = \big(f_1 + f_1', f_2 + f_2', f_3 + f_3'\big), \tag{18}$$

Subtraction of a triangular fuzzy number

$$\tilde{f}(-)\tilde{f}' = (f_1, f_2, f_3)(-)(f_1', f_2', f_3') = \big(f_1 - f_1', f_2 - f_2', f_3 - f_3'\big), \tag{19}$$

Multiplication of a triangular fuzzy number

$$\tilde{f}(\times)\tilde{f}' = (f_1, f_2, f_3)(\times)\big(f_1', f_2', f_3'\big) = \big(f_1 \times f_1', f_2 \times f_2', f_3 \times f_3'\big), \tag{20}$$

Division of a triangular fuzzy number

$$\tilde{f}(/)\tilde{f}' = (f_1, f_2, f_3)(/)\big(f_1', f_2', f_3'\big) = \big(f_1/f_3', f_2/f_2', f_3/f_1'\big), \tag{21}$$

where $\tilde{f} = (f_1, f_2, f_3)$ and $\tilde{f}' = (f_1', f_2', f_3')$ represent two fuzzy triangular numbers with lower, modal and upper values, respectively.

A Linguistic Variable

A linguistic variable is a variable with lingual expression as its values. Fuzzy numbers can also represent these linguistic variables. The corresponding relations between linguistic variables and positive triangular fuzzy numbers are given in Table 1.

The values of qualitative criteria and the weights, evaluating different redevelopment strategies in particular areas, are considered as linguistic variables in the current research.

Defuzzification

The results of fuzzy decisions are fuzzy numbers. Consequently, a problem of ranking fuzzy numbers appears in multiple criteria decision making. Concerning the peculiarities of this study where the crisp ranking methods COPRAS, TOPSIS and VIKOR have been applied, a defuzzification was performed. Defuzzification is a technique used to convert the fuzzy number into a crisp real number. The procedure of defuzzification is to locate the Best Non-fuzzy Performance (BNP) value. Various methods of defuzzification

Table 1

The relationships between linguistic variables and triangular fuzzy numbers

Linguistic variables	Triangular fuzzy numbers
Very poor (very light)	(0; 0.1; 0.2)
Poor (light)	(0.2; 0.3; 0.4)
Fair	(0.4; 0.5; 0.6)
Good (difficult)	(0.6; 0.7; 0.8)
Very good (very difficult)	(0.8; 0.9; 1)

are available, e.g., mean-of-maximum, center-of-area, α-cut method (Van Leekwijck and Kerre, 1999). In this research the center-of-area method is used. The defuzzified value of a fuzzy number is obtained by applying the equation:

$$\mathrm{BNP} = \big[(f_3 - f_1) + (f_2 - f_1)\big]/3 + f_1, \tag{22}$$

where BNP is the Best Non-fuzzy Performance value, f_2 is a mode, f_1 and f_3 are the lower and the upper limits of fuzzy triangular number $\tilde{f}$, respectively.

3. Multiple Criteria Analysis of Building Redevelopment Alternatives

3.1. *Problem Formulation and Initial Data – A Case Study of Lithuania*

The case study of multiple criteria evaluation of possible building redevelopment decisions is presented and revitalization of derelict and mismanaged buildings in rural areas of Lithuania is analyzed. Accordingly, based to the theoretical assumptions and a study of the existing situation as presented in previous papers of the authors (Zavadskas and Antucheviciene, 2006, 2007; Antucheviciene and Zavadskas, 2008), three potential alternative decisions for the regeneration of rural property are suggested and implicated in the future multiple criteria evaluation. The alternatives include reconstruction of rural buildings and adapting them to production (or commercial) activities (alternative A_1), improving and using them for farming (alternative A_2) or dismantling and recycling the demolition waste materials (alternative A_3). Three groups of criteria (indicators) describing the suggested alternatives, were suggested: existing state, development possibilities and impact. All suggested subsystems consisted of a number of indicators and were selected from the available and approved sustainability indicator systems and then adapted to local singularities and to the peculiarities of the problem (see the previous research of the authors: Antucheviciene and Zavadskas, 2008; Zavadskas and Antucheviciene, 2006, 2007).

The following fifteen criteria (or sustainability indicators) in evaluating regeneration alternatives of buildings have been taken into consideration, including the average soil fertility in the area X_1 (points), quality of life of the local population X_2 (points), population activity index X_3 (%), GDP proportion with respect to the average GDP of the country X_4 (%), material investment in the area X_5 (Lt per resident), foreign investments in the area X_6 (Lt $\times$ 10^3 per resident), building redevelopment costs X_7 (Lt $\times$ 10^6), increase the income of local population X_8 (Lt $\times$ 10^6 per year), increase of sales in the area X_9 (%), increase of employment in the area X_{10} (%), state income from business and property taxes X_{11} (Lt $\times$ 10^6 per year), business outlook X_{12}, difficulties in changing the original purpose of a site X_{13}, degree of contamination X_{14}, attractiveness of the countryside (i.e., image, landscape etc) X_{15}. The criteria X_{12}, X_{13}, X_{14} and X_{15} are qualitative and expressed by linguistic variables. Among the criteria considered X_2, X_7, X_{13} and X_{14} are associated with cost/loss and so their lower value is better, while the remaining criteria are associated with benefit and their greater value is better.

The values of the criteria $f_{ij},\ i = 1, \dots, m;\ j = 1, \dots, n$ are estimated according to official statistical data and on the basis of previous research by the authors. As the crisp data is fuzzyfied at the presented research, the lower and the upper values of a triplet $(f_{1_{ij}}; f_{2_{ij}}; f_{3_{ij}}),\ i = 1, \dots, m;\ j = 1, \dots, n$ of the state criteria are set according to the best and the worst possible values in the area considered, enabling one to determine smaller characteristic segments in the research, while values of the development possibilities and the impact criteria are established by considering the range of buildings to be redeveloped, minimum and maximum cost of alternative solutions' implementation, presumptive limits of possible workplaces and income, possible alterations of landscape quality and environmental contamination. The qualitative attributes X_{12}, X_{13}, X_{14} and X_{15} and their ratings are expressed by linguistic variables, as used in fuzzy decision-making. The relations between linguistic variables and triangular fuzzy numbers, used in this paper, are given in Table 1.

Development possibilities and the impact criteria are considered to be of equal importance, while weights are determined for state criteria. The weights $q_i,\ i = 1, \dots, m;$ $j = 1, \dots, n$ are determined according to the estimated statistical relations between factors in the course of the correlation analysis (Antucheviciene, 2003).

The data is grouped in three regions according to a concept of spatial development of the country: i.e., areas of active development, areas of regressing development and 'buffer' areas. Matrix of initial data for evaluation of derelict buildings regeneration alternatives in areas of different development activity is presented in Table 2.

3.2. *Ranking Results*

Based on presented initial data (Table 2) and described methodology of the research, six initial fuzzified decision making matrices are formed, i.e., potential redevelopment decisions are evaluated separately in three areas of different development activity as well as two development strategies, as presented in the Master Plan of the Territory Development of the Republic of Lithuania, that refer to the maintenance of the existing economic potential of a region (MEP) and the harmonization of regional development (HRD), are considered. Strategies presented in the Master Plan, and are evaluated in linguistic terms as well as expressed by fuzzy triangular numbers (Zavadskas and Antucheviciene, 2007).

After the initial data is prepared, calculations are performed using above (Section 2) described and fuzzified MCDM methods and applying calculation algorithms accord-

Table 2

Initial data for derelict buildings regeneration

Criteria	Value of criteria $(f_{ij_1}; f_{ij_2}; f_{ij_3})$		
	Alternative A_1	Alternative A_2	Alternative A_3
Areas of active development			
X_1	(30.9; 39.9; 50.0)	(30.9; 39.9; 50.0)	(30.9; 39.9; 50.0)
X_2	(39.3; 31.7; 23.1)	(39.3; 31.7; 23.1)	(39.3; 31.7; 23.1)
X_3	(39.8; 51.7; 68.1)	(39.8; 51.7; 68.1)	(39.8; 51.7; 68.1)
X_4	(73.9; 98.4; 137.3)	(73.9; 98.4; 137.3)	(73.9; 98.4; 137.3)
X_5	(552.0; 1304.0; 3561.0)	(552.0; 1304.0; 3561.0)	(552.0; 1304.0; 3561.0)
X_6	(73.2; 1028.7; 4160.0)	(73.2; 1028.7; 4160.0)	(73.2; 1028.7; 4160.0)
X_7	(766.1; 273.6; 35.6)	(144.9; 59.4; 28.5)	(20.2; 14.4; 8.6)
X_8	(31.1; 69.1; 241.9)	(7.8; 25.9; 48.4)	(0.3; 0.4; 1.2)
X_9	(2.3; 14.0; 39.1)	(0.7; 2.2; 4.7)	(0; 0; 0)
X_{10}	(2.1; 3.4; 9.6)	(0.5; 1.7; 2.4)	(0; 0; 0)
X_{11}	(8.6; 21.6; 50.4)	(2.2; 5.4; 10.1)	(0.1; 0.2; 0.5)
X_{12}	(0.8; 0.9; 1)	(0.2; 0.3; 0.4)	(0.6; 0.7; 0.8)
X_{13}	(0.8; 0.9; 1)	(0; 0.1; 0.2)	(0.6; 0.7; 0.8)
X_{14}	(0.6; 0.7; 0.8)	(0.4; 0.5; 0.6)	(0; 0.1; 0.2)
X_{15}	(0.6; 0.7; 0.8)	(0.4; 0.5; 0.6)	(0.2; 0.3; 0.4)
Areas of regressing development			
X_1	(31.1; 34.8; 44.3)	(31.1; 34.8; 44.3)	(31.1; 34.8; 44.3)
X_2	(37.78; 29.1; 20.78)	(37.78; 29.1; 20.78)	(37.78; 29.1; 20.78)
X_3	(47.1; 55.9; 66.2)	(47.1; 55.9; 66.2)	(47.1; 55.9; 66.2)
X_4	(79.5; 94.7; 137.3)	(79.5; 94.7; 137.3)	(79.5; 94.7; 137.3)
X_5	(212.0; 962.9; 3504.0)	(212.0; 962.9; 3504.0)	(212.0; 962.9; 3504.0)
X_6	(8.14; 833.1; 3550.5)	(8.14; 833.1; 3550.5)	(8.14; 833.1; 3550.5)
X_7	(667.3; 238.6; 31.0)	(100.1; 51.8; 24.8)	(17.6; 12.6; 7.6)
X_8	(27.1; 60.3; 210.7)	(6.8; 22.6; 42.1)	(0.2; 0.4; 1.1)
X_9	(12.7; 75.8; 212.1)	(3.6; 12.1; 25.4)	(0; 0; 0)
X_{10}	(1.6; 2.6; 7.3)	(0.4; 1.3; 1.8)	(0; 0; 0)
X_{11}	(7.5; 22.0; 43.9)	(1.9; 4.7; 8.8)	(0.1; 0.2; 0.4)
X_{12}	(0.2; 0.3; 0.4)	(0.4; 0.5; 0.6)	(0; 0.1; 0.2)
X_{13}	(0.4; 0.5; 0.6)	(0; 0.1; 0.2)	(0; 0.1; 0.2)
X_{14}	(0.4; 0.5; 0.6)	(0; 0.1; 0.2)	(0; 0.1; 0.2)
X_{15}	(0.6; 0.7; 0.8)	(0.6; 0.7; 0.8)	(0.4; 0.5; 0.6)
'Buffer' areas			
X_1	(30.4; 40.0; 48.2)	(30.4; 40.0; 48.2)	(30.4; 40.0; 48.2)
X_2	(32.9; 30.3; 26.8)	(32.9; 30.3; 26.8)	(32.9; 30.3; 26.8)
X_3	(47.3; 55.8; 61.2)	(47.3; 55.8; 61.2)	(47.3; 55.8; 61.2)
X_4	(59.9; 78.1; 97.8)	(59.9; 78.1; 97.8)	(59.9; 78.1; 97.8)
X_5	(356.5; 663.5; 1398.6)	(356.5; 663.5; 1398.6)	(356.5; 663.5; 1398.6)
X_6	(0.41; 244.0; 607.8)	(0.41; 244.0; 607.8)	(0.41; 244.0; 607.8)
X_7	(808.6; 288.8; 37.6)	(121.3; 62.7; 30.1)	(21.3; 15.2; 9.1)
X_8	(32.8; 73.0; 255.4)	(8.2; 27.4; 51.1)	(0.3; 0.5; 1.3)
X_9	(14.4; 85.5; 239.3)	(4.1; 13.7; 28.7)	(0; 0; 0)
X_{10}	(23.0; 3.8; 10.6)	(0.6; 1.9; 2.7)	(0; 0; 0)
X_{11}	(9.1; 26.6; 53.2)	(2.3; 5.7; 10.6)	(0.1; 0.2; 0.5)
X_{12}	(0.4; 0.5; 0.6)	(0.2; 0.3; 0.4)	(0.2; 0.3; 0.4)
X_{13}	(0.8; 0.9; 1)	(0; 0.1; 0.2)	(0.4; 0.5; 0.6)
X_{14}	(0.2; 0.3; 0.4)	(0; 0.1; 0.2)	(0; 0.1; 0.2)
X_{15}	(0.8; 0.9; 1)	(0.4; 0.5; 0.6)	(0.8; 0.9; 1)

ing to (1)–(22). Potential redevelopment variants of derelict buildings are evaluated applying fuzzified COPRAS, TOPSIS based on vector as well as linear normalization of initial criteria values and VIKOR methods. Relative significances of alternatives $(Q_{j_1}; Q_{j_2}; Q_{j_3}),\ j = 1, \ldots, n$ (see (4), (12), (16)) and defuzzified values $Q_j,\ j = 1, \ldots, n$ (22) are calculated, and priority order of evaluated alternatives is established.

An example of described calculations is presented. Weighted normalised fuzzy decision-making matrix in areas of active development after the implementation of the first strategy (maintenance of the existing potential of a region) and the results of multi-criteria analysis applying COPRAS method are presented in Tables 3 and 4.

The other twenty three weighted normalised fuzzy decision matrices are composed in a similar way as the presented one in Table 3. The relative significances as well as priorities of rural buildings redevelopment alternatives are determined by applying the described multiple criteria decision making methods and using adequate operations on fuzzy triangular numbers. Partial results of ranking building redevelopment alternatives applying particular multiple criteria decision making methods were published in previous papers of the authors (Zavadskas and Antucheviciene, 2006, 2007; Antucheviciene and Zavadskas, 2008). Final multiple criteria analysis results obtained for Lithuanian derelict rural building regeneration alternatives in areas of diverse development activities after the implementation of two main strategies for the regional policy and applying particular MCDM methods are presented in Table 5.

Table 3

Weighted normalised fuzzy decision matrix in areas of active development after implementation of the strategy of maintenance of existing potential in a region

Criteria	Numerical value of weighted normalised criteria $(w_{ij_1}; w_{ij_2}; w_{ij_3})$		
	Alternative A_1	Alternative A_2	Alternative A_3
X_1	(0.0343; 0.0318; 0.0300)	(0.0171; 0.0176; 0.0180)	(0.0086; 0.0106; 0.0120)
X_2	(0.0363; 0.0385; 0.0415)	(0.0218; 0.0214; 0.0208)	(0.0145; 0.0128; 0.0104)
X_3	(0.0427; 0.0395; 0.0373)	(0.0213; 0.0220; 0.0224)	(0.0107; 0.0132; 0.0149)
X_4	(0.0358; 0.0332; 0.0313)	(0.0179; 0.0184; 0.0188)	(0.0090; 0.0111; 0.0125)
X_5	(0.0385; 0.0356; 0.0337)	(0.0192; 0.0198; 0.0202)	(0.0096; 0.0119; 0.0135)
X_6	(0.0358; 0.0332; 0.0313)	(0.0179; 0.0184; 0.0188)	(0.0090; 0.0111; 0.0125)
X_7	(0.0593; 0.0586; 0.0456)	(0.0067; 0.0071; 0.0183)	(0.0006; 0.0010; 0.0028)
X_8	(0.0591; 0.0551; 0.0594)	(0.0074; 0.0115; 0.0071)	(0.0001; 0.0001; 0.0001)
X_9	(0.0579; 0.0613; 0.0622)	(0.0088; 0.0054; 0.0045)	(0.0000; 0.0000; 0.0000)
X_{10}	(0.0596; 0.0522; 0.0580)	(0.0071; 0.0145; 0.0087)	(0.0000; 0.0000; 0.0000)
X_{11}	(0.0590; 0.0584; 0.0593)	(0.0075; 0.0081; 0.0071)	(0.0002; 0.0002; 0.0002)
X_{12}	(0.0508; 0.0462; 0.0427)	(0.0063; 0.0085; 0.0103)	(0.0095; 0.0120; 0.0137)
X_{13}	(0.0463; 0.0505; 0.0561)	(0.0056; 0.0031; 0.0000)	(0.0148; 0.0131; 0.0105)
X_{14}	(0.0430; 0.0462; 0.0500)	(0.0194; 0.0183; 0.0167)	(0.0043; 0.0022; 0.0000)
X_{15}	(0.0471; 0.0433; 0.0404)	(0.0157; 0.0172; 0.0182)	(0.0039; 0.0062; 0.0081)

Table 4

Analysis results applying COPRAS method in areas of active development after implementation of the strategy of maintenance of existing potential in a region

Variables	Numerical values		
	Alternative A_1	Alternative A_2	Alternative A_3
Total maximising values $(S_{j1}^*; S_{j2}^*; S_{j3}^*)$	(0.5204; 0.4897; 0.4857)	(0.1464; 0.1614; 0.1541)	(0.0605; 0.0762; 0.0876)
Total minimising values $(S_{j1}^-; S_{j2}^-; S_{j3}^-)$	(0.1850; 0.1937; 0.1933)	(0.0534; 0.0499; 0.0557)	(0.0343; 0.0291; 0.0237)
Relative significance $(Q_{j1}; Q_{j2}; Q_{j3})$	(0.5481; 0.5133; 0.5073)	(0.2421; 0.2533; 0.2290)	(0.2098; 0.2334; 0.2638)
Defuzzified significance Q_j	0.5229	0.2415	0.2357
Priority order	1	2	3

4. Measuring Congruence (Incongruence) of Ranking Results

According to calculation results as presented in Table 6 we can formulate six conclusions concerning rural building redevelopment in Lithuania, i.e., different recommendations can be made in three areas of particular development activity and applying two redevelopment strategies in every area. However, when analysing multiple criteria evaluation of alternatives, one can observe that relative significances of alternatives and some time even the priority order of redevelopment alternatives differs when several MCDM methods are applied. The aim of the presented case study is to determine priorities as well as to produce some recommendations concerning rational redevelopment of buildings. For the above reason particular relative significances of alternatives $Q_j,\ j = 1, \ldots, n$ are not analyzed in detail. The main attention is paid to priority order of alternatives, established by applying different MCDM methods.

Correlation coefficients are calculated and objective congruence (incongruence) of ranks that were computed by using different MCDM methods is measured. In order to increase the reliability of correlation analysis, 234 experimental variants of building redevelopment initial decision making matrixes are composed (replacing values of criteria, relative significances of criteria, relative significances of redevelopment strategies). Multiple criteria analysis of described experimental variants is performed applying all analyzed methods (COPRAS, TOPSIS based on vector as well as linear normalization of initial criteria values and VIKOR). Calculation results are compared.

Method of non-parametrical correlation is applied to measure statistical relation of ranks of alternatives that were computed by using different MCDM methods (Deng *et al.*, 2000; Yurdakul and Ic, 2009; Raju and Kumar, 2010). Using Spearman's correlation coefficient relations are calculated not among values of variables themselves, but among

Table 5
Results of multiple criteria analysis

MCDM method	Area	Strategy	Significance of alternatives Q_j			Priority order
			A_1	A_2	A_3	
COPRAS	Active development	MEP*	0.52	0.24	0.23	$A_1 \succ A_2 \approx A_3$
		HRD**	0.35	0.36	0.29	$A_2 \approx A_1 \succ A_3$
	Regressing development	MEP*	0.28	0.44	0.29	$A_2 \succ A_3 \approx A_1$
		HRD**	0.50	0.26	0.24	$A_1 \succ A_2 \approx A_3$
	'Buffer'	MEP*	0.44	0.31	0.24	$A_1 \succ A_2 \succ$A3
		HRD**	0.45	0.31	0.24	$A_1 \succ A_2 \succ A_3$
TOPSIS based on vector normalization	Active development	MEP*	0.61	0.41	0.36	$A_1 \succ A_2 \succ A_3$
		HRD**	0.53	0.49	0.36	$A_1 \succ A_2 \succ A_3$
	Regressing development	MEP*	0.50	0.56	0.46	$A_2 \succ A_1 \succ A_3$
		HRD**	0.61	0.45	0.46	$A_1 \succ A_3 \approx A_2$
	'Buffer'	MEP*	0.59	0.43	0.38	$A_1 \succ A_2 \succ A_3$
		HRD**	0.61	0.47	0.36	$A_1 \succ A_2 \succ A_3$
TOPSIS based on linear normalization	Active development	MEP*	0.62	0.42	0.37	$A_1 \succ A_2 \succ A_3$
		HRD**	0.49	0.54	0.37	$A_2 \succ A_1 \succ A_3$
	Regressing development	MEP*	0.46	0.64	0.48	$A_2 \succ A_3 \approx A_1$
		HRD**	0.62	0.46	0.48	$A_1 \succ A_3 \approx A_2$
	'Buffer'	MEP*	0.47	0.37	0.53	$A_3 \succ A_1 \succ A_2$
		HRD**	0.64	0.55	0.35	$A_1 \succ A_2 \succ A_3$
VIKOR	Active development	MEP*	0.38	0.36	1.00	$A_2 \approx A_1 \succ A_3$
		HRD**	0.65	0.00	1.00	$A_2 \succ A_1 \succ A_3$
	Regressing development	MEP*	1.00	0.00	0.64	$A_2 \succ A_3 \succ A_1$
		HRD**	0.00	1.00	0.45	$A_1 \succ A_3 \succ A_2$
	'Buffer'	MEP*	0.67	1.00	0.00	$A_3 \succ A_1 \succ A_2$
		HRD**	0.00	0.17	1.00	$A_1 \succ A_2 \succ A_3$

* Maintenance of existing economic potential in a region.
** Harmonization of regional development.

ranks of variables. The current coefficient best fits the aim of the presented research, because the aim of this research is to compare priorities (ranks) of alternative decisions obtained in a process of multiple criteria analysis when applying different MCDM methods. Accordingly, Spearman's rank correlation coefficients r_s and confidence intervals of correlation coefficients with the probability $p = 1 - q = 0.95$ are calculated (Aivazian and Mkhitarian, 1998).

Spearman's rank correlation coefficients are calculated for the ranks provided by every possible pairs of the applied multiple criteria decision making algorithms. It is found that all correlation coefficients are statistically significant with the probability of 95 percent.

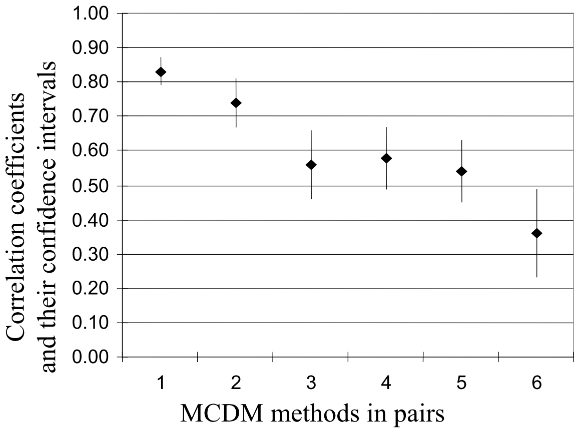

Fig. 1. Spearman's rank correlation coefficients and confidence intervals: 1–6 – Spearman's rank correlation coefficients between results of two multiple criteria decision making methods (1 – TOPSIS, applying vector normalization and TOPSIS, applying linear normalization; 2 – TOPSIS, linear normalization and VIKOR; 3 – TOPSIS, vector normalization, and VIKOR; 4 – TOPSIS, vector normalization, and COPRAS; 5 – TOPSIS, linear normalization, and COPRAS; 6 – COPRAS and VIKOR); ♦ – rank correlation coefficient; | – confidence interval of rank correlation coefficient with the reliability level $q = 0.05$.

Accordingly, we can state that the ranks in the every pair of compared methods have statistically significant relations and results of comparison are statistically reliable.

Empirical Pirson's correlation coefficients of particular comparative variants are calculated in order to check the results. Incongruence of empirical correlation coefficients and Spearman's rank correlation coefficients is not higher than 10 percents in all analyzed cases. The average incongruence is 4 percent.

Confidence intervals of correlation coefficients with the reliability level $q = 0.05$ are calculated. Calculation results are presented in Fig. 1.

In Fig. 1 we can observe that some of the results have higher rank correlation relationship and some have the lower one when a particular pairs of multiple criteria decision making methods are analyzed.

Priorities of alternatives, computed by TOPSIS method, applying vector as well as linear normalization methods to eliminate the units of the criteria values, provide the strongest statistical relations. However, the results are not identical and congruence of 100 percent is not observed. The value of Spearman's rank correlation coefficient is high enough (0.83) and is statistically significant, but not equals to 1. Consequently, experimental calculations prove the theoretical presumption that normalization methods applied to eliminate the units of the criteria values influence the final ranking results.

TOPSIS and COPRAS ranking results also have significant relations. Correlation coefficients are 0.58 and 0.54, applying vector and linear normalization in TOPSIS, respectively.

The lowest correlation relation is established when congruence (incongruence) of COPRAS and VIKOR methods is analyzed. Estimated Spearman's rank correlation coefficient is 0.36.

The above Spearman's rank correlation coefficients are calculated with a particular level of reliability. We can state that the real values of Spearman's rank correlation coefficients are within the limits of confidence intervals with the probability $p = 1 - q$. In Fig. 1 we can observe that the major parts of confidence intervals overlap. Then the question arises if rank correlation coefficients of particular pairs of MCDM methods are really different. Are the calculated differences significant? The above dilemma is solved by the authors not by subjective evaluation but applying methods of mathematical statistics as presented further in the paper.

Statistical identity (or nonidentity) of values of correlation coefficients, calculated for $N_1, N_2, \ldots, N_s$ samples of data pairs, is checked not only based on confidence intervals, but also applying statistics V (Aivazian and Mkhitarian, 1998). Hypothesis that all correlation coefficients, calculated for particular samples of data pairs, are identical with the probability $p = 1 - q$ (i.e., calculated incongruence is within the limits of random errors) can be accepted in a case if

$$V \leqslant \chi^2_{k,q}, \tag{23}$$

where $\chi^2_{k,q}$ – Pirson's distribution with the reliability q and $k = s - 1$ degrees of freedom, where s – number of compared correlation coefficients.

Fisher's transformation z and overall Fisher's transformation of correlation set $\bar{z}$ is calculated (Aivazian and Mkhitarian, 1998). Value r of correlation coefficient generalized for all correlation set is calculated in the research.

First of all, Spearman's rank correlation coefficients as calculated for six pairs of data samples are compared, i.e., r_1 – TOPSIS, applying vector normalization, and TOPSIS, applying linear normalization; r_2 – TOPSIS, linear normalization, and VIKOR; r_3 – TOPSIS, vector normalization, and VIKOR; r_4 – TOPSIS, vector normalization, and COPRAS; r_5 – TOPSIS, linear normalization, and COPRAS; r_6 – COPRAS and VIKOR.

Hypothesis that all six correlation coefficients are identical, i.e., calculated incongruence is within the limits of random errors, is not accepted after calculations, because requirement according to (23) is not fulfilled.

As the primary hypothesis was not accepted, the research is proceeded by variously grouping calculated correlation coefficients and verifying the hypothesis. The main results of the current research are presented in Table 6.

First of all, correlation coefficient with the lower value is eliminated, showing connections between VIKOR and TOPSIS results. Correlation coefficient for an entire set slightly increases (from 0.63 to 0.67), but the hypothesis is still unaccepted.

Then the authors intended to eliminate the results of evaluation of derelict rural buildings redevelopment alternatives applying VIKOR method. Therefore all coefficients describing relations with VIKOR results are rejected in the next step of calculation. But any positive effect is observed. Correlation coefficient for an entire set remains the same (0.67).

Connections of COPRAS results with the results of other analyzed methods are checked in the next step. For that reason calculations are performed using all correlation coefficients showing statistical connections between COPRAS and the other three

Table 6

Verification of hypothesis regarding incongruence of correlation coefficients (within the reliability level $q = 0.05$). Estimation of correlation coefficient generalized for an entire correlation set

Correlation coefficients r_i	Values of coefficients	Statistics V	$\chi^2_{k,q}$	Correlation coefficient for an entire set r
r_1	0.83	85.77	11.07	0.63
r_2	0.74			
r_3	0.56			
r_4	0.58			
r_5	0.54			
r_6	0.36			
r_1	0.83	57.05	9.48	0.67
r_2	0.74			
r_3	0.56			
r_4	0.58			
r_5	0.54			
r_1	0.83	47.80	5.99	0.67
r_4	0.58			
r_5	0.54			
r_4	0.58	8.91	5.99	0.51
r_5	0.54			
r_6	0.36			
r_4	0.58	0.39	3.84	0.56
r_5	0.54			
r_1	0.83	31.20	5.99	0.74
r_2	0.74			
r_3	0.56			

methods (TOPSIS with vector as well as linear normalization and VIKOR). We can state that correlation coefficients are still different with the reliability level $q = 0.05$.

In a case when VIKOR method is eliminated, the hypothesis concerning congruence of Spearman's rank correlation coefficients between COPRAS and TOPSIS results is accepted with the reliability level $q = 0.05$.

Also an attempt to eliminate COPRAS method is made. Spearman's rank correlation coefficients between ranks in TOPSIS and VIKOR methods are compared. Unfortunately, the hypothesis concerning congruence of coefficients is not accepted.

The general conclusion based on the research is that Spearman's rank correlation coefficients between ranking results of alternatives applying COPRAS and TOPSIS methods (using vector as well as linear criteria values normalization) can be considered to be identical with the probability $p \geqslant 0.95$. Ranking results of the particular methods can be considered to be congruous with the same probability.

5. Conclusions

Ranking of building redevelopment alternatives was performed by using fuzzified COPRAS, TOPSIS that applied vector and linear criteria normalization and VIKOR multiple-criteria decision making methods. It was found that the priority order of the redevelopment alternatives of buildings was not always the same in a particular region.

Spearman's rank correlation coefficients were calculated to measure objective congruence (incongruence) of ranks of derelict buildings' management alternatives. It was found that every correlation coefficient was statistically significant with the probability of 95 percent and experimental results were statistically reliable.

It was found that Spearman's rank correlation coefficients between the COPRAS and the TOPSIS (using vector as well as linear criteria values normalization) methods can be considered congruous within the probability of $p \geqslant 0.95$. Accordingly, multiple criteria evaluation results applying COPRAS and TOPSIS methods can be considered to be identical within the same probability. It was proved that the final decision should be adopted by giving the priority to the results of COPRAS and TOPSIS methods instead of VIKOR, if the ranking results of the analyzed methods differ.

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Rangavimo rezultatų, taikant skirtingus daugiatikslių sprendimų priėmimo metodus, sutapimo vertinimas

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Šio tyrimo metu norima nustatyti objektyvius alternatyvų prioritetų eilės sutapimus (nesutapimus), kuomet racionalių sprendimų paieška atliekama taikant kelis skirtingus daugiatikslių sprendimų priėmimo metodus. Metodika rangavimo rezultatams vertinti parengta sprendžiant realų apleistų pastatų sutvarkymo atvejį bei modeliuojant eksperimentinius uždavinius. Alternatyvų prioritetams nustatyti naudoti COPRAS, TOPSIS ir VIKOR metodai, papildyti neraiškiųjų aibių elementais. Skaičiavimo rezultatų neapibrėžtims įvertinti taikyti matematiniai statistiniai metodai. Pasiūlyta metodika alternatyvų rangų sutapimams (nesutapimams) nustatyti.