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MULTIPLE CRITERIA CONSTRUCTION MANAGEMENT DECISIONS CONSIDERING RELATIONS BETWEEN CRITERIA

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Abstract. Decision making in construction management has been always complicated especially if there were more than one criterion under consideration. Multiple criteria decision making (MCDM) has been often applied for complex decisions in construction when a lot of criteria were involved. Traditional MCDM methods, however, operate with independent and conflicting criteria. While in every day problems a decision maker often faces interactive and interrelated criteria. Accordingly, the need of improving and supplementing the methodology of compromise decisions arose. It was proposed to supplement TOPSIS (Technique for the Order Preference by Similarity to Ideal Solution) method and integrate the Mahalanobis distance in the usual algorythm of TOPSIS. Mahalanobis distance measure offered an option to take the correlations between the criteria into considerations while making the decision. A case study of building redevelopment in Lithuanian rural areas was presented that demonstrated the application of the proposed methodology. The case study proved that the proposed TOPSIS-M (TOPSIS applying Mahalanobis distance measure) method could have substantial influence in carrying the proper decision.

Keywords: construction management, MCDM, TOPSIS, TOPSIS-M, criteria, correlation, covariance, Euclidean distance, Mahalanobis distance.

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1. Introduction

One of the most perpetual challenges in science and engineering is how to make the optimal decision in a given situation. In construction management one is constantly confronted with various problems that require effective decisions. From a single person and a single criterion (profit), decision environments eventually became multi-person and multi-criteria.

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To determine the value ant the utility degree of the construction projects and to establish the priority order of their implementation, multiple criteria decision making methods (MCDM) can be used effectively. MCDM methods examine the problem of evaluating a discrete set of alternatives in terms of a set of decision criteria. Since different criteria represent different dimensions of the alternatives, they may conflict with each other. For instance, cost may conflict with profit, etc. But very often no such conflict is assumed. In this paper, on the ground of real life situations and with reference to Triantaphyllou (2000), it is stated otherwise. Complex decisions in construction are analysed when a lot of conflicting as well as interactive criteria are involved.

Accordingly, multiple criteria decision making theory is supplemented by the elements of mathematical statistics and the MCDM methodology that considered statistical relations between criteria is developed. TOPSIS (Technique for the Order Preference by Similarity to Ideal Solution) method is modified in the paper.

Usual crisp TOPSIS as presented by Hwang and Yoon in 1981 (Hwang and Yoon 1981) or fuzzy TOPSIS has been widely applied in construction management, as well as some other MCDM methods like SAW (Simple Additive Weighting), COPRAS (Complex Proportional Assesment), ELECTRE (Elimination Et Choix Traduisant la Realite) for ranking of construction-technological alternatives (Zavadskas 1986), selection of resource-saving decisions (Zavadskas 1987), accepting other technological or facility management decisions (Fiedler *et al.* 1986). The paper (Zavadskas *et al.* 2003) gives the description of software considering the main positions of one-sided and two-sided problems. For one-sided problems the method of solution of the distance to the ideal point is discussed as well as an example of an investment variant estimation is presented. Karablikovas and Ustinovicius (2002) suggest optimizing ways of repairing matched roofs applying TOPSIS method. Zavadskas, Ginevicius and other authors analyze alternative solutions of external walls and wall insulation as well as estimate effective variants of walls by multiple criteria methods (Zavadskas *et al.* 2007b, 2008; Ginevičius *et al.* 2008). Deng (2006) performs plant location selection based on fuzzy TOPSIS. Banaitienė *et al.* (2008) considers the multivariant design and multiple criteria analysis of the life cycle of a building. In the above paper the theoretical basis of the methodology is developed. A proposed methodology allows everyone (i.e. client, investor, contractor, etc.), who has to make the decisions, to design alternatives of the building life cycle and to evaluate its qualitative and quantitative aspects. The procedure of the evaluating of a building's life cycle is discussed using an example and applying COPRAS method. Also multi-attribute decision making models and methods as well as their application in construction are presented in some works (Lin *et al.* 2008; Liu 2009; Huang *et al.* 2009). In the study of Ulubeyli and Kazaz (2009) the ELECTRE III method is considered in a selection problem of concrete pumps. The paper can be valuable to researchers studying the theory of decision making in equipment selection in general and investigating selection criteria of concrete pumps in particular. The paper (Zavadskas *et al.* 2009) presents the comparative analysis of dwelling maintenance contractors aimed at determining the degree of their utility for users and bidding price of services by applying COPRAS method. The aim of the research of Zavadskas and Antuchevičienė (2004, 2006) is to rank derelict buildings' redevelopment alternatives from the multiple sustainability approach. Moreover, handling of MCDM techniques is discussed. The techniques used are: TOPSIS and compromise ranking method VIKOR. A Lithuanian case study is presented, the comparisons of the results after multiple criteria analysis implementation are made and scientific recommendations for a sustainable redevelopment of derelict buildings in Lithuanian rural areas are suggested. 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 is developed. An algorithm of TOPSIS that applies criteria values' transformation through a normalization of vectors and the linear transformation is considered. An application of methodology for building management problem is presented. Also for sustainable development problems Ginevičius and Podvezko (2009) use multiple criteria evaluation methods that can take into consideration the major aspects of economic, social and environmental development as well as multidimensional character of the development criteria, different directions of their changing and significances. As in project development it is rather hard to get exhaustive and accurate information and the situations occur the consequences of which can be very damaging to the project, assessment of investment risk and construction risk is widely performed by applying usual and extended TOPSIS or other multiple criteria decision making methods (Wang and Elhag 2006; Zavadskas *et al.* 2008; Shevchenko *et al.* 2008). Partner or contractor selection is held (Marzouk 2008, Jianbing *et al.* 2009), or a method for selecting projects and related contractors simultaneously is proposed (Mahdi and Hossein 2008) in which firstly contractors that have not minimal qualifications are eliminated from consideration, then closeness coefficient of contractors to each proposal is computed by fuzzy TOPSIS method and finally these coefficients as a successful indicators for each contractor are fed into a linear programming to select most profitable projects and related contractors with respect to the constraints. Territory planning decisions, i.e. road design and transport systems are evaluated applying COPRAS (Zavadskas *et al.* 2007a), TOPSIS and SAW methods (Jakimavičius and Burinskienė 2007, 2009a, 2009b). Selection of proper methods is discussed and multiple criteria evaluation of real estate projects' efficiency is carried out in (Ginevičius and Zubrecovas, 2009).

Algorithm of usual TOPSIS is presented in the following Subchapter 2.1 (Hwang and Yoon 1981, Zavadskas *et al.* 1994, Triantaphyllou 2000). However, according to E. Triantaphyllou (2000), the Euclidean distances defined in expressions (5) and (6) represent some plausible assumptions. E. Triantaphyllou maintains that it is possible to use other alternative distance measures and, respectively, to get different answers for the same problem. Also Chen and Tsao (2007) performed an experimental analysis to observe the intuitionistic fuzzy TOPSIS results yielded by different distance measures. Accordingly, the above assumptions are implemented by the authors in the current paper and the Mahalanobis distance is implicated in TOPSIS algorithm. In statistics, Mahalanobis distance is a distance measure introduced by P. C. Mahalanobis in 1936 (Mahalanobis 1936). It is based on correlations between variables by which different patterns can be identified and analyzed. It is a useful way of determining similarity of an unknown sample set to a known one. It differs from Euclidean distance in that it takes into account the correlations of the data set. Mahalanobis distance metric is a proper method for data clustering and classification, pattern recognition (Xiang *et al.* 2008). The metric mainly relies on classical multivariate statistical methods and its applications are explored across a wide range of disciplines from engineering and manufacturing to environmental sciences, agriculture and medicine (Mahalakshmi and Ganesan 2009). Also the Mahalanobis-Taguchi strategy presents methods for developing multidimensional measurement scales that are up to date with the most current trends in multivariate diagnosis and pattern recognition (Williams and Heglund 2009). The system can be applied as a tool to facilitate the selection of prime set of criteria, which is a subset of the original criteria. Mahalanobis distance can be combined with neural network methodology and a statistical multivariate analysis based on the Mahalanobis distance can be employed to perform data clustering and parameter reduction to reduce the size of the input space for the subsequent step of classification by the particular neural network (Ghosh-Dastidar and Adeli 2003). In multiple criteria decision making an attemt to use extended TOPSIS method with different distance aproaches for mutual funds performance was published (Chang *et al.* 2008). Two diferent distance ideas, namely Minkowski's metric and Mahalanobis distance were applied. The purpose of the above mentioned paper was to see how the TOPSIS method affects the performance evaluation on the mutual funds by using different distance ideas under a specific weight method.

In the proposed case applying the Mahalanobis distance instead of Euclidean distance in TOPSIS method helps to consider relations between decision criteria and to determine the influence of statistical relations between criteria on the ranking results of alternatives.

2. TOPSIS methodology considering relations between criteria

2.1. TOPSIS based on Euclidean distance

The basic concept of the TOPSIS method (the Technique for Order Preference by Similarity to Ideal Solution) is that the selected alternative should have the shortest distance from the ideal solution and the longest distance from the negative-ideal solution, in a geometrical sense. The TOPSIS method assumes that each criterion has a tendency of monotonically increasing or decreasing utility. Therefore, it is easy to define the ideal and the negative-ideal solution (Triantaphyllou 2000).

In the usual TOPSIS (Hwang and Yoon 1981) the Euclidean distance approach was proposed to evaluate the relative closeness of the alternatives to the ideal solution. Thus, the preference order of the alternatives can be derived by a series of comparisons of these relative distances.

The basic algorithm of TOPSIS is presented with reference to Hwang and Yoon (1981), Zavadskas *et al.* (1994), Triantaphyllou (2000). The method evaluates the decision matrix, which refers to n alternatives that are evaluated in terms of m criteria. The member ij denotes the performance measure of the j-th alternative in terms of the i-th criterion.

The normalized decision matrix when the various criteria dimensions are converted into non-dimensional criteria is calculated as follows:

$$a_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}}, \tag{1}$$

where a_{ij} is the normalized value, $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, n$.

The weighted normalized value v_{ij} is calculated as

$$v_{ij} = q_i a_{ij}, \tag{2}$$

where q_i is the weight of i-th criterion, $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, n$.

The ideal and the negative-ideal solutions denoted respectively as A^* and A^- are defined as follows:

$$A^* = \left\{ \left(\max_j v_{ij} \,\middle|\, i \in I \right), \left(\min_j v_{ij} \,\middle|\, i \in I' \right), j = 1, 2, \ldots, n \right\} = \left\{ v_{1^*}, v_{1^*}, \ldots, v_{n^*} \right\}, \tag{3}$$

$$A^- = \left\{ \left(\min_j v_{ij} \,\middle|\, i \in I \right), \left(\max_j v_{ij} \,\middle|\, i \in I' \right), j = 1, 2, \ldots, n \right\} = \left\{ v_{1^-}, v_{2^-}, \ldots, v_{n^-} \right\}, \tag{4}$$

where $I = \{ i = 1, 2, \ldots, m \}$ and i is associated with the benefit criteria, $I' = \{ i = 1, 2, \ldots, m \}$ and i is associated with the cost/loss criteria.

The n-dimensional Euclidean distance method is then applied to measure the distances of each alternative from the ideal solution S_{j^*} and the negative-ideal solution S_{j^-}:

$$S_{j^*} = \sqrt{\sum_{i=1}^{m} \left(v_{ij} - v_{i^*} \right)^2}, \text{ for } j = 1, 2, \ldots, n, \tag{5}$$

$$S_{j^-} = \sqrt{\sum_{i=1}^{m} \left(v_{ij} - v_{i^-} \right)^2}, \text{ for } j = 1, 2, \ldots, n, \tag{6}$$

where $v_{i^*} = \max_j v_{ij}$, $v_{i^-} = \min_j v_{ij}$.

The relative significance of an alternative is defined as follows:

$$C_j = \frac{S_{j^-}}{S_{j^*} + S_{j^-}}, \tag{7}$$

where $1 \geq C_j \geq 0$ and $j = 1, 2, \ldots, n$.

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

2.2. TOPSIS based on Mahalanobis distance (TOPSIS-M)

Applying usual TOPSIS (Hwang and Yoon 1981), estimation of priorities of alternatives (7) is based on values of Euclidean distances in multidimensional space (5), (6). But in this way ranking of alternatives is simply performed only in the case when the criteria describing the alternatives are statistically independent. However, in real life multicriteria decisions, criteria interconnected by correlation relations are very often applied. In the case when alternatives are described by statistically connected criteria, application of TOPSIS based on Euclidean distances can lead to inaccurate estimation of relative significances of alternatives and can cause the improper ranking results. In order to avoid the described inaccuracies, the need to improve the methodology of estimation of relative significances of ranking alternatives arose, incorporating evaluation of interrelations between criteria.

The authors suggest applying the Mahalanobis distance (Mahalanobis 1936; De Maesschalck *et al.* 2000; Schinka *et al.* 2003; McLachlan 1992) instead of Euclidean distance in TOPSIS algorithm to measure the distances of each alternative from the ideal solution and the negative-ideal solution and to rank the alternatives.

Suppose, there is the matrix of initial criteria (8) and the normalized matrix (9):

$$X = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{pmatrix}, \quad (8)$$

$$A = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{pmatrix}, \quad (9)$$

where m is a number of criteria and n is a number of alternatives.

Respectively, the ideal and the negative-ideal solutions, applying expressions (3) and (4) and normalized matrix (9), are defined as follows:

$$A^* = \left(a_i^*\right) = \begin{pmatrix} a_1^* \\ \vdots \\ a_2^* \\ a_m^* \end{pmatrix}, \quad (10)$$

$$A^- = \left(a_i^-\right) = \begin{pmatrix} a_1^- \\ \vdots \\ a_2^- \\ a_m^- \end{pmatrix}. \quad (11)$$

Relations between criteria can be defined by covariance matrix:

$$\Sigma = \frac{1}{p-1} \tilde{X}^T \tilde{X}, \quad (12)$$

where $\tilde{X}$ is a centered initial matrix (8), $\tilde{X}^T$ is a transposed matrix $\tilde{X}$ and p is a number of data variants in a sample.

Significances of criteria are defined by a diagonal matrix of weights:

$$\Delta = \begin{pmatrix} q_1 & & & \\ & q_2 & & \\ & & \ddots & \\ & & & q_m \end{pmatrix}. \quad (13)$$

Accordingly, Mahalanobis distances (Mahalanobis 1936; De Maesschalck *et al.* 2000) calculated following the expressions (9)–(13) and applied instead of Euclidean distances in (5) and (6), could be defined as follows:

$$S_{j^*} = \sqrt{\left(A_j - A^*\right)^T \Delta^T \Sigma^{-1} \Delta \left(A_j - A^*\right)}, \tag{14}$$

$$S_{j^-} = \sqrt{\left(A_j - A^-\right)^T \Delta^T \Sigma^{-1} \Delta \left(A_j - A^-\right)}, \tag{15}$$

where Δ^T is a transposed matrix of weights (13), Σ^{-1} is an inverse matrix of covariance matrix (12),

$$A_j = \begin{pmatrix} a_{1j} \\ a_{2j} \\ \vdots \\ a_{mj} \end{pmatrix}, \tag{16}$$

where $j = 1, 2, \ldots, n$.

The relative significances of alternatives are defined by (7) and are calculated applying expressions of distances (14) and (15).

In a process of implementation of TOPSIS algorithm when relative significances of alternatives are calculated applying Mahalanobis distances, two main questions arise, i.e. how to normalize the matrix of initial data (8) and to obtain the matrix (9), as well as how to estimate criteria interrelations. These both questions should be solved in a complex way.

Covariance matrix could be calculated directly from initial data (8) or normalized data (9) only if there were no fewer alternatives than criteria describing the alternatives. But such cases could be observed rarely. Also, if the number of alternatives is only slightly higher than the number of criteria, statistically very inaccurate estimates could be obtained. Accordingly, a higher number of data is required for calculating of covariance matrix (12). On the other hand, when a higher number of initial data is analyzed, it is doubtful if covariance matrix properly describes covariances of data in a particular case, because covariances depend on values of a particular data set.

Consequently, it is suggested to change over from covariance matrices to correlation matrices, because values of correlation matrices do not depend on absolute values of initial data, and to calculate correlations of a larger sample set.

Correlation and covariance matrices are coincident if standard deviation of initial data $\sigma = 1$ (Aivazian and Mkhitarian 1998). Accordingly, a proper method of normalization of initial data matrix (8) should be used to ensure standard deviations of initial data to be equal to 1. Following the described condition, the elements of normalized initial data matrix (9) are defined:

$$a_{ij} = \frac{x_{ij}}{\sigma_i}, \tag{17}$$

where

$$\sigma_i = \sqrt{\Sigma_{ii}}, \tag{18}$$

and Σ_{ii} are diagonal elements of covariance matrix obtained from a larger sample size of initial data, $i = 1, 2, \dots, m$.

Applying the described criteria normalization method (17) the main requirement of normalization is realized, that is the various criteria dimensions are converted into non-dimensional criteria, as well as preconditions are set to use inverse correlation matrix K^{-1} instead of inverse covariance matrix Σ^{-1}. Correlation matrix is calculated from a larger sample size of initial data and is defined as follows:

$$K = \begin{pmatrix} k_{11} & k_{12} & \cdots & k_{1m} \\ k_{21} & k_{22} & \cdots & k_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ k_{m1} & k_{m2} & \cdots & k_{mm} \end{pmatrix}. \tag{19}$$

Correlation coefficients are defined:

$$k_{ij} = \left(\frac{\Sigma_{ij}}{\Sigma_{ii}\Sigma_{jj}} \right)^{\frac{1}{2}}, \tag{20}$$

where $i = j = 1, 2, \dots, m$.

3. A case study: application of the proposed methodology for ranking building redevelopment alternatives

A simple numerical example is presented to illustrate similarities and differences of ranking results by applying TOPSIS and both the Euclidean and the Mahalanobis measurement of distances in a particular situation of construction management problem.

3.1. Description of the problem

In the case study presented here, revitalization of derelict and mismanaged buildings in Lithuania's rural areas was analysed. These structures were built during the Socialist Years, mostly for farming and, partly, for rural infrastructure. Due to political and economical changes as well as restructuring of the agricultural sector, they have become derelict and are mismanaged at present. Today, many rural buildings, due to their large parameters, energy susceptibility, and technological and economic depreciation do not meet contemporary production requirements. Individual farmers are not capable of using or holding large complexes and maintaining their proper conditions. Large investments are required to make these objects useful. These buildings are not used for any kind of activity and many of them are in a poor state. Such contaminated and abandoned sites are negatively influencing the environment and landscape, threatening people's safety and wasting the full potential of the immovable property as they decay further and irreversibly. There is an urgent need for redevelopment of rural buildings because this property is a national asset of Lithuania and must be protected and used more effectively.

Sustainable development approach is used for identifying rational development trends of abandoned rural buildings. Revitalization of buildings should be a contribution towards sustainable construction, incorporating protection of natural and social environmental, improvement of life quality and implementation of economic goals. For this purpose, a set of criteria was developed according to the principles of sustainable construction and sustainable development. The model of an indicator system for the sustainable revitalization of derelict buildings has been developed according to research of a situation in transition and was based on an analytical review of the literature on sustainability indicators. A classification of the indicators according to the typology was applied. The total system was made up of a number of component systems. These subsystems described various components of sustainability that have been chosen according to the singularity of the problem. The component systems involved the environmental impact of derelict, renovated or dismantled buildings, the economic benefits and changes in the local population's quality of life after the implementation of restoration variants and the outlook of business. 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 that were based on previous research of the authors (Antuchevičiene 2003; Antucheviciene and Zavadskas 2004, 2008; Zavadskas and Antucheviciene 2006, 2007).

The data was grouped in three regions according to a concept of the country's spatial development: i.e. areas of active development, areas of regressing development and 'buffer' areas. The largest amount of facilities, the greatest variety of activities and the maximum internal as well as foreign investment was found to be characteristic of areas with active development. The largest cities, the main industrial, scientific, cultural and facilities centres as well as major highways were found to be located in the above-mentioned territories, and in contradistinction to areas of regressive development. The economic basis of areas with regressing development includes agricultural, forestry and recreational activities. Such areas cover the northern-eastern and southern parts of Lithuania. 'Buffer' areas take a middle place according to the characteristic of activity, geographical and environmental situation and the peculiarities of the local population. They are also situated in territories that are not strongly influenced by the largest cities.

3.2. Ranking of alternatives

In this paper, the above-mentioned criteria system was abridged and adapted for calculations that were performed to determine the priorities of buildings' redevelopment alternatives.

In the present case study, three alternatives and seven criteria were considered. The alternatives included the reconstruction of rural buildings and adapting them for production or commercial activities in areas of active development (alternative A_1), in regressing areas (alternative A_2) and in 'buffer' areas (i.e. areas of middle development activity) (alternative A_3). The following criteria were taken into consideration, including the average soil fertility grade in the area a_1 (points), quality of life of the local population a_2 (points), population's activity index a_3 (%), GDP in proportion to the average GDP of the country a_4 (%), building's redevelopment costs a_5 (Lt $\times 10^6$), growth of employment a_6 (%), state income from business and property taxes a_7 (Lt$\times 10^6$ per year).

The criteria a_2 and a_5 were associated with the cost (their smaller value was better), while the remaining attributes were associated with benefit criteria (their greater value was better).

Initial data (evaluating a particular set of alternatives in terms of a set of decision criteria) for multiple criteria problem of revitalization of derelict and mismanaged buildings in Lithuania's rural areas is presented in Table 1.

Table 1. Initial data

Criteria	Optimisation direction	Alternatives		
		A_1	A_2	A_3
x_1	max	39.9	34.8	40.0
x_2	min	31.7	29.1	30.3
x_3	max	51.7	55.9	55.8
x_4	max	98.4	94.7	78.1
x_5	min	273.6	238.6	288.8
x_6	max	3.4	2.6	3.8
x_7	max	21.6	22.0	26.6

Standard deviations of criteria were calculated from a larger set of a parallel data, obtained analyzing various redevelopment variants of rural buildings throughout the whole territory of the country.

Estimated standard deviations are as follows: $\sigma_1 = 7.2$; $\sigma_2 = 5.9$; $\sigma_3 = 9.1$; $\sigma_4 = 25.9$; $\sigma_5 = 232.3$; $\sigma_6 = 4.9$; $\sigma_7 = 15.6$.

Initial data as presented in Table 1 was normalized applying expression (17). Normalized initial data is presented in Table 2.

The correlation matrix and the inverse correlation matrix are presented in Table 3 and Table 4.

Table 2. Normalized initial data

Criteria	Alternatives		
	A_1	A_2	A_3
a_1	5.54	4.83	5.56
a_2	5.37	4.93	5.14
a_3	5.68	6.14	6.13
a_4	3.80	3.66	3.02
a_5	1.18	1.03	1.24
a_6	0.69	0.53	0.78
a_7	1.38	1.41	1.71

Table 3. Correlation matrix

Criteria	a_1	a_2	a_3	a_4	a_5	a_6	a_7
a_1	1	–0.84	0.90	0.80	–0.46	0.07	0.43
a_2	–0.84	1	–0.97	–0.84	0.45	0.14	0.39
a_3	0.90	–0.97	1	0.86	–0.47	0.10	0.41
a_4	0.80	–0.84	0.86	1	–0.42	–0.02	0.35
a_5	–0.46	0.45	–0.47	–0.42	1	0.48	0.03
a_6	0.07	0.14	0.10	–0.02	0.48	1	0.55
a_7	0.43	0.39	0.41	0.35	0.03	0.55	1

Table 4. Inverse correlation matrix

Criteria	a_1	a_2	a_3	a_4	a_5	a_6	a_7
a_1	5.91	–2.87	–6.98	–0.73	0.53	–0.18	–0.49
a_2	–2.87	18.51	18.71	1.56	1.21	2.16	–0.85
a_3	–6.98	18.71	26.93	–1.76	–0.14	0.91	–0.53
a_4	–0.73	1.56	–1.76	4.38	–0.53	1.07	–0.47
a_5	0.53	1.21	–0.14	–0.53	2.16	–1.39	0.24
a_6	–0.18	2.16	0.91	1.07	–1.39	2.60	–1.21
a_7	–0.49	–0.85	–0.53	–0.47	0.24	–1.21	1.92

Virtual the ideal alternative (10) and the negative-ideal alternative (11) are as follows:

$$A^* = \begin{pmatrix} 5.56 \\ 4.93 \\ 6.14 \\ 3.80 \\ 1.03 \\ 0.78 \\ 1.71 \end{pmatrix}, \; A^- = \begin{pmatrix} 4.83 \\ 5.37 \\ 5.68 \\ 3.02 \\ 1.24 \\ 0.53 \\ 1.38 \end{pmatrix}.$$

Assuming that the criteria are of equal significances, the matrix of weights (13) becomes a unitary matrix:

$$\Delta = \begin{pmatrix} 1 & & & & & & \\ & 1 & & & & & \\ & & 1 & & & & \\ & & & 1 & & & \\ & & & & 1 & & \\ & & & & & 1 & \\ & & & & & & 1 \end{pmatrix}.$$

Let us give an example of calculation of Mahalanobis distance applying expression (14). The square of S_{1^*} distance of the first alternative is calculated as follows:

$$\left(S_1^*\right)^2 = \begin{pmatrix} -0.02 \\ 0.44 \\ -0.46 \\ 0.00 \\ 0.15 \\ -0.9 \\ -0.33 \end{pmatrix} \cdot \begin{pmatrix} 1 & & & & & & \\ & 1 & & & & & \\ & & 1 & & & & \\ & & & 1 & & & \\ & & & & 1 & & \\ & & & & & 1 & \\ & & & & & & 1 \end{pmatrix} \cdot$$

$$\cdot\begin{pmatrix} 5.91 & -2.87 & -6.98 & -0.73 & 0.53 & -0.18 & -0.49 \\ -2.87 & 18.51 & 18.71 & 1.56 & 1.21 & 2.16 & -0.85 \\ -6.98 & 18.71 & 26.93 & -1.76 & -0.14 & 0.91 & -0.53 \\ -0.73 & 1.56 & -1.76 & 4.38 & -0.53 & 1.07 & -0.47 \\ 0,53 & 1.21 & -0.14 & -0.53 & 2.16 & -1.39 & 0.24 \\ -0.18 & 2.16 & 0.91 & 1.07 & -1.39 & 2.60 & -1.21 \\ -0.49 & -0.85 & -0.53 & -0.47 & 0.24 & -1.21 & 1.92 \end{pmatrix}\cdot$$

$$\cdot\begin{pmatrix} 1 & & & & & & \\ & 1 & & & & & \\ & & 1 & & & & \\ & & & 1 & & & \\ & & & & 1 & & \\ & & & & & 1 & \\ & & & & & & 1 \end{pmatrix}\cdot\begin{pmatrix} -0.02 \\ 0.44 \\ -0.46 \\ 0.00 \\ 0.15 \\ -0.9 \\ -0.33 \end{pmatrix}^T = 1.693.$$

$$S_{1^*} = \sqrt{1.693} = 1.301.$$

Others distances of Mahalanobis that are applied for estimating relative significances of every other alternative solution are calculated at the same way as described in the above example.

On purpose to compare the results, multicriteria analysis of initial data (Table 1) was performed applying usual TOPSIS method (1–7), as well as applying improved method, when correlation relations between criteria are considered and Mahalanobis distance is used (8–20).

Calculation results of TOPSIS applying Euclidean distance and Mahalanobis distance (TOPSIS-M) are presented in Table 5 and in Figure 1.

Table 5. Ranking results

Alternatives	C_j	
	TOPSIS	TOPSIS-M
A_1	0.545	0.662
A_2	0.396	0.428
A_3	0.605	0.439

The presented calculation example proved the assumption that it was possible to use alternative distance measures and to get different answers for the same problem. Relative significances of alternatives that describe revitalization possibilities of derelict and mismanaged buildings differ when applying TOPSIS using Euclidean distance and Mahalanobis distance (Table 5, Fig. 1).

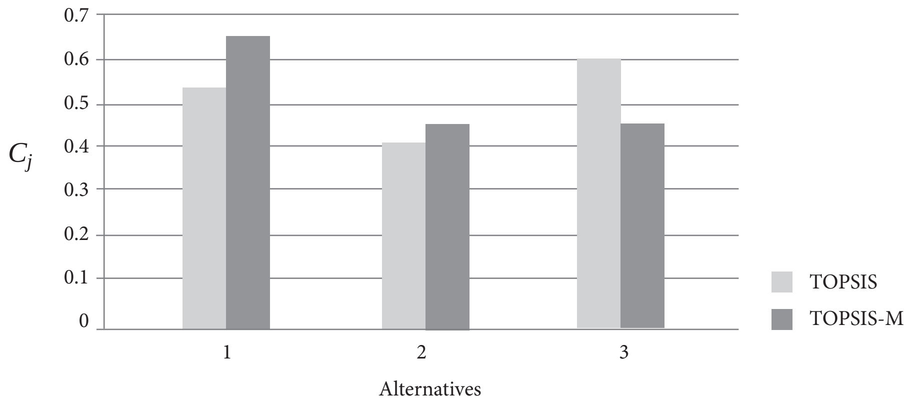

Fig. 1. Comparison of results

Applying Euclidean distance the best alternative in terms of sustainable development was reconstruction of rural buildings and adapting them for production or commercial activities in areas of middle development activity (alternative A_3), the next one was in areas of active development (alternative A_1) and the last one was in regressing areas (alternative A_2). While applying Mahalanobis distance it was estimated that relative significances of alternatives and even ranking of alternatives was different. The optimal alternative was A_1, namely reconstruction of buildings in areas of active development. Relative significances of alternatives A_2 and A_3 were rather similar in the analysed case.

4. Conclusions

1. Estimation of relative significances of alternatives better correspond to real life situations when applying TOPSIS-M in multiple criteria construction management decisions. Applying the proposed TOPSIS-M method when estimation of significances of alternatives is based on Mahalanobis distances, interrelations between criteria are considered.

2. When correlation relations between criteria are considered, relative significances as well as priority order of alternatives can vary in comparison with usual TOPSIS method.

3. The presented calculation example proved that relative significances of alternatives when applying TOPISIS and TOPSIS-M methods varied from 8 to 35 percent, as well as a priority order of alternatives changed from $A_3 \succ A_1 \succ A_2$ to $A_1 \succ A_3 \succ A_2$. Consequently, the above example proved that the proposed modified method could have substantial influence on decision making results.

4. When applying TOPSIS-M method in practice it is very important properly to estimate correlation interrelations between criteria describing decision alternatives. An estimation depends on a particular problem and circumstances of a research.

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DAUGIATIKSLIAI STATYBOS VALDYMO SPRENDIMAI ATSIŽVELGIANT Į RODIKLIŲ TARPUSAVIO PRIKLAUSOMYBĘ

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Santrauka

Statybos valdymo spendimų priėmimas visuomet yra komplikuotas, ypač jei turime atsižvelgti į daugelį rodiklių. Kompleksiniams statybos sprendimams, kurie apibūdinami daugeliu rodiklių, taikomi daugiatiksliai sprendimų priėmimo metodai (MCDM – *Multiple Criteria Decision Making*). Šie metodai skirti sprendimams priimti tuomet, kai vertinami konfliktuojantys bei nepriklausomi rodikliai. Tačiau realiose situacijose, priešingai, nuolat susiduriame su sąveikaujančiais ir tarpusavio priklausomybę turinčiais rodikliais. Dėl šios priežasties kyla poreikis patobulinti sprendimų metodologiją. Straipsnyje siūloma papildyti variantų racionalumo nustatymo metodą TOPSIS (*Technique for the Order Preference by Similarity to Ideal Solution*), taikant Mahalanobio metodą atstumams nustatyti. Mahalanobio atstumų nustatymo metodas suteikia galimybę įvertinti koreliacines rodiklių priklausomybes priimant daugiatikslį sprendimą. Siūlomos metodologijos taikymas iliustruojamas sprendžiant apleistų pastatų Lietuvos kaimo vietovėse racionalaus sutvarkymo uždavinį. Pateiktas pavyzdys patvirtina, kad TOPSIS-M metodo (t. y. TOPSIS naudojant Mahalanobio atstumą) taikymas gali turėti esminę įtaką priimant sprendimą.

Reikšminiai žodžiai: statybos valdymas, MCDM, TOPSIS, TOPSIS-M, rodikliai, koreliacija, kovariacija, Euklido atstumas, Mahalanobio atstumas.

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