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MULTIPLE CRITERIA SELECTION OF PILE-COLUMN CONSTRUCTION TECHNOLOGY

Edmundas Kazimieras Zavadskas[1], Saulius Sušinskas[2], Alfonsas Daniūnas[3], Zenonas Turskis[4], Henrikas Sivilevičius[5]

[1, 3, 4, 5]*Vilnius Gediminas Technical University, Saulėtekio al. 11, 10223 Vilnius, Lithuania*
[2]*Kaunas University of Technology Panevėžys Institute, S. Daukanto g. 12-138, 37164 Panevėžys, Lithuania*
E-mails: [1]*edmundas.zavadskas@vgtu.lt;* [2]*saulius.susinskas@ktu.lt;* [3]*alfonsas.daniunas@vgtu.lt;* [4]*zenonas.turskis@vgtu.lt (corresponding author);* [5]*henrikas.sivilevicius@vgtu.lt*

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Abstract. Numerous alternatives exist for foundation systems and construction technologies. The systems can be described by different criteria values which are incorporated in the conventional design process. Decision on the most suitable construction technology is vital for success and depends on many effectiveness criteria. The business success depends on the right choice. The mandate of a construction management researcher is to use rational, systematic, science-based techniques to inform and improve various decisions. The paper presents multiple criteria decision making model for selection of a pile-column technology. The technological criteria are determined by an experimental study. Based on in-situ investigation of natural soil conditions, criteria values are determined. The decision making model incorporates five different methods and techniques. To solve a problem, it uses three multiple criteria decision making methods. Integrated criteria weights are determined by using the analytic hierarchy process and the expert judgement method. This model could be used to solve complicated problems pertaining to the selection of a construction technology.

Keywords: pile-columns, technology, multiple criteria, construction site, MCDM, TOPSIS, ARAS, COPRAS, AHP, the expert judgement method, integrated weights.

1. Introduction

In construction, piles can be used in various ways. In urban areas, many high-rise buildings and viaducts are founded on a pile foundation. Construction technologies are highly dependent on in-situ conditions, e.g. soil conditions are particularly important for a foundation. The way the designed and actual founding depths of foundations correspond to variability of geological conditions has long been a concern (Zhang *et al.* 2011b). Tomlinson and Woodward (2008) presented a lot of pile design examples. Sivilevičius *et al.* (2012) presented results of an experimental study on technological indicators of pile-columns at a construction site. Based on in-situ investigation of natural soil conditions, regression equations have been determined, which can be very useful when planning similar works at a construction site. Besides, they allow determining duration and energy consumption of construction works. Zhang and Dasaka (2010) evaluated the spatial variability characteristics at a weathered soil site. Sušinskas *et al.* (2011) presented the process for selection of the most fitting and effective pile-column instalment alternative. The model is based on ARAS method and AHP technique. Zhang *et al.* (2011a) proposed a two-stage analysis method to study the behaviour of pile groups with rigid elevated caps. A single pile foundation utilizes a single, generally a large-diameter structural element to support all of the loads (weight, wind, etc.) of a large above-surface structure. Yoon *et al.* (2011) presented the evaluation results of the load test on columns and the rationale used for the selection of the resistance factor. Zhao *et al.* (2009) presented the model for stability analysis of high pile-column bridge pier. Zhang *et al.* (2011b) analysed excavation-induced responses of loaded pile foundations considering the uploading effect. Zhao *et al.* (2007) revisited the stability analysis regarding the pile-columns of a bridge pier.

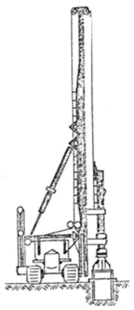
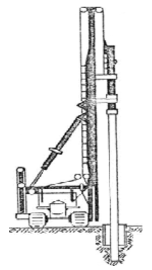
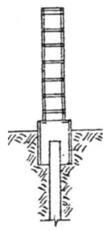
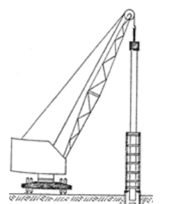
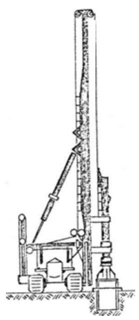
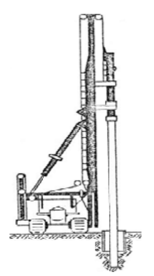
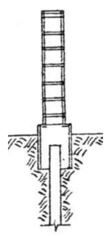
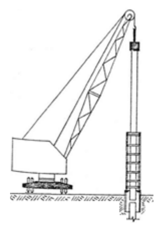
Sustainable development aims to reconcile economic growth, social progress and frugal use of natural resources, to maintain ecological balance and to ensure favourable living conditions for current and future generations (Raslanas *et al.* 2011). Selection of an investment strategy and related decision making relies heavily on personal experience and behaviour (Wu *et al.* 2012; Šaparauskas *et al.* 2011; Banaitienė *et al.* 2011). Multiple criteria decision making is an important part of modern decision science (Zavadskas, Turskis 2011; Zavadskas *et al.* 2008). How to select an effective algorithm for a multiclass classification task is an important yet difficult issue (Peng *et al.* 2011). Most of the real-world multiple criteria decision-making problems contain a mixture of quantitative and qualitative criteria (Nieto-Morote, Ruz-Vila 2011; Kaklauskas *et al.* 2011; Merigo, Gil-Laufente 2011). The typical MCDM problem is concerned with the task of ranking. In order to evaluate the overall efficiency of technological alternatives, typically it is necessary: a) to identify the system for evaluation of criteria that relates the system capabilities to goals; b) to develop alternative systems for attaining the goals (generating alternatives); c) to assess a finite number of decision alternatives, each of which is described in terms of different decision criteria which are taken into account simultaneously; d) to apply a normative multiple criteria analysis method; e) to accept one alternative as the most preferable; f) to gather new information and go into the next iteration of multiple criteria optimization if the final solution is not accepted.

At the beginning of his book, Zeleny (1982) stated that "It has become more and more difficult to see the world around us in a unidimensional way and to use only a single criterion when judging what we see". In reality, the modelling of engineering problems is based on a different kind of logic taking into consideration the existence of multiple criteria, the conflicting aims of decision maker, the complex, subjective and different nature of the evaluation process, and the participation of several decision makers. The use of the new and modernisation of the existing technologies as well as the selection of the most suitable alternative among those feasible with the help of different models are challenging tasks for the modern civil engineering (Prentkovskis *et al.* 2012; Krayushkina *et al.* 2012). Estimation and modelling of problems depends the recent advances achieved in different fields (Dzemyda, Sakalauskas 2011). Selection of the right construction technology plays a vital role in the overall performance of a project, thus posing the most crucial challenge for any contractor. Numerous and often conflicting objectives and alternatives, such as tender price, completion date, and experience, need to be considered. Recently, to assist contractors and stakeholders in decision-making, there has been a trend to move away from the "lowest-price wins" principle and subjective judgement to the multiple criteria selection approach in the selection of alternatives (San Cristóbal 2012).

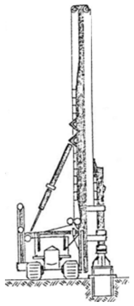
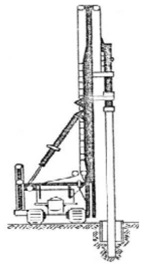
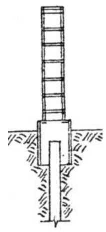
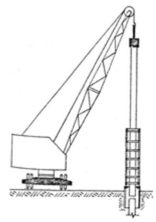
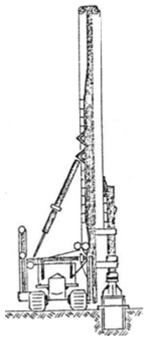
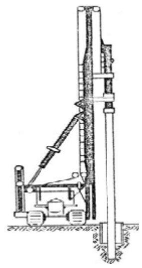
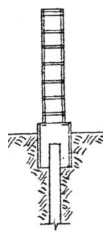
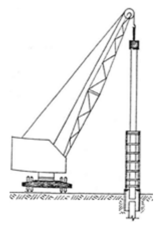
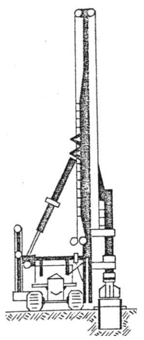
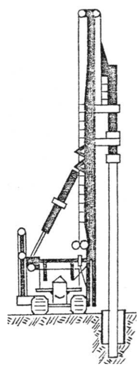
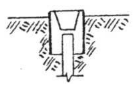
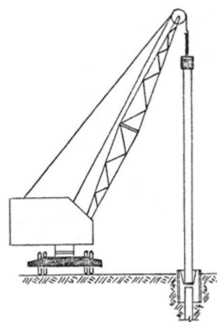
2. Case study

Projects with pile-columns are complex systems that are rather difficult to select in practice. For this reason, a decision-maker should possess a large amount of multidisciplinary knowledge and be familiar with multidisciplinary techniques of operations research. The case study presents the process of selecting the pile-column alternative for a building that stands on the aquiferous soil. The aim of the study is to design and install the most effective pile-columns. The study shows how a decision-maker can find the most reasonable alternative with the help of a certain dataset. Taking into account the aforementioned suggestions and references of experts as well as the aim to install the most effective pile-columns, the five following alternatives were considered (Table 1).

Table 1. Considered technological alternatives for installing pile-columns (driving the rings)

Alternative	Short description of the alternative
a_1	Driving the reinforced concrete ring using a punch, driving the pole, construction, positioning and adjustment of the mounting jig for the column, placing *in situ* concrete, and column mounting.
	 Driving the reinforced concrete ring  Driving the pole  Positioning and adjusting the mounting jig  Column mounting
a_2	Driving the reinforced concrete ring by applying a punch, driving the pile, placing *in situ* concrete mixture basement with a nest for the column mounting, and column mounting.
	 Driving the reinforced concrete ring  Driving the pole  Positioning and adjusting the mounting jig  Column mounting

Continue of Table 1

Alternative	Short description of the alternative
a_3	Driving the steel ring by applying a punch, driving the pile, placing *in situ* concrete mixture basement with a nest for the column mounting, and column mounting.
	 Driving the reinforced concrete ring  Driving the pole  Positioning and adjusting the mounting jig  Column mounting
a_4	Driving the steel ring by applying a punch, driving the pile, placing *in situ* concrete basement with a nest for the column mounting, removing the steel ring, and column mounting.
	 Driving the reinforced concrete ring  Driving the pole  Positioning and adjusting the mounting jig  Column mounting
a_5	Drilling the leader bore with 0.8 m in diameter and 1.0 m in height, driving the reinforced concrete ring, driving the pile, positioning and adjusting the mounting jig for the column, placing *in situ* concrete mixture, and column mounting.
	 Driving the reinforced concrete ring  Driving the pole  Placing *in situ* concrete basement with a nest for the column  Column mounting
Remark	*The inner diameter of all driven rings equals to 1.0 m.*

The construction technology of alternatives is described by six criteria. The set of criteria was determined by qualified civil engineers and shown in Table 2. The selection is based on a set of criteria: labour expenditures (x_1, hours), cost of instalment (x_2, €), consumption of concrete (x_3, m^3), consumption of steel (x_4, kg), machinery expenditures (x_5, hours), and consumption of energy (x_6, GJ). The criteria set for evaluation is selected considering the factors that influence the efficiency of the construction process. Significance of criteria significances (weights) was determined with the help of the expert judgement method and the analytic hierarchy process (AHP) method. Integrated criteria weights were applied in the solution process.

Table 2. The Expert judgement method

Expert	x_1	x_2	x_3	x_4	x_5	x_6
E_1	5	6	4	3	1	2
E_2	1	5	6	3	2	4
E_3	3	5	6	4	1	2
E_4	5	4	6	3	1	2
E_5	6	5	3	4	2	1
E_6	3	4	6	5	2	1
E_7	4	6	5	3	1	2
E_8	1	3	5	4	2	6
E_9	5	6	3	4	1	2
E_{10}	6	5	3	4	1	2
E_{11}	5	6	4	3	2	1
E_{12}	5	6	3	2	4	1
E_{13}	5	2	6	4	3	1
E_{14}	4	3	6	5	1	2
E_{15}	6	5	3	4	2	1
E_{16}	3	4	6	5	1	2
E_{17}	5	6	4	3	2	1
E_{18}	5	6	3	4	2	1
E_{19}	6	4	5	3	1	2
E_{20}	5	6	4	3	1	2
E_{21}	4	6	5	3	2	1
E_{22}	4	6	3	5	1	2
E_{23}	5	6	1	2	4	3
E_{24}	5	6	3	4	1	2
E_{25}	5	6	2	4	3	1
E_{26}	5	6	4	3	1	2
Sum of ranks	116	133	109	94	45	49
Mean value	4.462	5.115	4.192	3.615	1.731	1.885
Rank	2	1	3	4	6	5
Weight of criterion p_j	0.212	0.244	0.200	0.172	0.082	0.090

2.1. Determining criteria weights

One of the major tasks is to determine the weights of the criteria. The weights demonstrate which criterion is the most important in comparison to the other criteria (Kersuliene *et al.* 2010). The expert judgment method was applied (Kendall 1970) at the first stage of criteria weight determination. Zavadskas *et al.* (2010a) provided a detailed presentation of the algorithm and discussed peculiarities of weight determination. The weights p_j of attributes presented in Table 1 were determined by application of the expert judgment method proposed by Kendall. This expert judgment method was implemented at the following stages: a) calculation of values t; b) calculation of weights w; c) calculation of values S; d) calculation of values T_k; e) calculation of concordance value W; f) calculation of values χ^2; g) testing the statement $\chi^2 > \chi^2_{tbl}$.

The values t_{jk} for statistical processing were obtained by interviewing the respondents.

Kendall (1970) has demonstrated that, when $n > 7$, the value $\chi^2_{\alpha,v} = W \cdot r \cdot (n - 1)$ has a distribution with degrees of freedom $v = n - 1$, where n is the number of attributes considered and r – the number of experts. If the calculated value χ^2 is larger than the critical tabular value χ^2_{tbl} for the pre-selected level of significance α, then the hypothesis about the agreement of independent expert judgments is not rejected. In the case study, the number of experts $r = 26$, the degrees of freedom $v = n - 1 = 5$ and the pre-selected level of significance is $\alpha = 0.05$. The calculated concordance coefficient based on the weights of attributes is $W = 0.558$. The tabular value $\chi^2_{tbl} = 15.08$ ($\alpha = 0.05$) (Fisher, Yates 1963).

Since $\chi^2_{tbl} = 15.08 > \chi^2_{\alpha,v} = 72.55$ then the assumption is made that the coefficient of concordance is significant and expert rankings are in concordance with 95% probability.

During the next step, experts applied the WEAR software (which contains the AHP method) to determine criteria weights (Zavadskas *et al.* 2012) (see Table 3).

In decision analysis, the analytical hierarchy process (AHP) and the analytical network process (ANP) are widely used to assess the key factors and analyse the impacts and preferences of decision alternatives (Ergu *et al.* 2011a, b).

The recent developments of decision making models based on the AHP (Saaty 1980; Saaty, Zoffer 2011; Vaidogas, Sakenaite 2011) methods are listed below: Medineckiene *et al.* (2010) applied the AHP in sustainable construction; Maskeliūnaitė *et al.* (2009), Sivilevičius and Maskeliūnaitė (2010), and Sivilevičius (2011a) applied the AHP in modelling of transport systems; and Sivilevičius (2011b) used the AHP to determine the quality of technology.

Table 3. Criteria weights according to the AHP method

Determined criteria weights							
Expert	x_1	x_2	x_3	x_4	x_5	x_6	
E_1	0.249	0.379	0.102	0.16	0.043	0.065	
E_2	0.043	0.249	0.379	0.16	0.065	0.102	
E_3	0.16	0.249	0.379	0.102	0.043	0.065	
E_4	0.249	0.102	0.379	0.16	0.043	0.065	
E_5	0.379	0.249	0.16	0.102	0.065	0.043	
E_6	0.16	0.102	0.379	0.249	0.065	0.043	
E_7	0.102	0.379	0.249	0.16	0.043	0.065	
E_8	0.043	0.16	0.249	0.102	0.065	0.379	
E_9	0.249	0.379	0.16	0.102	0.043	0.065	
E_{10}	0.379	0.249	0.16	0.102	0.043	0.065	
E_{11}	0.249	0.379	0.102	0.16	0.065	0.043	
E_{12}	0.249	0.379	0.16	0.065	0.102	0.043	
E_{13}	0.249	0.065	0.379	0.102	0.16	0.043	
E_{14}	0.102	0.16	0.379	0.249	0.043	0.065	
E_{15}	0.379	0.249	0.16	0.102	0.065	0.043	
E_{16}	0.16	0.102	0.379	0.249	0.043	0.065	
E_{17}	0.249	0.379	0.102	0.16	0.065	0.043	
E_{18}	0.249	0.379	0.16	0.102	0.065	0.043	
E_{19}	0.379	0.102	0.249	0.16	0.043	0.065	
E_{20}	0.249	0.379	0.102	0.16	0.043	0.065	
E_{21}	0.102	0.379	0.249	0.16	0.065	0.043	
E_{22}	0.102	0.379	0.16	0.249	0.043	0.065	
E_{23}	0.249	0.379	0.043	0.065	0.102	0.16	
E_{24}	0.249	0.379	0.16	0.102	0.043	0.065	
E_{25}	0.249	0.379	0.065	0.102	0.16	0.043	
E_{26}	0.249	0.379	0.102	0.16	0.043	0.065	$\sum\sum$
$\sum$	5.727	7.344	5.547	3.746	1.668	1.916	25.948
	Established weights						
q_i	0.221	0.283	0.214	0.144	0.064	0.074	

Integrated criteria weights were calculated during the third stage of criteria weight determination (Table 4).

Table 4. Integrated criteria weights

	Criteria						Weights
	x_1	x_2	x_3	x_4	x_5	x_6	
q_j	0.221	0.283	0.214	0.144	0.064	0.074	AHP
p_j	0.212	0.244	0.2	0.172	0.082	0.09	Kendall
w_j	0.217	0.263	0.207	0.158	0.073	0.082	Integrated $w_j = \frac{q_j p_j}{\sum_{j=1}^{n} (q_j p_j)}; j = \overline{1, n}$

2.2. Problem solving

Three different multiple criteria decision making methods – TOPSIS, COPRAS and ARAS – were selected to solve the investigated problem *An Additive Ratio Assessment* (ARAS) method (Zavadskas, Turskis 2010; Turskis, Zavadskas 2010a) is based on the argument that complicated phenomena could to be understood by using simple relative comparisons. It is argued that the ratio of the sum of normalised and weighted values of criteria, which describe an alternative under consideration, to the sum of the values of normalised and weighted criteria, which describes the optimal alternative, is the degree of optimality, which is reached by the alternative under comparison.

The recent developments of decision making models based on the ARAS method are listed below: Keršulienė and Turskis (2011) presented an integrated fuzzy multiple criteria decision making model for the selection of an architect; Turskis and Zavadskas (2010b) performed multiple criteria analysis in order to select the location for a logistics centres; and Zavadskas *et al.* (2010b) analysed foundation alternatives.

The method of complex proportional assessment COPRAS (Zavadskas, Kaklauskas 1996) assumes direct and proportional dependence of significance and utility degree of investigated alternatives on a system of criteria adequately describing the alternatives, and on values and weights of the criteria. This method was used to solve various problems in construction.

The recent developments of decision making models based on COPRAS methods (Podvezko 2011) are listed below: Datta *et al.* (2009) solved the problem of determining the compromise to selection of a supervisor; Bindu Madhuri *et al.* (2010) presented the model for selection of alternatives based on COPRAS-G and AHP methods; Uzsilaityte and Martinaitis (2010) investigated and compared different alternatives for the renovation of buildings taking into account energy, economic and environmental criteria while evaluating impact of renovation measures during their life cycle; Chatterjee *et al.* (2011) presented materials selection model based on COPRAS and EVAMIX methods; Yazdani *et al.* (2011) applied the COPRAS method to analyse critical infrastructures.

The TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method determines a solution with the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution (Hwang, Yoon 1981). Kalibatas *et al.* (2011) used it in order to solve the problem of the assessment of dwelling-houses, determining the ideal indoor environment. Rudzianskaite-Kvaraciejiene *et al.* (2010) evaluated the effectiveness of road investment projects.

The description of the methods is presented in Table 5.

First of all, the initial decision making matrix was prepared. The problem was solved by applying three different multiple criteria decision making methods: TOPSIS, COPRAS and ARAS. The solution process of the problem is presented in Table 6.

Table 5. Description of TOPSIS, COPRAS and ARAS methods

	TOPSIS	COPRAS	ARAS
	m – number of alternatives, n – number of criteria describing each alternative, x_{ij} – value representing the performance value of the i alternative in terms of the j criterion.		
	The alternatives are described by relative distance from the positive ideal solution a^+ and from the negative ideal solution a^-	The alternatives are described by sums of minimizing indexes S_{+i} and maximizing indexes S_{-i}	The alternatives are described by ratios with the optimal alternative
	$i = \overline{1, m}; \; j = \overline{1, n},$	$i = \overline{1, m}; \; j = \overline{1, n},$	$i = \overline{0, m}; \; j = \overline{1, n},$ x_{0j} – optimal value of j criterion. $x_{0j} = \max_i x_{ij}, \textit{if} \max_i x_{ij} \textit{ is preferable, and}$ $x_{0j} = \min_i x_{ij}^*, \; \textit{if} \min_i x_{ij}^* \textit{ is preferable.}$
The initial decision making matrix	$X = \begin{bmatrix} x_{11} & \cdots & x_{1j} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix}$	$X = \begin{bmatrix} x_{11} & \cdots & x_{1j} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix}$	$X = \begin{bmatrix} x_{01} & \cdots & x_{0j} & \cdots & x_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix}$

Continue of Table 5

	TOPSIS	COPRAS	ARAS
Normalisation of the initial decision making matrix	$\bar{x}_{ij} = \frac{x_{ij}}{\left(\sum_{i=1}^{m}(x_{ij})^2\right)^{0.5}}$	$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}$	$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}}, \textit{if } \max_i x_{ij} \textit{ is preferable};$ $\bar{x}_{ij} = \frac{1}{x_{ij}\sum_{i=0}^{m}\frac{1}{x_{ij}}}, \textit{if } \min_i x_{ij}^{*} \textit{ is preferable}.$
Normalised matrix	$\bar{X} = \begin{bmatrix} \bar{x}_{11} & \cdots & \bar{x}_{1j} & \cdots & \bar{x}_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{i1} & \cdots & \bar{x}_{ij} & \cdots & \bar{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{m1} & \cdots & \bar{x}_{mj} & \cdots & \bar{x}_{mn} \end{bmatrix}$		$\bar{X} = \begin{bmatrix} \bar{x}_{01} & \cdots & \bar{x}_{0j} & \cdots & \bar{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{i1} & \cdots & \bar{x}_{ij} & \cdots & \bar{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{m1} & \cdots & \bar{x}_{mj} & \cdots & \bar{x}_{mn} \end{bmatrix}$
Weighting of normalised matrix	$\hat{x}_{ij} = \bar{x}_{ij} w_j$		
Determining the ideal positive and the ideal negative solution	$a^+ = \{\hat{x}_1^+, ..., \hat{x}_n^+\} = \left\{\left(\max_i \hat{x}_{ij} \middle\| i \in I'\right), \left(\min_i \hat{x}_{ij} \middle\| i \in I''\right)\right\}$ $a^- = \{\hat{x}_1^-, ..., \hat{x}_n^-\} = \left\{\left(\min_i \hat{x}_{ij} \middle\| i \in I'\right), \left(\max_i \hat{x}_{ij} \middle\| i \in I''\right)\right\}$		
Normalised-weighted matrix	$\hat{X} = \begin{bmatrix} \hat{x}_{11} & \cdots & \hat{x}_{1j} & \cdots & \bar{x}_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{i1} & \cdots & \hat{x}_{ij} & \cdots & \hat{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{m1} & \cdots & \hat{x}_{mj} & \cdots & \hat{x}_{mn} \\ \hat{x}_1^+ & \cdots & \hat{x}_j^+ & \cdots & \hat{x}_n^+ \\ \hat{x}_1^- & \cdots & \hat{x}_j^- & \cdots & \hat{x}_n^- \end{bmatrix}$	$\hat{X} = \begin{bmatrix} \hat{x}_{11} & \cdots & \hat{x}_{1j} & \cdots & \hat{x}_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{i1} & \cdots & \hat{x}_{ij} & \cdots & \hat{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{m1} & \cdots & \hat{x}_{mj} & \cdots & \hat{x}_{mn} \end{bmatrix}$	$\hat{X} = \begin{bmatrix} \hat{x}_{01} & \cdots & \hat{x}_{0j} & \cdots & \hat{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{i1} & \cdots & \hat{x}_{ij} & \cdots & \hat{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{m1} & \cdots & \hat{x}_{mj} & \cdots & \hat{x}_{mn} \end{bmatrix}$
Determining values of the optimality function	The separations of each alternative from the positive ideal solution D_i^+ and from the negative ideal solution D_i^- in Euclidean distance are given as $D_i^+ = \left(\sum_{j=1}^{n}\left(\hat{x}_{ij} - \hat{x}_j^+\right)^2\right)^{0.5};$ $D_i^- = \left(\sum_{j=1}^{n}\left(\hat{x}_{ij} - \hat{x}_j^-\right)^2\right)^{0.5}.$	$S_{+i} = \sum_{j=1}^{n} \hat{x}_{+ij}, \textit{when } \max_i x_{ij} \textit{ is preferable};$ $S_{-i} = \sum_{j=1}^{n} \hat{x}_{-ij}, \textit{when } \min_i x_{ij} \textit{ is preferable};$ $S_+ = \sum_{i=1}^{m} S_{+i} = \sum_{i=1}^{m}\sum_{j=1}^{n} \hat{x}_{+ij};$ $S_- = \sum_{i=1}^{m} S_{-i} = \sum_{i=1}^{m}\sum_{j=1}^{n} \hat{x}_{-ij};$ $S_i = S_{+i} + \frac{S_{-\min} \cdot \sum_{i=1}^{m} S_{-i}}{S_{-i} \cdot \sum_{i=1}^{m} S_{-\min}/S_{-i}}.$	$S_i = \sum_{j=1}^{n} \hat{x}_{ij}.$
Utility degree K_i of the alternative a_i	$K_i = \frac{D_i^-}{D_i^- + D_i^+}.$	$K_i = \frac{S_i}{\max_i S_i}.$	$K_i = \frac{S_i}{S_0}.$
Ranking of alternatives	$\max_i K_i$, *is the most preferable*		

Table 6. The problem solution process and results

The initial decision making matrix

Alternatives	Attributes					
	x_1	x_2	x_3	x_4	x_5	x_6
Optimum	*min*	*min*	*min*	*min*	*min*	*min*
Weights *w*	0.212	0.244	0.200	0.172	0.082	0.090
a_1	9.7	405	3.53	247	2	13.9
a_2	10.2	429	3.53	247	2.5	9.3
a_3	8.6	404	3.38	495	2	16.2
a_4	9.8	320	3.38	246	2.3	7.8
a_5	7.9	327	3.53	247	2.2	13.8

TOPSIS method

	$\hat{x}_1$	$\hat{x}_2$	$\hat{x}_3$	$\hat{x}_4$	$\hat{x}_5$	$\hat{x}_6$	D^+	D^-	K	Rank
Optimum	*min*	*min*	*min*	*min*	*min*	*min*				
a_1	0.099	0.116	0.091	0.061	0.033	0.044	0.036	0.075	0.673	3
a_2	0.104	0.123	0.091	0.061	0.042	0.030	0.041	0.075	0.649	4
a_3	0.088	0.116	0.087	0.122	0.033	0.052	0.071	0.013	0.158	5
a_4	0.100	0.092	0.087	0.061	0.038	0.025	0.020	0.094	0.824	1
a_5	0.081	0.094	0.091	0.061	0.037	0.044	0.020	0.090	0.819	2
a^+	0.081	0.092	0.087	0.061	0.033	0.025	0.000	0.108	1.000	
a^-	0.104	0.123	0.091	0.122	0.042	0.052	0.078	0.000	0.000	

COPRAS method

	$\hat{x}_1$	$\hat{x}_2$	$\hat{x}_3$	$\hat{x}_4$	$\hat{x}_5$	$\hat{x}_6$	S_-	S_+	S	K	Rank
Optimum	*min*	*min*	*min*	*min*	*min*	*min*					
a_1	0.045	0.052	0.041	0.029	0.015	0.020	0.000	0.202	0.197	0.905	3
a_2	0.047	0.055	0.041	0.029	0.019	0.014	0.000	0.204	0.195	0.895	4
a_3	0.040	0.052	0.039	0.058	0.015	0.024	0.000	0.227	0.175	0.804	5
a_4	0.045	0.041	0.039	0.029	0.017	0.011	0.000	0.183	0.218	1.000	1
a_5	0.036	0.042	0.041	0.029	0.016	0.020	0.000	0.185	0.215	0.989	2

ARAS method

	$\hat{x}_1$	$\hat{x}_2$	$\hat{x}_3$	$\hat{x}_4$	$\hat{x}_5$	$\hat{x}_6$	S	K	Rank
Optimum	*min*	*min*	*min*	*min*	*min*	*min*			
a_1	0.040	0.045	0.039	0.038	0.018	0.015	0.195	0.897	3
a_2	0.038	0.042	0.039	0.038	0.014	0.022	0.194	0.893	4
a_3	0.045	0.045	0.041	0.019	0.018	0.013	0.181	0.831	5
a_4	0.040	0.057	0.041	0.038	0.016	0.026	0.217	1.000	1
a_5	0.049	0.055	0.039	0.038	0.016	0.015	0.213	0.981	2
a_0	0.049	0.057	0.041	0.038	0.018	0.026	0.217	1.000	

3. Conclusions

Overall, the main advantages that the MCDM provides in decision making could be summarized in the following aspects: the possibility to analyse complex problems; the possibility to aggregate both quantitative and qualitative criteria in the evaluation process; good evidence of decisions; the option for a decision-maker to participate actively in the decision-making process; and the use of flexible scientific methods in the decision making process.

According to the newly proposed model, the priorities of alternatives can be determined according to the utility function value. Consequently, it is convenient to evaluate and rank decision alternatives when this model is used.

The degree of the alternative utility is determined by comparison of the analysed variant with ideally the best one.

It can be stated that the ratio with an optimal alternative may be used in cases when it is required to rank alternatives and find ways to improve alternative projects.

Three MCDM methods were applied. Alternatives according to all methods rank in the same way: $a_4 \succ a_5 \succ a_1 \succ a_2 \succ a_3$.

This means that the most preferable alternative is a_4 that must be selected and implemented.

The proposed model can be modified and applied to solve different problems: to select, assess and rank constructions, technologies and other alternatives.

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Edmundas Kazimieras ZAVADSKAS. Dr Habil, Professor, Head of the Research Institute of Internet and Intelligent Technologies and Head of the Department of Construction Technology and Management of Vilnius Gediminas Technical University, Lithuania. Research interests: building technology and management, decision-making theory, automation in design and decision support systems.

Saulius SUŠINSKAS. Doctor, Associate Professor, Head of the Department of Civil Engineering of Panevėžys Institute Faculty of Technologies, Kaunas University of Technology, Lithuania. Research interests: civil engineering, construction materials and their strength and durability, analysis of changes in substrate stiffness and its effect on the behaviour of the building.

Alfonsas DANIŪNAS. Doctor, Associate Professor at the Department of Steel and Timber Structures of Vilnius Gediminas Technical University, Lithuania. Research interests: analysis and optimization of elastic and plastic steel structures, numerical methods, semi-rigid joints of steel structures.

Zenonas TURSKIS. Doctor of Technical Science, Chief Research Fellow at Construction Technology and Management Laboratory of Vilnius Gediminas Technical University. Research interests: civil engineering, construction technology and management, decision-making theory, computer-aided automation in design, expert systems.

Henrikas SIVILEVIČIUS. Dr Habil, Professor at the Department of Transport Technological Equipment of Vilnius Gediminas Technical University, Lithuania. Research interests: flexible pavement life-cycle, hot mix asphalt mixture production technology, application of statistical and quality control methods, recycling asphalt pavement technologies and design, decision-making and expert systems theory.