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ABSTRACT

Choice of location in many cases is a key factor setting up a new business object. In this article the KEMIRA-M method is proposed to establish priority of criteria and determine criteria weights. Weighted sum of criteria values was applied for ranking the alternatives. This technique is useful if the evaluation criteria naturally consist of several logically explained groups of criteria. Method requires much less initial information and is based upon searching the solution of optimisation problem. KEMIRA-M is applied for the case study of construction site for non-hazardous waste incineration plant in Vilnius City.

1. Introduction

The problem of choosing the best alternative location among several alternatives is relevant in many fields of human economic activity such as marketing, capital investments, logistics, construction, cultural heritage management, hospitality management, location of facilities, etc. Optimal solutions of the location problem can help not only by saving money and resources, but also by improving the environmental situation. A number of articles devoted to this problem have been published recently.

Van Asperen and Dekker (2013) evaluated a number of alternative strategies of port-of-entry choices by means of simulation. The optimal solution results in the lowest cost per container. Broll, Roldán-Ponce, and Wahl (2013) investigated the impact of economic risk and risk preferences upon regional allocation of capital investments. Gilvear, Spray, and Casas-Mulet (2013) presented methodology of optimising the outcomes of river rehabilitation in terms of delivery of multiple ecosystem services. In the article, trajectories over time for attaining the long-term ecosystem service score for each river rehabilitation measures are given. Ansar (2013) analysed the procurement of infrastructure services prior to making durable and immobile investments by large firms through a case study of a large manufacturing firm, ThyssenKrupp AG. Gerritse and Moreno-Monroy (2012) built a modified Core-Periphery model where formal and informal firms compete in consumer

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markets. Fuzzy Data Envelopment Analysis was used for measuring the relative efficiency of foreign direct investment in 12 transition economies that separated from USSR (Aydın & Zortuk, 2014). A hybrid multi-objective meta-heuristic algorithm for obtaining Pareto optimal solutions of the location routing problem minimising both total cost and total environmental effect applied in Mohammadi, Razmi, and Tavakkoli-Moghaddam (2013). Jureniene and Radzevicius (2014) compared three cultural heritage management models which are generally used in the world UNESCO practices. Iqbal, Choudhry, Ahsan Ali, and Tamošaitienė (2015) analysed risk management in construction projects in Pakistan. Two types of risk management techniques were considered: preventive techniques and remedial techniques. A model of assessing contaminated sites in Lithuania is proposed by Vasarevičius, Kadūnas, and Baltrėnaitė (2013). Calculations of the level of contamination have been based on statistical analysis and experience gained by the EU countries.

Lich and Tournemaine (2013) developed an endogenous growth model with human capital accumulation and pollution unequally spread across geographical locations when individuals must decide where to live. It was found that individuals prefer a greater level of consumption and leisure but lower growth and environmental quality than those which are possible to achieve. Yamashita, Matsuura, and Nakajima (2014) revealed the agglomeration effects of multinational firms on the location decisions of first-time Japanese manufacturing investors in China by calculating the conditional and mixed logit estimates. Bryson and Ronayne (2014) analysed the British textile industry since the 1960s highlighting deindustrialisation and the transfer of production and employment to newly industrialised regions. Yang, Luo, and Law (2014) reviewed past literature on hotel location models and provided future research directions related the development of more sophisticated hotel location models and the use of Geographic Information System in hotel location analysis. Determining the locations of facilities for prepositioning supplies to be used during a disaster is analysed in Akgün, Gümüşbuğa, and Tansel (2015). A non-linear p-centre type facility location model to minimise maximum risk is developed in the article. Jaskowski, Sobotka, and Czarnigowska (2014) proposed mixed binary linear programming models for the contractor's logistic decisions assessment.

From the great variety of decision evaluation models applied for solution of location alternatives problems we would like to distinguish Multiple Criteria Decision Making (MCDM) or Multiple Attribute Decision Making (MADM) methods. These methods are naturally suitable for solving the problem of selection an optimal alternative having the set of criteria which are sometimes conflicting with each other. Furthermore, respective fuzzy modifications of MCDM methods allow solving such problems under vague conditions.

Various MCDM methods were used for solving the location problems recently. Brauers and Zavadskas (2008) proposed Multiple Objectives Optimisation by Ratio Analysis (MOORA) method to resolve location problems. Rikhtegar et al. (2014) applied Analytic Network Process (ANP) and fuzzy Simple Additive Weight (F-SAW) to formulate the environmental risks pertaining to mining projects. Turskis and Zavadskas (2010) proposed fuzzy additive ratio assessment (ARAS-F) method to select the most suitable site for logistic centre among a set of alternatives. Shariati, Yazdani-Chamzini, Salsani, and Tamosaitiene (2014) considered technical, economic and environmental factors for waste dump site selection by using the ARAS based group decision-making fuzzy Group Additive Ratio Assessment (GARAS) technique. Hashemkhani Zolfani, Aghdaie, Derakhti, Zavadskas, and Varzandeh (2013) presented the new hybrid MCDM model: Stepwise Weight Assessment Ratio Analysis (SWARA) and Weighted Aggregated Sum

Product Assessment (WASPAS) methods in shopping mall locating. Bagočius, Zavadskas, and Turskis (2014a) compared three different MCDM methods: SAW, fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Complex Proportional Assessment (COPRAS) for selecting a location for a liquefied natural gas terminal in the Eastern Baltic Sea. Zavadskas, Turskis, and Bagočius (2015) applied a combination of Analytic Hierarchy Process (AHP) and ARAS-F methods for selection of a deep-water port. Yazdani-Chamzini, Yakhchali, and Zavadskas (2012) used integrated model based on fuzzy AHP and fuzzy TOPSIS for mining method selection under the uncertainty. Choosing logistics freight centre locations with Fuzzy Preference Ranking Organisation METHod for Enrichment Evaluation (F-PROMETHEE) is carried out by Elevli (2014). Sánchez-Lozano, Antunes, García-Cascales, and Dias (2014) proposed the use of Geographic Information System (GIS) and Elimination and Choice Translating Reality (ELECTRE-TRI) method to identify the best plots suitable for installing photovoltaic solar farms.

Lee (2014) combined DEMATEL-based Analytic Network Process (DANP) and VIšekriterijumsko KOmpromisno Rangiranje (VIKOR) methods for selection of location real estate brokerage services. PROMETHEE is used by Ishizaka and Nemery (2013) for the site location where partners are working and sharing resources together. AHP and SAW methods were applied for selection of rural building sites by Jeong, García-Moruno, and Hernández-Blanco (2013). Dheena and Mohanraj (2011) used Ordered Weighted Averaging (OWA) operators with maximal entropy for aggregating fuzzy data. Ekmekçioğlu, Kaya, and Kahraman (2010) proposed AHP and modified fuzzy TOPSIS methodology for selection the site for municipal solid waste. For the same problem Aragonés-Beltrán, Pastor-Ferrando, García-García, and Pascual-Agulló (2010) proposed ANP and AHP methods. Rezaeiniya, Hashemkhani Zolfani, and Zavadskas (2012) developed the hybrid of MCDM methods – ANP and COPRAS-G – for greenhouse locating. The article by Lee (2015) proposes a strengths, weaknesses, opportunities, and threats – fuzzy analytic network process (SWOT-FANP) analysis of location selection for a second tier city in China. MCDM method WASPAS applied for selection and ranking of the feasible location areas of wind farms in Bagočius, Zavadskas, and Turskis (2014b). The performance of a site assessment model for the property management company by the integrated TOPSIS method and the signal-to-noise ratio is proposed by Lin and Pan (2014). Tamošaitienė, Šipalis, Banaitis, and Gaudutis (2013) analysed models for the assessment of the location of high-rise buildings. SWOT and SAW methods combination applied for comparison of visions of urban development. Hsueh, Lee, and Chen (2013) used the Delphi method, fuzzy logic, and AHP (DFAHP) as a risk assessment model to redevelop derelict public buildings.

The alternative to MCDM approach is Cost-benefit analysis (CBA), where the total expected cost and the total expected benefit are calculated and compared for each alternative (Rietveld, van Binsbergen, Schoemaker, & Peeters, 1998). The debate on CBA and multicriteria analysis tends to regard these two approaches as complementary rather than competitive analytical tools.

In addition to the above methods for selection the best alternative of several possible options the new KEMIRA method is proposed by Krylovas, Zavadskas, Kosareva, and Dadelo (2014). Frequently there are situations when solving MCDM tasks there is a need not only to rank alternatives certified by the entirety of criteria. The essence of KEMIRA method can be formulated as follows: if we can logically distinguish few subsets of criteria, then for setting criteria weights it is important to include interactions between subsets of

criteria. KEMIRA method – only one of the possible ways of balancing criteria weights. In our knowledge it is a new approach and it hasn't more bibliography. Other balancing techniques are also possible – one of them is referred to in Dadelo et al. (2014).

At the first stage of the MCDM problem solution it is proposed to determine a priority of the criteria (indicators) on the basis of expert assessments. For this purpose, Kemeni median method (Dadelo, Krylovas, Kosareva, Zavadskas, & Dadeliene, 2014) is applied. Consequently, it becomes clear which criterion will have lower weight and which will have greater weight. It should be noted that only during this phase criteria priorities determined by the experts are used. Next, criteria weights must be determined. In most articles criteria weights are established either by objective, or by subjective methods in both cases using expert opinions. In this article, we use the Indicator Rank Accordance method presented for determining weights of the criteria at the second stage of the problem solution. This method is based entirely on calculations and does not require expert assessments. On the one hand, decisions must be made based on various expert judgments summary. On the other hand, the aim is to ensure that decisions made on the basis of the separate groups of evaluation criteria to be compatible with each other. Therefore, we are solving an additional optimisation problem – maximisation of criteria interaction. When weights of the criteria are determined, at the third stage the objective function value is calculated for each alternative and the alternatives are ranked according to the objective function values. Usually this function is a weighted average of all the criteria values calculated with weights, found by Indicator Rank Accordance method. It should be mentioned that KEMIRA is designed for determining criteria weights. Method can be applied together with any other method of establishing priority of the alternatives – SAW, TOPSIS, WASPAS, etc.

Later in this article a concrete example of KEMIRA-M decision method application in solving the task of construction site choice for non-hazardous waste incineration plant is shown. The data used are of the Vilnius city.

2. MCDM problem under investigation

Construction site alternatives for non-hazardous waste incineration plant in Vilnius city were analysed in Turskis, Lazauskas, and Zavadskas (2012). A problem of siting the waste incineration plant is a complex process which includes social, economic, urban and technologic factors. With the objective to highlight aspects of the application of KEMIRA method, we use less of data from the article by Turskis et al. (2012). We selected four engineering factors, which form one separate group of criteria X = (x_1, x_2, x_3, x_4): x_1 - distance to centralised heating network mains (Ø400), km, x_2 - distance to the high-pressure (12 bar) gas supply pipeline (Ø150), km, x_3 - distance to 110 kW electric supply networks, km, x_4 - distance to water supply networks (Ø110), km. Engineering factors include a part of investments required for project development. For initiation of incineration process or its maintenance, fossil fuel or electric energy will be provided. It is clear that all these factors will be treated due to their minimisation, i.e., criteria, whose preferable values are minimal.

Urban and social factors in our investigation are combined in the second group of criteria Y=(y_1, y_2, y_3): y_1 - distance to the Vilnius city centre, km, y_2 - average number of people living on the territory of the determined alternative, 1 km², y_3 - usable area of apartments owned by people living in the territory intended for project implementation, m². Urban and social factors are maybe the most controversial. The distance to the city centre evaluates the location of an incineration plant and considers the possible impact on architecture of the

Table 1. Alternative assessment factors.

Engineering factors	
x_1	Distance to centralised heating network mains (∅400), km
x_2	Distance to the high-pressure (12 bar) gas supply pipeline (Ø150), km
x_3	Distance to 110 kW electric supply networks, km
x_4	Distance to water supply networks (Ø110), km
Urban and social factors	
y_1	Distance to the Vilnius city centre, km
y_2	Average number of people living on the territory of the determined alternative, 1 km^2
y_3	Usable area of apartments owned by people living in the territory intended for project implementation, m^2

Source: Turskis et al., 2012.

Table 2. Significance of factors (criteria) determined by five representatives of concerned groups.

Expert group	x_1	x_2	x_3	x_4	y_1	y_2	y_3
1	1	3	4	2	2	3	1
2	1	3	4	2	1	2	3
3	1	2	3	4	3	1	2
4	1	2	4	3	3	1	2
5	1	2	4	3	1	3	2

Source: Turskis et al., 2012.

city and the resulting problems such as noise, odour or aesthetic view. To avoid all these negative factors construction site of waste incineration plant should be located as far away from the city centre as possible. Urban and social factors represent the general evaluation of conflicting public interests. According to the public opinion survey it was considered that the site, selected for the Project implementation should have the smallest density of population. Assessing the Project from the point of view of the state or a private investor, it is rational to construct a power plant in a densely populated territory to ensure energy needs. Usable area of apartments owned by citizens shows the area to be supplied with the energy generated by the new energy facility. In our research all urban and social factors will be treated due to their maximisation, as it was done in Turskis et al. (2012), i.e. criteria, whose preferable values are maximal. Alternative assessment factors are proposed in Table 1.

Requirements were formulated by five representatives of concerned groups: citizens, potential investors, specialists of environmental protection, architects and construction contractors. Representatives of the above-state groups assessed the stated factors priorities within each group. Results are given in the Table 2. The lower number in the Table 2 represents the higher rank (priority) of corresponding criterion.

Note, that priorities of factors x_l, y_m were determined independently and separately for both groups of criteria – engineering and urban/social by non-quantitative assessments only comparing them to each other. For example, five experts sorted criteria within the first group as follows:

$$\left. \begin{array}{l} (E1)\, x_1 \succ x_4 \succ x_2 \succ x_3 \\ (E2)\, x_1 \succ x_4 \succ x_2 \succ x_3 \\ (E3)\, x_1 \succ x_2 \succ x_3 \succ x_4 \\ (E4)\, x_1 \succ x_2 \succ x_4 \succ x_3 \\ (E5)\, x_1 \succ x_2 \succ x_4 \succ x_3 \end{array} \right]. \tag{1}$$

Table 3. Specification of initial values of criteria for seven alternative waste incineration plants sitting in the Vilnius city.

Alternatives	Criteria						
	x_1	x_2	x_3	x_4	y_1	y_2	y_3
a_1	1.5	0.6	2.5	1.37	9.26	3188.6	55,269
a_2	3.5	1.2	4.5	0.5	8.64	497.5	9,327
a_3	0.8	0.5	3	0.1	6.44	2,484	50,798
a_4	4.8	1.2	1,6	2	11.19	2,676	56,206
a_5	5.5	1	1.6	0.3	5.9	3,291	66,807
a_6	0.6	0.7	2	0.6	6.09	6,490	132,136
a_7	0.3	0.4	2	0.6	5.72	5946.7	123,314

Source: Turskis et al., 2012.

Table 4. Specification of transformed criteria values treated due to their maximisation.

Alternatives	Criteria						
	x_1	x_2	x_3	x_4	y_1	y_2	y_3
a_1	0.667	1.667	0.4	0.730	9.26	3188.6	55,269
a_2	0.286	0.833	0.222	2.0	8.64	497.5	9,327
a_3	1.250	2.0	0.333	10.0	6.44	2,484	50,798
a_4	0.208	0.833	0.625	0.5	11.19	2,676	56,206
a_5	0.182	1.0	0.625	3.333	5.9	3,291	66,807
a_6	1.667	1.429	0.50	1.667	6.09	6,490	132,136
a_7	3.333	2.50	0.50	1.667	5.72	5946.7	123,314

Source: calculated by the authors.

Table 5. Normalised criteria values for seven alternative waste incineration plant sitting in the Vilnius city.

Alternatives	Criteria						
	x_1^*	x_2^*	x_3^*	x_4^*	y_1^*	y_2^*	y_3^*
a_1	0.154	0.5	0.441	0.024	0.647	0.449	0.374
a_2	0.033	0,0	0.0	0.158	0.534	0.0	0.0
a_3	0.339	0.7	0.276	1.0	0.132	0.331	0.338
a_4	0.008	0.0	1.0	0.0	1.0	0.364	0.382
a_5	0.0	0.1	1.0	0.298	0.033	0.466	0.468
a_6	0.471	0.357	0.690	0.123	0.068	1.0	1.0
a_7	1.0	1.0	0.690	0.123	0.0	0.909	0.928

Source: created by the authors.

In the article by Turskis et al. (2012), the five expert's quantitative information is processed using fuzzy sets. In this article, we will use the aggregated data for determination of the order found by each expert. Dividing criteria into groups makes it easier to rank them, because experts must rank shorter lists of criteria (factors) – four and three factors respectively. Seven local assessments of alternative sites a_1 - a_7 located in densely populated urban and industrial development areas have been evaluated. In the Table 3 numerical estimates of the matrix factors for all the alternatives are presented: $X(a) = \left\| x_{ij} \right\|_{7x4}, Y(a) = \left\| y_{ij} \right\|_{7x3}$.

At the next step all criteria values must be transformed to the factors treated due to their maximisation, i.e., for x_1-x_4 inverse values $(1 / x_i)$ must be calculated. Since y_1-y_3 are treated due to their maximisation, we do not accomplish any transformations of these factors. Transformed values are presented in Table 4.

Further, all criteria values are normalised according to the formulas:

$$x_j^{(i)*} = \frac{x_j^{(i)} - x_{\min}^{(i)}}{x_{\max}^{(i)} - x_{\min}^{(i)}}, \quad y_j^{(i)*} = \frac{y_j^{(i)} - y_{\min}^{(i)}}{y_{\max}^{(i)} - y_{\min}^{(i)}}, \quad i = 1, 2, ..., 7. \tag{2}$$

Table 5 presents normalised criteria values for 7 alternatives.

Normalised criteria values are belonging to the interval [0; 1]. Furthermore, all criteria values in Table 5 are due to their maximisation.

3. Determining priority of criteria by Kemeny median method

The main idea of KEMIRA method is to construct the median, i.e., generalised expert opinion of (1) estimates. It would be one or few of all $4! = 24$ possible rankings, since there are 24 permutations of ranks 1, 2, 3, 4. Then on the basis of the median we form weighted average:

$$X_{W_X} = \varpi_{x_1} x_1 + \varpi_{x_2} x_2 + \varpi_{x_3} x_3 + \varpi_{x_4} x_4, \quad W_X = (\varpi_{x_1}, \varpi_{x_2}, \varpi_{x_3}, \varpi_{x_4}). \tag{3}$$

For example, if the median priority is an order $x_1 \succ x_4 \succ x_2 \succ x_3$, then the weights in (3) must satisfy the following constraints:

$$\varpi_{x_1} \geq \varpi_{x_4} \geq \varpi_{x2} \geq \varpi_{x_3}, \quad \varpi_{x_1} + \varpi_{x_4} + \varpi_{x_2} + \varpi_{x_3} = 1. \tag{4}$$

The weighted average of the other factor Y_{W_Y} is constructed by analogy. Weights ϖ_x, ϖ_y are chosen so that the criteria X_{W_X} and Y_{W_Y} values are as close as possible. KEMIRA method algorithm consists of the following steps:

(1) All criteria represent a benefit, i.e., the bigger is a value, the better is the respective alternative. If criterion x_i is representing lost, when the lower value is better, then inverse value $(1/x_i)$ must be calculated.

(2) Normalisation of elements of decision-making matrices $X(a)$, $Y(a)$ by formula (2). All criteria values after normalisation belong to the interval [0; 1].

(3) Determining median priorities of criteria X and Y (obtaining one or few medians).

(4) The weights W_X, W_Y are chosen so that they satisfy the constraints (4) and the difference of weighted averages X_{W_X} and Y_{W_Y} for real data is minimised at all the alternatives. In order to achieve this goal optimisation problem described below is solved.

(5) The best alternative is the one for which the sum of weighted averages $X_{W_X} + Y_{W_Y}$ reach its maximum value.

3.1. Factor X median construction

According to KEMIRA method at the first stage Kemeny median method is applied for the data in the Table 2 for establishing priority of criteria separately and independently in both groups - engineering and urban/social factors. Priority of criteria X = (x_1, x_2, x_3, x_4) and Y = (y_1, y_2, y_3) was estimated by five experts (see data in Table 2). Notice, that all experts identified the first factor as the most important one. Meanwhile, expert opinions on importance of the other factors differ. We must ascertain generalised expert opinion. Each of the five experts' formations can be seen as a simple oriented graph (Krylovas, 2009). For example, first expert

formation $x_1 \succ x_4 \succ x_2 \succ x_3$ is expressed by graph $R^{(1)} = \{(1;2), (1;3);(1;4);(4;2), (4;3), (2;3)\}$ which is depicted in Fig. 1.

The same graph can be written in the form of the square matrix $A^{(r)} = \left(a_{ij} \right)_{4x4}$, $r = 1, 2, ..., 5$ which elements are as follows: $a_{ij} = \begin{cases} 0, \text{ if } x_i \prec x_j \\ 1, \text{ if } x_i \succ x_j \end{cases}$. Diagonal elements of this matrix are equal to zero: $x_{ii} = 0$, $i = 1, 2, 3, 4$. Moreover, $a_{ij} = 1 - a_{ji}$, $i \neq j$. For example, significance of factors $x_1 - x_4$ set by first and second experts (E1) - (E2) can be described by matrices: $A^{(1)} = A^{(2)} = \begin{pmatrix} 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 \end{pmatrix}$, other experts matrices are as follows:

$A^{(3)} = \begin{pmatrix} 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \end{pmatrix}$, $A^{(4)} = A^{(5)} = \begin{pmatrix} 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix}$.

The measure of distance between two different ranking orders described by matrices $A^{(r)}$ and $A^{(s)}$ is defined by formula (5):

$$\rho(R^{(r)}, R^{(s)}) = \rho(A^{(r)}, A^{(s)}) = \sum_{i=1}^{n} \sum_{j=1}^{n} \left| a_{ij}^{(r)} - a_{ij}^{(s)} \right|. \tag{5}$$

Here n is number of factors $x_1, x_2, ..., x_n$ ($n = 4$). Formula (5) calculates sum of absolute values of corresponding elements differences. For example,

$$\rho(A^{(1)}, A^{(3)}) = |0 - 0| + |1 - 1| + |1 - 1| + |1 - 1| +$$
$$|0 - 0| + |0 - 0| + |1 - 1| + |0 - 1| +$$
$$|0 - 0| + |0 - 0| + |0 - 0| + |0 - 1| +$$
$$|0 - 0| + |1 - 0| + |1 - 0| + |0 - 0| = 4 .$$

Suppose that S experts established priorities which can be described by matrices $A^{(1)}, A^{(2)}, ..., A^{(S)}$ ($S = 5$). Most consistent with these estimates will be priority described by matrix $A^{(M)}$, which is called *median*. For the median $A = A^{(M)}$ the sum $\sum_{j=1}^{S} \rho(A, A^{(j)})$ is gaining its minimum value. Theoretically, we must search the median matrix $A^{(M)} = \left\| a_{ij} \right\|_{4x4}$ within all 24 possible matrices. But we can narrow down the search area. Notice that if elements of all five matrices with the corresponding indices i and j are equal, then $a_{ij}^{(M)} = a_{ij}^{(1)} = a_{ij}^{(2)} = ... = a_{ij}^{(5)}$. Then $A^{(M)} = \begin{pmatrix} 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & a_{24} \\ 0 & 0 & 0 & a_{34} \\ 0 & a_{42} & a_{43} & 0 \end{pmatrix}$. We have only 2 unknown elements of median matrix, because the identities $a_{ij} + a_{ji} = 1$, $i \neq j$ are valid for the simple
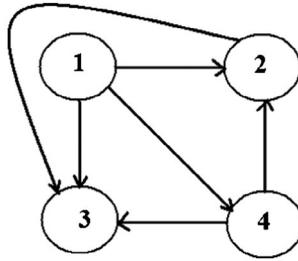
Figure 1. Simple oriented graph describing priority of criteria X by first expert $x_1 > x_4 > x_2 > x_3$. Source: created by the authors.

oriented graph matrix (Krylovas, 2009). Therefore $a_{42} = 1 - a_{24}$, $a_{43} = 1 - a_{34}$. Thus, we can search the median within these 4 matrices:

$$A' = \begin{pmatrix} 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \end{pmatrix}, \; A'' = \begin{pmatrix} 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix}, \; A''' = \begin{pmatrix} 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \end{pmatrix}, \; A'''' = \begin{pmatrix} 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 \end{pmatrix}$$

Calculate sums (5) for each of these matrices:

$$\sum_{j=1}^{5} \rho(A', A^{(j)}) = 4 + 4 + 0 + 2 + 2 = 12, \; \sum_{j=1}^{5} \rho(A'', A^{(j)}) = 2 + 2 + 2 + 0 + 0 = 6,$$

$$\sum_{j=1}^{5} \rho(A''', A^{(j)}) = 2 + 2 + 2 + 4 + 4 = 14, \; \sum_{j=1}^{5} \rho(A'''', A^{(j)}) = 0 + 0 + 4 + 2 + 2 = 8.$$

Minimum value of sum (5) is reached for matrix A''.[1] Hence, median value which in the best way represents all five experts' opinions is (1, 2, 4, 3) which corresponds to preference of engineering factors as follows:

$$x_1 > x_2 > x_4 > x_3. \tag{6}$$

The highest priority has the distance to centralised heating network mains, then goes distance to the high-pressure gas supply pipeline, after this goes the distance to water supply networks, and finally, the lowest priority has distance to electric supply networks. Write down the weighted average of type (3) for each alternative $X_{W_X}(a) = \sum_{j=1}^{4} \varpi_{x_j} x_j(a)$. Here the weights $\varpi_{x_1}, \varpi_{x_2}, \varpi_{x_3}, \varpi_{x_4}$ must satisfy the following constraints:

$$\varpi_{x_1} \geq \varpi_{x_2} \geq \varpi_{x_4} \geq \varpi_{x_3} \geq 0, \; \varpi_{x_1} + \varpi_{x_2} + \varpi_{x_3} + \varpi_{x_4} = 1. \tag{7}$$

3.2. Factor Y median construction

The same procedure is carried out with other group of factors – urban and social factors y_1, y_2, y_3. Five matrices, describing experts' priorities (2,3,1), (1,2,3), (3,1,2), (3,1,2) and (1,3,2) (see Table 2) are as follows:

Table 6. Permutations of three ranks describing three factors prioritisation options, corresponding matrices and values of function **F**.

Permutation	(1, 2, 3)	(1, 3, 2)	(2, 1, 3)	(2, 3, 1)	(3, 1, 2)	(3, 2, 1)
Priority of factors	$y_1 > y_2 > y_3$	$y_1 > y_3 > y_2$	$y_2 > y_1 > y_3$	$y_3 > y_1 > y_2$	$y_2 > y_3 > y_1$	$y_3 > y_2 > y_1$
Matrix A	$\begin{pmatrix} 0 & 1 & 1 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{pmatrix}$	$\begin{pmatrix} 0 & 1 & 1 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}$	$\begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 1 \\ 0 & 0 & 0 \end{pmatrix}$	$\begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ 1 & 1 & 0 \end{pmatrix}$	$\begin{pmatrix} 0 & 0 & 0 \\ 1 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix}$	$\begin{pmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 1 & 1 & 0 \end{pmatrix}$
F	14	16	16	14	14	16

Source: created by the authors.

$$A^{(1)} = \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ 1 & 1 & 0 \end{pmatrix}, \; A^{(2)} = \begin{pmatrix} 0 & 1 & 1 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{pmatrix}, \; A^{(3)} = A^{(4)} = \begin{pmatrix} 0 & 0 & 0 \\ 1 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix}, \; A^{(5)} = \begin{pmatrix} 0 & 1 & 1 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}$$

Next we search median matrix $A^{(M)}$ within 6 possible matrices, representing different priorities of three factors. In the last row of Table 6 calculated values of function $F = \sum_{i=1}^{5} \rho(A, A^{(i)})$ are given. Here $\rho(A^{(r)}, A^{(s)}) = \sum_{i=1}^{3} \sum_{j=1}^{3} \left| a_{ij}^{(r)} - a_{ij}^{(s)} \right|$. For example, if

$$A = \begin{pmatrix} 0 & 1 & 1 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{pmatrix}, \; \sum_{j=1}^{5} \rho(A, A^{(j)}) = 4 + 0 + 4 + 4 + 2 = 14.$$

Median components priority is not unique is this case. There are three median values for which functions F value equals to 14: (1, 2, 3), (2, 3, 1), (3, 1, 2). Respective preferences of urban/social factors are as follows:

$$y_1 > y_2 > y_3, \; y_3 > y_1 > y_2, \; y_2 > y_3 > y_1. \tag{8}$$

For the purpose of demonstration of our method let's choose second median priority of urban/social factors: $y_3 > y_1 > y_2$. Thus, the highest priority has usable area of apartments owned by people living in the territory intended for project implementation, after goes the distance to Vilnius city centre and the lowest priority has the number of people living in the territory of the determined alternative. Then we calculate the weighted average $Y_{W_Y}(a) = \sum_{j=1}^{3} \varpi_{y_j} y_j(a)$ with the weights satisfying conditions:

$$\varpi_{y_3} \geq \varpi_{y_1} \geq \varpi_{y_2} \geq 0, \; \varpi_{y_1} + \varpi_{y_2} + \varpi_{y_3} = 1. \tag{9}$$

4. Calculation of weights by modified Indicator Rank Accordance method and ranking the alternatives

Now when priority of criteria is clear, the next step is finding weighted coefficients $\varpi_{xi}, \varpi_{yi} \in [0; 1]$ which satisfy conditions (7) and (9). Further, the decision on ranking the alternatives will be made according to the values of sums of linear combinations $X_{W_X}(a) + Y_{W_Y}(a)$, calculated for each alternative $a_1, a_2, ..., a_7$:

Table 7. Weights ϖ_{x_i} combinations satisfying condition $\varpi_{x_1} \geq \varpi_{x_2} \geq \varpi_{x_4} \geq \varpi_{x_3} \geq 0$.

No.	ϖ_{x_3}	ϖ_{x_4}	ϖ_{x_2}	ϖ_{x_1}	Nr.	ϖ_{x_3}	ϖ_{x_4}	ϖ_{x_2}	ϖ_{x_1}
1	0	0	0	1	13	0	0.1	0.4	0.5
2	0	0	0.1	0.9	14	0	0.2	0.3	0.5
3	0	0	0.2	0.8	15	0.1	0.1	0.3	0.5
4	0	0.1	0.1	0.8	16	0.1	0.2	0.2	0.5
5	0	0	0.3	0.7	17	0	0.2	0.4	0.4
6	0	0.1	0.2	0.7	18	0.1	0.1	0.4	0.4
7	0.1	0.1	0.1	0.7	19	0	0.3	0.3	0.4
8	0	0	0.4	0.6	20	0.1	0.2	0.3	0.4
9	0	0.1	0.3	0.6	21	0.2	0.2	0.2	0.4
10	0	0.2	0.2	0.6	22	0.1	0.3	0.3	0.3
11	0.1	0.1	0.2	0.6	23	0.2	0.2	0.3	0.3
12	0	0	0.5	0.5					

Source: created by the authors.

Table 8. Weights ϖ_{y_i} combinations satisfying condition $\varpi_{y_3} \geq \varpi_{y_1} \geq \varpi_{y_2} \geq 0$.

No.	ϖ_{y_2}	ϖ_{y_1}	ϖ_{y_3}	Nr.	ϖ_{y_2}	ϖ_{y_1}	ϖ_{y_3}
1	0	0	1	8	0.1	0.3	0.6
2	0	0.1	0.9	9	0.2	0.2	0.6
3	0	0.2	0.8	10	0	0.5	0.5
4	0.1	0.1	0.8	11	0.1	0.4	0.5
5	0	0.3	0.7	12	0.2	0.3	0.5
6	0.1	0.2	0.7	13	0.2	0.4	0.4
7	0	0.4	0.6	14	0.3	0.3	0.4

Source: created by the authors.

$$X_{W_X}(a) = \sum_{i=1}^{4} \varpi_{xi} x_i^*(a), \quad Y_{W_Y}(a) = \sum_{i=1}^{3} \varpi_{yi} y_i^*(a) \tag{10}$$

$x_i^*(a)$ and $y_i^*(a)$ are normalised elements of decision-making matrix, whose all criteria are due to their maximum value. The idea of modified Indicator Rank Accordance method is to select such values of coefficients $W_X = (\varpi_{x_1}, \varpi_{x_2}, \varpi_{x_3}, \varpi_{x_4})$ and $W_Y = (\varpi_{y_1}, \varpi_{y_2}, \varpi_{y_3})$ which guarantee the proximity of values $X_{W_X}(a)$ and $Y_{W_Y}(a)$:

$$F(X, Y) = \min_{W_X, W_Y} \sum_{a} \left| X_{W_X}(a) - Y_{W_Y}(a) \right| \tag{11}$$

Note, that in the original KEMIRA method sum of squares of *ranks* differences are minimised instead of minimising the differences of functions $X_{W_X}(a)$ and $Y_{W_Y}(a)$ original values (11). The other difference of KEMIRA-M from KEMIRA method is that sum (11) is over all the alternatives, while in the original KEMIRA sum is over only the best alternatives. However, if there are only few criteria in each criteria group (4 and 3 in our problem), the number of coefficients W_X and W_Y collections minimising objective function usually became very big and it is impossible to find the unique solution of the problem. The variety of function (11) values is much wider than when using sum of squares of *ranks* differences. We will show that the solution of optimisation problem (11) in this case is unique. We will search for the approximate solution of the problem constructing finite sets of options under consideration. Weights W_X are constructed in the following way. Suppose that W_{X_i}

Table 9. Values of function $F(X, Y)$ for all possible weights combinations.

	1	2	3	4	5	6	7
1	1.696	1.750	1.869	1.756	1.988	1.877	2.107
2	1.696	1.757	1.876	1.765	1.995	1.884	2.114
3	1.697	1.764	1.883	1.772	2.002	1.891	2.121
4	1.738	1.742	1.861	1.750	1.980	1.869	2.099
5	1.698	1.771	1.890	1.779	2.009	1.898	2.128
6	1.739	1.749	1.868	1.757	1.987	1.876	2.106
7	1.510	1.458	1.577	1.466	1.696	1.585	1.815
8	1.698	1.778	1.897	1.786	2.016	1.905	2.135
9	1.739	1.756	1.875	1.746	1.994	1.883	2.113
10	1.924	1.755	1.852	1.759	1.972	1.860	2.091
11	1.511	1.465	1.584	1.473	1.703	1.592	1.822
12	1.698	1.785	1.904	1.793	2.023	1.912	2.142

	8	9	10	11	12	13	14
1	1.996	1.885	2.227	2.115	2.004	2.123	2.012
2	2.003	1.892	2.234	2.122	2.011	2.130	2.019
3	2.010	1.899	2.241	2.130	2.018	2.137	2.026
4	1.988	1.877	2.218	2.107	1.996	2.115	2.004
5	2.017	1.906	2.248	2.136	2.025	2.114	2.033
6	1.995	1.884	2.225	2.114	2.003	2.122	2.011
7	1.704	1.593	1.935	1.823	1.712	1.831	1.720
8	2.024	1.913	2.255	2.143	2.032	2.151	2.040
9	2.002	1.891	2.232	2.121	2.010	2.129	2.018
10	1.980	1.868	2.210	2.100	1.988	2.107	1.996
11	1.711	1.600	1.942	1.830	1.719	1.838	1.727
12	2.031	1.920	2.262	2.151	2.039	2.158	2.047

	1	2	3	4	5	6	7
13	1.740	1.763	1.882	1.771	2.000	1.890	2.120
14	1.924	1.762	1.859	1.766	1.979	1.867	2.098
15	1.511	1.472	1.591	1.480	1.710	1.599	1.829
16	1.696	1.533	1.569	1.537	1.688	1.577	1.807
17	1.925	1.769	1.866	1.773	1.986	1.874	2.105
18	1.511	1.479	1.598	1.487	1.717	1.606	1.836
19	2.110	1.936	1.856	1.941	1.963	1.860	2.083
20	1.696	1.540	1.576	1.544	1.695	1.584	1.814
21	1.467	1.311	**1.285**	1.316	1.404	1.293	1.523
22	1.881	1.708	1.634	1.712	1.680	1.638	1.799
23	1.468	1.318	1.292	1.322	1.411	1.300	1.530

	8	9	10	11	12	13	14
13	2.009	1.898	2.239	2.128	2.017	2.136	2.025
14	1.987	1.875	2.217	2.106	1.995	2.114	2.003
15	1.718	1.607	1.949	1.837	1.726	1.845	1.734
16	1.696	1.585	1.926	1.815	1.704	1.823	1.712
17	1.994	1.883	2.224	2.113	2.002	2.121	2.010
18	1.725	1.614	1.956	1.844	1.733	1.852	1.741
19	1.971	1.864	2.202	2.091	1.979	2.099	1.987
20	1.703	1.592	1.933	1.822	1.711	1.830	1.917
21	1.412	1.301	1.701	1.531	1.420	1.539	1.428
22	1.688	1.642	1.918	1.807	1.696	1.815	1.704
23	1.419	1.308	1.728	1.538	1.427	1.546	1.435

Source: calculated by the authors.

are non-negative integers 0, 1, 2, ..., 10 and $\varpi_{x_i} = W_{X_i}/10$. Then all 23 weights combinations satisfying conditions (7) are written in the Table 7.

Then by analogy we construct 14 weights $\varpi_{y_i} = W_{Y_i}/10$ combinations satisfying conditions (9). These weights are presented in the Table 8.

Calculate and write in the Table 9 values of function $F(X, Y)$ for all $23 \cdot 14 = 322$ cases.

Function $F(X, Y)$ gains its minimum value 1.285. First solution with factor X median (6) and factor Y median $y_3 \succ y_1 \succ y_2$ was reached with the following coefficients values:

Table 10. Final ranking of alternatives for setting the optimal solution.

ϖ_x, ϖ_y	0.2	0.2	0.2	0.4	0	0.2	0.8				
Alternative	x_3	x_4	x_2	x_1	y_2	y_1	y_3	X_{W_x}	Y_{W_y}	$X_{W_x} + Y_{W_y}$	Rank
a_1	0.4414	0.0242	0.5000	0.1538	0.4491	0.6472	0.3741	0.2547	0.4287	0.6834	5
a_2	0.0000	0.1579	0.0000	0.0330	0.0000	0.5338	0.0000	0.0448	0.1068	0.1515	7
a_3	0.2759	1.000	0.7000	0.3389	0.3315	0.1316	0.3377	0.5307	0.2965	0.8272	3
a_4	1.0000	0.0000	0.0000	0.0084	0.3635	1.0000	0.3817	0.2034	0.5054	0.7087	4
a_5	1.0000	0.2982	0.1000	0.000	0.4662	0.0329	0.4680	0.2796	0.3810	0.6607	6
a_6	0.6897	0.1228	0.3571	0.4712	1.0000	0.0676	1.000	0.4224	0.8135	1.2359	2
a_7	0.6897	0.1228	1.000	1.000	0.9093	0.0000	0.9282	0.7625	0.7425	1.5050	1

Source: calculated by the authors.

$$\varpi_{x_1} = 0.4, \ \varpi_{x_2} = \varpi_{x_4} = \varpi_{x_3} = 0.2, \ \varpi_{y_3} = 0.8, \ \varpi_{y_1} = 0.2, \ \varpi_{y_2} = 0. \quad (12)$$

By analogy calculations were repeated for other two medians of urban/social factors group. For the median $y_1 \succ y_2 \succ y_3$ minimum value of function $F(X, Y) = 1.547$ was obtained with the following coefficients values:

$\varpi_{x_1} = 0.4, \quad \varpi_{x_2} = \varpi_{x_4} = \varpi_{x_3} = 0.2, \quad \varpi_{y_1} = 0.4, \quad \varpi_{y_2} = \varpi_{y_3} = 0.3$ and finally, for the median $y_2 \succ y_3 \succ y_1$ minimum value was $F(X, Y) = 1.317$ with the coefficients $\varpi_{x_1} = 0.4, \ \varpi_{x_2} = \varpi_{x_4} = \varpi_{x_3} = 0.2, \varpi_{y_2} = \varpi_{y_3} = 0.4, \ \varpi_{y_1} = 0.2$. The lowest value is 1.285 and calculated weights are (12). Further we must rank our alternatives by calculating values of both functions (10) and their sum $X_{W_x}(a) + Y_{W_y}(a)$ and rank alternatives according to its value. Final results presented in the Table 10.

Final ranks assigned to the alternatives according to the values $X_{W_x}(a) + Y_{W_y}(a)$ are in the last column of Table 10. Thus ranking order of the alternatives is $a_7 \succ a_6 \succ a_3 \succ a_4 \succ a_1 \succ a_5 \succ a_2$. Note that the solution of the same problem obtained in the article by Turskis et al. (2012) gives slightly different order of alternatives, namely alternatives a_4 and a_5 switched places.

5. Conclusion and discussion

Modified KEMIRA method is convenient and recommended to use for establishing criteria weights when there are few groups of factors (criteria) and the number of criteria in each group is small. In the case study we had four engineering factors and three social/urban factors. For this example, procedure of median search is rather simple especially if we can restrict our search to the reduced number of possible cases as we did with factor X. Significance of criteria determined by experts was used. Procedure or setting criteria order separately in each group is easier, because experts must rank shorter lists of criteria. The next advantage of the method – using much less information compared with other MCDM methods. It is enough to have only information about criteria rankings accomplished by few experts. The demonstrated procedure of problem solving by modified KEMIRA method is not difficult comparing with other MCDM methods and it is easier to carry out calculations compared to original KEMIRA method.

The main idea of the method is to create uniform mesh and calculate values of objective function for all points of this mesh. As the result we obtained the approximate solution. If it is need to search more accurate solution the mesh should be smaller. Compared with Turskis et al. (2012) the obtained solution is very similar – only two alternatives switched

places. The advantage of KEMIRA method is that having much less initial information – we have operated with seven criteria instead of 10, as in Turskis et al. (2012) – we obtained analogous result. Therefore, KEMIRA together with weighted sum of criteria values used for ranking the alternatives is superior in comparison with AHP with ARAS-F method. This example showed that KEMIRA is suitable for solving MCDM problems in urban planning. Suitability of the method is based on the fact that it is rather difficult to gather information for the decision-making matrix and expert evaluation of the criteria. For the same reason this method is appropriate for application in the fields where information is difficult to gather or it is rather expensive.

All methods of balancing criteria weights are applicable only under the restrictions described in the article and for this reason it is difficult to compare them with other methods precisely.

KEMIRA method can be easily summarised for three types of criteria (we are currently conducting such studies). For the case when there is only one type of criteria it should be either some other additional external criteria, or the set of criteria has to be divided to few groups artificially. Brute force (i.e. the total re-selection) algorithm implementation in Excel was chosen for this particular task, as these resources are enough and our objective was to introduce the method so that it could be applied by engineers. In the previous investigation (Dadelo et el. 2014) we employed the partial re-selection and random search combination. The authors of the article are currently conducting global and local random search algorithm implementation with C ++.

Note

1. Notice, that matrix A''' can't represent any priority of criteria, because it doesn't contain the row with all zero values.

Disclosure statement

No potential conflict of interest was reported by the authors.

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