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MULTI-ATTRIBUTE ASSESSMENT OF ROAD DESIGN SOLUTIONS BY USING THE COPRAS METHOD

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Abstract. Multi-attribute analysis is a popular tool in many economical, managerial, constructional etc problems. The objective of this research is to develop and implement a methodology for multi-attribute assessment of multi-alternative decisions in road construction. After a rough overview of multi-attribute decision support for assessment of road design alternatives, the COPRAS approach was selected. This methodology is applicable to the problems with large numbers of scenarios and criteria. A case study is used to demonstrate the concept of multi-attribute assessment of road design alternatives and the best road design alternative is determined. The research has concluded that the COPRAS method is appropriate for use.

Keywords: road design, alternative, multi-attribute assessment, COPRAS method.

1. Introduction

Roads and bridges have a special role in infrastructure of cities and residential areas. These infrastructure objects are complex engineering facilities and their construction and use require much special scientific knowledge.

The harmony in the residential environment much depends on the density of road network and the number and capacity of bridges. As of late, the research of general plans [1] and the sustainable development [2–8] and transport flows [9–11] receives increasing attention. Methods to evaluate citizen opinions [12–15], special forecasting methods [16] and decision support systems [17] are being developed for integrated assessment of variants of sustainable urban development.

Constant growth of the number of traffic participants demands expansion of district, national and arterial roads and especially the highway network. Alongside with construction of new roads, adding of more lanes to the existing highways plays an exclusive role.

In expansion of the highway network, preparation of good design documentation has an important role. Considering large costs of road construction and widening, it is very important to select as rational solutions as possible. Therefore it is also necessary to assess accumulated previous experience in order to improve quality and longevity of roads. A special attention must be paid to road safety. Quite a few scientific researches are performed in these fields.

Roads in the Baltic States are affected by varying Northern climate, which causes additional problems of maintenance. In order to improve road safety in winter, additional measures are needed, which damage road surface and have negative effect on the environment [18].

Currently, the road safety on Lithuanian roads is the worst compared to other EU countries. Lithuania ranks the last among all EU countries according to the number of people killed in fatal traffic accidents per one million residents. Ratkevičiūtė et al [19] provide an exhaustive analysis of causes behind the accident rates and offer means to increase the road safety. Kapski and Leonovich [20] analyse probabilities of accident rates. Kapski et al [21] attempt to adjust the theory of catastrophe to the progress of a traffic situation when a conflict results in a road accident. Kashevskaya [22] and Leonovich and Kashevskaja [23] analyse the problems related to the quality of road infrastructure and, on the basis of the main statements of the road quality management theory, offer a few methods to guarantee high quality road maintenance.

The quality of roads and bridges and flyovers as part of roads depends on the quality of design solutions. The quality of these solutions is determined by knowledge of designers and their ability to apply the latest and the most advanced constructional and technological solutions. Road surfacing was analysed by Ziari and Khabiri [24], Laurinavičius et al [25], Petkevičius et al [26], Radziszewski [27], Chang et al [28], Ziari et al [29] in order to improve its longevity and maintenance qualities. Bridge constructions were analysed by Kamaitis [30, 31], Witzany and Zigler [32], Witzany and Cejka [33], Marzouk et al [34], Frangopol and Liu [35], Miyamoto et al [36] seeking to improve their maintenance qualities and longevity.

Important research is being performed in order to apply the theory of reliability in designing roads and bridges [37–41].

When planning to construct roads and determining which road sections need repair of surfacing, the actual condition of road surface must be assessed. However, methods for assessment of road surface and its construction have their limitations. It is easy to notice that some of them are insufficiently precise, others too complex. When assessments are based on one of the attributes – as is usually the case – the best solutions are not always selected.

In construction of new or renovation of old highways, the following attributes for assessing design solutions are the most important: cost, duration of construction, longevity, environmental issues, economic validity. The best solution is sought, to achieve the best values of these attributes. However, it is impossible to get all the best values at a time. Thus Multi Attribute Decision Making (MADM) methods are used to deal with such tasks.

2. Short review of use of MADM methods to deal with civil engineering problems

Considering the nature of information available to decision makers, MADM can be classified into the following groups [42]:

1) Methods based on quantitative measurements. This group consists of common methods of the multiple criteria utility theory and of some new methods: TOPSIS, VIKOR, COPRAS.
2) Methods based on initial qualitative assessment, the results of which later take a quantitative form. This group consists of analytic hierarchy methods (AHP), as well as the methods based of game theory and fuzzy sets.
3) Methods based on quantitative measurements but using a few criteria to compare the alternatives (comparison preference method). This group consists of preference comparison methods: ELECTRE, PROMETEE.
4) Methods based on qualitative data not using a transformation to quantitative variables. This group comprises verbal decision analysis (VDA).

Methods within all these 4 groups are successfully applied to deal with engineering, including civil engineering, problems [1–8, 10, 13, 15–17, 28, 43–58].

The COPRAS [43] method developed by the authors was used for real estate [44], to assess sustainability of the city of Vilnius [16] and its residential areas [2, 8], to make sustainable revitalisation of derelict property [55], to assess construction investment projects [42], to select rational technological construction processes [45], to assess building refurbishment processes [46], to select variants of monolith floors [47] and to develop decision support systems [17].

The TOPSIS method is successfully used in designing road surfacing [28], in dealing with issues related to sustainable revitalisation of derelict property [7, 48, 55] and reliability of bridges [40], in selection of the most effective variants for external walls of multi-storey residential houses [56] etc.

The VIKOR method was used to deal with issues related to sustainable revitalisation of derelict property [54].

The methods of the theory of gambling were used to select a rational variant for road reconstruction [41], to model refurbishment of construction objects [50], to assess compactness of a sustainable city [6] and to assess the solutions for external walls of multi-storey residential houses [57]. The AHP method was used to select a rational variant of the design documentation for a large transportation system [10]. Fuzzy sets methods were used to deal with the task related to construction of a water supply pipeline [52], to select house construction strategy [53] and to deal with the aforementioned tasks [7, 40, 48, 54].

The ELECTRE-3 method was used to determine preferences when selecting a public transport expansion scenario [13]. The PROMETEE method was used to assess investment projects [51]. Verbal analysis of engineering and construction designing work was performed [54].

It must be noted that only a few of the mentioned MADM applications are related to dealing with road and bridge construction tasks. Use of MADM methods in other fields of construction is justified. This article – using the COPRAS method [43] developed by the authors – attempts to select a variant for expansion of a highway in Thuringia (Germany) from 4 to 6 lanes. It is attempted to illustrate the rationality of use of MADM methods in road and bridge construction.

3. Case study

A typical assessment and selection of alternatives based on multiple criteria is a multi-stage process and follows the algorithm provided in Fig 1.

3.1. Assessment attributes [41]

***Longevity* – x_1.** Longevity is one of the most important attributes in assessment of highway design documentation. The total price much depends on the needed longevity. Thus we have a road while it can be used without expenditures on renovation. Cheap solutions determine large renovation costs and usually become more expensive in the end. For instance, asphalt and concrete surfacing can be compared.

***Construction price* – x_2.** One of the main requirements for designing is to strive at as small construction price as possible. But at the same time to guarantee good quality, hardness, to achieve the shortest duration of construction, to guarantee smaller number of detours or changes of direction and to reduce the number of accidents in stages of construction and maintenance. It is important to consider interests of all owners living in neighbouring land plots.

***Environment protection* – x_3.** Construction of new or renovation of old highways has negative effect on nature. Damage to environment must be minimised during construction. The roads are part of the landscape. They cannot deface the terrain. The amount of earthworks and duration of construction must be minimised during construction. Special methods are being developed for this purpose using the theory of mass service and neural mathematical models [59] and special methods for preparation of work schedules [60].

Strategic environment studies are used in the EU. Therefore special studies must be performed. The effect on flora, fauna, soil, water, air, climate, landscape, existing situation and environment quality must be determined, also considering the demand growing with time. Consumption of natural resources, CO_2 emissions and increased noise must be assessed as well.

***Economic validity* – x_4.** Economic validity of construction much depends on average distance for soil transportation. Thus when preparing profiles of a road, the distance between the embankment and excavations must be considered. Transportation distances and volumes of transported soil have serious influence on construction costs and duration.

***Construction duration* – x_5.** Because reconstruction of highways impedes communication, endeavours are made to reduce the duration of work as much as possible. Speed-up requires additional costs and foreseeing more capacity (labour force and machinery). Thus it must be considered whether it is really necessary. The most rational way is to find such construction variants that could help to reduce construction duration.

Asphalt surfacing is not rigid. It usually consists of an upper layer, the lower layer and the roadbase. Weather and temperature variations during construction can affect the quality and longevity of different variants of asphalt surfacing.

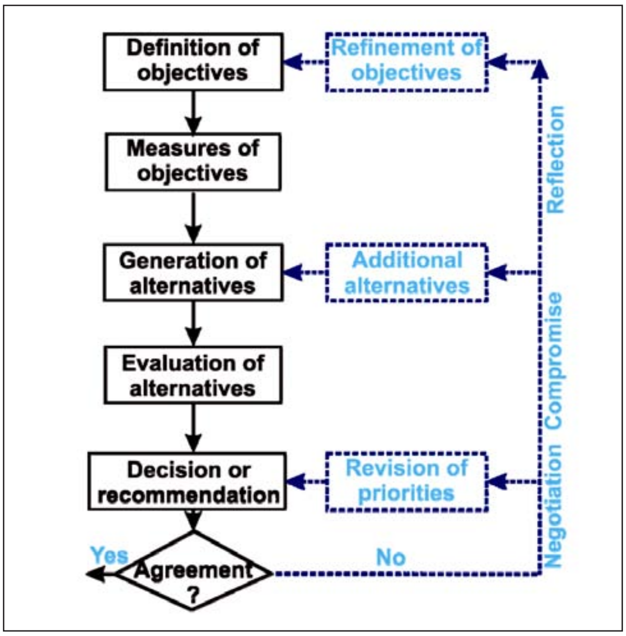


Fig 1. Structure of the multi-criteria assessment of road design alternatives

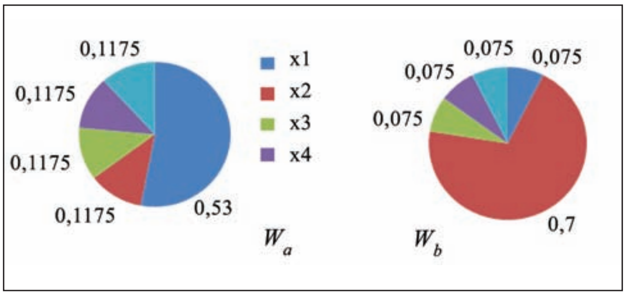


Fig 2. Weights of attributes representing different stakeholder groups (W_a and W_b)

Highways with concrete surfacing have an advantage. This surfacing is rigid, rheology depends less on loads and temperature, thus it is stable and does not deform. No tracks appear and elevations emerge due to stopping heavy vehicles. Besides, concrete roads are less sensitive to the effect of water. The older and more porous is the asphalt, the more serious the effect of water on asphalt concrete solidity. Therefore the lifetime of concrete roads is from 20 to 30 years and of asphalt concrete road surfacing from 15 to 20 years. Upon expiration of this term the road must be renovated.

3.2. Weights of attributes [41]

Two expert groups representing different stakeholders from the society interested in project implementation were formed to assess weight of attributes. Their survey and the processing of data revealed two variants of weights of efficiency attributes provided as diagrams in Fig 2.

3.3. Construction variants [41]

***Variant* 1.** Construction of a new road by changing the axis and gradients of the highway and using concrete surfacing. Change of gradients requires deep excavations and embankments, ie large amount of earthwork. It makes up 70 m^3/m in average.

***Variant* 2.** Construction of a new road by changing the axes and gradients of the highway and using asphalt concrete surfacing. Only the surfacing differs compared to variant 1.

***Variant* 3.** Construction of a new road by changing the axes and retaining the gradients of the highway with concrete surfacing. When the gradients are retained, the amount of earthwork is reduced in variant 3. It makes up 36,2 m^3/m.

***Variant* 4.** Construction of a new road by changing the axes and retaining the gradients of the highway but with asphalt concrete surfacing. This variant corresponds to variant 3, only surfacing differs.

***Variant* 5.** Construction of a new road retaining the axis and the gradient of the highway with concrete surfacing. The amount of earthworks in this variant is similar to that of variant 3. Only duration differs.

***Variant* 6.** Construction of a new road retaining the axes and the gradient of the highway with asphalt concrete surfacing. Variant 6 corresponds to variant 5, only the road surfacing differs.

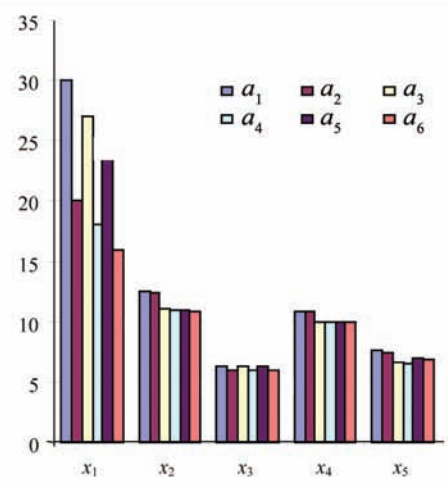
The following efficiency attributes are calculated to assess the listed variants according to design documentation: price, duration of construction, distance of transportation, noise level and longevity. They are taken from the article by Peldschus [41] and provided in Table 1.

Table 1 shows that there are no alternatives where all values of attributes are the best. Normalised values of the first attribute are the most varied among themselves. If we take the ratio between the optimal and the biggest value, this ratio is within the interval [0,53; 1,00]. The ratios of other attributes are as follows: second [0,87; 1,00], third [0,95; 1,00], fourth [0,91; 1,00] and fifth [0,90; 1,00]. If these intervals would be multiplied by corresponding attribute weights, then these intervals with weights W_a would be the following: the first attribute [0,28; 0,53], the second attribute [0,10; 0,12], the third attribute [0,10; 0,12], the fourth attribute [0,10; 0,12] and the fifth attribute [0,10; 0,12]. And in case of weights W_b the values would be the following: the first attribute [0,04; 0,08], the second attribute

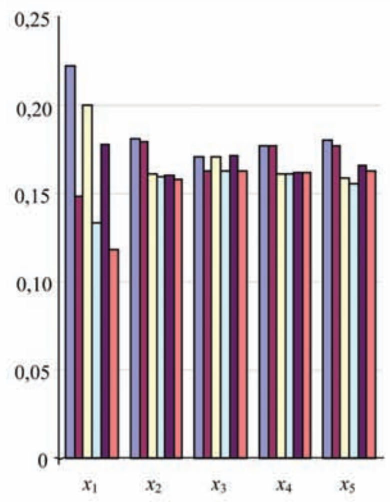
Table 1. Decision-making matrix: values of attributes for road design alternatives

Initial decision-making matrix												
No	Attributes	Units			Attribute weights		Alternatives					
				[a]	W_a	W_b	a_1	a_2	a_3	a_4	a_5	a_6
1.	Longevity	Years	x_1	max	0,5300	0,075	30	20	27	18	24	16
2.	Price	million €	x_2	min	0,1175	0,700	12,487	12,372	11,096	10,982	11,017	10,903
3.	Environment protection	10 dB (A)	x_3	min	0,1175	0,075	6,261	5,961	6,262	5,962	6,283	5,983
4.	Economic validity	100 m	x_4	min	0,1175	0,075	10,880	10,880	9,920	9,920	9,980	9,980
5.	Construction duration	100 days	x_5	min	0,1175	0,075	7,610	7,460	6,690	6,540	7,000	6,850
Normalised decision-making matrix												
			x_1	max	0,5300	0,075	0,2222	0,1481	0,2000	0,1333	0,1778	0,1185
			x_2	min	0,1175	0,700	0,1813	0,1797	0,1611	0,1595	0,1600	0,1583
			x_3	min	0,1175	0,075	0,1705	0,1624	0,1705	0,1624	0,1711	0,1630
			x_4	min	0,1175	0,075	0,1767	0,1767	0,1611	0,1611	0,1621	0,1621
			x_5	min	0,1175	0,075	0,1805	0,1770	0,1587	0,1552	0,1661	0,1625

Initial decision-making matrix



Normalised decision-making matrix



[a] *Optimisation direction (indicates that a higher/lower criterion value satisfies a client).*

[0,50; 0,70], the third attribute [0,07; 0,08], the fourth attribute [0,07; 0,08] and the fifth attribute [0,07; 0,08]. When assessment is based only on the most important attribute (biggest weight), then based on the first attribute and with weights W_a, the following string of alternatives would be obtained (starting with the best alternative): 1 > 3 > 5 > 2 > 4 > 6. Whereas based on the second attribute and with weights W_b only the first and the second alternatives differ from the remaining four, thus we have the following string of alternatives: 6 ≈ 3 =4 = 5 > 2 ≈ 1.

3.4. Applying COPRAS (the multiple criteria complex proportional assessment of alternatives) method

The MADM method assumes direct and proportional dependence of the significance and utility degree of investigated versions on a system of adequate description of the alternatives and on values and weights of the attributes.

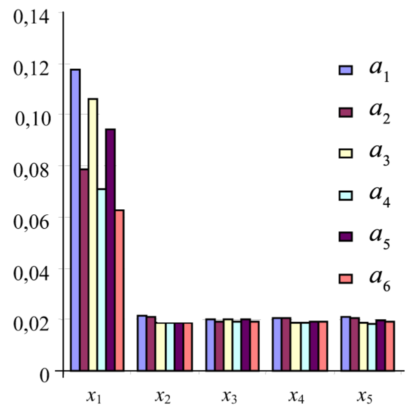
Determination of significance, the priority order and the utility degree of the alternatives is carried out in 5 stages:

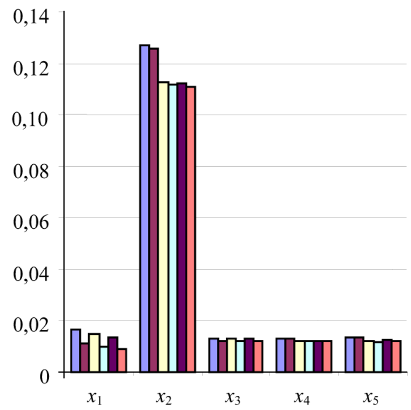
1. Weighted normalised decision-making matrix D is formed (Table 2).
2. The sums of weighted normalised indices describing the j^{th} alternative are calculated.
3. The significances Q_j of the compared alternatives describing the advantages S_{+j} and disadvantages S_{-j} of the alternatives are determined.
4. The utility degree N_j of alternative a_j is calculated.
5. The priority order of the alternatives is determined.

Stage 1. The weighted normalised decision-making matrix D is formed. The purpose of this stage is to receive dimensionless weighted values from the comparative indexes. When the dimensionless values of the indexes are known, all criteria, originally with different dimensions, can be compared.

Table 2. The data obtained in multi-attribute analysis of road design alternatives

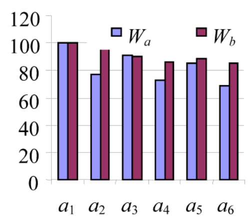
	Weighted normalised values of the described the compared alternatives (matrix D)											
	Weights variant W_a						Weights variant W_b					
	a_1	a_2	a_3	a_4	a_5	a_6	a_1	a_2	a_3	a_4	a_5	a_6
x_1	0,1178	0,0785	0,1060	0,0707	0,0942	0,0628	0,0167	0,0111	0,0150	0,0100	0,0133	0,0088
x_2	0,0213	0,0211	0,0189	0,0187	0,0188	0,0186	0,1269	0,1258	0,1128	0,1116	0,1120	0,1108
x_3	0,0200	0,0191	0,0200	0,0191	0,0201	0,0191	0,0128	0,0122	0,0128	0,0122	0,0128	0,0122
x_4	0,0208	0,0208	0,0189	0,0189	0,0190	0,0190	0,0132	0,0132	0,0121	0,0121	0,0122	0,0122
x_5	0,0212	0,0208	0,0186	0,0182	0,0195	0,0191	0,0135	0,0133	0,0119	0,0116	0,0124	0,0122





	a_1	a_2	a_3	a_4	a_5	a_6	a_1	a_2	a_3	a_4	a_5	a_6
S_{+j}	0,1178	0,0785	0,1060	0,0707	0,0942	0,0628	0,0167	0,0111	0,0150	0,0100	0,0133	0,0089
S_{-j}	0,0833	0,0818	0,0766	0,0750	0,0775	0,0759	0,1665	0,1645	0,1496	0,1475	0,1494	0,1474
Q_j	0,2011	0,1603	0,1826	0,1456	0,1717	0,1387	0,1832	0,1756	0,1646	0,1575	0,1628	0,1563
N_j, %	100	76,70	90,78	72,43	85,37	68,98	100	95,85	89,84	86,00	88,86	85,32
Rank	1	4	2	5	3	6	1	2	3	5	4	6

Utility degree of alternatives



The equation is used as shown below:

$$d_{ij} = \frac{x_{ij} \cdot q_i}{\sum_{j=1}^{n} x_{ij}}, \quad i = \overline{1, m}; \quad j = \overline{1, n}, \tag{1}$$

where x_{ij} is the value of the i criterion in the j alternative of a solution; m – the number of criteria; n – the number of the alternatives compared; q_i – the weight of i criterion.

The sum of dimensionless weighed index values d_{ij} of each criterion x_i is always equal to the weight q_i of this criterion:

$$q_i = \sum_{j=1}^{n} d_{ij}, \quad i = \overline{1, m}; \quad j = \overline{1, n}. \tag{2}$$

Stage 2. The sums of weighted normalised indexes describing the j version are calculated. The versions are described by minimising indexes S_{-j} and maximising indexes S_{+j}. The lower the value of minimising indexes, the better (price, noise level, distance of transportation, duration of construction). The greater the value of maximising indexes, the better (using time). The sums are calculated as follows:

$$S_{+j} = \sum_{i=1}^{m} d_{+ij}; \quad S_{-j} = \sum_{i=1}^{m} d_{-ij}, \quad i = \overline{1, m}; \quad j = \overline{1, n}. \tag{3}$$

In this case, the values S_{+j} (the greater this value, the more satisfied the stakeholders) and S_{-j} (the lower this value, the better is the goal attainment by the stakeholders) express the degree of goals attained by the stakeholders in each alternative project. In any case, the sums of 'pluses' S_{+j} and 'minuses' S_{-j} of all alternative projects are always respectively equal to all sums of the weights of maximising and minimising criteria by

$$S_{+} = \sum_{j=1}^{n} S_{+j} = \sum_{i=1}^{m} \sum_{j=1}^{n} d_{+ij}, \quad S_{-} = \sum_{j=1}^{n} S_{-j} = \sum_{i=1}^{m} \sum_{j=1}^{n} d_{-ij},$$
$$i = \overline{1, m}; \quad j = \overline{1, n}. \tag{4}$$

Stage 3. The significance of comparative alternatives is determined based on description of positive (pluses) and negative (minuses) project characteristics. Relative significance Q of each project a_j is calculated as follows:

$$Q_j = S_{+j} + \frac{S_{-\min} \cdot \sum_{j=1}^{n} S_{-j}}{S_{-j} \cdot \sum_{j=1}^{n} \frac{S_{-\min}}{S_{-j}}}, \quad j = \overline{1, n}. \tag{5}$$

Stage 4. Project priority is determined. The greater is Q_j, the higher the project efficiency. When $Q_1 > Q_3 > Q_5 > Q_2 > Q_4 > Q_6$ (in case of weights W_a), then the first version has the highest priority (Table 2). And when $Q_1 > Q_2 > Q_3 > Q_5 > Q_4 > Q_6$ (in case of weights W_b), then the first version has the highest priority again. The first alternative in all cases of weights is the best alternative.

Significance Q_j of project a_j indicates the degree of satisfaction of demands and goals pursued by the stakeholders. The greater is Q_j, the higher the efficiency of the project. In this case, the significance $Q_{\max}$ of the most rational project will always be the highest. The significance of remaining projects is lower as compared with the most rational one. This means that all demands and goals of stakeholders will be satisfied to a smaller extent than it would be in case of the best project.

The degree of project utility is determined by comparison of the analysed project with the most efficient project. In this case, all the utility degree values related to the analysed project will range from 0 to 100 %. This will facilitate a visual assessment of the project's efficiency.

The equation used for calculating project a_j utility degree N_j is given below:

$$N_j = \frac{Q_j}{Q_{\max}} 100\,\%; \tag{6}$$

where Q_j and $Q_{\max}$ – the significance of the project obtained from Eq (5).

The degree of utility N_j of alternative a_j indicates the level of satisfying the needs of the stakeholders in the project.

Having determined the ratio between the degree of utility and the value of a project, one can see the level of the complex effect achieved by investing money into any of the projects. There is a complete clarity about the better variants of investment and about the efficiency degree of the investment.

The results of the multi-attribute assessment of alternative road designs are in Table 2. From the values, it can be seen that the first version is the best. The utility degree N_1 = 100 %. The second alternative according to its priority in case of W_a was established as the fourth best variant. Its utility degree is N_2 = 76,70 %. The second alternative according to its priority in case of W_b was established as the second best variant. Its utility degree is N_2 = 95,85 %.

The degree of project utility reflects the extent to which the goals of the stakeholders are attained. For example, the significance of the difference between the utility degree of Project 1 (N_1 = 100,00 %) and Project 3 (N_3 = 90,78 %) shows that Project 1 is by 5,98 % more useful than Project 3 (in case W_a).

The results of calculation (Table 2) show that the first variant of the project according to established conditions conformed to purposes and needs of decision makers. The 6 alternative is the worst one considering its utility degree in all cases of attribute weights. The utility degree with W_a is N_6 = 68,98 % and N_6 = 85,32 % with weights W_b. This shows that the first alternative is by 31,02 % more useful than the 6 with W_a, and by 14,68 % with W_b.

4. Conclusions

In order to effectively select a road design, it is necessary to carry out an exhaustive investigation of all possible solutions (alternatives). The efficiency level of a particular road design alternative depends on a large number of factors, including longevity, construction price, environment protection, economic validity, construction duration etc.

The MADM method COPRAS provides an opportunity to select the best alternative of road design taking into account multi-attributes having different measurement units.

The priority (rank) of alternatives depends on attribute weights (on stakeholder priorities) and on values of the selected evaluation attributes.

The selection of a road design alternative by this method allows evaluating different interests of different stakeholder groups.

The research has concluded that the COPRAS method is adequate for complex evaluation of road design alternatives. Applying this method, the best road design alternative – the first alternative – was selected and implemented.

References

1. BARDAUSKIENĖ, D. The expert‘s estimates application in the preparation of city general plan. *Technological and Economic Development of Economy*, 2007, Vol 13, No 3, p. 223–236.
2. VITEIKIENĖ, M. Sustainable residential areas evaluation. *Technological and Economic Development of Economy,* 2006, Vol 12, No. 2, p. 152–160.
3. ZAGORSKAS, J.; TURSKIS, Z. Multi-attribute model for estimation of retail centres influence of the city structure. Kaunas-city case study. *Technological and Economic Development of Economy*, 2006, Vol 12, No 4, p. 347–352.
4. MELNIKAS, B. Urban development and property management in context of societal transformations strategic decision-making. *International Journal of Strategic Property Management*, 2005, Vol 9, No 4, p. 247–268.
5. ŠAPARAUSKAS, J.; TURSKIS, Z. Evaluation of construction sustainability by multiple criteria methods. *Technological and Economic Development of Economy*, 2006, Vol 12, No 4, p. 321–326.
6. TURSKIS, Z.; ZAVADSKAS, E. K; ZAGORSKAS, J. Sustainable city compactness evaluation on the basis of GIS and Bayes rule. *International Journal of Strategic Property Management*, 2006, Vol 10, No 3, p. 185–207.
7. ZAVADSKAS, E. K.; ANTUCHEVIČIENĖ, J. Development of an indicator model and ranking of sustainable revitalization alternatives of derelict property: a Lithuanian case study. *Sustainable Development*, 2006, Vol 14, p. 287–299.
8. VITEIKIENĖ, M.; ZAVADSKAS, E. K. Evaluating the sustainability of Vilnius city residential areas. *Journal of Civil Engineering and Management*, 2007, Vol 13, No 2, p. 149–155.
9. JAKIMAVIČIUS, M.; MAČERINSKIENĖ, A. A GIS-based modelling of vehicles rational routes. *Journal of Civil Engineering and Management*, 2006, Vol 12, No 4, p. 303–309.
10. SU, Ch.-W.; CHENG, M.-Y.; LIN, F.-B. Simulation-enhanced approach for ranking major transport projects. *Journal of Civil Engineering and Managemen*t, 2006, Vol 12, No 4, p. 285–291.
11. UŽPALYTĖ-VITKŪNIENĖ, R. Modelling of Vilnius public transport route network. *Technological and Economic Development of Economy*, 2006, Vol 12, No 4, p. 334–340.
12. LÖBNER B. Determination of the construction time for bridges over railway lines from the public clients' perspective. *Technological and Economic Development of Economy*, 2006, Vol 12, No 3, p. 215–221.
13. THIEL, T. A proposal of defining participant preferences in a decision aiding process with the participant representing a collective body. *Technological and Economic Development of Economy*, 2006, Vol 12, No 3, p. 257–262.
14. UŽPALYTĖ-VITKŪNIENĖ, R.; BURINSKIENĖ, M. Analysis of the dynamics of walking distances to public transport routes and influence on housing prices. *Journal of Civil Engineering and Management*, 2006, Vol 12, No 3, p. 261–267.
15. ZAVADSKAS, E. K.; VILUTIENĖ, T. A multiple criteria evaluation of multi-family apartment block's maintenance contracts: I-Model for maintenance contractor evaluation and determination of its selection criteria. *Building and Environment*, 2006, Vol 41, p. 621–632.
16. ZAVADSKAS, E. K.; KAKLAUSKAS, A.; KAKLAUSKIENĖ, J. Modelling and forecasting of a rational and sustainable development of Vilnius: emphasis on pollution. *International Journal of Environment and Pollution*, 2007, Vol 30, Nos 3/4, p. 485–500.
17. KAKLAUSKAS, A.; ZAVADSKAS, E. K. Decision support system for innovation with special emphasis on pollution. *International Journal of Environment and Pollution*, 2007, Vol 30, Nos 3/4, p. 518–528.
18. HÄÄL, M. L.; SÜRJE, P. Environmental problems related to winter traffic safety conditions. *The Baltic Journal of Road and Bridge Engineering*, 2006, Vol 1, No 1, p. 45–53.
19. RATKEVIČIŪTĖ, K.; ČYGAS, D.; LAURINAVIČIUS, A.; MAČIULIS, A. Analysis and evaluation of the efficiency of road safety measures applied to Lithuanian roads. *The Baltic Journal of Road and Bridge Engineering*, 2007, Vol 2, No 2, p. 81–87.
20. KAPSKI, D.; LEONOVICH, J. Improvement of traffic safety on the basis of forecasting a potential danger in places of conflict situations. *The Baltic Journal of Road and Bridge Engineering*, 2006, Vol 1, No 2, p. 83–92.
21. KAPSKI, D.; LEONOVICH, J.; RATKEVIČIŪTĖ, K. Theoretical principles of forecasting accident rate in the conflict

sections of the cities by the method of potential danger. *The Baltic Journal of Road and Bridge Engineering*, 2007, Vol 2, No 3, p. 133–140.

22. KASHEVSKAYA, E. Bases of quality management of construction and repair of highways. *The Baltic Journal of Road and Bridge Engineering*, 2007, Vol 2, No 3, p. 101–109.
23. LEONOVICH, I.; KASHEVSKAJA, E. Selection of criteria for process monitoring at the operative level of road quality management. *Technological and Economic Development of Economy*, 2007, Vol 13, No 2, p. 144–152.
24. ZIARI, H.; KHABIRI, M. M. Interface condition influence on prediction of flexible pavement life. *Journal of Civil Engineering and Management*, 2007, Vol 13, No 1, p. 71–76.
25. LAURINAVIČIUS, A.; OGINSKAS, R. Experimental research on the development of rutting in asphalt concrete pavements reinforced with geosynthetic materials. *Journal of Civil Engineering and Management*, 2006, Vol 12, No 4, p. 311–317.
26. PETKEVIČIUS, E.; PETKEVIČIUS, R.; BABICKAS, R. Investigation of asphalt concrete pavement quality of Lithuanian highways. *The Baltic Journal of Road and Bridge Engineering*, 2006, Vol 1, No 2, p. 71–76.
27. RADZISZEWSKI, B. Modified asphalt mixtures resistance to permanent deformations. *Journal of Civil Engineering and Management*, 2007, Vol 13, No 4, p. 307–315.
28. CHANG, J.-R.; CHEN, D.-H.; Hung, Ch.-T. Selecting preventive maintenance treatments in Texas. Using the technique for order preference by similarity to the ideal solution for specific pavement Study-3 sites. *Transportation Research Record. Journal of the Transportation Research Board*, 2005, No 1933, p. 62–71.
29. ZIARI, H.; AMERI, M.; KHABIRI, M. M. Resilient behaviour of hot mixed and crack sealed asphalt concrete under repeated leading. *Technological and Economic Development of Economy*, 2007, Vol 13, No 1, p. 56–60.
30. KAMAITIS, Z. Structural design of polymer protective coatings for reinforced concrete structures, Part 1: theoretical consideration. *Journal of Civil Engineering and Management*, 2007, Vol 13, No 1, p. 11–17.
31. KAMAITIS, Z. Structural design of polymer protective coatings for reinforced concrete structures. Part II: experimental verification. *Journal of Civil Engineering and Management*, 2007, Vol 13, No 1, p. 19–26.
32. WITZANY, J.; ZIGLER, R. The analysis of non-stress effects on historical stone bridge structures (monitoring, theoretical analysis, maintenance). *Journal of Civil Engineering and Management*, 2007, Vol 13, No 2, p. 157–167.
33. WITZANY, J.; CEJKA, T. Reliability and failure resistance of the stone bridge structure of Charles Bridge during floods. *Journal of Civil Engineering and Management*, 2007, Vol 13, No 3, p. 227–236.
34. MARZOUK, M.; ZEIN EL-DEIN, H.; EL-SAID, M. Application of computer simulation to construction of incremental launching bridges. *Journal of Civil Engineering and Management*, 2007, Vol 13, No 1, p. 27–36.
35. FRANGOPOL, D. M.; LIU, M. Maintenance and management of civil infrastructure based on condition, safety, optimization and life-cycle cost. *Structure and Infrastructure Engineering*, 2007, Vol 3, No 1, p. 29–41.
36. MIYAMOTO, A.; KONNO, M.; NAKAMURA, H.; BRUHWILER, E. Maintenance plan optimization system for existing concrete bridge groups. *Structure and Infrastructure Engineering*, 2006, Vol 2, No 2, p. 91–115.
37. VAIDOGAS, E. R. Actions imposed on structures during man-made accident: predication via simulation-based uncertainty propagation. *Journal of Civil Engineering and Management*, 2005, Vol 11, No 3, p. 225–242.
38. VAIDOGAS, E. R.; JUOCEVIČIUS, V. Assessing external threats to structures using limited statistical data: an approach based on data resampling. *Technological and Economic Development of Economy*, 2007, Vol 13, No 2, p. 170–175.
39. MARCINKOWSKA, E.; REJMENT, M. Effect risk on economic efficiency of overcladding system. *Journal of Civil Engineering and Management*, 2006, Vol 12, No 3, p. 247–253.
40. WANG, Y. M; ELHAG, T. M. S. Fuzzy TOPSIS method based on alpha level sets with an application to bridge risk assessment. *Expert Systems with Applications*, 2006, Vol 31, No 2, p. 309–319.
41. PELDSCHUS, F. Multiple-criteria analysis in the construction of motorways. *Technological and Economic Development of Economy*, 2005, Vol 11, No 1, p. 32–35.
42. USTINOVICHIUS, L.; ZAVADSKAS, E. K.; PODVEZKO, V. Application of a quantitative multiple criteria decision making (MCDM-1) approach to the analysis of investments in construction. *Control and Cybernetics*, 2007, Vol 36, No 1, p. 251–268.
43. ZAVADSKAS, E. K.; KAKLAUSKAS, A.; ŠARKA, V. The new method of multicriteria complex proportional assessment of projects. *Technological and Economic Development of Economy*, 1994, Vol 1, No 3, p. 131–139.
44. KAKLAUSKAS, A.; ZAVADSKAS, E. K.; BANAITIS, A.; ŠATKAUSKAS, G. Defining the utility and market value of real estate a multiple criteria approach. *International Journal of Strategic Property Management*, 2007, Vol 11, No 2, p. 107–120.
45. KALIBATAS, D.; KRUTINIS, M.; VITEIKIENĖ, M. Multiobjective evaluation of microclimate in dwelling. *Technological and Economic Development of Economy*, 2007, Vol 13, No 1, p. 24–31.
46. MALINAUSKAS, P.; KALIBATAS, D. The selection of rational constructional technology processes variants using COPRAS method. *Technological and Economic Development of Economy*, 2005, Vol 11, No 3, p. 197–205.
47. KAKLAUSKAS, A.; GULBINAS, A. Knowledge based decision support system for building refurbishment. *Technological and Economic Development of Economy*, 2005, Vol 11, No 3, p. 176–182.
48. ANTUCHEVIČIENĖ, J. Evaluation of alternatives applying TOPSIS method in a fuzzy environment. *Technological and Economic Development of Economy*, 2005, Vol 11, No 4, p. 242–247.

49. KAPLIŃSKI, O.; JANUSZ, L. Three phases of multifactor modelling of construction processes. *Journal of Civil Engineering and Management*, 2006, Vol 12, No 2, p. 127–134.

50. ANTUCHEVIČIENĖ, J.; TURSKIS, Z.; ZAVADSKAS, E. K. Modelling renewal of construction objects applying methods of the game theory. *Technological and Economic Development of Economy*, 2006, Vol 12, No 4, p. 263–268.

51. NOWAK, M. Investment projects evaluation by simulation and multiple criteria decision aiding procedure. *Journal of Civil Engineering and Management*, 2005, Vol 11, No 3, p. 193–202.

52. PELDSCHUS, F.; ZAVADSKAS, E. K. Fuzzy matrix games multi-criteria model for decision-making in engineering. *Informatica*, 2005, Vol 16, No 1, p. 107–120.

53. PERNG, Y.-H., HSUEH, S.-L.; YAN, M.-R. Evaluation of housing construction strategies in China using fuzzy-logic system. *International Journal of Strategic Property Management*, 2005, Vol 9, No 4, p. 215–232.

54. USTINOVIČIUS, L.; ANDRUŠKEVIČIUS, A.; KUTUT, V.; BALCEVIČ, R.; BARVIDAS, A. Verbal analysis of contracts of engineering and design of buildings. *Technological and Economic Development of Economy*, 2005, Vol 11, No 1, p. 36–49.

55. ZAVADSKAS, E. K.; ANTUCHEVIČIENĖ, J. Multiple criteria evaluation of rural building's regeneration alternatives. *Building and Environment*, 2007, Vol 42, Issue 1, p. 436–451

56. ZAVADSKAS, E. K.; ZAKAREVICIUS, A.; ANTUCHEVIČIENĖ, J. Evaluation of ranking accuracy in multi-criteria decisions. *Informatica*, 2006, Vol 17, No 4, p. 601–618.

57. ZAVADSKAS, E. K.; USTINOVIČIUS, L.; TURSKIS, Z.; AMBRASAS, G.; KUTUT, V. Estimation of external walls decisions of multistorey residential buildings applying methods of multicriteria analysis. *Technological and Economic Development of Economy*, 2005, Vol 11, No 1, p. 59–68.

58. ŽIOGAS, V.; JUOČIŪNAS, S. Design and installation peculiarities of monolithic concrete floor. *Journal of Civil Engineering and Management*, 2005, Vol 11, No 2, p. 153–162.

59. SCHABOVICZ, K.; HOLA, B. Mathematical-neural model for assessing productivity of earthmoving machinery. *Journal of Civil Engineering and Management*, 2007, Vol 13, No 1, p. 47–54.

60. ROGALSKA, M.; HEJDUCKI, Z. Time buffers in construction process scheduling. *Journal of Civil Engineering and Management*, 2007, Vol 13, No 2, p. 143–148.

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