TECHNOLOGICAL AND ECONOMIC DEVELOPMENT OF ECONOMY
Baltic Journal on Sustainability
2010
16(2): 159–172

A NEW ADDITIVE RATIO ASSESSMENT (ARAS) METHOD IN MULTICRITERIA DECISION-MAKING

Edmundas Kazimieras Zavadskas[1], Zenonas Turskis[2]

Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius, Lithuania
E-mail: [1]edmundas.zavadskas@vgtu.lt; [2]zenonas.turskis@vgtu.lt

Received 11 January 2010; accepted 27 April 2010

Abstract. Multicriteria decision-making (MCDM) methods are used in many areas of human activities. Each alternative in a multicriteria decision-making problem can be described by a set of criteria. Criteria can be qualitative and quantitative. They usually have different units of measurement and a different optimization direction. The normalization aims at obtaining comparable scales of criteria values. The paper introduces a new ***A****dditive* ***R****atio* ***AS****sessment* (ARAS) method. In order to illustrate the described ARAS method a real case study of evaluation of microclimate in office rooms is presented. The case study aims to determine the inside climate of the premises, where people work, and to define measures to be taken to improve their environment. Based on the analysis, the following criteria for inside climate evaluation are suggested: air turnover inside the premises, air humidity, air temperature, illumination intensity, air flow rate, and dew point. The criteria weights were determined by the method of pairwise comparison based on the estimates of experts.

Keywords: MCDM, decision-making, alternative, ARAS, weights.

Reference to this paper should be made as follows: Zavadskas, E. K.; Turskis, Z. 2010. A new additive ratio assessment (ARAS) method in multicriteria decision-making, *Technological and Economic Development of Economy* 16(2): 159–172.

1. Introduction

Real-world decision-making problems are usually too complex and unstructured to be considered through the examination of a single criterion, or point of view that will lead to an optimum decision. Operating in the marketplace requires some knowledge of areas generating critical situations and insolvency. It is necessary to learn about criteria determining both development and downfall of feasible alternatives (Kapliński 2008a). In a monocriterion approach, the analyst builds a unique criterion capturing all the relevant aspects of the problem. Such a one-dimensional approach is an oversimplification of the actual nature of

ISSN 1392-8619 print/ISSN 1822-3613 online doi: 10.3846/tede.2010.10
http://www.tede.vgtu.lt

the problem. In many real-world decision problems, a decision-maker has a set of multiple conflicting objectives. All new ideas and possible variants of decisions must be compared according to many criteria (Turskis *et al.* 2009). The problem of a decision-maker consists of evaluating a finite set of alternatives in order to find the best one, to rank them from the best to the worst, to group them into predefined homogeneous classes, or to describe how well each alternative meets all the criteria simultaneously. There are many methods for determining the ranking of a set of alternatives in terms of a set of decision criteria. In a multicriteria approach, the analyst seeks to build several criteria using several points of view. MCDM is one of the most widely used decision methodologies in science, business, and governments, which are based on the assumption of a complex world, and can help to improve the quality of decisions by making the decision-making process more explicit, rational, and efficient. In real life, a decision-maker first of all must understand and describe the situation. This stage includes the determination and assessment of the stakeholders, different alternatives of feasible actions, a large number of different and important decision criteria, the type and quality of information, etc. It appears to be the key point defining MCDM as a formal approach. For Zeleny (1982), decision criteria are rules, measures and standards that guide decision-making. Bouyssou (1990) proposed a general definition of a criterion as a tool allowing comparison of alternatives according to a particular point of view. When building a criterion, the analyst should keep in mind that it is necessary that all the actors of the decision process adhere to the comparisons that will be deduced from that model. Criteria (relatively precise, but usually conflicting) are measures, rules and standards that guide decision-making, which also incorporates a model of preferences between the elements of a set of real or fictitious actions. Typical examples of MCDM problems are referred to as discrete MCDM problems, involve the selection among different investment projects, personnel ranking problem, and financial classification problem, and are decision-support oriented. The major strength of multicriteria methods is their ability to address problems marked by various conflicting interests. An overview of widely used MCDM methods is given by Figueira *et al.* (2005).

Classical methods of multicriteria optimization and determination of priority and utility function were first applied by Pareto in 1896 (Pareto 1971). These methods were strongly related to economic theory, concerning the averages of thousands of decisions. Methods of multicriteria analysis were developed to meet the increasing requirements of human society and the environment. Keeney and Raiffa (1976) offered the representation theorems for determining multicriteria utility functions under preferential and utility independence assumptions. Saaty (1977) showed the global importance of solving problems with conflicting goals by using multicriteria models and presented decision-making models with incomplete information. Keeney (1982) outlined the essential features and concepts of decision analysis, formulated axioms and major stages. Keeney and Winterfeldt (2001) suggested following the prudence principle in the decision process, making decisions precisely and evaluating all possible alternatives, the aims of interested parties, subsequences of decision results and value changes, hereby minimizing the decision-making risk.

The available wide range of MCDM problem solution techniques, varying in complexity and possible solutions, confuses potential users. Each method has its own strength, weaknesses and possibilities to be applied. This causes phenomenon known as the inconsistent problem ranking caused by different MCDM methods. A major criticism of MCDM methods is that due to the differences among different techniques, different results are obtained when applied to the same problem. These differences of algorithms are:

- different use of weights;
- different selecting of the best solution;
- attempting to scale the objectives;
- introducing additional parameters that affect solution.

MCDM research in civil engineering and management is dominating in the Lithuanian-German-Polish triangle (Vilnius Gediminas Technical University, Poznan University of Technology, and Leipzig University of Applied Science). There are lots of even sophisticated issues investigated in collaboration with specialists representing other domains of science (e.g. mathematicians) (Kapliński 2008b). Techniques and planning methods and decision-making methods develop dynamically (Kapliński 2008c; Peldschus 2008; Ginevičius and Podvezko 2008..., a, b; Zavadskas *et al.* 2008c; Ustinovichius *et al.* 2007; Plebankiewicz 2009; Ulubeyli and Kazaz 2009; Jakimavicius and Burinskiene 2009; Šijanec Zavrl *et al.* 2009; Sobotka and Rolak 2009; Selih *et al.* 2008; Liaudanskiene *et al.* 2009).

The need of comparing MCDM methods and the importance of the selection problem were first recognized by MacCrimmon who suggested taxonomy of MCDM methods. There are many comparative studies presented in scientific research works. Guitoni and Martel (1998) proposed a methodological approach to select an appropriate MCDM method for a specific decision-making situation. The selection may be done via comparing MCDM methods (Zanakis *et al.* 1998). A simulation by Zanakis *et al.* (1998) evaluated eight MCDM methods: SAW, multiplicative exponential weighting (MEW); ELECTRE, and AHPs: SAW and MEW performed best. Computations of different examples reveal the fact that evaluation outcome depends on both choice of utility function and its parameters (Podvezko and Podviezko 2010).

There are many ways to classify MCDM methods (Hwang and Yoon 1981; Larichev 2000; Figueira *et al.* 2005). The classification of MCDM methods according to the type of information based on the Larichev's (Larichev 2000) proposal is given bellow:

- Methods based on quantitative measurements. The methods based on multicriteria utility theory may be referred to this group (TOPSIS – *Technique for Order Preference by Similarity to Ideal Solution* (Hwang and Yoon 1981; Arditi and Günaydın 1998), SAW – *Simple Additive Weighting* (MacCrimon 1968), LINMAP – *Linear Programming Techniques for Multidimensional Analysis of Preference* (Srinivasan and Shocker 1973), MOORA – *Multi-Objective Optimization by Ratio Analysis Method* (Brauers and Zavadskas 2006), COPRAS – *Complex Proportional ASsessment* (Zavadskas and Kaklauskas 1996; Zavadskas *et al.* 2007, 2009a) and its modification COPRAS-G (*Complex Proportional ASsessment method with Grey interval numbers*) (Zavadskas *et al.* 2008a, b; 2009b, 2010)).
- Methods based on qualitative initial measurements. These include two widely known groups of methods, i.e. *Analytic Hierarchy Methods* (AHP) (Saaty 1977, 1994) and fuzzy set theory methods (Zimmermann 2000).

- Comparative preference methods based on pairwise comparison of alternatives. This group comprises the modifications of the ELECTRE (Roy 1990, 1996), PROMETHEE (Brans *et al.* 1984), TACTIC (Vansnick 1986), ORESTE (Roubens 1982) and other methods.
- Methods based on qualitative measurements not converted to quantitative variables. This group includes methods of verbal decision-making analysis (Berkeley *et al.* 1991; Larichev 2000; Flanders *et al.* 1998) and uses qualitative data for decision environments involving high levels of uncertainty.

MCDM problems can be categorized as continuous or discrete, depending on the domain of alternatives. Hwang and Yoon (1981) classify them as:

- MCDM with discrete, usually limited, number of alternatives, requiring criterion comparisons, involving implicit or explicit tradeoffs; and
- MODM (multiple objective decision-making) with decision variable values to be determined in a continuous or integer domain, of infinite on a large number of choices, to satisfy best the decision-maker constraints, preferences or priorities.

In particular, the main steps of multicriteria decision-making are the following:

- determining the main goal of a problem;
- establishing a system of the main objectives or criteria by which the alternatives are to be judged;
- generating feasible alternatives (a finite number of alternative plans or options) that can be implemented to achieve goals;
- evaluating an impact of each criterion on the decision-making function or weights of criteria. A decision-maker should express his/her preferences in terms of the relative importance of criteria, and one approach is to introduce criteria weights. These weights in MCDM do not have a clear economic significance (Opricovic and Tzeng 2004), but their use provides opportunity to model the actual aspects of the preference structure:
  - a set of performance evaluations of alternatives for each criterion;
  - a method for ranking the alternatives based on how well they satisfy the criteria;
  - aggregating alternative evaluations (preferences);
  - accepting one alternative as the best (the most preferable);
  - gathering new information and the next iteration of MCDM if the final solution is not accepted;
  - making recommendations for decision-making.

An alternative in multicriteria evaluation is usually described by quantitative and qualitative criteria. The criteria have different units of measurement. Normalization aims at obtaining comparable scales of the criteria values. Different techniques of criteria value normalization are used. The impact of the decision-matrix normalization methods on the decision results has been investigated by many authors (Jüttler 1966; Körth 1969; Stopp 1975; Weitendorf 1976; Zavadskas 1987; Hovanov 1996; Cloquell and Santamarina 2001; Peldschus 2007, 2009; Ginevicius and Podvezko 2007; Ginevičius 2008; Noorul Haq and Kannan 2007; Brauers *et al.*

2007; Brauers *et al.* 2008; Brauers 2007a, b). There are still no rules determining the application of multicriteria evaluation methods and interpretation of the results obtained.

2. A new *Additive Ratio Assessment* (ARAS) method in multicriteria decision-making

The typical MCDM problem is concerned with the task of ranking a finite number of decision alternatives, each of which is explicitly described in terms of different decision criteria which have to be taken into account simultaneously. According to the ARAS method, a utility function value determining the complex relative efficiency of a feasible alternative is directly proportional to the relative effect of values and weights of the main criteria considered in a project.

The first stage is decision-making matrix (DMM) forming. In the MCDM of the discrete optimization problem any problem to be solved is represented by the following DMM of preferences for m feasible alternatives (rows) rated on n signfull criteria (columns):

$$X = \begin{bmatrix} x_{01} & \cdots & x_{0j} & \cdots & x_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix}; \quad i = \overline{0, m}; \; j = \overline{1, n}, \tag{1}$$

where m – number of alternatives, n – number of criteria describing each alternative, x_{ij} – value represening the performance value of the i alternative in terms of the j criterion, x_{0j} – optimal value of j criterion.

If optimal value of j criterion is uncknown, then

$$\begin{aligned} x_{0j} &= \max_i x_{ij}, \mathit{if} \max_i x_{ij} \; \mathit{is\ preferable}; \\ x_{0j} &= \min_i x_{ij}^*, \mathit{if} \min_i x_{ij}^* \; \mathit{is\ preferable}. \end{aligned} \tag{2}$$

Usually, the performance values x_{ij} and the criteria weights w_j are viewed as the entries of a DMM. The system of criteria as well as the values and initial weights of criteria are determined by experts. The information can be corrected by the interested parties by taking into account their goals and opportunities.

Then the determination of the priorities of alternatives is carried out in several stages.

Usually, the criteria have different dimensions. The purpose of the next stage is to receive dimensionless weighted values from the comparative criteria. In order to avoid the difficulties caused by different dimensions of the criteria, the ratio to the optimal value is used. There are various theories describing the ratio to the optimal value. However, the values are mapped either on the interval [0; 1] or the interval [0; ∞] by applying the normalization of a DMM.

In the second stage the initial values of all the criteria are normalized – defining values $\bar{x}_{ij}$ of normalised decision-making matrix $\bar{X}$.

$$\bar{X} = \begin{bmatrix} \bar{x}_{01} & \cdots & \bar{x}_{0j} & \cdots & \bar{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{i1} & \cdots & \bar{x}_{ij} & \cdots & \bar{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{m1} & \cdots & \bar{x}_{mj} & \cdots & \bar{x}_{mn} \end{bmatrix}; \quad i = \overline{0, m}; \; j = \overline{1, n}. \tag{3}$$

The criteria, whose preferable values are maxima, are normalized as follows:

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}}. \tag{4}$$

The criteria, whose preferable values are minima, are normalized by applying two-stage procedure:

$$x_{ij} = \frac{1}{x_{ij}^{*}}; \; \bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}}. \tag{5}$$

When the dimensionless values of the criteria are known, all the criteria, originally having different dimensions, can be compared.

The third stage is defining normalized-weighted matrix – $\hat{X}$. It is possible to evaluate the criteria with weights $0 < w_j < 1$. Only well-founded weights should be used because weights are always subjective and influence the solution. The values of weight w_j are usually determined by the expert evaluation method. The sum of weights w_j would be limited as follows:

$$\sum_{j=1}^{n} w_j = 1. \tag{6}$$

$$\hat{X} = \begin{bmatrix} \hat{x}_{01} & \cdots & \hat{x}_{0j} & \cdots & \hat{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{i1} & \cdots & \hat{x}_{ij} & \cdots & \hat{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{m1} & \cdots & \hat{x}_{mj} & \cdots & \hat{x}_{mn} \end{bmatrix}; \quad i = \overline{0, m}; \; j = \overline{1, n}. \tag{7}$$

Normalized-weighted values of all the criteria are calculated as follows:

$$\hat{x}_{ij} = \bar{x}_{ij} w_j; \; i = \overline{0, m}, \tag{8}$$

where w_j is the weight (importance) of the j criterion and $\bar{x}_{ij}$ is the normalized rating of the j criterion.

The following task is determining values of optimality function:

$$S_i = \sum_{j=1}^{n} \hat{x}_{ij}; \; i = \overline{0, m}, \tag{9}$$

where S_i is the value of optimality function of i alternative.

The bigest value is the best, and the least one is the worst. Taking into account the calculation process, the optimality function S_i has a direct and proportional relationship with the values x_{ij} and weights w_j of the investigated criteria and their relative influence on the final result. Therefore, the greater the value of the optimality function S_i, the more effective the alternative. The priorities of alternatives can be determined according to the value S_i. Consequently, it is convenient to evaluate and rank decision alternatives when this method is used.

The degree of the alternative utility is determined by a comparison of the variant, which is analysed, with the ideally best one S_0. The equation used for the calculation of the utility degree K_i of an alternative a_i is given below:

$$K_i = \frac{S_i}{S_0};\ i = \overline{0,\ m}, \tag{10}$$

where S_i and S_0 are the optimality criterion values, obtained from Eq. (9).

It is clear, that the calculated values K_i are in the interval [0, 1] and can be ordered in an increasing sequence, which is the wanted order of precedence. The complex relative efficiency of the feasible alternative can be determined according to the utility function values.

3. Case study: evaluation of microclimate in office rooms

In order to test the described ARAS method the case study will be considered. The development of construction technologies and building mterials, growing demands of citizens raises the problem to evaluate the inside climate of a building as a final product. Newly-built or existing houses are evaluated taking into account only their price, maintenance costs, space, location, ignoring such parameters as inside climate, which largely determines how healthy and able-bodied the residents will be (Kalibatas and Turskis 2008). Inside climate should be taken into account in real estate valuation because some data obtained in the research reveal significant drawbacks and defects of buildings, thereby helping to avoid the potential expenses in the case of purchasing low-quality real property.

An ordinary customer making a decision about purchasing or renting a real estate unit cannot get generalized data on the inside climate of the premises because he lacks the respective qualification, knowledge and time required to carry out a study, formalize and generalize the data, etc. This is the work of highly qualified specialists. The graphs of the inside climate are provided with estate valuation because some data obtained in the study reveal significant drawbacks and defects of buildings, thereby helping to avoid the potential losses which he/she could suffer trying to restore it.

One commercial firm asked to evaluate microclimate in an office. The study aimed to determine the inside climate of the premises, where people work, and to define measures to be taken to improve their environment. The study was performed in December 2009 on the sixth story of an office house in Vilnius.

Based on the analysis, the following criteria for inside climate evaluation are suggested:

- air turnover of the premises – x_1, optimal $x_{01} \geq 15$ m^3/h;
- air humidity – x_2, $x_{i2} \geq 0$; optimal $x_{02} = 50\%$;

- air temperature – x_3, $x_{i3} \geq 0$. The most comfortable temperature is in the range 24–25 °C. The investigated values are in the range 16–22 °C. On this basis it can be stated that the maximal investigated value is the most preferable, and, with a small error, it can be assumed that it is a linear function;
- illumination intensity – x_4;
- air flow rate – x_5; $x_{i5} \leq 0.05$ m^3/h;
- dew point – x_6.

The criteria weights were determined by the method of pairwise comparison based on the estimates of 38 experts. The obtained weight vector of criteria *w* is presented in Table 1.

The required measurements in the rooms were made by using equipment having a calibration certificate.

The data of measurement are presented in Table 1 (initial decision-making matrix *X*), Table 2 represents the normalized values of measurement in rooms (normalized decision-

Table 1. Measurement results in rooms (initial decision-making matrix *X*)

Room No.	**Criteria**					
	The amount of air per head	**Relative air humidity**	**Air temperature**	**Illumination during work hours (8÷17)**	**Rate of air flow**	**Dew point**
	x_1	x_2	x_3	x_4	x_5^*	x_6^*
Measurement units	m^3/h	%	°C	lx	m/s	°C
Optimisation direction	max	max	max	max	min	min
Weight of criteria – *w*	0.21	0.16	0.26	0.17	0.12	0.08
0 – Optimal value	15	50	24.5	400	0.05	5
1	7.6	46	18	390	0.1	11
2	5.5	32	21	360	0.05	11
3	5.3	32	21	290	0.05	11
4	5.7	37	19	270	0.05	9
5	4.2	38	19	240	0.1	8
6	4.4	38	19	260	0.1	8
7	3.9	42	16	270	0.1	5
8	7.9	44	20	400	0.05	6
9	8.1	44	20	380	0.05	6
10	4.5	46	18	320	0.1	7
11	5.7	48	20	320	0.05	11
12	5.2	48	20	310	0.05	11
13	7.1	49	19	280	0.1	12
14	6.9	50	16	250	0.05	10

making matrix $\bar{X}$), and Table 3 shows the weighted-normalized values of measurement in rooms (weighted-normalized decision-making matrix $\hat{X}$) and solution results using the ARAS method.

Table 2. Normalised values of measurement in rooms (normalized decision-making matrix $\bar{X}$)

	$\bar{x}_1$	$\bar{x}_2$	$\bar{x}_3$	$\bar{x}_4$	$\bar{x}_5$	$\bar{x}_6$
w	0.21	0.16	0.26	0.17	0.12	0.08
0	0.1546	0.0776	0.0843	0.0846	0.0833	0.1067
1	0.0784	0.0714	0.0620	0.0825	0.0417	0.0485
2	0.0567	0.0497	0.0723	0.0761	0.0833	0.0485
3	0.0546	0.0497	0.0723	0.0613	0.0833	0.0485
4	0.0588	0.0575	0.0654	0.0571	0.0833	0.0593
5	0.0433	0.0590	0.0654	0.0507	0.0417	0.0667
6	0.0454	0.0590	0.0654	0.0550	0.0417	0.0667
7	0.0402	0.0652	0.0551	0.0571	0.0417	0.1067
8	0.0814	0.0683	0.0688	0.0825	0.0833	0.0889
9	0.0835	0.0683	0.0688	0.0803	0.0833	0.0889
10	0.0464	0.0714	0.0620	0.0677	0.0417	0.0762
11	0.0588	0.0745	0.0688	0.0677	0.0833	0.0485
12	0.0536	0.0745	0.0688	0.0655	0.0833	0.0485
13	0.0732	0.0761	0.0654	0.0592	0.0417	0.0444
14	0.0711	0.0776	0.0551	0.0529	0.0833	0.0533

Table 3. Weighted-normalized values of measurement in rooms (weighted-normalized decision-making matrix $\hat{X}$) and solution results

	$\hat{x}_1$	$\hat{x}_2$	$\hat{x}_3$	$\hat{x}_4$	$\hat{x}_5$	$\hat{x}_6$	S	K	**Rank of the room**
0	0.0325	0.0124	0.0219	0.0144	0.0100	0.0085	0.0997	1.0000	
1	0.0165	0.0114	0.0161	0.0140	0.0050	0.0039	0.0669	0.6707	4
2	0.0119	0.0080	0.0188	0.0129	0.0100	0.0039	0.0655	0.6564	6
3	0.0115	0.0080	0.0188	0.0104	0.0100	0.0039	0.0625	0.6269	10
4	0.0123	0.0092	0.0170	0.0097	0.0100	0.0047	0.0630	0.6315	9
5	0.0091	0.0094	0.0170	0.0086	0.0050	0.0053	0.0545	0.5464	14
6	0.0095	0.0094	0.0170	0.0093	0.0050	0.0053	0.0556	0.5580	13
7	0.0084	0.0104	0.0143	0.0097	0.0050	0.0085	0.0564	0.5659	12
8	0.0171	0.0109	0.0179	0.0140	0.0100	0.0071	0.0771	0.7727	2
9	0.0175	0.0109	0.0179	0.0137	0.0100	0.0071	0.0771	0.7734	1
10	0.0097	0.0114	0.0161	0.0115	0.0050	0.0061	0.0599	0.6004	11
11	0.0123	0.0119	0.0179	0.0115	0.0100	0.0039	0.0675	0.6773	3
12	0.0113	0.0119	0.0179	0.0111	0.0100	0.0039	0.0661	0.6628	5
13	0.0154	0.0122	0.0170	0.0101	0.0050	0.0036	0.0632	0.6334	8
14	0.0149	0.0124	0.0143	0.0090	0.0100	0.0043	0.0649	0.6511	7

Acoording to the given data on the criteria describing the inside climate, rational solutions about its improvement and maintenance cost reduction can be made. The studies performed help to identify the inside climate parameters of the workplace, which do not meet specifications. The data obtained can also be used for developing and implementing measures aimed at maintaining favourable inside climate at workplaces.

The results obtained (quality ratio with an optimal office room alternative according to its rank) represent inside climate characteristics with some error.

The study of the inside climate in office rooms and a comparative analysis of the obtained data with the values provided by the hygienic norms allowed us to state that most of the investigated parameters do not meet the current specifications. Forced ventilation should be installed in these working rooms to ensure the required rate of air turnover.

The priority order of the investigated rooms can be represented as:

$v_9 \succ v_8 \succ v_{11} \succ v_1 \succ v_{12} \succ v_2 \succ v_{14} \succ v_{13} \succ v_4 \succ v_3 \succ v_{10} \succ v_7 \succ v_6 \succ v_5$. It means that the best microclimate is in room 9, and the worst microclimate is in room 5. It can be stated that in room 9 the microclimate makes only 77 percent of optimally balanced microclimate, and in the worst room the ratio with an optimally balanced microclimate is only of 55 percent.

4. Conclusions

It is hardly possible to evaluate the effect of various methods of a problem solution.

According to the newly-proposed ARAS method, the utility function value determining the complex efficiency of a feasible alternative is directly proportional to the relative effect of values and weights of the main criteria considered in a project.

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 method is used.

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

It can be stated that the ratio with an optimal alternative may be used when seeking to rank alternatives and find ways of improving alternative projects.

References

Arditi, D.; Günaydın, H. M. 1998. Perceptions of process quality in building projects, *Journal of Management in Engineering – ASCE* 15(2): 43–53. doi:10.1061/(ASCE)0742-597X(1999)15:2(43)

Berkeley, D.; Humphreys, P.; Larichev, O.; Moshkovich, H. 1991. Aiding strategic decision making: Derivation and development of ASTRIDA, in Vecsenyi, Y. and Sol, H. (Eds.). *Environment for Supporting Decision Processes*. North-Holland, Amsterdam.

Bouysou, D. 1990. Building criteria: A perquisite for MCDA, in Bana a Costa, C. A. (Ed.). *Readings in Multiple Criteria Decision Aid.* Berlin: Springer-Verlag, 319–334.

Brans, J. P.; Mareschal, B.; Vincke, P. 1984. PROMETHEE: anew family of outranking methods in multicriteria analysis, in Brans, J. P. (Ed.). *IFORS 84.* North Holland, Amsterdam, 477–490.

Brauers, W. K. 2007a. What is meant by normalization in decision making? *International Journal of Management and Decision Making* 8(5–6): 445–460. doi:10.1504/IJMDM.2007.013411

Brauers, W. K. 2007b. Normalisation in multiobjective optimization: a general overview, *International Journal of Management and Decision Making* 8(5–6): 461–474. doi:10.1504/IJMDM.2007.013412

Brauers, W. K. M.; Ginevicius, R.; Zavadskas, E. K.; Antucheviciene, J. 2007. The European Union in a transition economy, *Transformations in Business and Economics* 6(2): 21–37.

Brauers, W. K. M.; Zavadskas, E. K.; Peldschus, F.; Turskis, Z. 2008. Multi-objective decision-making for road design, *Transport* 23(3): 183–193. doi:10.3846/1648-4142.2008.23.183-193

Brauers, W. K. M.; Zavadskas, E. K. 2006. The MOORA method and its application to privatization in a transition economy, *Control and Cybernetics* 35(2): 443–468.

Cloquell, V. A.; Santamarina, C. 2001. A new Procedure for the Numerical Values Normalization in Multicriteria Decision Techniques, in *MCDA 54th meeting in Durbuy,* Valencia: Universidad Politécnica de Valencia, 1–10.

Figueira, J.; Greco, S.; Ehrgott, M. (Eds.). 2005. *Multiple Criteria Decision Analysis: State of the Art Surveys*. Springer.

Flanders, N. E.; Brown, R. V.; Andre'eva, Y.; Larichev, O. 1998. Justifying public decisions in Arctic oil and gas development: American and Russian approaches, *Arctic* 51(3): 262–279.

Ginevičius, R. 2008. Normalization of quantities of various dimensions, *Journal of Business Economics and Management* 9(1): 79–86. doi:10.3846/1611-1699.2008.9.79-86

Ginevičius, R.; Podvezko, V. 2008a. Multicriteria evaluation of Lithuanian banks from the perspective of their reliability for clients, *Journal of Business Economics and Management* 9(4): 257–267. doi:10.3846/1611-1699.2008.9.257-267

Ginevicius, R.; Podvezko, V.; Raslanas, S. 2008b. Evaluating the alternative solutions of wall insulation by multicriteria methods, *Journal of Civil Engineering and Management* 14(4): 217–226. doi:10.3846/1392-3730.2008.14.20

Ginevicius, R.; Podvezko, V. 2007. Some problems of evaluating multicriteria decision methods, *International Journal of Management and Decision Making* 8(5–6): 527–539. doi:10.1504/IJMDM.2007.013415

Guitoni, A.; Martel, J. M. 1998. Tentative guidelines to help choosing an appropriate MCDA method, *European Journal of Operational Research* 109: 501–521. doi:10.1016/S0377-2217(98)00073-3

Hovanov, N. 1996. *Analysis and Synthesis of Parameters under Information Deficiency*. St. Petersburg: St. Petersburg University Press.

Hwang, C. L.; Yoon, K. 1981. *Multiple attribute decision making, Lecture Notes in Economics and Mathematical Systems 186*. Springer-Verlag, Berlin.

Jakimavicius, M.; Burinskiene, M. 2009. Assessment of Vilnius city development scenarios based on transport system modelling and multicriteria analysis, *Journal of Civil Engineering and Management* 15(4): 361–368. doi:10.3846/1392-3730.2009.15.361-368

Jüttler, H. 1966. *Untersuchungen zur Fragen der Operations Aforschung und ihrer Anwendungsmöglichkeiten auf ökonomische Problemstellungen unter besonderer Berücksichtigung der Spieltheorie*: Dissertation A an der Wirtschaftswissenschaftlichen Fakultät der Humboldt-Universität, Berlin.

Kalibatas, D.; Turskis, Z. 2008. Multicriteria evaluation of inner climate by using MOORA method, *Information Technology and Control* 37(1): 79–83.

Kapliński, O. 2008a. Usefulness and credibility of scoring methods in construction industry, *Journal of Civil Engineering and Management* 14(1): 21–28. doi:10.3846/1392-3730.2008.14.21-28

Kapliński, O. 2008b. Planing instruments in construction management, *Technological and Economic Development of Economy* 14(4): 449–451. doi:10.3846/1392-8619.2008.14.449-451

Kapliński, O. 2008c. Development and usefulness of planning techniques and decision-making foundations on the example of construction enterprises in Poland, *Technological and Economic Development of Economy* 14(4): 492–502. doi:10.3846/1392-8619.2008.14.492-502

Keeney, R. L. 1982. Decision analysis: an overview, *Operations Research* 30(5): 803–838. doi:10.1287/opre.30.5.803

Keeney, R. L.; Raiffa, H. 1976. *Decision with Multiple Objectives: Preferences and Value Tradeoffs*. New York, John Wiley & Sons.

Keeney, R. L; von Winterfeldt, D. 2001. Appraising the precautionary principle – a decision analysis perspective, *Journal of Risk Research* 4(2): 191–202. doi:10.1080/13669870010027631

Körth, H. 1969. Zur Berücksichtigung mehrer Zielfunktionen bei der Optimierung von Produktionsplanen, *Mathematik und Wirtschaft* 6: 184–201.

Larichev, O. 2000. *Decision-making Theory and Methods*. Moscow: Logos (in Russian).

Liaudanskiene, R.; Ustinovicius, L.; Bogdanovicius, A. 2009. Evaluation of construction process safety solutions using the TOPSIS method, *Inzinerine Ekonomika – Engineering Economics* (4): 32–40.

MacCrimon, K. R. 1968. *Decision Making Among Multiple–Attribute Alternatives: A Survey and Consolidated Approach, RAND Memorandum, RM-4823-ARPA*. The Rand Corporation, Santa Monica, Calif.

Noarul Haq, A.; Kannan, G. 2007. A hybrid normalised multi criteria decision making for the vendor selection in a supply chain model, *International Journal of Management and Decision Making* 8(5–6): 601–622.

Opricovic, S.; Tzeng, G.-H. 2004. Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS, *European Journal of Operational Research* 156(2): 445–455. doi:10.1016/S0377-2217(03)00020-1

Pareto, V. 1971. *Manual of Political Economy*. A. M. Kelley, New York.

Peldschus, F. 2007. The effectiveness of assessment in multiple criteria decisions, *International Journal of Management and Decision Making* 8(5–6): 519–526. doi:10.1504/IJMDM.2007.013416

Peldschus, F. 2008. Experience of the game theory application in construction management, *Technological and Economic Development of Economy*14(4): 531–545. doi:10.3846/1392-8619.2008.14.531-545

Peldschus, F. 2009. The analysis of the quality of the results obtained with the methods of multi-criteria decisions, *Technological and Economic Development of Economy* 15(4): 580–592. doi:10.3846/1392-8619.2009.15.580-592

Plebankiewicz, E. 2009. Contractor prequalification model using fuzzy sets, *Journal of Civil Engineering and Management* 15(4): 377–385. doi:10.3846/1392-3730.2009.15.377-385

Podvezko, V.; Podviezko, A. 2010. Dependence of multi-criteria evaluation result on choice of preference functions and their parameters, *Technological and Economic Development of Economy* 16(1): 143–158. doi:10.3846/tede.2010.09

Roubens, M. 1982. Preference relations on actions and criteria in multi-criteria decision making, *European Journal of Operational Research* 10 (1): 51–55. doi:10.1016/0377-2217(82)90131-X

Roy, B. 1990. Decision-aid and decision-making, *Eur. J. Operational. Res.* 45: 324–331. doi:10.1016/0377-2217(90)90196-I

Roy, B. 1996. *Multicriteria Methodology for Decision Aiding*. Kluwer Academic Publishers, Dortrecht.

Saaty, T. L. 1994. Highlights and critical points in theory and application of the analytic hierarchy process, *European Journal of Operational Research* 74: 426–447. doi:10.1016/0377-2217(94)90222-4

Saaty, T. L. 1977. *Mathematical Models of Conflict Situations.* Moscow: Sov. Radio (in Russian).

Sobotka, A.; Rolak, Z. 2009. Multi-attribute analysis for the eco-energetic assessment of the building life cycle, *Technological and Economic Development of Economy* 15(4): 593–611. doi:10.3846/1392-8619.2009.15.593-611

Srinivasan, V.; Shocker, A. D. 1973. Linear programming techniques for multidimensional analysis of privileged, *Psychometrika* 38: 337–369. doi:10.1007/BF02291658

Stopp, F. 1975. Variantenvergleich durch Matrixspiele, *Wissenschaftliche Zeitschrift der Hochschule für Bauwesen Leipzig* 2: 117.

Šelih, J.; Kne, A.; Srdić, A.; Žura, M. 2008. Multiple-criteria decision support system in highway infrastructure management, *Transport* 23(4): 299–305. doi:10.3846/1648-4142.2008.23.299-305

Šijanec Zavrl, M.; Žarnić, R.; Šelih, J. 2009. Multicriterial sustainability assessment of residential buildings, *Technological and Economic Development of Economy* 15(4): 612–630. doi:10.3846/1392-8619.2009.15.612-630

Turskis, Z.; Zavadskas, E. K.; Peldschus, F. 2009. Multi-criteria optimization system for decision making in construction design and management, *Inzinerine Ekonomika – Engineering Economics* (1): 7–17.

Ulubeyli, S.; Kazaz, A. 2009. A multiple criteria decision-making approach to the selection of concrete pumps, *Journal of Civil Engineering and Management* 15(4): 369–376. doi:10.3846/1392-3730.2009.15.369-376

Ustinovichius, L.; Zavadskas, E. K.; Podvezko, V. 2007. Application of a quantitative multiple criteria decision making (MCDM-1) approach to the analysis of investment in construction, *Control and Cybernetics* 36(1): 251–268.

Vansnick, J. C. 1986. On the problem of weights in multiple criteria decision making (the noncompensatory approach), *European Journal of Operational Research* 24: 288–294. doi:10.1016/0377-2217(86)90051-2

Weitendorf, D. 1976. *Beitrag zur Optimierung der räumlichen Struktur eines Gebäudes:* Dissertation A, Hochschule für Architektur und Bauwesen. Weimar.

Zanakis, S. H.; Solomon, A.; Wishart, N.; Dublish, S. 1998. Multi-attribute decision making: A simulation comparison of select methods, *European Journal of Operational Research* 107: 507–529. doi:10.1016/S0377-2217(97)00147-1

Zavadskas, E. K. 1987. *Multiple Criteria Evaluation of Technological Decisions of Construction*: Dissertation of Dr. Sc. Moscow Civil Engineering Institute, Moscow (in Russian).

Zavadskas, E. K.; Kaklauskas, A. 1996. Determination of an efficient contractor by using the new method of multicriteria assessment, in Langford, D. A.; Retik, A. (Eds.). *International Symposium for "The Organisation and Management of Construction". Shaping Theory and Practice. Vol. 2: Managing the Construction Project and Managing Risk.* CIB W 65; London, Weinheim, New York, Tokyo, Melbourne, Madras. London: E and FN SPON, 94–104.

Zavadskas, E. K.; Kaklauskas, A.; Peldschus, F.; Turskis, Z. 2007. Multi-attribute assessment of road design solutions by using the COPRAS method, *The Baltic Journal of Road and Bridge Engineering* 2(4): 195–203.

Zavadskas, E. K.; Kaklauskas, A.; Turskis, Z.; Tamošaitienė, J. 2008a. Selection of the effective dwelling house walls by applying attributes values determined at intervals, *Journal of Civil Engineering and Management* 14(2): 85–93. doi:10.3846/1392-3730.2008.14.3

Zavadskas, E. K.; Turskis, Z.; Tamošaitienė, K.; Marina, V. 2008b. Multicriteria selection of project managers by applying grey criteria, *Technological and Economic Development of Economy* 14(4): 462–477. doi:10.3846/1392-8619.2008.14.462-477

Zavadskas, E. K.; Turskis, Z.; Tamosaitiene, J. 2008c. Contractor selection of construction in a competitive environment, *Journal of Business Economics and Management* 9(3): 181–187. doi:10.3846/1611-1699.2008.9.181-187

Zavadskas, E. K.; Kaklauskas, A.; Vilutienė, T. 2009a. Multicriteria evaluation of apartment blocks maintenance contractors: Lithuanian case study, *International Journal of Strategic Property Management* 13(4): 319–338. doi:10.3846/1648-715X.2009.13.319-338

Zavadskas, E. K.; Kaklauskas, A.; Turskis, Z.; Tamosaitiene, J. 2009b. Multi-attribute decision-making model by applying grey numbers, *Informatica* 20(2): 305–320.

Zavadskas, E. K.; Turskis, Z.; Tamosaitiene, J. 2010. Risk assessment of construction projects, *Journal of Civil Engineering and Management* 16(1): 33–46. doi:10.3846/jcem.2010.03

Zeleny, M. 1982. *Multiple Criteria Decision Making.* New York: McGraw-Hill.

Zimmermann, H.-J. 2000. An application-oriented view of modelling uncertainty, *European Journal of Operational Research* 122(2): 190–198. doi:10.1016/S0377-2217(99)00228-3

NAUJAS ADITYVINIS KRITERIJŲ SANTYKIŲ ĮVERTINIMO METODAS (ARAS) DAUGIAKRITERINIAMS UŽDAVINIAMS SPRĘSTI

E. K. Zavadskas, Z. Turskis

Santrauka

Daugiakriteriniai sprendimų metodai taikomi daugelyje žmogaus veiklos sričių. Kiekviena alternatyva, sprendžiant daugiakriterinius uždavinius, gali būti apibūdinta kriterijų aibe. Kriterijai gali būti kokybiniai ir kiekybiniai. Jie paprastai turi skirtingus matavimo vienetus ir įvairią optimizavimo kryptį. Kriterijų vertės yra normalizuojamos lyginamos skalės vertėms gauti. Straipsnyje pateikiamas naujas adityvinis kriterijų santykių įvertinimo metodas (ARAS) daugiakriteriniams uždaviniams spręsti. ARAS metodo taikymui pavaizduoti pateiktas realus mikroklimato biuro patalpose vertinimo tyrimas. Tyrimo tikslas – įvertinti patalpų, kurioje žmonės dirba, mikroklimatą ir nustatyti priemones, kurių reikia imtis aplinkai pagerinti. Remiantis uždavinio tikslų analize, siūlomi šie kriterijai vidaus klimatui įvertinti: oro pasikeitimas, patalpų oro santykinė drėgmė, oro temperatūra, apšvietimo intensyvumas, oro srautas ir rasos taškas. Kriterijų svoriai nustatomi porinio lyginimo metodu remiantis ekspertų vertinimais. Kriterijų reikšmės nustatytos sertifikuotu prietaisu.

Reikšminiai žodžiai: daugiakriterinis sprendimų priėmimas, alternatyva, adityvinis kriterijų santykių įvertinimo metodas, ARAS, svoriai.

Edmundas Kazimieras ZAVADSKAS is Principal Vice-Rector of Vilnius Gediminas Technical University, and Head of the Dept. of Construction Technology and Management at Vilnius Gediminas Technical University, Vilnius, Lithuania. He has a PhD in Building Structures (1973) and Dr Sc. (1987) in Building Technology and Management. He is a member of the Lithuanian and several foreign Academies of Sciences. He is Doctore Honoris Causa at Poznan, Saint-Petersburg, and Kiev. He is a member of international organisations and has been a member of steering and programme committees at many international conferences. E. K. Zavadskas is a member of editorial boards of several research journals. He is author and co-author of more than 400 papers and a number of monographs in Lithuanian, English, German and Russian. Research interests are: building technology and management, decision making theory, automation in design and decision-support systems.

Zenonas TURSKIS (PhD) is a senior research worker at Laboratory of Construction Technology and Management in Vilnius Gediminas Technical University, Lithuania. His research interests include building technology and management, decision-making theory, computer-aided automation in design and expert systems. He is the author of 60 research papers.