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SELECTION OF THE RAILROAD CONTAINER TERMINAL IN SERBIA BASED ON MULTI CRITERIA DECISION-MAKING METHODS

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Abstract: *Intermodal transport is one of the key elements for sustainable freight transport at large and medium distances. However, its efficiency in many cases depends on the location of the railroad container terminals (CT). The favorable position of Serbia provides an opportunity to establish a large number of container trains, which can lead to a more developed intermodal transport system in the entire Balkans and beyond. In this paper the problem of the container terminal location in Serbia has been considered and resolved. The aim of this paper is to determine the potential macro location of the CT in Serbia, which will be most suitable for different stakeholders in the transport chain. Choosing the most suitable alternative is a complex multi-criteria task. For this reason, a multi criteria decision-making model has been formulated which consists of a number of alternatives and criteria. Alternatives represent potential areas for a site, while some of the criteria are: cargo flows, infrastructure, economic development, social and transport attractiveness and environmental acceptability. For defining weights of the criteria two approaches are used, namely, the Delphi and the Entropy method. In this paper three methods of the multi criteria decision-making, namely, TOPSIS, ELECTRE and MABAC are used. By comparing the results of these three methods, an answer to the question where to locate CT will be presented. This is the first step in determining the location of the container terminal. The next phase should respond to the issue of micro location of the terminal. Also, after certain customization, the model can be used for solving other categories of location problems.*

Key Words: *Location Model, Container Terminal, TOPSIS, ELECTRE, MABAC.*

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1. Introduction

The efficiency of intermodal transport largely depends on the location of the container terminals. The sustainability of transport in Europe requires an increasing reallocation between different modes of transport in order to reduce traffic congestion and environmental protection. Therefore, the choice of the most favorable location of the railroad terminal is one of the most important strategies for optimization of the entire transport chain. Due to its favorable geographical position and important transport corridors located on its territory, the Republic of Serbia has a great potential for developing intermodal transport. Considering that there is almost no such type of terminal in Serbia, along with the tendency to join the European transport network, the aim of this paper is to determine the potential location of CT.

There is a number of developed methods used for finding the most suitable location of the terminal, such as standard methods for finding the optimal location defined as the p-median problem (Limbourg & Jorquin, 2009). Klose & Drexl (2005) deals with different location problems formulated as optimization ones.

In addition, a large number of location problems are solved using multi criteria decision-making methods. Unlike conventional methods and techniques of operational research, these methods do not provide for an „objectively the best" solution. These methods are based on mathematical algorithms that are developed to help decision-makers in choosing the most suitable variant.

There is a large number of papers devoted to this issue, such as determining the location of the logistic center based on ELECTRE method (Žak & Weglinski, 2014), location of logistic center on the Black Sea in Turkey (Uysal &Yavuz, 2014), ELECTRE I method (Maroi et al., 2017), determining the location of the main postal center using TOPSIS method (Miletić, 2007), logistic center location in the area of western Serbia (Tomić et al., 2014), location problem based on AHP method (Stević et al., 2015). Some authors have compared several multi criteria methods, doing, for example, a comparative analysis of two weighting criteria methods entropy and CRITIC for air conditioner selection using MOORA and SAW (Vujičić et al., 2017).

More recently, combinations of multi criteria decision-making techniques and fuzzy logic are used for solving location problems (Tadić et al., 2015), fuzzy-TOPSIS method for selecting hospital locations (Senvar et al., 2016), fuzzy-AHP method for determining solar fields location (Asakereh et al., 2017). In addition to conventional methods, there are also others such as the MABAC for solving location problems of wind farms in Vojvodina (Gigović et al., 2017), COPRAS-G method for container terminal operations optimization (Barysiene, 2012), hybrid fuzzy-APH-MABAC model for selecting the location of masking bindings (Božanić et al., 2016), selection of transport and handling resources in logistics centers (Pamučar et al., 2015) and the like.

2. Problem formulation

The observed problem lies in the selection of the most suitable location/region on which the railroad terminal will be located. As a potential location for this terminal, railway sections from Serbia are used, as well as the areas in which these sections are located. Total numbers of variants are 11, although the Serbian railway network is divided into 12 sections: Požarevac, Lapovo, Niš, Zaječar, Kraljevo, Užice, Pančevo, Zrenjanin, Novi Sad, Subotica and Ruma. Belgrade railway section was not taken into consideration due to the existence of a container terminal in Belgrade in Belgrade marshalling yard „Makiš“.

2.1. Definition of variants

For each variant, a railway section is associated with a particular area in which the section is located although the boundaries of the section are different in terms of administrative division. The data about loading and unloading railway freight cars are based on the real railway sections although they cross the administrative boundaries of the area, while the other data used in this paper are taken from the areas in which the section is located.

Variant 1 - Subotica is a railway section located in the northern part of Serbia and it is the administrative center of Severna Bačka District. Its total area is close to 1784 km^2, and its population amounts to 186 906 people. The region is characterized as average in many regards. It is characterized by an average level of economic development, annual GDV per capita of 429 000 rsd and logistical and transport activities imply one important road and rail corridor. The main advantage of this variant is high investment attractiveness because of two free zones, Subotica and Apatin. The unemployment rate in this region ranks among the lowest in the country (10,7%). The volume of transported goods and number of freight cars are the lowest (4599 freight cars - 126 277 t), while in the case of unloading goods in domestic and international traffic region it is in the pre-position.

Variant 2 - Novi Sad is the capital of Južna Bačka District. Population in this area amounts to 615 371 people, while the total area is close to 4026 km^2. The economic potential is high, when considering GDV per capita of 608 000 rsd, which is of the highest value in the whole territory of Serbia, without Belgrade. Novi Sad offers a great opportunity for education of younger people with the highest number of high schools and faculties. The total volume of all transported goods in this section is average and close to 890 819 t, and 23675 used freight cars. Through the Novi Sad pass international road corridor E75 and railway corridor E85. The weakness of variant 2 is a high unemployment rate of 15,9% and existence of one free zone Novi Sad. The region is attractive is terms of environment-friendliness with low noise emission and national park Fruška Gora.

Variant 3 - Zrenjanin is the capital of Srednji Banat District, located in the northeast part of Serbia. Its total area is 3257 km^2 and its population amounts to 187 667 people. The region is characterized by a high unemployment rate of 14,1% which places this variant at the very top according to this criterion. GDV per capita is 416 000 rsd, while transport and logistic competitiveness is small because there is no large number of economic entities. Although the volume of railway transport has been growing in recent years, this section is at very bottom for number of loaded freight cars. With 5644 unloaded cars and 152 492 t of transported goods this region occupies the lowest position. Transport infrastructure in variant 3 is in a very poor condition. There is only one international railway line, while there are no state IA roads. This area is environment-friendly.

Variant 4 - Pančevo is the capital of Južni Banat District, with population of 293 730 people and an area close to 4246 km^2. The economic potential of this variant is slightly lower than average because of GDV per capita which is 384 000 rsd, and a huge unemployment rate of 20,9%. Another weakness of this variant is a very poor condition of transport infrastructure and connection with other nearby cities. Availability of transport infrastructure is lower than average with two international railway lines and no state IA roads. Investment attractiveness is low because there is a large number of business subjects. Azotara, Petrohemija and Oil Refinery in combination with the port are some of the subjects that can contribute positively to this variant. Unfortunately, it does not possess free zones. The total number of loaded and unloaded freight cars in domestic and international transport is 43849 with 1 600 600 t of transported goods.

Variant 5 - Ruma is located in the north-eastern part of the country, and it is the capital of Srem District. Its area is around 3485 km^2 and its population amounts to 312 278 people. The region is characterized by a higher than average level of GDV per capita is 411 000 rsd, and a higher unemployment rate of 18,3%. Near to this region is Šabac free zone which increases investment attractiveness. Variant 5 is environment-friendly with a low level of noise. The industrial attractiveness of this variant is reflected in the number of transported goods, which amounts to 1 102 168 t in 2016 and 30 398 used freight cars.

Variant 6 - Požarevac is located in the region of Braničevo. Its total area is 3857 km^2, and its population amounts to 183 625 people. This variant has a low unemployment rate of 11% and large industrial attractiveness. With 89 877 freight cars and 3 154 202 t transported cargo, this is the first of all the variants. The reason for this is a steel company in Smederevo, which uses two railway stations Radinac and Smederevo. Near to Smederevo passes European corridor E75 as well as state IA road and railway lines E70 and E85.

Variant 7 - Zaječar is located in the eastern part of the country in the region of Zaječar. The total area of the region is 3624 km^2 and the population is close to 119 967 people. GDV per capita is 314 000 rsd which is the second lowest value. The unemployment rate is 18,3%, but this variant has a big potential which is evident in a small number of logistic and transport companies and business subjects. The weakness of this variant is that both road and rail transport infrastructures are undeveloped; there are no state IA roads while there is only one railway line. Industrial attractiveness is good because of the mines in Bor and Majdanpek, and the total number of used freight cars is 58602 with 1 508 932 t. No free zones are in this region, either.

Variant 8 - Lapovo is the railway section which is located in the central part of Serbia in the region of Pomoravlje. The total area of this section is 2614 km^2 and its population amounts to 71 231 people. This section is located near two state IA roads, and railway corridors E70 and E85. The unemployment rate is huge (19%) and GDV per capita is 322 000 rsd. Investment attractiveness is average. Svilajnac free zone is located in this region. Number of used freight cars is 23562, and total volume of transported goods is 946 831 t.

Variant 9 - Niš is the railway section which covers the southern part of the country; it is the center of the region of Niš. The total population of the region is 376 319 people while the total area is 2728 km^2. This variant has the highest unemployment rate in Serbia 24,7%. GDV per capita is 348 000 rsd, and there are two free zones, Pirot and Vranje. With 14 faculties and higher schools this region attracts a lot of young people and offers them a great opportunity for education. Volume of loaded and unloaded cargo is very small amounting to 202 385 t loaded cargo and 499 144 t unloaded cargo. There are two road corridors and three important railway lines.

Variant 10 - Kraljevo section is located in the region of Raška. Population of this region is 309 258 people and the total area of the region is 3923 km^2. It is characterized by a low level of GDV per capita of 240 000 rsd. The region is attractive from the logistic and transport point of view. Its benefits are big industrial companies and centers located in Kragujevac as well as the existence of two free zones, Kruševac and Kragujevac. Total volume of transported goods in 2016 was 765 523 t. The weaknesses of this region are: a relatively poor condition of the transport infrastructure and serious social problems, including a very high unemployment rate of 21,6%. No highways in this region; the railway line in this variant is in a very bad condition. The region is considered to be environment-friendly because of national park Kopaonik and a low level of noise.

Variant 11 - Užice is the railway section which is located in western part of Serbia in the region of Zlatibor. This region has the largest area close to 6140 km^2. Total population is 286 549 people according to 2011 Population Census. Unemployment rate is 15% and GDV per capita is 369 000 rsd. The level of logistics and transport competitiveness is small which makes this region favorable only in terms of its location. Volume of transport is 1 051 473 t in 2016. Railway line Belgrade - Bar is in a very bad condition while a highway from Belgrade to Bar is under construction.

2.2. Formulation of criteria

C1 - availability of transport infrastructure (points). This maximized criterion is defined as number of state IA roads and international railway lines that pass through each region or section of the railway network. It measures region accessibility and transport efficiency for distributing goods. Also, it shows the condition of the road and rail infrastructure, taking into account water traffic in the case there is a port of terminal in the same region. The criterion is measured on the scale 1-6, whereby point 1 is given for a region with the lowest numbers of corridors and the worst infrastructure condition; point 6 is given, consequently, for the best region.

C2 - economic development (in thousand rsd). This maximized criterion is defined as an annual value of GDV per capita for each region in Serbia. Based on this criterion, we can measure the economic potential of each region, i.e. it can be determined whether an investor would like to invest in the given region or not.

C3 - investment attractiveness (points). This maximized criterion uses the measurement scale of 1 to 10 points for assessment of the overall level of attractiveness of the region. It is defined as a total number of free zones in regions and close to regions.

C4 - level of transport and logistics competitiveness (points). This minimized criterion is defined on the scale of 1 to 10 and it shows share of logistic and transport companies and business subjects in the region compared to their total number in Serbia. This criterion is minimized because any new investor shall first opt for the region with no competition whatsoever. The data necessary for this criterion were based on experience and interviews with experts.

C5 - transport and logistics attractiveness (t). This criterion measures the industry attractiveness of each region (max). It is expressed in total loaded and unloaded weight and transported by rail in domestic and international transport. Unfortunately, this criterion does not include data about transported goods by road. Also, given that statistics about transported containers and volume of transport goods in transit on the Serbian railway network are only conducted for the whole network, this data are not relevant and have not been taken into account when settling the problem.

C6 - unemployment rate (%). This minimized criterion is defined as a percentage of unemployed residents in the region. The level of social satisfaction affects the region. This criterion can be defined by the components such as opportunities for education and career development (number of state faculties and high schools).

C7 – environment-friendliness (points). This criterion (max) defines the environment-friendliness of each region. It includes an average daily and night level of noise in the centers of regions and the number of fully protected territories like national parks.

3. A multi criteria decision-making model

Existence of a multi criteria analysis means existence of more variants and criteria, of which some have to be minimized or maximized, where decisions are made in conflict conditions with the application of instruments that are more flexible than the mathematical method of pure optimization. Criteria that are to be maximized are in the profit criteria category although they may not necessarily be profit criteria. Similarly, the criteria that are to be minimized are in the cost criteria category. An ideal solution would maximize all the profit criteria and minimize all the cost criteria. Normally, this solution is not obtainable. In literature a large number of methods of multi criteria analysis can be found. However, not all the methods are equally theoretically and practically represented and important.

There are two types of multi criteria decision-making methods. One is compensatory and the other is a non-compensatory one. Compensatory methods are those which calculate the final solution by tolerating some of bad features of a variant under the condition that all other features of this variant are favorable. They actually permit „tradeoffs“ between attributes. A slight decline in one attribute is acceptable if it is compensated by some enhancement in one or more of other attributes. Some of these methods are (Dimitrijević, 2016):

- Simple Additive Weighting (SAW),
- Technique for Order Preference by Similarity to Ideal Solution (TOPSIS),
- Preference Ranking Organization METhod of Enrichment Evaluation (PROMETHEE),
- Analytic Hierarchy Process (AHP), and,
- Elimination Et Choix Traduisant la REalite (ELECTRE).

In addition to these conventional methods, the following methods are increasingly used:

- Evaluation based on Distance from Average Solution (EDAS),
- COmplex PRoportional Assessment (COPRAS),
- EVAluation of MIXed data (EVAMIX),
- Combinative Distance-based ASessment (CODAS),
- Weighted Aggregated Sum Product ASsessment (WASPAS), and,
- Multi-Attribute Border Approximation area Comparison (MABAC).

The presented model of macro location of the container terminal was done using three compensatory methods, i.e., TOPSIS, ELECTRE and MABAC, after which the results are compared by methods, and the most favorable variant was adopted for the macro location of the container terminal in Serbia. These methods are used because of their common use in solving this type of problem in addition to their simple use and easy definition of input parameters. Models are solved by Microsoft Excel, i.e. its addition for a multi criteria analysis which is called Sanna.

The aim of this paper is to compare 11 variants, which represent sections on the railway network, in order to find an optimal solution for the railroad container terminal location. These sections are district control offices, from which the management of a certain part of the railway network is performed. There are twelve sections on the Serbian railway network, but in this model section Belgrade is not used because there is already a railroad container terminal in Belgrade marshaling yard.

The criteria for comparison and selecting the best variant are described in the previous section and their values are shown in Table 1.

Table 1 The values of the criteria for the observed variants

Variants	C1	C2	C3	C4	C5	C6	C7
Subotica	2	429	2	6	441268	10,7	7,00
Novi Sad	2	608	1	10	890819	15,9	4,25
Zrenjanin	1	416	1	2	386899	14,1	8,00
Pančevo	2	384	0	9	1592715	20,9	3,75
Ruma	3	411	1	1	1102168	18,3	8,00
Požarevac	2	405	1	8	3154202	11,0	6,00
Zaječar	1	316	0	7	1508932	15,5	7,50
Lapovo	5	322	1	5	946831	19,0	5,50
Niš	6	348	2	10	701979	24,7	3,25
Kraljevo	1	245	2	4	765523	21,6	6,00
Užice	1	369	1	3	1051473	15,0	4,75

According to Table 1, each of the above criteria needs to be maximized, except for criterion 4 (level of transport and logistic competitiveness) and criterion 6 (unemployment rate, which is a logical conclusion because a lower unemployment rate is more favorable for the development of each region).

Data about transported goods by railway and number of freight cars (C5) are obtained thanks to the statistics from sector for freight transport „Serbian Railways“ and nowadays „Serbia Cargo“. Criterion 1, availability of transport infrastructure, is covered by the data from the Statistical Office of the Republic of Serbia and working timetable which we use for calculation the number of railway lines. Data from the Statistical Office of the Republic of Serbia are used for the following criteria: economic development (C2), investment attractiveness (C3) and unemployment rate (C6). Yearly statistic handbook from the Statistical Office of the Republic of Serbia and statistics of local government are used for defining criterion 7, environment-friendliness.

3.1. Criteria weighting

One of the main problems in multi criteria problems belong to criteria (Vuković, 2014). Taking into account that the weight of criteria can significantly affect the decision-making process, special attention must be paid to the criteria weighting, which, unfortunately, is not always present in problem-solving. For that reason we use two methods, the Delphi and the Entropy.

3.1.1. Delphi method

Weights of criteria are defined through interviews with experts in the field of railway transport. The final values of weight coefficients, based on experts' answers and using the Delphi method are given in Table 2.

Weight criteria are calculated through three iterations. Mean values, standard deviation and coefficient of variation for each criterion are made, and the obtained average value of the coefficient of variation is 12,81%. In the next section, models for location railroad container terminal using TOPSIS, ELECTRE and MABAC methods are shown.

Table 2 Weight of criteria by the Delphi method

Criteria	C1	C2 (thou. rsd)	C3	C4	C5 (t)	C6 (%)	C7
Normalized weights of criteria	0,27	0,13	0,10	0,12	0,23	0,08	0,07

3.1.2. Entropy method

Determination of the objective criteria weights according to the entropy method is based on the measurement of uncertain information contained in the decision matrix. It directly generates a set of weights for a given criteria based on mutual contrast of individual criteria values of variants for each criteria and then for all the criteria at the same time (Vuković, 2014).

Determination of objective criteria weights w_j according to the entropy method is carried out in three steps (Dimitrijević, 2016). Step One involves the normalization of criteria values of variants x_{ij} from decision matrix $X = \left\| x_{ij} \right\|_{mxn}$:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}, \forall i, j, \tag{1}$$

Entropy E_j of all variants is calculated as:

$$E_j = -\varepsilon \sum_{i=1}^{m} p_{ij} \ln p_{ij}, \forall j, \tag{2}$$

a constant ε, $\varepsilon = 1/\ln m$, is used to guarantee that $0 \le E_j \le 1$.
The degree of divergence d_j is calculated as:

$$d_j = 1 - E_j, \; j = 1, \ldots, n, \tag{3}$$

Since the value of d_j is a specific measure of the intensity of a criteria contrast C_j, the final relative weight of the criteria, in the third step of the method, can be obtained by simple additive normalization:

$$W_j = \frac{d_j}{\sum_{i=1}^{n} d_j}, \forall j, \tag{4}$$

Final values of weight coefficients, based on Entropy method are given in Table 3.

Table 3 Weight of criteria by the Entropy method

Criteria	C1	C2	C3	C4	C5	C6	C7
e_j	0,915	0,990	0,977	0,938	0,928	0,987	0,984
d_j	0,085	0,010	0,023	0,062	0,072	0,013	0,016

w_j	0,301	0,036	0,083	0,220	0,256	0,046	0,058

3.2. Application of the TOPSIS method

TOPSIS method is the one which compares variants based on their distance from a positive and negative ideal solution (Hwang & Yoon, 1981). The method is characterized by calculation of the weighted normalized decision matrix and formulation of the positive and negative ideal solution. Also, this method is based on the concept that the chosen variant should have the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution (Čičak, 2003). Weighted criterion matrix is shown in Table 4.

Table 4 Weighted criterion matrix with the Delphi method

Variants	C1	C2	C3	C4	C5	C6	C7	di+	di-	ci
Subotica	0,05692	0,04243	0,04714	0,02843	0,02258	0,03842	0,02448	0,18392	0,07634	0,29332
Novi Sad	0,05692	0,06013	0,02357	0,00000	0,04559	0,02415	0,01486	0,17721	0,06257	0,26095
Zrenjanin	0,02846	0,04114	0,02357	0,05687	0,01980	0,02909	0,02797	0,20338	0,07209	0,26171
Pančevo	0,05692	0,03798	0,00000	0,00711	0,08151	0,01043	0,01311	0,16217	0,07050	0,30300
Ruma	0,08538	0,04065	0,02357	0,06397	0,05641	0,01756	0,02797	0,14032	0,10041	0,41711
Požarevac	0,05692	0,04005	0,02357	0,01422	0,16143	0,03760	0,02098	0,12823	0,15291	0,54389
Zaječar	0,02846	0,03125	0,00000	0,02132	0,07723	0,02525	0,02623	0,17998	0,06826	0,27499
Lapovo	0,14230	0,03184	0,02357	0,03554	0,04846	0,01564	0,01923	0,12780	0,12635	0,49716
Niš	0,17076	0,03442	0,04714	0,00000	0,03593	0,00000	0,01136	0,14919	0,15112	0,50321
Kraljevo	0,02846	0,02423	0,04714	0,04265	0,03918	0,00851	0,02098	0,19463	0,06769	0,25803
Užice	0,02846	0,03649	0,02357	0,04976	0,05381	0,02662	0,01661	0,18280	0,07124	0,28042
Weights	0,27000	0,13000	0,10000	0,12000	0,23000	0,08000	0,07000			
Ideal	0,17076	0,06013	0,04714	0,06397	0,16143	0,03842	0,02797			
Basal	0,02846	0,02423	0,00000	0,00000	0,01980	0,00000	0,01136			

3.3. Application of the ELECTRE I method

Evaluation matrix for the ELECTRE method is the same as in the case with the TOPSIS method. The only difference is in the steps leading to the final solution. In this method, the variants are compared with each other as a couple; dominant and weak (or dominant and recessive) variants are identified and then weak and defeated alternatives are removed.

In the ELECTRE method, it is also necessary to define the concordance and discordance index which can be defined as the average values of all values c_{kl} and d_{kl} calculated according to the following equations (5) and (6) (Dimitrijević, 2016).

$$\bar{c} = \frac{\sum_{k=1}^{m}\sum_{s=1}^{m} c_{kl}}{m(m-1)}, \forall k \neq l, \tag{5}$$

$$\bar{d} = \frac{\sum_{k=1}^{m}\sum_{s=1}^{m} d_{kl}}{m(m-1)}, \forall k \neq l, \tag{6}$$

Based on value of concordance index *ckl* which represents domination of variant *Vk* relative to *Vl* based on weight criteria, we calculate preference threshold value ($\bar{c}$) and its value is 0,5596. Index where variant *Vk* is worse than variant *Vl* shows another index - discordance index *dkl*. In that case we calculate dispreference threshold value ($\bar{d}$) and its value is 0,7364.

3.4. Application of the MABAC method

The basic setting of the MABAC method is reflected in the definition of the distance of the criterion function of each of the observed alternatives from the approximate border area (Pamučar & Ćirović, 2015). Mathematical computation of this method is presented through six steps as follows (Božanić & Pamučar, 2016):

Step 1 Creating initial decision matrix *X*.

Step 2 Normalization of the elements of initial decision matrix *X*.

Step 3 Calculation of weighted matrix elements *V*.

Step 4 Border approximate area for each criterion is determined by expression:

$$g_i = \left(\prod_{j=1}^{m} v_{ij} \right)^{1/m}, \tag{7}$$

Matrix of approximate border areas *G* in both variants is given in Table 5.

Table 5 Matrix of approximate border areas

	Weight of criteria	C1	C2	C3	C4	C5	C6	C7
G	Delphi method	0,3342	0,1782	0,1507	0,1698	0,2873	0,1217	0,1051
	Entropy method	0,3726	0,0494	0,1251	0,3113	0,3198	0,0700	0,0871

Step 5 Calculation of the matrix elements distance from the border approximate area *Q*

Step 6 Ranking variant

Calculation of the criteria function values by variants is obtained as the sum of the distances of the variants from the border approximate areas q_i. Summing up the elements of matrix *Q* by rows gives the final values of the criteria function variants:

$$S_i = \sum_{j=1}^{n} q_{ij},\ j = 1,2,\ldots,n, i = 1,2,\ldots,m, \tag{8}$$

where n represents the number of criteria, and m represents the number of variants.

4. Results

Based on the previously defined input parameters and weight criteria, the results of the considered methods show which of the given variants is the best for the container terminal location.

4.1. Results obtained by TOPSIS method

Complete ranking of the variants using TOPSIS method is shown in Table 6. The best variant for micro location of the railroad container terminal in both the variants is variant v_6 railway section Požarevac.

Table 6 Complete order of variants with the TOPSIS method

Variant	Delphi method		Entropy method	
	R.U.V.	Rank	R.U.V.	Rank
Subotica	0,29332	6	0,26737	10
Novi Sad	0,26095	10	0,18773	11
Zrenjanin	0,26171	9	0,32506	6
Pančevo	0,30300	5	0,28655	8
Ruma	0,41711	4	0,48188	3
Požarevac	0,54389	1	0,81239	1
Zaječar	0,27499	8	0,27463	9
Lapovo	0,49716	3	0,50997	2
Niš	0,50321	2	0,47136	4
Kraljevo	0,25803	11	0,29766	7
Užice	0,28042	7	0,33564	5

4.2. Results obtained by the ELECTRE method

Using ELECTRE I method two variants are dominant and much better than the others. These variants are 5 and 6, railway sections Ruma and Požarevac. This method gave 40 preference relations of all the variants, and nine inefficient variants when using the Delphi method for weight criteria, and 42 preference relations when using the Entropy method. The final results are shown through aggregate dominance matrix in Table 7, where the first number means variant one, Delphi method and the second number means variant two, Entropy method.

Table 7 Aggregate dominance matrix

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11
V1	0/0	0/0	1/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
V2	1/1	0/0	1/1	0/0	0/0	0/0	0/0	0/0	1/1	1/1	0/0
V3	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
V4	0/0	1/1	0/0	0/0	0/0	0/0	1/1	0/0	1/1	1/1	1/1
V5	1/1	1/1	1/1	0/0	0/0	0/0	0/0	1/0	1/1	1/1	1/1
V6	0/0	1/1	1/1	1/1	0/0	0/0	1/1	1/0	1/1	1/1	1/1
V7	0/0	0/1	0/0	0/0	0/0	0/0	0/0	0/0	0/1	1/1	1/1
V8	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	0/1	1/1	0/0
V9	1/1	0/0	1/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
V10	0/0	0/0	1/1	0/0	0/0	0/0	0/0	0/0	1/1	0/0	0/0
V11	0/0	1/1	1/1	0/0	0	0	0	1/1	1/1	1/1	0/0

4.3. Results obtained by MABAC method

Ranking of all variants using MABAC method is shown in Table 8.

Table 8 Rank of the variants using MABAC method

Variant	Delphi method		Entropy method	
	S_i	Rank	S_i	Rank
Subotica	0,0659	5	0,0208	5
Novi Sad	-0,0062	7	-0,1098	11
Zrenjanin	0,0014	6	0,0116	6
Pančevo	-0,1007	11	-0,1066	10
Ruma	0,1564	2	0,2083	1
Požarevac	0,1897	1	0,1658	3
Zaječar	-0,0732	9	-0,0689	9
Lapovo	0,1254	3	0,1749	2
Niš	0,0860	4	0,0881	4
Kraljevo	-0,0774	10	-0,0268	8
Užice	-0,0266	8	0,0014	7

4.4. Comparison between methods

Based on the obtained results using the ELECTRE method, the best variants and only efficient variants in both the variants are v_5 and v_6 Požarevac and Ruma. By comparison the TOPSIS and MABAC method, in both variants, in three of four cases the best variant is v_6. Also, in all situations the first four variants are always the same, Požarevac (v_6), Ruma (v_5), Lapovo (v_8) and Niš (v_9). Rank of variants is given in Table 9.

Table 9 Comparison of TOPSIS and MABAC method

Variant	MABAC	TOPSIS	MABAC	TOPSIS
	Delphi method	Delphi method	Entropy method	Entropy method
Subotica	5	6	5	10
Novi Sad	7	10	11	11
Zrenjanin	6	9	6	6
Pančevo	11	5	10	8
Ruma	2	4	1	3
Požarevac	1	1	3	1
Zaječar	9	8	9	9
Lapovo	3	3	2	2
Niš	4	2	4	4
Kraljevo	10	11	8	7
Užice	8	7	7	5

General conclusion is that the railroad container terminal should be first located in the area of the railway section Požarevac, in the region of Braničevo.

The best region for location is Požarevac. This variant is high in terms of its volume of transported goods and high investment attractiveness. The transportation infrastructure of this region represents an average level, while the unemployment rate is very low. A clear advantage of this region is great connectivity with other regions and the existence of main road and rail corridors.

By looking at the complete range of variants, with all the methods, and variants of weighting criteria it can be concluded that those with a high volume of transport and accessibility of infrastructure can be potential locations. Regions (railway sections) like Kraljevo or Zrenjanin should not be taken into further consideration because they would not justify terminal existence by any parameter.

5. Conclusion

A railroad container terminal location problem, like any other location problem, is a very complex task, which requires a detailed analysis of different segments and parameters. Using multi criteria decision-making methods, the model presented in this paper was developed. The macro location of the terminal is defined, which represents the first phase of determining its potential location.

The proposed methodology has a universal character and can be applied to different types of location models, both for the selection of the location of railroad terminals, as well as for other railway logistics location problems.

A further model development is based on a more detailed analysis of all input parameters. In particular, it is necessary to analyze the flows of goods more closely, including the volume of transported goods from road or water transport. Also, the analysis of transport infrastructure can be expanded, using water transport and its impact on potential locations. In addition, an analysis of environmental parameters as well as transport safety in each region can be approached in more detail.

Market analysis, investment attractiveness and other economic criteria are another direction in the development of the model. The model can be improved using more relevant data for weight criteria, using some other methods for its calculation. For a more detailed analysis, and comparison of the results, other methods such as ELECTRE III/IV, SAW and some newer ones can be applied.

The next step in our research and development is the formulation and solving of the second phase of the observed problem, that is, micro location of the railroad container terminal. This approach requires an analysis of the micro plan, within the region, in order to find the most suitable field for the location of the railroad container terminal.

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SUPPLIER SELECTION USING THE ROUGH BWM-MAIRCA MODEL: A CASE STUDY IN PHARMACEUTICAL SUPPLYING IN LIBYA

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Abstract: *The quality of health system in Libya has witnessed a considerable decline since the revolution in 2011. One of the major problems this sector is facing is the loss of control over supply medicines and pharmaceutical equipments from international suppliers for both public and private sectors. In order to take the right decision and select the best medical suppliers among the available ones, many criteria have to be considered and tested. This paper presents a multiple criteria decision-making analysis using modified BWM (Best-Worst method) and MAIRCA (Multi-Attribute Ideal-Real Comparative Analysis) methods. In the present case study five criteria and three suppliers are identified for supplier selection. The results of the study show that cost comes first, followed by quality as the second and company profile as the third relevant criterion. The model was tested and validated on a study of the optimal selection of supplier*.

Key Words: *Supplier Selection, Multi-criteria Decision-making, Rough Numbers, BWM, MAIRCA.*

1 Introduction

Selecting and managing medicines and pharmaceutical equipment supplies for primary health care services have a significant impact on the quality of patient care and represent a high proportion of health care costs. In developing countries health services need to choose appropriate supplies, equipment and drugs, in order to meet priority health needs and avoid wasting their limited resources. Items can be inappropriate because they are technically unsuitable or incompatible with existing equipment, if spare parts are not available, or, because staff have not been trained to use them (Kaur et al., 2001). Recently, supplier evaluation and selection have received more attention from various researchers in the literature (Mardani et al.,

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2016; De Boer et al., 2001; Govidan et al., 2015; Chai et al., 2013; Prakash et al., 2015; Abdulshahed et al., 2017; Badi et al., 2018; Stević et al., 2017 a). Supplier selection is a multi-criteria problem which includes both quantitative and qualitative factors (Liang et al., 2013). Generally, the criterion for supplier selection is highly dependent on individual industries and companies. Therefore, different companies have different management strategies, enterprise culture and competitiveness. Furthermore, company background can make a huge difference and can impact supplier selection. Thus, the identification of supplier selection criteria is largely requiring the domain expert's assessment and judgment. To select the best supplier, it is necessary to make a trade-off between these qualitative and quantitative factors some of which may be in conflict (Ghodsypour & O'Brien, 1998). The traditional supplier selection methods are often based on the quoted price, which ignores significant direct and indirect costs associated with quality, delivery, and service cost of purchased materials; however, uncertainty is present because the future can never be exactly predicted.

The selection of the best supplier is done based on quoted price and considering all the possibilities of the analysis, but there is always uncertainty about indirect costs associated with quality, delivery time, and the like. One of the key problems in the supplier selection is to find the best supplier among several alternatives according to various criteria, such as service, cost, risk, and others. After identifying the criteria, a systematic methodology is required to integrate experts' assessments in order to find the best supplier. At present, various methods have been used for the supplier selection, such as the analytic network process (ANP) and the analytical hierarchy process (AHP) (Porras-Alvarado et al., 2017). AHP is a common multi-criteria decision-making method; it is developed by Saaty (Saaty, 1979; Saaty, 1990) to provide a flexible and easily understood way of analyzing complex problems. The method breaks a complex problem into hierarchy or levels, and then makes comparisons among all possible pairs in a matrix to give a weight for each factor and a consistency ratio.

Libya began privatizing the pharmaceutical system in 2003. Pharmaceutical supplies were previously provided to both public and private sectors by the National Company of Pharmaceutical Industry (NCPI), but drug companies are also permitted to market and supply their products to both public and private health sectors through local agencies. In 2009, over 300 international pharmaceutical manufacturers from Europe, Asia, and the Middle East were registered as permitted drug suppliers for Libya (Alsageer, 2013).

All the drugs consumed in Libya are imported except few items, which are manufactured locally. The headquarters of the NCPI until 2003 was responsible for all drug manufacture and imports in Libya. Its branches are the channels of drugs distribution for governmental hospitals, private pharmacies, and clinics (Khalifa et al., 2017).

From 2004 till date the Libyan Secretariat of Health, by executing a public tender through Medical Supply Organization (MSO), has been responsible for purchasing and distributing drugs to public hospitals and clinics. Worth noting is that, on sporadic intervals, the budget has been allocated to the major public hospitals to locally purchase their own general drug demands. However, since 2011 (post-17th February 2011 revolution) MSO has lost its control on importing medicines due to receiving many drugs as donations from different international sources without acceptable level of coordination (Zhai et al., 2008); this has resulted in the supply of pharmaceuticals and medical equipment growing considerably in recent years. For instance, in Misrata (the third-largest city in Libya) the number of companies operating in the field of medical supply exceeded 170 companies, and more than 425 companies in Tripoli (Capital city). The items that are supplied vary but the most common drugs are capsules, injections, ointments, inhalants, solutions, etc.; these drugs and materials are supplied from several countries, including Arab (e.g. Egypt, Morocco, Algeria, UAE, and Jordan), European (e.g. Germany, Switzerland, and Britain), and Asian ones (e.g. India, China, and Malaysia) as well as America. The suppliers in each of these countries have some special characteristics distinguishing them from others. The closest Arab countries have the ability to speed supply and hence the flexibility in providing these drugs more quickly than the rest. On the other hand, products coming from European countries are of better quality, but their prices are higher compared to competitors from other countries. Thus, to make informed choices about what to buy and what to select among available suppliers, clear criteria for selection remain important, and efforts should be made to make suitable decision support tools for right decision-making.

In this paper, a Rough BWM-MAIRCA model for selection of the best supplier is proposed. The presented model is used for the analysis of the supplier selection process in pharmaceutical supplies in Libya. In this case study there are three suppliers with high medicine supplies to Libya. In order to maintain confidentiality of the supplier, we have denoted the given suppliers as A, B, and C.

2. Rough numbers

In group decision-making problems, the priorities are defined with respect to multi-expert's aggregated decision and process subjective evaluation of the expert's decisions. Rough numbers consisting of upper, lower and boundary interval, respectively, determine intervals of their evaluations without requiring additional information by relying only on original data (Zhai et al., 2008). Hence, the obtained expert decision-makers (DMs) perceptions objectively present and improve their decision-making process. According to Zhai *et al*. (2010), the definition of rough number is shown below.

Let's U be a universe containing all objects and X be a random object from U. Then we assume that there exists a set built with k classes representing DMs preferences, $R=(J_1, J_2, ..., J_k)$ with condition $J_1 < J_2 <, ..., < J_k$. Then, $\forall\ X \in U,\ J_q \in R,\ 1 \le q \le k$ lower approximation $\underline{Apr}(J_q)$, upper approximation $\overline{Apr}(J_q)$ and boundary interval $Bnd(J_q)$ are determined, respectively, as follows:

$$\underline{Apr}(J_q) = \cup\left\{X \in U / R(X) \le J_q\right\} \tag{1}$$

$$\overline{Apr}(J_q) = \cup\left\{X \in U / R(X) \ge J_q\right\} \tag{2}$$

$$\begin{aligned} Bnd(J_q) &= \cup\left\{X \in U / R(X) \ne J_q\right\} \\ &= \left\{X \in U / R(X) > J_q\right\} \cup \left\{X \in U / R(X) < J_q\right\} \end{aligned} \tag{3}$$

The object can be presented with rough number (RN) defined with lower limit $\underline{Lim}(J_q)$ and upper limit $\overline{Lim}(J_q)$, respectively:

$$\underline{Lim}(J_q) = \frac{1}{M_L} \sum R(X) \big| X \in \underline{Apr}(J_q) \quad (4)$$

$$\overline{Lim}(J_q) = \frac{1}{M_U} \sum R(X) \big| X \in \overline{Apr}(J_q) \quad (5)$$

where M_L and M_U represent the sum of objects contained in the lower and upper object approximation of J_q, respectively. For object J_q, rough boundary interval $\left(IRBnd(J_q)\right)$ presents an interval between the lower and the upper limits as:

$$IRBnd(J_q) = \overline{Lim}(J_q) - \underline{Lim}(J_q) \quad (6)$$

The rough boundary interval presents measure of uncertainty. The bigger $IRBnd(J_q)$ value shows that variations in the experts' preferences exist, while smaller values show that the experts have harmonized opinions without major deviations.

In $IRBnd(J_q)$ are comprised all the objects between lower limit $\underline{Lim}(J_q)$ and upper limit $\overline{Lim}(J_q)$ of rough number $RN(J_q)$. That means that $RN(J_q)$ can be presented using $\underline{Lim}(J_q)$ and $\overline{Lim}(J_q)$.

$$RN(J_q) = \left[\underline{Lim}(J_q), \overline{Lim}(J_q)\right] \quad (7)$$

Since rough numbers belong to the group of interval numbers, arithmetic operations applied in interval numbers are also appropriate for rough numbers (Zhu et al., 2015).

3. Rough based Best-Worst method (R-BWM)

In order to take into account the subjectivity that appears in group decision-making more comprehensively, in this study a modification of the Best-Worst method (BWM) is carried out using rough numbers (RN). The application of RN eliminates the necessity for additional information when determining uncertain intervals of numbers. In this way, the quality of the existing data is retained in group decision-making and the perception of experts is expressed in an objective way in aggregated Best-to-Others (BO) and Others-to-Worst (OW) matrices. Since the method is very recent, the literature so far only has the traditional (crisp) BWM (Rezaei, 2015; Rezaei et al., 2015; Rezaei, 2016; Ren et al., 2017) and modification of the BWM carried out using fuzzy numbers (Guo and Zhao, 2017). Also, Stević et al., (Stević et al., 2017b) used rough BWM to solve an internal transportation problem of the paper manufacturing company. The approach in this section introduces RN which enables a more objective expert evaluation of criteria in a subjective environment. The proposed modification of the BWM using RN (R-BWM) makes it possible to take into account the doubts that occur during the expert evaluation of criteria. R-BWM makes it possible to bridge the existing gap in the BWM methodology with the application of a novel approach in the treatment of uncertainty based on RN. The following section presents the algorithm for the R-BWM that includes the following steps:

Step 1 Determining a set of evaluation criteria. This starts from the assumption that the process of decision-making involves *m* experts. In this step, the experts consider a set of evaluation criteria and select the final one $C=\{c_1,c_2,...c_n\}$, where *n* represents the total number of criteria.

Step 2 Determining the most significant (most influential) and worst (least significant) criteria. The experts decide on the best and the worst criteria from the set of criteria $C=\{c_1,c_2,...c_n\}$. If the experts decide on two or more criteria as the best, or worst, the best and worst criteria are selected arbitrarily.

Step 3 Determining the preferences of the most significant (most influential) criteria (*B*) from set C over the remaining criteria from the defined set. Under the assumption that there are *m* experts and *n* criteria under consideration, each expert should determine the degree of influence of best criterion *B* on criteria *j* ($j=1,2,...,n$). This is how we obtain a comparison between the best criterion and the others. The preference of criterion *B* compared to the *j*-th criterion defined by the *e*-th expert is denoted with a_{Bj}^e ($j=1,2,...,n; 1\le e\le m$). The value of each pair a_{Bj}^e takes a value from the predefined scale in interval $a_{Bj}^e \in [1,9]$. As a result a Best-to-Others (BO) vector is obtained:

$$A_B^e=(a_{B1}^e,\ a_{B2}^e\ ,...,\ a_{Bn}^e);\ \ 1\le e\le m \tag{8}$$

where a_{Bj}^e represents the influence (preference) of best criterion *B* over criterion *j,* whereby $a_{BB}^e=1$. This is how we obtain BO matrices A_B^1, A_B^2, ..., A_B^m for each expert.

Step 4 Determining the preferences of the criteria from set C over the worst criterion (*W*) from the defined set. Each expert should determine the degree of influence of criterion *j* ($j=1,2,...,n$) in relation to criterion *W*. The preference of criterion *j* in relation to criterion *W* defined by the *e*-th expert is denoted as a_{jW}^e ($j=1,2,...,n; 1\le e\le m$). The value of each pair a_{jW}^e takes a value from the predefined scale in interval $a_{jW}^e \in [1,9]$. As a result an Others-to-Worst (OW) vector is obtained:

$$A_W^e=(a_{1W}^e,\ a_{2W}^e\ ,...,\ a_{nW}^e);\ \ 1\le e\le m \tag{9}$$

where a_{jW}^e represents the influence (preference) of criterion *j* in relation to criterion *W*, whereby $a_{WW}^e=1$. This is how we obtain OW matrices A_W^1, A_W^2, ..., A_W^m for each expert.

Step 5 Determining the rough BO matrix for the average answers of the experts. Based on the BO matrices of the experts' answers $A_B^e=\left[a_{Bj}^e\right]_{1\times n}$, we form matrices of the aggregated sequences of experts A_B^{*e}

$$A_B^{*e}=\left[a_{B1}^m,a_{B1}^2,\ldots,a_{B1}^k;\quad a_{B2}^1;a_{B2}^2;\ldots;a_{B2}^m,\quad \ldots,\quad a_{Bn}^1;a_{Bn}^2,\ldots,a_{Bn}^m\right]_{1\times n} \tag{10}$$

where $a_{Bj}^{e}=\left\{a_{Bj}^{1},a_{Bj}^{2},\ldots,a_{Bn}^{m}\right\}$ represents sequences by means of which the relative significance of criterion *B* is described in relation to criterion *j*. Using equations (1)-(7) each sequence a_{Bj}^{e} is transformed into rough sequence $RN\left(a_{Bj}^{e}\right)=\left[\underline{Lim}(a_{Bj}^{e}),\ \overline{Lim}(a_{Bj}^{e})\right]$, where $\underline{Lim}(a_{Bj}^{e})$ represent the lower limits, and $\overline{Lim}(a_{Bj}^{e})$ the upper limit of rough sequence $RN\left(a_{Bj}^{e}\right)$, respectively.

So for sequence $RN\left(a_{Bj}^{e}\right)$ we obtain a BO matrix A_B^{*1}, A_B^{*2}, ..., A_B^{*m}. By applying equation (11), we obtain the average rough sequence of the BO matrix

$$RN(\overline{a}_{Bj})=RN(a_{Bj}^{1},a_{Bj}^{2},...,a_{Bj}^{e})=\begin{cases}\overline{a}_{Bj}^{L}=\dfrac{1}{m}\sum\limits_{e=1}^{m}a_{Bj}^{eL}\\ \overline{a}_{Bj}^{U}=\dfrac{1}{m}\sum\limits_{e=1}^{m}a_{Bj}^{eU}\end{cases} \tag{11}$$

where *e* represents the *e*-th expert ($e=1,2,...,m$), while $RN\left(a_{Bj}^{e}\right)$ represents the rough sequences. We thus obtain the averaged rough BO matrix of average responses $\overline{A}_B$

$$\overline{A}_B=\left[\overline{a}_{B1},\overline{a}_{B2},...,\overline{a}_{Bn}\right]_{1\times n} \tag{12}$$

Step 6 Determining the rough OW matrix of average expert responses. Based on the WO matrices of the expert responses $A_W^{e}=\left[a_{jW}^{e}\right]_{1\times n}$, as with the rough BO matrices, for each element a_{jW}^{e} we form matrices of the aggregated sequences of the experts A_W^{*e}

$$A_W^{*e}=\left[a_{1W}^{1},a_{1W}^{2},\ldots,a_{1W}^{m};\quad a_{2W}^{1};a_{2W}^{2};\ldots;a_{2W}^{m},\quad\ldots,\quad a_{nW}^{1};a_{nW}^{2},\ldots,a_{nW}^{m}\right]_{1\times n} \tag{13}$$

where $a_{jW}^{e}=\left\{a_{jW}^{1},a_{jW}^{2},\ldots,a_{nW}^{m}\right\}$ represents sequence with which the relative significance of criterion *j* is described in relation to criterion *W*.

As in step 5, using (1)-(7), sequences a_{jW}^{e} are transformed into rough sequences $RN\left(a_{jW}^{e}\right)=\left[\underline{Lim}(a_{jW}^{e}),\ \overline{Lim}(a_{jW}^{e})\right]$. Thus for each rough sequence of expert *e* ($1\le e\le m$) a rough BO matrix is formed. Equation (14) is used to average the rough sequences of the OW matrix of the experts to obtain an averaged rough OW matrix.

$$RN(\overline{a}_{jW})=RN(a_{jW}^{1},a_{jW}^{2},...,a_{jW}^{e})=\begin{cases}\overline{a}_{jW}^{L}=\dfrac{1}{m}\sum\limits_{e=1}^{m}a_{jW}^{eL}\\ \overline{a}_{jW}^{U}=\dfrac{1}{m}\sum\limits_{e=1}^{m}a_{jW}^{eU}\end{cases} \tag{14}$$

Where *e* represents the *e*-th expert ($e=1,2,...,m$), while $RN(a_{jW})$ represents the rough sequences. Thus, we obtain the averaged rough OW matrix of average responses $\overline{A}_W$

$$\overline{A}_W=\left[\overline{a}_{1W},\overline{a}_{2W},...,\overline{a}_{nW}\right]_{1\times n} \tag{15}$$

Step 7 Calculation of the optimal rough values of the weight coefficients of criteria $[RN(w_1),RN(w_2),...,RN(w_n)]$ from set C. The goal is to determine the optimal value of the evaluation criteria, which should satisfy the condition that the difference in the maximum absolute values (16)

$$\left|\frac{RN(w_B)}{RN(w_j)}-RN(a_{Bj})\right| \quad and \quad \left|\frac{RN(w_j)}{RN(w_W)}-RN(w_{jW})\right| \tag{16}$$

for each value of *j* is minimized. In order to meet these conditions, the solution that satisfies the maximum differences according to the absolute value $\left|\frac{RN(w_B)}{RN(w_j)}-RN(a_{Bj})\right|$ and $\left|\frac{RN(w_j)}{RN(w_W)}-RN(w_{jW})\right|$ should be minimized for all values of *j*. For all values of the interval rough weight coefficients of the criteria $RN(w_j)=\left[\underline{Lim}(w_j),\ \overline{Lim}(w_j)\right]=[w_j^L,w_j^U]$ the condition is met that $0\le w_j^L\le w_j^U\le 1$ for each evaluation criterion $c_j\in C$. Weight coefficient w_j belongs to interval $[w_j^L,w_j^U]$, that is $w_j^L\le w_j^U$ for each value $j=1,2,...,n$. On this basis we can conclude that in the case of the rough of the weight coefficients of the criteria the condition is met that $\sum_{j=1}^{n}w_j^L\le 1$ and $\sum_{j=1}^{n}w_j^U\ge 1$. In this way the condition is met that the weight coefficients are found at interval $w_j\in[0,1],\ \ (j=1,2,...,n)$ and that $\sum_{j=1}^{n}w_j=1.$

The previously defined limits will be presented in the following min-max model:

$$\min\max_j\left\{\left|\frac{RN(w_B)}{RN(w_j)}-RN(a_{Bj})\right|,\left|\frac{RN(w_j)}{RN(w_W)}-RN(w_{jW})\right|\right\}$$

$$s.t. \tag{17}$$

$$\begin{cases}\sum_{j=1}^{n}w_j^L\le 1\\ \sum_{j=1}^{n}w_j^U\ge 1;\\ w_j^L\le w_j^U,\ \ \forall j=1,2,...,n\\ w_j^L,w_j^U\ge 0,\ \ \forall j=1,2,...,n\end{cases}$$

Where $RN(w_j)=\left[\underline{Lim}(w_j),\ \overline{Lim}(w_j)\right]=[w_j^L,w_j^U]$ is the rough weight coefficient of a criterion.

Model (17) is equivalent to the following model:

$$\min \xi$$
$$s.t.$$
$$\begin{cases} \left| \dfrac{w_B^L}{w_j^U} - \overline{a}_{Bj}^U \right| \le \xi; \ \left| \dfrac{w_B^U}{w_j^L} - \overline{a}_{Bj}^L \right| \le \xi; \\ \left| \dfrac{w_j^L}{w_W^U} - \overline{a}_{jW}^U \right| \le \xi; \ \left| \dfrac{w_j^U}{w_W^L} - \overline{a}_{jW}^L \right| \le \xi; \\ \sum_{j=1}^{n} w_j^L \le 1; \\ \sum_{j=1}^{n} w_j^U \ge 1; \\ w_j^L \le w_j^U, \ \ \forall j = 1,2,...,n \\ w_j^L, w_j^U \ge 0, \ \ \forall j = 1,2,...,n \end{cases} \tag{18}$$

where $RN(w_j) = [w_j^L, w_j^U]$ represents the optimum values of the weight coefficients, $RN(w_B) = [w_B^L, w_B^U]$ and $RN(w_W) = [w_W^L, w_W^U]$ represents the weight coefficients of the best and worst criterion, respectively, while $RN(\overline{a}_{jW}) = \left[\overline{a}_j^L, \overline{a}_j^U \right]$ and $RN(\overline{a}_{Bj}) = \left[\overline{a}_{Bj}^L, \overline{a}_{Bj}^U \right]$, respectively, represent the values from the average rough OW and rough BO matrices (see equations (12) and (15)).

By solving model (18) we obtain the optimal values of the weight coefficients of evaluation criteria $[RN(w_1), RN(w_2),..., RN(w_n)]$ and ξ^*.

The consistency ratio of the rough BWM

The consistency ratio is a very important indicator by means of which we check the consistency of the pair wise comparison of the criteria in the rough BO and rough OW matrices.

Definition 1 Comparison of the criteria is consistent when condition $RN(a_{Bj}) \times RN(a_{jW}) = RN(a_{BW})$ is fulfilled for all criteria *j*, where $RN(a_{Bj})$, $RN(a_{jW})$ and $RN(a_{BW})$, respectively, represent the preference of the best criterion over criterion *j*, the preference of criterion *j* over the worst criterion, and the preference of the best criterion over the worst criterion.

However, when comparing the criteria it can happen that some pairs of criteria *j* are not completely consistent. Therefore, the next section defines consistency ratio (*CR*), which gives us information on the consistency of the comparison between the rough BO and the rough OW matrices. In order to show how *CR* is determined we start from calculation of the minimum consistency when comparing the criteria, which is explained in the following section.

As previously indicated, the pair wise comparison of the criteria is carried out based on a predefined scale in which the highest value is 9 or any other maximum from a scale defined by the decision-maker. The consistency of the comparison decreases when $RN(a_{Bj})\times RN(a_{jW})$ is less or greater than $RN(a_{BW})$, that is when $RN(a_{Bj})\times RN(a_{jW})\neq RN(a_{BW})$. It is clear that the greatest inequality occurs when $RN(a_{Bj})$ and $RN(a_{jW})$ have the maximum values that are equal to $RN(a_{BW})$, which continues to affect the value of ξ. Based on these relationships we can conclude that

$$\left[RN(w_B)/RN(w_j)\right]\times\left[RN(w_j)/RN(w_W)\right]=RN(w_B)/RN(w_W) \quad (19)$$

As the largest inequality occurs when $RN(a_{Bj})$ and $RN(a_{jW})$ have their maximum values, then we need to subtract the value ξ from $RN(a_{Bj})$ and $RN(a_{jW})$ and add $RN(a_{BW})$. Thus we obtain equation (20)

$$\left[RN(a_{Bj})-\xi\right]\times\left[RN(a_{jW})-\xi\right]=\left[RN(a_{BW})+\xi\right] \quad (20)$$

Since for the minimum consistency $RN(a_{Bj})=RN(a_{jW})=RN(a_{BW})$ applies, we present equation (20) as

$$\left[RN(a_{BW})-\xi\right]\times\left[RN(a_{BW})-\xi\right]=\left[RN(a_{BW})+\xi\right] \;\Rightarrow$$
$$\xi^2-\left[1-2RN(a_{BW})\right]\xi+\left[RN(a_{BW})^2-RN(a_{BW})\right]=0$$

Since we are using rough numbers, and if there is no consensus between the DM on their preferences of the best criterion over the worst criterion, then $RN(a_{BW})$ will not have a crisp value but we will use $RN(\overline{a}_{BW})=\left[\overline{a}_{BW}^{L},\overline{a}_{BW}^{U}\right]$. Since for RN condition $\overline{a}_{BW}^{L}\leq\overline{a}_{BW}^{U}$ applies, we can conclude that the preference of the best criterion over the worst cannot be greater than $\overline{a}_{BW}^{U}$. In this case, when we use upper limit $\overline{a}_{BW}^{U}$ for determining the value of *CI*, then all the values connected with $RN(\overline{a}_{BW})$ can use the *CI* obtained for calculating the value of *CR*. We can conclude this from the fact that the consistency index which corresponds to $\overline{a}_{BW}^{U}$ has the highest value in interval $\left[\overline{a}_{BW}^{L},\overline{a}_{BW}^{U}\right]$. Based on this conclusion we can transform equation (21) in the following way:

$$\xi^2-\left(1+2\overline{a}_{BW}^{U}\right)\xi+\left({\overline{a}_{BW}^{U}}^{2}-\overline{a}_{BW}^{U}\right)=0 \quad (22)$$

By solving equation (22) for the different values of $\overline{a}_{BW}^{U}$ we can determine the maximum possible values of ξ ,which is the *CI* for the R-BW method. Since we obtain the values of $RN(\overline{a}_{BW})$, i.e. $\overline{a}_{BW}^{U}$ on the basis of the aggregated decisions of the DM, and these change the IVFRN interval, it is not possible to predefine the values of ξ. The values of ξ depend on uncertainties in the decisions, since uncertainties change the RN interval. As explained in the algorithm for the R-BW method, interval $\left[a_{BW}^{L},a_{BW}^{U}\right]$ changes depending on uncertainties in evaluating the criteria.

If the DM agree on their preference for the best criterion over the worst then a_{BW} represents the crisp value of a_{BW} from the defined scale and then the maximum values of ξ apply for different values of $a_{BW} \in \{1,2,...,9\}$, Table 1.

Table1 Values of the consistency index (CI)

a_{BW}	1	2	3	4	5	6	7	8	9
CI ($\max\xi$)	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

In Table 1 values a_{BW} are taken from the scale $\{1,2,...,9\}$ which is defined in Rezaei (2015). On the basis of CI (Table 1) we obtain consistency ratio (CR)

$$CR = \frac{\xi^*}{CI} \tag{23}$$

CR takes values from interval $[0,1]$, where the values closer to zero show high consistency while the values of CR closer to one show low consistency.

4. Rough MAIRCA method

The basic assumption of the MAIRCA method is to determine the gap between ideal and empirical weights. The summation of the gaps for each criterion gives the total gap for every observed alternative. Finally, alternatives will be ranked, and the best ranked alternative is the one with the smallest value of the total gap. The MAIRCA method shall be carried out in 6 steps (Pamučar et al., 2014; Gigović et al., 2016):

Step 1 Formation of the initial decision matrix (Y). The first step includes evaluation of l alternatives per n criteria. Based on response matrices $Y_k=[y^k_{ij}]_{l\times n}$by all m experts we obtain matrix Y^* of aggregated sequences of experts

$$Y^* = \begin{bmatrix} y_{11}^1, y_{11}^2, \ldots, y_{11}^m & y_{12}^1; y_{12}^2; \ldots; y_{12}^m, & \ldots, & y_{1n}^1; y_{1n}^2, \ldots, y_{1n}^m \\ y_{21}^1, y_{21}^2, \ldots, y_{21}^m & y_{22}^1; y_{22}^2; \ldots; y_{22}^m, & \ldots, & y_{2n}^1; y_{2n}^2, \ldots, y_{2n}^m \\ \ldots & \ldots & \ldots & \ldots \\ y_{n1}^1, y_{n1}^2, \ldots, y_{n1}^m & y_{n2}^1; y_{n2}^2; \ldots; y_{n2}^m, & \ldots, & y_{nn}^1; y_{nn}^2, \ldots, y_{nn}^m \end{bmatrix} \tag{24}$$

where $y_{ij} = \{y_{ij}^1, y_{ij}^2, \ldots, y_{ij}^m\}$ denote sequences for describing relative importance of criterion i in relation to alternative j. By applying equations (1) through (7), sequences y_{ij}^m are transformed into rough sequences $RN\left(y_{ij}^m\right)$. Consequently, rough matrices Y^{1L}, Y^{2L}, ...,Y^{mL} will be obtained for rough sequence $RN\left(y_{ij}^m\right)$, where m denotes the number of experts. Therefore, for the group of rough matrices Y^1, Y^2, ...,Y^m we obtain rough sequences

$$RN\left(y_{ij}\right) = \left\{\left[\underline{Lim}(y_{ij}^1), \overline{Lim}(y_{ij}^1)\right], \left[\underline{Lim}(y_{ij}^2), \overline{Lim}(y_{ij}^2)\right], \ldots, \left[\underline{Lim}(y_{ij}^m), \overline{Lim}(y_{ij}^m)\right]\right\}.$$

By applying equation (25), we obtain mean rough sequences

$$RN(y_{ij}) = RN(y_{ij}^1, y_{ij}^2, ..., y_{ij}^e) = \begin{cases} y_{ij}^L = \frac{1}{m}\sum_{e=1}^{m} y_{ij}^{eL} \\ y_{ij}^U = \frac{1}{m}\sum_{e=1}^{m} y_{ij}^{eU} \end{cases} \tag{25}$$

Where *e* denotes *e*-th expert ($e = 1, 2, ..., m$), $RN(y_{ij})$ denotes rough number $RN(y_{ij}) = \left[\underline{Lim}(y_{ij}), \overline{Lim}(y_{ij})\right]$.

In such a way, rough vectors $A_i = \left(RN\left(y_{i1}\right), RN\left(y_{i2}\right), ..., RN\left(y_{in}\right)\right)$ of mean initial decision matrix is obtained, where $RN(y_{ij}) = \left[\underline{Lim}(y_{ij}), \overline{Lim}(y_{ij})\right] = \left[y_{ij}^L, y_{ij}^U\right]$ denotes value of i-th alternative as per j-th criterion ($i = 1, 2, ..., l;\ j = 1, 2, ..., n$).

$$Y = \begin{array}{c} \\ A_1 \\ A_2 \\ ... \\ A_l \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & ... & C_n \end{array} \\ \begin{bmatrix} RN(y_{11}) & RN(y_{12}) & ... & RN(y_{1n}) \\ RN(y_{21}) & RN(y_{22}) & & RN(y_{2n}) \\ ... & ... & ... & ... \\ RN(y_{l1}) & RN(y_{l2}) & ... & RN(y_{ln}) \end{bmatrix}_{l \times n} \end{array} \tag{26}$$

Where *l* denotes the number of alternatives, and *n* denotes total sum of criteria.

*Step 2*Define preferences according to selection of alternatives P_{A_i}. When selecting alternative, the decision maker (DM) is neutral, i.e. does not have preferences to any of the proposed alternatives. Since any alternative can be chosen with equal probability, preference per selection of one of *l* possible alternatives is as follows:

$$P_{A_i} = \frac{1}{l};\ \sum_{i=1}^{l} P_{A_i} = 1,\ i = 1, 2, ..., l \tag{27}$$

Where *l* denotes the number of alternatives.

Step 3 Calculate theoretical evaluation matrix elements (T_p). Theoretical evaluation matrix (T_p) is developed in $l\ x\ n$ format (*l* denotes the number of alternatives, *n* denotes the number of criteria). Theoretical evaluation matrix elements ($RN(t_{pij})$) are calculated as the multiplication of the preferences according to alternatives P_{A_i} and criteria weights ($RN(w_i),\ i = 1, 2, ..., n$) obtained by application of R-BWM.

$$T_p = \begin{array}{c} \\ P_{A_1} \\ P_{A_2} \\ ... \\ P_{A_l} \end{array} \begin{array}{c} \begin{array}{cccc} RN(w_1) & RN(w_2) & ... & RN(w_n) \end{array} \\ \begin{bmatrix} RN(t_{p11}) & RN(t_{p12}) & ... & RN(t_{p1n}) \\ RN(t_{p21}) & RN(t_{p22}) & & RN(t_{p2n}) \\ ... & ... & ... & ... \\ RN(t_{pl1}) & RN(t_{pl2}) & ... & RN(t_{pln}) \end{bmatrix}_{l \times n} \end{array} \tag{28}$$

where P_{A_i} denotes preferences per selection of alternatives, $RN(w_i)$ weight coefficients of evaluation criteria, and $RN(t_{pij})$ theoretical assessment of alternative for the analyzed evaluation criterion. Elements constituting matrix T_p will be then defined by applying equation (29)

$$t_{pij} = P_{Ai} \cdot RN(w_i) = P_{Ai} \cdot \left[w_i^L, w_i^U \right] \tag{29}$$

Since DM is neutral to the initial selection of alternatives, all preferences (P_{A_i}) are equal for all alternatives. Since preferences (P_{A_i}) are equal for all alternatives, then matrix (28) will have $1\,x\,n$ format (n denotes the number of criteria).

$$T_p = P_{A_i} \begin{array}{c} \begin{matrix} RN(w_1) & RN(w_2) & \dots & RN(w_n) \end{matrix} \\ \left[\left[t_{p1}^L, t_{p1}^U \right], \quad \left[t_{p2}^L, t_{p2}^U \right] \quad \dots \quad \left[t_{pn}^L, t_{pn}^U \right] \right]_{1xn} \end{array} \tag{30}$$

where n denotes the number of criteria, P_{A_i} preferences according to selection of alternatives, $RN(w_i)$ weight coefficients of evaluation criteria.

Step 4 Determination of real evaluation (T_r). Calculation of the real evaluation matrix elements (T_r) is done by multiplying real evaluation matrix elements (T_p) and elements of initial decision-making matrix (X) according to the following equation:

$$RN(t_{rij}) = RN(t_{pij}) \cdot RN(x_{nij}) = \left[t_{pij}^L, t_{pij}^U \right] \cdot \left[\overset{L}{y}_{ij}, \overset{U}{y}_{ij} \right] \tag{31}$$

where $RN(t_{pij})$ denotes elements of theoretical assessment matrix, and $RN(y_{ij})$ denotes elements of normalized matrix $Y = \left[RN(y_{ij}) \right]_{l \times n}$. Normalization of the mean initial decision matrix (25) is done by applying equation (32) and (33)

$$RN(y_{ij}) = \left[\underline{Lim}(y_{ij}), \overline{Lim}(y_{ij}) \right] = \left[\overset{L}{y}_{ij}, \overset{U}{y}_{ij} \right] = \left[\frac{y_{ij}^L - y_{ij}^-}{y_{ij}^+ - y_{ij}^-}, \frac{y_{ij}^U - y_{ij}^-}{y_{ij}^+ - y_{ij}^-} \right] \tag{32}$$

b) For the „cost“ type criteria (lower criterion value is preferable)

$$IRN(y_{ij}) = \left[\underline{Lim}(y_{ij}), \overline{Lim}(y_{ij}) \right] = \left[\overset{L}{y}_{ij}, \overset{U}{y}_{ij} \right] = \left[\frac{y_{ij}^U - y_{ij}^+}{y_{ij}^- - y_{ij}^+}, \frac{y_{ij}^L - y_{ij}^+}{y_{ij}^- - y_{ij}^+} \right] \tag{33}$$

where y_i^- and y_i^+ denote minimum and maximum values of the marked criterion by its alternatives, respectively:

$$y_{ij}^- = \min_j \left\{ y_{ij}^L \right\} \tag{34}$$

$$y_{ij}^+ = \max_j \left\{ y_{ij}^U \right\} \tag{35}$$

Step 5 Calculation of total gap matrix (G). Elements of G matrix are obtained as difference (gap) between theoretical (t_{pij}) and real evaluations (t_{rij}), or by actually subtracting the elements of theoretical evaluation matrix (T_p) with the elements of real evaluation matrix (T_r)

$$G = T_p - T_r = \begin{bmatrix} RN(g_{11}) & RN(g_{12}) & \dots & RN(g_{1n}) \\ RN(g_{21}) & RN(g_{22}) & \dots & RN(g_{2n}) \\ \dots & \dots & \dots & \dots \\ RN(g_{l1}) & RN(g_{l2}) & \dots & RN(g_{ln}) \end{bmatrix}_{l \times n}$$

where *n* denotes the number of criteria, *l* denotes the number of alternatives, and g_{ij} represents the obtained gap of alternative *i* as per criterion *j*. Gap g_{ij} takes values from the interval rough number according to equation (37)

$$RN(g_{ij}) = RN(t_{pij}) - RN(t_{r_{ij}}) = \left[t_{pij}^{L}, t_{pij}^{U}\right] - \left[t_{rij}^{L}, t_{rij}^{U}\right] \tag{37}$$

It is preferable that $RN(g_{ij})$ value goes to zero ($RN(g_{ij}) \to 0$) since the alternative with the smallest difference between theoretical ($RN(t_{pij})$) and real evaluation ($RN(t_{rij})$) shall be chosen. If alternative A_i for criterion C_i has a theoretical evaluation value equal to the real evaluation value ($RN(t_{pij}) = RN(t_{rij})$) then the gap for alternative A_i for criterion C_i is zero, i.e. alternative A_i per criterion C_i is the best (ideal) alternative.

If alternative A_i for criterion C_i has a theoretical evaluation value $RN(t_{pij})$ and the real ponder value is zero, then the gap for alternative A_i for criterion C_i is $RN(g_{ij}) \approx RN(t_{pij})$. This means that alternative A_i for criterion C_i is the worst (anti-ideal) alternative.

Step 6 Calculation of the final values of criteria functions (Q_i) per alternatives. Values of criteria functions are obtained by summing the gaps from matrix (36) for each alternative as per evaluation criteria, i.e. by summing matrix elements (G) per columns as shown in equation (38)

$$RN(Q_i) = \sum_{j=1}^{n} RN(g_{ij}),\ i = 1, 2, \dots, m \tag{38}$$

Where *n* denotes the number of criteria, *m* denotes the number of the chosen alternatives.

Ranking of alternatives can be done by applying rules governing ranking of rough numbers described in (Stević et al., 2017).

5. Calculation part

Application of the hybrid rough BWM-MAIRCA model is shown using a case study related to the selection of an optimal supplier selection in Libya. Based on an analysis of the available literature and expert evaluation of suppliers, five criteria were used: Price and costs (C1), Quality (C2), Supplier profile (C3), Delivery (C4) and Flexibility (C5).

Four experts took part in the research. The R-BWM was used to determine the weight coefficients of the criteria. After defining the criteria for evaluation, the experts also determined the best (*B*) and worst (*W*) criteria. On this basis, the experts determined the BO and OW matrices in which the preferences of the *B* and *W* over the criteria were considered for the remaining criteria from the defined set. Evaluation of the criteria was carried out using a scale $a_{ij}^{e} \in [1,9]$ [18]. The BO and OW matrices are presented in Table 2.

Table 2 The BO and OW expert evaluation matrices

Best: C1	Expert evaluation	Worst: C5	Expert evaluation
C1	1, 1, 1, 1	C1	8, 7, 8, 7
C2	2, 2, 3, 3	C2	4, 4, 3, 4
C3	2, 3, 3, 2	C3	4, 4, 5, 5
C4	4, 5, 5, 4	C4	2, 3, 2, 3
C5	8, 8, 9, 9	C5	1, 1, 1, 1

Using equations (1)-(7) the evaluations in the BO and OW matrices were transformed into rough numbers. After transforming crisp numbers into rough numbers, equations (9)-(15) were used to transform the BO and OW of the expert matrices into aggregated rough BO and rough OW matrices, Table 3.

Table 3 Aggregating the rough BO and rough OW matrices

Best: C1	RN	Worst: C5	RN
C1	[1.00, 1.00]	C1	[7.25, 7.75]
C2	[2.25, 2.75]	C2	[3.56, 3.94]
C3	[2.25, 2.75]	C3	[4.25, 4.75]
C4	[4.25, 4.75]	C4	[2.25, 2.75]
C5	[8.25, 8.75]	C5	[1.00, 1.00]

On the basis of the rough BO and rough OW matrices for criteria, the optimal values of the rough weight coefficients of the criteria were calculated. Based on model (18) the optimal values of the weight coefficients of the criteria were calculated, Table 4.

Table 4 Optimal values of the criteria

Criterion	Weights	Rank
C1	[0.4113, 0.4286]	1
C2	[0.2035, 0.2169]	2
C3	[0.1498, 0.1576]	3
C4	[0.1062, 0.1424]	4
C5	[0.0667, 0.0748]	5

By solving the model (18) the value of ξ^* is obtained, $\xi^* = 0.8464$. The value of ξ^* is used to determine consistency ratio (*CR*=0.16), equation (23). Since we obtain the value of $\overline{a}_{BW}$ i.e. $\overline{a}_{BW}^{U}$ on the basis of the aggregated decisions of the experts, and they affect the interval of the RN, it is not possible to predefine the values of consistency index ξ. Using equation (22), the values of consistency index (ξ) is defined (CI=5.04). After calculating the weight coefficients of the criteria, expert evaluation of the alternatives was carried out with the predefined evaluation criteria. Once the evaluation process is completed by applying equations from (24) through (26) decisions were aggregated and initial decision-making matrix Y^* obtained, Table 5. Evaluation of the alternatives was carried out using a scale $y_{ij}^e \in [1,5]$.

Table 5 Aggregated initial decision-making matrix

Criteria/ Alternatives	C1	C2	C3	C4	C5
A1	[2.05, 2.39]	[2.06, 2.43]	[2.23, 2.73]	[2.25, 3.20]	[1.98, 2.86]
A2	[2.43, 3.44]	[4.58, 4.95]	[2.10, 2.77]	[4.55, 4.93]	[4.00, 4.00]
A3	[4.26, 4.76]	[4.55, 4.93]	[4.54, 4.93]	[4.46, 5.00]	[4.46, 5.00]

After aggregation of evaluated criteria (Table 5) preferences were determined as per selection of alternatives P_{Ai}=1/m=0.33, where m denotes the number of alternatives and $P_{A1}=P_{A2}=P_{A3}=0.33$. Based on preferences P_{Ai}, and by applying equation (29), theoretical evaluation matrix (T_p) rank *1xn*, will be obtained. In order to determine real evaluation matrix T_r (Table 6), elements of the theoretical evaluation matrix will be multiplied with normalized elements of the aggregated initial decision matrix.

Table 6 Real evaluation matrix T_r

Criteria/ Alternatives	C1	C2	C3	C4	C5
A1	[0.12, 0.14]	[0.00, 0.01]	[0.00, 0.01]	[0.00, 0.02]	[0.00, 0.01]
A2	[0.07, 0.12]	[0.06, 0.07]	[0.00, 0.01]	[0.03, 0.05]	[0.01, 0.02]
A3	[0.00, 0.03]	[0.06, 0.07]	[0.04, 0.05]	[0.03, 0.05]	[0.02, 0.02]

Normalization of the initial decision-making aggregated matrix will be done by applying equations (32) and (33). In next step, elements of theoretical evaluation matrix (T_p) will be deducted from the elements of real evaluation matrix (T_p) to obtain total gap matrix (G). By summing up the rows of the total gap matrix we obtain the total gap for every alternative, equation (37). Based on the obtained values of the total gap between theoretical and real evaluations, the initial evaluation of alternatives will be performed, Table 7.

Table 7 Values of the total gap of alternatives and their ranking

Alternatives	Alternative gap $RN(Q_i)$	Rank
A1	[0.13, 0.22]	3
A2	[0.04, 0.17]	1
A3	[0.09, 0.19]	2

6 Conclusion

Supplier selection is a very important step in the purchasing process; therefore, to carry out the selection process, it is first important to identify the criteria for selection. This is particularly important for a company operating in the pharmaceutical industry and working mainly with international suppliers. The study addresses the problem of medicine supply from international suppliers for both public and private sectors in Libya. Five criteria and three suppliers are identified for supplier selection in this problem. This multiple criteria decision-making analysis problem is solved using the rough BWM method. As a result of the presented calculations, it is shown that cost comes first, followed by quality as the second and company profile as the third relevant criterion.

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EVALUATION OF THE RAILWAY MANAGEMENT MODEL BY USING A NEW INTEGRATED MODEL DELPHI-SWARA-MABAC

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Abstract *The functioning of each traffic system depends to a great extent on the way the rail transport system operates. Taking into account the aspect of market turbulence and the dependence on adequate delivery when it comes to freight transport and traffic in accordance with a yearly Timetable in passenger traffic, transport policies are changing with time. Therefore, this document is considering the railway management models on the territory of Bosnia and Herzegovina. For the purpose of evaluating these models, a new hybrid model has been applied, i.e. the model which includes a combination of the Delphi, SWARA (Step-Wise Weight Assessment Ratio Analysis) and MABAC (Multi-Attributive Border Approximation Area Comparison) methods. In the first phase of the study, the criteria ranking was determined based on 16 expert grades used in the Delphi Method. After that, a total of 14 decision-makers determined the mutual criteria impact, which is a prerequisite for the application of the SWARA Method used to determine the relative weight values of the criteria. The third phase involves the application of the MABAC Method for evaluating and determining the most suitable variant. In addition, a sensitivity analysis involving the application of the ARAS, WASPAS, SAW and EDAS methods has been performed, thus verifying the previously obtained variant ranking.*

Key Words: *Railways, Transport Policy, Delphi, SWARA, MABAC.*

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1 Introduction

Although the railway has significant advantages which are reflected in a high level of safety, considerably less energy consumption per unit of transport and minimal impact on the environment, as well as the least impact on external transport costs comparing to other modes of transport, its participation in transport market has decreased significantly in the second half of the 20th century. To a large extent, it has been caused by historical, traditional and national influences on railway companies, and above all:

- a high level of government intervention in the business operations of national railway companies - railway companies, through state control and intervention - were used to meet political and social goals rather than to function in accordance with market principles, and,
- costs subsidizing and lack of incentives for change – a high proportion of passenger transport, which was unprofitable and politically supported, placed railway companies in the public service area, and they often transported passengers without an adequate compensation.

In Europe, all national railway administrations used to be state owned organizations which, for the sake of economic and social policy, were obliged to execute public passenger transport services. Due to lower prices, the revenues did not cover actual costs, resulting in their inability to finance exploitation and infrastructure development. The lack of financial resources further led to economic weakening of the railway companies and their position on the market.

National railway companies are integrated, i.e. they perform both functions of the infrastructure manager and operator. The regulatory framework is national with no competition in the form of foreign railways while there is no domestic market.

Due to non-profitability of the railway companies, there was a debt accumulation process in most European countries, especially in the late 1980s. The loss of railway competitiveness in the transport market in intermodal competition, a growing deficit and an increasing debt burden of the state-owned companies have triggered off reforms.

In the EU Member States and beyond, views and directives concerning the restructuring of the rail system have been adopted. Prior reforms did not allow complete railway's liberalization and meeting the requirements of transport market, the expected positive operation of the railway system, the necessary level of rail services quality, satisfaction of the interests of the social community at the national, regional and local level. Positive business results were partly achieved on the main railways (pan-European Corridors), primarily in transit traffic. Although the quality of services on railway system has improved, it is still far from the level required by transport market.

Defining the method of national railway companies restructuring, and thus the way of infrastructure management in Europe, was mainly based on experts opinions, and it depended on the defined traffic policy, the country's level of development, and the readiness to accept changes (political, social and others). Determination of the reforming method, or the most acceptable model of restructuring, is based on experiences, intuitions and subjective attitudes of individual institutions and experts.

However, the countries have undertaken reforms aimed at easing the debt burden on national rail companies, reducing demands for high subsidies, mitigating and halting the fall of railways in market share comparing to other modes of transport. There was a need to create an efficient integrated railway system in the EU and to facilitate border crossing of goods within a single European market with the ultimate aim to:

- establish a railway transport market,
- develop competition in the railway sector, and,
- reduce state subsidies in the railway sector.

The first task of railway restructuring is to transform the state organization into a business organization capable of carrying out transport operations both on the national and international transport market. In this process, the state has a role to create appropriate conditions for the development of a transport system that functions with the maximum application of market mechanisms and meets the transport needs of the society. In order to establish a harmonized market environment in which transporters functioning in different types of transport are affirmed on the basis of equal conditions of competition, it is necessary to calculate the total transport costs generated. The total costs of transport company include not only direct transport costs, infrastructure costs, traffic management and accident compensation, but also compensation for damage to the environment (CER, 2005). The actual situation is that in such conditions the railway has significant advantages over other modes of transport.

In order to fully evaluate these facts, it is necessary to reform traditional railway companies and establish optimal models for their organization and functioning.

This paper examines four different models of organization and structure of the Railways of the Republic of Srpska (ŽRS), which are defined on the base of existing solutions for the reform of national rail companies in Europe (predominantly in the European Union member states).

2 Literature review

Many studies in the domain of railway transport rely on the application of multi-criteria decision-making methods. In (Krmac & Djordjević, 2017) the Group Analytical Hierarchical Process (AHP) was used to determine the key performance indicators for assessing intelligent transport systems. An integrated model consisting of the Delphi, Group Analytical Hierarchical Process and PROMETHEE methods in (Nassereddine & Eskandari 2017) was applied in the field of public passenger transport, where, as a result, the metro is the most important passenger transport system. Also, the integrated MCDM Model (DEMATEL, ANP and VIKOR) was used to choose the transport mode in Hualien (Kuo & Chen, 2015). Aydin, (2017) commenced a three-year research in Istanbul for measuring performances of the railway transit lines. For this purpose he used the TOPSIS Method. The performance evaluation of the railway zones in India (Ranjan et al. 2016)) was conducted by combining the DEMATEL and VIKOR Methods, while in their research Sang et al. (2015) used the Fuzzy AHP Method for selection and evaluation of railway freight Third-Party-Logistics. Leonardi (2016) applied a combination of fuzzy logics with multiple-criteria decision-making (AHP Method) to plan a railway infrastructure, while in (Santarremigia et al. 2018) the AHP was also applied in the safety area during the railway transport of dangerous materials. A combination of the BWM and SAW methods was used in (Stević et al. 2017a) to determine the importance of criteria in purchasing wagons in a logistics company.

According to Hashemkhani Zolfani & Bahrami (2014), the SWARA method is suitable for decision-making at a high level of decision-making and also instead of policy-making. Its convenience in a decision-making process is reflected in the advantages it has in comparison to other methods for obtaining the weight values of criteria. These advantages are primarily seen in a significantly smaller number of comparisons in relation to other criteria, and the possibility to evaluate the opinions of experts on the significance of criteria in a process of determining their weights. Over the few past years since this method came into existence, it has been used in a number of publications to determine weight values of the criteria. The SWARA was used to assess the relation between the floods and influencing parameters in (Hong et al. 2017), while the ANFIS model is applied to flood spatial modeling and zonation, and it is used for the R&D project evaluation in (Hashemkhani Zolfani et al. 2015). Using the SWARA method in (Heidary Dahooie et al. 2018), it is concluded that subject competency is the main criteria in IT personnel selection. In (Keshavarz Ghorabaee et al. 2018), it is used to determine the significance of criteria in a process of evaluating construction equipment in sustainable conditions, while Ruzgys et al. (2014) apply it to the evaluation of external wall insulation in residential buildings. It is successfully applied to risk assessment (Valipour et al. 2017), for selection of a basic shape of the single-family residential house's plan (Juodagalvienė et al. 2017), while Karabašević et al. (2017) used the adapted SWARA with the Delphi method for selection of personnel.

The combination of the SWARA and WASPAS is used for solar power plant site selection in (Vafaeipour et al. 2014), as well as in (Ghorshi Nezhad et al. 2015) where the combination of these two methods is applied in the nanotechnology industry. This combination is also integrated in (Urošević et al. 2017) where it is used for the selection of personnel in tourism. The integration of the SWARA, Fuzzy Kano Model and ROV methods is proposed in (Jain & Singh, 2017) to solve supplier selection. The Fuzzy SWARA is used to determine the significance of criteria, and the Fuzzy COPRAS for ranking and selecting sustainable 3PRLPs in the presence risk factors. The suggested model was applied to a case study from automotive industry (Zarbakhshnia et al. 2018). A combination of the Fuzzy SWARA and the Fuzzy MOORA is used for sustainable third-party reverse logistic provider selection in plastic industry (Mavi et al. 2017). The authors in (Panahi et al. 2017) use the SWARA method for prospecting copper in the Anarak region, central Iran, while the authors in (Ighravwe & Oke, 2017) use it for sustenance of zero-loss on production lines from a cement plant.

3 Methods

3.1 Delphi method

The Delphi Method does the study of and gives projections of uncertain or possible future situations for which we are unable to perform objective statistical legalities, in order to form a model, or apply a formal method. These phenomena are very difficult to quantify because they are mainly qualitative in their nature, i.e. not enough statistical data about them exist that could be used as the basis for our studies. The Delphi Method is one of the basic forecasting methods, the most famous and most widely used expert judgment method. Methods of expert's assessments are representing significant improvement of the classical ways of obtaining the forecast by joint consultation of an expert's group for a given studied phenomenon. In other words, this is a methodologically organized use of the expert's knowledge to predict future states and phenomena. A typical group in one Delphi session ranges from a few to thirty experts. Each interviewed expert, participant in the method, relies on knowledge, experience and his / her own opinion. The goal of the Delphi Method is to exploit the collective, group thinking of experts about certain field. The goal is to reach a consensus on an event by group thinking. This is a method of indirect collective testing but with a return link. It consists of eight steps:

1: Selection of the prognostic task, defining basic questions and fields for it;
2: Selection of experts;
3: Preparation of questionnaires;
4: Delivery of questionnaires to experts;
5: Collecting responses and their evaluating;
6: Analysis and interpretation of responses;
7: Re-exams;
8: Interpretation of responses and setting up final forecast.

The advantages of the Delphi Method

- It covers the large number of respondents;
- Expert's statements are objective because they do not know the statements of others until the end of the circle;
- It is possible to examine the opinion and attitude of an individual according to a task;
- The method strengthens the sense of community and encourages thinking about the future of the organization.

Delphi Method disadvantages:

- The success of the method depends exclusively on the participants in the expert panel;
- Complicated implementation process;
- Absence of the possibility to exactly identify the number of participants in the expert panel;
- Long duration of research.

According to the rules of the Delphi Method, the submitted forecasts of the first circle are statistically processed and sent to the experts again to make possible corrections if they consider other opinions. It is characteristic that most experts remain in their first-round prognosis.

3.2 SWARA method

The SWARA (Step-wise Weight Assessment Ratio Analysis) method is one of the methods for determining weight values that play an important role in a decision-making process. The method was developed by Kersuliene et al. (2010) and, in their opinion, its basic characteristic is the possibility of assessing the opinion of experts on the significance of criteria in the process of determining their weights. After defining and forming a list of criteria involved in a decision-making process, the SWARA method consists of the following steps:

Step 1: Criteria need to be sorted according to their significance. In this step, the experts perform the ranking of the defined criteria according to the significance they have; for example, the most significant is in the first place, the least significant is in the last place, while the criteria in-between have ranked significance.

Step 2: Determine s_j - comparative importance of average value. Starting from the second ranked criterion, it is necessary to determine their significance, that is, how much criterion c_j is more important than criterion c_{j+1}.

Step 3: Calculate coefficient k_j as follows:

$$k_j = \begin{cases} 1 & j = 1 \\ s_{j+1} & j > 1 \end{cases} \tag{1}$$

Step 4: Determine recalculated weight q_j as follows:

$$q_j = \begin{cases} 1 & j = 1 \\ \dfrac{q_{j-1}}{k_j} & j > 1 \end{cases} \tag{2}$$

Step 5: Calculate the weight values of the criteria with the sum that is equal to one:

$$w_j = \frac{q_j}{\sum_{k=1}^{m} q_j} \tag{3}$$

where w_j represents the relative weight value of the criteria.

3.3 MABAC method

The MABAC Method (Multi-Attributive Border Approximation Area Comparison) is one of the recent methods. The MABAC Method was developed by Dragan Pamučar in the Defense Research Center for Defense Logistics in Belgrade and was first presented to the scientific public in 2015 (Pamučar & Ćirović, 2015). To date, it has found very wide application and modifications solving numerous problems in the field of multi-criteria decision-making.

The basic setting of the MABAC Method is reflected in defining the distance of the criterion function of each observed alternative from the boundary approximation domain. In the following section, the procedure for implementing the MABAC Method consisting of 6 steps is shown:

Step 1: Forming initial decision matrix (X). As a first step, m alternatives are evaluated by n criteria. Alternatives are shown with vectors $A_i = (x_{i1}, x_{i2}, \ldots, x_{in})$, where x_{ij} is the value of *i*-... alternative by *j*-... criteria $(i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n)$.

$$X = \begin{array}{c} \\ A_1 \\ A_2 \\ \ldots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \ldots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1n} \\ x_{21} & x_{22} & & x_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ x_{m1} & x_{m2} & \ldots & x_{mn} \end{bmatrix} \end{array} \tag{4}$$

Step 2: Normalization of elements of starting matrix (X).

$$N = \begin{array}{c} \\ A_1 \\ A_2 \\ \ldots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \ldots & C_n \end{array} \\ \begin{bmatrix} t_{11} & t_{12} & \ldots & t_{1n} \\ t_{21} & t_{22} & & t_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ t_{m1} & t_{m2} & \ldots & t_{mn} \end{bmatrix} \end{array} \tag{5}$$

The elements of normalized matrix (N) are determined using the expression:

For criteria belonging to a "benefit" type (greater value of criteria is more desirable)

$$t_{ij} = \frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \tag{6}$$

For criteria belonging to a "cost" type (lower value of criteria is more desirable)

$$t_{ij} = \frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \tag{7}$$

where x_{ij}, x_i^+ and x_i^- are representing elements of the starting matrix of making decision (*X*), where x_i^+ and x_i^- are defined as:

$x_i^+ = \max\left(x_1, x_2, ..., x_m\right)$ and representing maximal values of the observed criteria by alternatives.

$x_i^- = \min\left(x_1, x_2, ..., x_m\right)$ and representing minimal values of the observed criteria by alternatives.

Step 3: Calculation of the element of more difficult matrix (*V*). Elements of more difficult matrix (*V*) are being calculated on the basis of expression (8)

$$v_{ij} = w_i \cdot t_{ij} + w_i \tag{8}$$

where t_{ij} are representing the elements of normalized matrix (*N*), w_i represents weighting coefficients of the criteria. By applying expression (8) we will get more difficult matrix V

$$V = \begin{bmatrix} v_{11} & v_{12} & \dots & v_{1n} \\ v_{21} & v_{22} & & v_{2n} \\ \dots & \dots & \dots & \dots \\ v_{m1} & v_{m2} & \dots & v_{mn} \end{bmatrix} = \begin{bmatrix} w_1 \cdot t_{11} + w_1 & w_2 \cdot t_{12} + w_2 & \dots & w_n \cdot t_{1n} + w_n \\ w_1 \cdot t_{21} + w_1 & w_2 \cdot t_{22} + w_2 & \dots & w_n \cdot t_{2n} + w_n \\ \dots & \dots & \dots & \dots \\ w_1 \cdot t_{m1} + w_1 & w_2 \cdot t_{m2} + w_2 & \dots & w_n \cdot t_{mn} + w_n \end{bmatrix}$$

where *n* represents the total number of the criteria, *m* represents the total number of the alternatives.

Step 4: Determining the matrix of bordering approximative fields (*G*). Bordering approximative field (GAO) is being determined by expression (9)

$$g_i = \left(\prod_{j=1}^{m} v_{ij} \right)^{1/m} \tag{9}$$

where v_{ij} are representing the elements of weighted matrix (*V*), *m* represents the total number of the alternatives.

After calculating value g_i the matrix of bordering approximative fields is being formed according to criteria *G* (10) in format $n \ x \ 1$ (*n* represents the total number of the criteria by which the offered alternatives are being chosen).

$$\begin{array}{cccc} & C_1 & C_2 & \dots & C_n \\ G = & [g_1 & g_2 & \dots & g_n] \end{array} \tag{10}$$

Step 5: The calculation of the distance matrix element is an alternative to boundary approximative area (*Q*)

$$Q=\begin{bmatrix} q_{11} & q_{12} & \dots & q_{1n} \\ q_{21} & q_{22} & & q_{2n} \\ \dots & \dots & \dots & \dots \\ q_{m1} & q_{m2} & \dots & q_{mn} \end{bmatrix} \tag{11}$$

Distance of alternatives from boundary approximative area (q_{ij}) is being determined as a difference of elements of heavier matrix (*V*) and values of bordering approximative areas (*G*).

$$Q=V-G=\begin{bmatrix} v_{11} & v_{12} & \dots & v_{1n} \\ v_{21} & v_{22} & & v_{2n} \\ \dots & \dots & \dots & \dots \\ v_{m1} & v_{m2} & \dots & v_{mn} \end{bmatrix}-\begin{bmatrix} g_1 & g_2 & \dots & g_n \end{bmatrix} \tag{12}$$

$$Q=\begin{bmatrix} v_{11}-g_1 & v_{12}-g_2 & \dots & v_{1n}-g_n \\ v_{21}-g_1 & v_{22}-g_2 & \dots & v_{2n}-g_n \\ \dots & \dots & \dots & \dots \\ v_{m1}-g_1 & v_{m2}-g_2 & \dots & v_{mn}-g_n \end{bmatrix}=\begin{bmatrix} q_{11} & q_{12} & \dots & q_{1n} \\ q_{21} & q_{22} & & q_{2n} \\ \dots & \dots & \dots & \dots \\ q_{m1} & q_{m2} & \dots & q_{mn} \end{bmatrix} \tag{13}$$

where g_i represents the bordering approximative areas for criterion C_i, v_{ij} represents elements of heavier matrix (*V*), *n* represents the number of the criteria, *m* represents the number of the alternatives.

Alternative A_i may belong to a bordering approximative area (*G*), upper bordering approximative area (G^+) or lower bordering approximative area (G^-), i.e. $A_i \in \{G \vee G^+ \vee G^-\}$. Upper approximative area (G^+) represents the area in which ideal alternative (A^+) is located, while lower approximative area (G^-) represents the area in which the anti-ideal alternative is located (A^-) (Fig. 1).

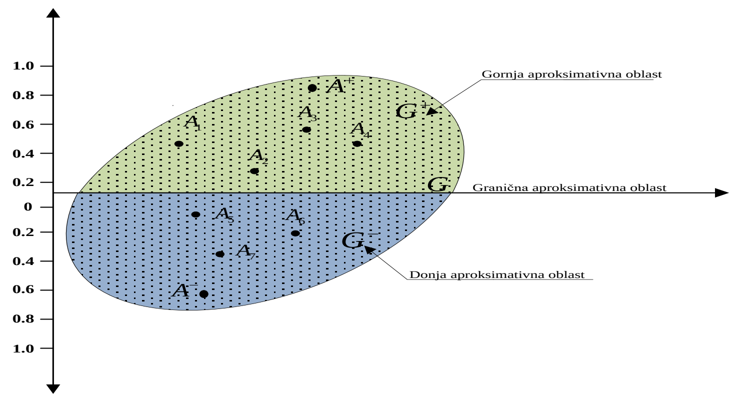

Fig. 1 Display of the upper, lower and bordering approximative areas (Pamučar & Ćirović, 2015)

Affiliation of alternative A_i to approximative area (G, G+ or G-) is determined on the basis of expression (14)

$$A_i \in \begin{cases} G^+ \ if \ q_{ij} > g_i \\ G \ \ if \ q_{ij} = g_i \\ G^- \ if \ q_{ij} < g_i \end{cases} \tag{14}$$

In order for an alternative A_i to be selected as the best from a given set, it is necessary for it to belong to the upper approximating field by as many criteria as possible (G^+). If, for example, an alternative A_i belongs to the upper approximative area by 5 criteria (out of 6 in total), and to the lower approximative area by one criterion, (G^-) that means that, by 5 criteria, this alternative is close to or equal with the ideal one, while by one criterion it is close to or equal to the anti-ideal one. If value $q_{ij} > 0$, i.e. $q_{ij} \in G^+$, then alternative A_i is close or equal to the ideal alternative. Value $q_{ij} < 0$, i.e. $q_{ij} \in G^-$, shows that alternative A_i is close or equal to the anti/ideal alternative.

Step 6: Alternatives ranking. Calculation of values of the criteria functions by alternatives (15) is obtained as the sum of distance of the alternatives from bordering approximative fields (q_i). By summarizing the elements of the Q matrix by rows, we obtain the final values of the criterion functions of alternatives (15)

$$S_i = \sum_{j=1}^{n} q_{ij},\ j = 1,2,...,n,\ i = 1,2,...,m \tag{15}$$

where n represents the number of the criteria, and m represents the number of the alternatives.

3 Case study

Four variants of the management model for railway companies were considered:

1) **__Variant 1__** - Model of a single (independent) legal entity with a simple organizational structure and a high degree of centralization.

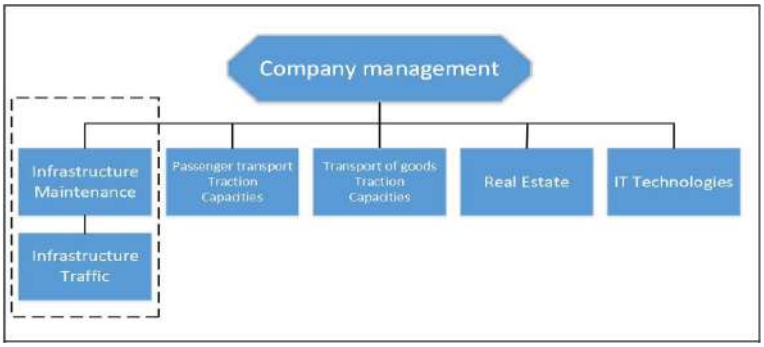

Fig. 2 Variant 1 – Model of unique (independent) legal subject

2) **<u>Variant 2</u>** - Clear holding is a company exclusively dealing with management activities: establishment, financing and management of companies. This type of holding does not have any other special activities. Clear holding does not deal with production or sale; neither does it perform any other business functions, even those that are common to companies - daughters or members of the holding.

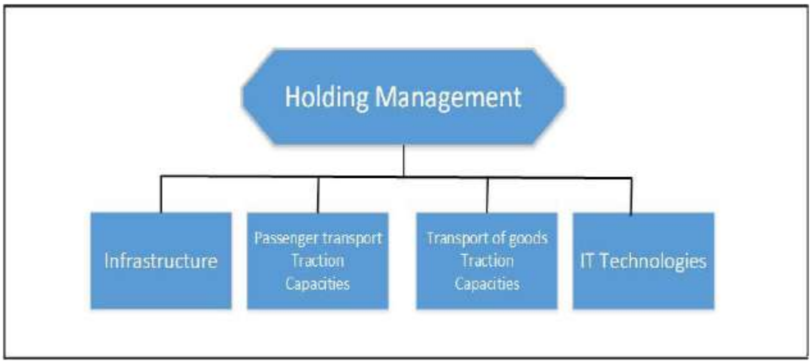

Fig. 3 Variant 2 - Clear holding

<u>3) **Varianta 3**</u> Mixed holding - In addition to management tasks, Mixed holding also performs other types of activities in the field of production, trade, research, finance or service activities. Within the mixed-activity holding company there is a parent company (infrastructure) and companies engaged in the transport and traction of trains.

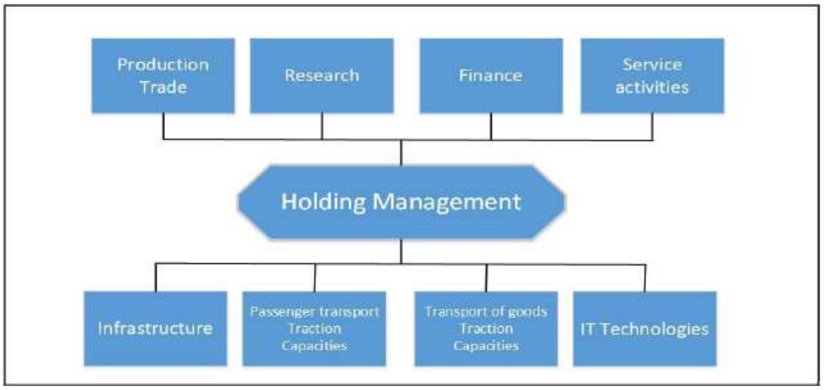

Fig. 4 Variant 3 - Mixed holding

4) **<u>Variant 4</u>** – Mixed holding – Model of three independent companies: Infrastructure, Transport of passengers and Transport of goods.

Criteria for selecting the most favorable model of restructuring and organization of railway companies are:

K_1 – Model's efficiency;
K_2 – The attractiveness of the model to attract an operator;
K_3 – Satisfying the needs of transport market;
K_4 – Compliance with EU directives;
K_5 – Financial independence of the model;

K_6 – Possibility of model realization.

K_1 – Efficiency is the ability to achieve results and business goals. This means that the offered model should enable its efficient exploitation and maintenance. This criterion refers to management and functionality as well as the ability to use all the resources of the model in order to achieve the necessary effectiveness. **The criterion should be maximized.**

K_2 –"The attractiveness of the model to attract an operator" implies the ability of the model to provide an open access to infrastructure operators, the use of railway infrastructure by operators under equal conditions without discrimination. In this way, preconditions for multiple operators will be created. **The criterion should be maximized.**

K_3 – It refers to the possibility of the offered model to satisfy the needs of operators in the transport market in relation to the state and capacity of railway infrastructure capacities (permitted speed, throughput, electrification, permissible axial load, etc.). Regardless of the operator's capability (transport time, prices, frequency, reliability, etc.), the state of the infrastructure significantly influences the definition of customers' demands on the market (population and economy). **The criterion should be maximized.**

K_4 – Certain models can be fully or to some extent harmonized with EU directives aimed at the creation of a single transport market, its liberalization and ensuring the independence of the management of railway undertakings. **The criterion should be maximized.**

K_5 – The infrastructure manager should be a functionally sound and financially stable company. The state allocates financial resources to infrastructure managers only for the development of railway infrastructure, and not for workers' salaries. The K_5 criterion should assess the extent to which the model can satisfy these requirements. **The criterion should be maximized.**

K_6 – It refers to the possibility of realization of the observed model from the aspect of legislation, environment, support of political, social and other participants, etc. **The criterion should be maximized.**

In the first phase of the study, the ranking of criteria was determined based on 16 expert grades in the Delphi Method. After that, a total of 14 decision-makers determined the mutual impact of the criteria, which is a prerequisite for the application of the SWARA Method used to determine relative weight values of the criteria. After applying Eqs. (1) - (3), we have obtained weight values of the criteria shown in Table 1.

Table 1 Calculation procedure and results of weight values of criteria obtained using SWARA Method

	Sj	Kj=Sj+1	qj	wj
K3	1.000	1.000	1.000	0.224
K1	0.100	1.100	0.909	0.203
K5	0.148	1.148	0.792	0.177
K2	0.179	1.179	0.672	0.150
K4	0.168	1.168	0.575	0.129
K6	0.102	1.102	0.522	0.117
			4.471	1.000

Table 1 shows, in the first column, the alternative's ranking that was previously determined using the Delphi Method, while the second column represents the effect of the previous one in relation to the next criterion, which is the average value of the response of the decision-makers. Based on the obtained results using the SWARA Method, the most important is the first criterion of the model's efficiency, while the second criterion is the attractiveness of the model to attract operators elsewhere with a slightly lower value. The general conclusion when it comes to the value of the criteria considered in this study is that all the criteria have sufficient influence on the decision-making with respect to their values. In future research related to determining the significance of the criteria, it is recommended to use the Rough SWARA Method developed in (Zavadskas et al. 2018). After obtaining the relative criteria values, it is necessary to determine the most favorable variant of Railways management in Bosnia and Herzegovina. For this purpose, the MABAC Method is used. All 14 decision-makers who had previously determined the mutual impact of the criteria have also carried out the evaluation of the alternatives. By applying the geometric middle of all the answers, the initial decision matrix is shown in Table 2.

Table 2 Starting matrix of decision-making based on the responses from 14 decision-makers

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	4.238	3.918	4.530	3.710	4.502	4.810
A_2	5.142	4.786	4.698	5.433	5.174	6.706
A_3	6.470	4.909	5.463	6.069	6.020	6.392
A_4	4.341	7.471	4.900	7.796	5.051	3.580

After the initial decision matrix, Eqs. (6) and (7) must be applied in order to start normalization. Since in this study all the criteria belong to a group of benefits for normalization, equation (6) is used, and the normalized matrix shown in Table 3 is obtained.

Table 3 Normalized matrix

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	0.000	0.000	0.000	0.000	0.000	0.393
A_2	0.405	0.244	0.180	0.422	0.442	1.000
A_3	1.000	0.279	1.000	0.577	1.000	0.899
A_4	0.046	1.000	0.396	1.000	0.361	0.000

Table 4 shows a more difficult normalized matrix obtained by multiplying the normalized matrix from Table 3 with the weight values of the criteria obtained using the SWARA Method. Equation (8) is used to aggravate the normalized matrix. In addition, in the integral part of Table 4, the values of the bordering approximative area are obtained by applying equation (9).

Table 4 Weighted normalized matrix

V	C_1	C_2	C_3	C_4	C_5	C_6
A_1	0.224	0.203	0.177	0.150	0.129	0.163
A_2	0.314	0.253	0.209	0.214	0.186	0.234
A_3	0.447	0.260	0354	0.237	0.257	0.222
A_4	0.234	0.407	0.247	0.301	0.175	0.117
G	0.293	0.272	0.239	0.219	0.181	0.177

Table 5 shows the distance matrix of the alternative from the bordering approximative area (Q) obtained by applying Eqs. (12) and (13) and the ranking of the model variant using equation (15).

Table 5 The distance matrix is an alternative to bordering approximative area (Q) and alternative's range

Q=V-G	C_1	C_2	C_3	C_4	C_5	C_6	S_i	Rank
A_1	-0.069	-0.068	-0.062	-0.068	-0.052	-0.014	-0.334	**4**
A_2	0.021	-0.019	-0.030	-0.005	0.004	0.056	0.029	**3**
A_3	0.154	-0.012	0.116	0.018	0.076	0.045	0.398	**1**
A_4	-0.059	0.135	0.009	0.082	-0.006	-0.060	0100	**2**

After executing the budget and applying the Hybrid model, the best-ranked variant of the Railway Management is a variant number 1 which implies that the model of a unified (independent) legal entity has a simple organizational structure with a high degree of centralization, while the worst ranking option is number 3.

4 Sensitivity analysis

In order to determine the stability of the previously obtained results using the hybrid Delphi-SWARA-MABAC Model, the budget calculation for the multi-criteria model was carried out with four more ARAS methods (Zavadskas and Turksis, 2010), WASPAS (Zavadskas et al. 2012), SAW (MacCrimmon, 1968, Stević et al. 2017a), and EDAS (Keshavarz Ghorabaee et al., 2015; Stević et al. 2016; Stević et al. 2017b). The results of the sensitivity analysis are shown in Table 6.

Table 6 The results of the sensitivity analysis

	MABAC		ARAS		WASPAS		SAW		EDAS	
V_1	-0.334	4	0.644	4	0.381	4	0.652	4	0.652	4
V_2	0.029	3	0.787	3	0.463	3	0.793	3	0.793	3
V_3	0.398	1	0.884	1	0.521	1	0.891	1	0.891	1
V_4	0.100	2	0.836	2	0.486	2	0.833	2	0.833	2

Based on the obtained results of the sensitivity analysis, the model's stability and obtained levels of variant solutions are confirmed because in applying all the four methods in the analysis of sensitivity, the levels do not change, that is, each variant retains its initial level.

5 Conclusion

Evaluation of the level of railway market restructuring and reforms is an important process that shows the phase in which a country is. Level alignment is of great importance to the countries in the environment because in this way a more stable transport market can be established. This is especially important for the railways located in strong transit directions and pan-European corridors. The European rail system should not be "scraped" on the non-synchronized rail national reform levels since this does not contribute to the creation of a single European transport market, and thus to the desired open rail market. In addition, such a situation inevitably leads to a reduction in the quality of rail services and an uncompetitive position of the railways in the transport market.

EU directives provide no unique solution in terms of selecting rail management models. The issue this document deals with is the development of a general model that provides a solution to the institutional management of rail national companies. Quantified relevant criteria have been identified for the choice of management model. The synchronization of railway reforms has been promoted through various institutions, and the implementation of reforms and liberalization has often been carried out on the basis of experts' opinions or the application of inadequate methods. This document presents a new way of determining adequate restructuring model for railway national companies, which implies the integration of the Delphi, SWARA and MABAC methods.

The three-phase hybrid model takes into account all the relevant facts and aspects that need to be considered in such research, and the integration of the above-mentioned methods is also one of the contributions of the work. In order to determine the stability of the model, a sensitivity analysis was performed in which four other methods of multi-criteria analysis were applied, the results of which have confirmed the obtained results using the hybrid model proposed in this document.

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A SENSITIVITY ANALYSIS IN MCDM PROBLEMS: A STATISTICAL APPROACH

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Abstract: *This study provides a model for result consistency evaluation of multi-criteria decision-making (MDM) methods and selection of the optimal one. The study presents the results of an analysis of the sensitivity of decision-making based on the rank methods: SAW, MOORA, VIKOR, COPRAS, CODAS, TOPSIS, D'IDEAL, MABAC, PROMETHEE-I,II, ORESTE-II with variations in the elements in the decision matrix within a given error (imprecision). It is suggested to use multiple simulation of the elements estimations of the decision matrix within a given error for calculating the ranks of alternatives, which allows obtaining statistical estimates of ranks. Based on the statistics of simulations, decision-making can be carried out not only on the alternatives statistics having rank I but also on the statistics of alternatives having the largest total I and II rank or I, II and III ranks. This is especially true when the difference in rank values is not large and is distributed evenly among the first three ranks. The calculations results for the task of selecting the adequate location of 8 objects by 11 criteria are presented here. The main result shows that the alternatives having I, II and III ranks for some ranking methods are not distinguishable within the selected error value of the elements in the decision matrix. A quantitative analysis can only narrow the number of effective alternatives for a final decision. A statistical analysis makes the number of options estimation possible in which an alternative has a priority. Additional criteria that take into account both aggregate priorities and the availability of possible priorities for other alternatives with small variations in the decision matrix provide additional important information for the decision-maker.*

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Key Words: *Multi-criteria Decision-making, SAW, MOORA, VIKOR, COPRAS, CODAS, TOPSIS, D'IDEAL, MABAC, PROMETHEE-I,II, ORESTE-II, Sensitivity Analysis*

1 Introduction

Decision-making processes are present in all activities of daily life. The decision attempts aim at solving problems in a particular case in the best way but it is worth remembering that this process is complex and takes place in an environment of uncertainty.

The multi-criteria decision-making methods (MCDMM) are the tool for reducing subjectivity in decision-making by creating a series of filters selection and helping to make choice among the complex alternatives. They are characterized by a particular mathematical apparatus which makes the application of different methods to the same problem often result in different solutions. Consequentially, the alternative choice does not depend solely on the criteria that one uses to evaluate those alternatives but on the MCDMM that one uses as well (Pamučar et al, 2017).

There is no consensus on how to determine the sensitivity analysis, i.e. the "quality" of a decision method and the reliability of the results. The sensitivity analysis can be defined as stability or behavior of the solution to small changes in preferences which occur during the resolution process or to small changes in the values taken for parameters; it is what some authors consider as efficiency multicriteria decision method (Pamučar & Ćirović, 2015).

Barron and Schmidt (1988) recommended two procedures to accomplish a sensitivity analysis in multi-attribute value models (entropy based procedure and a least squares procedure). These procedures calculate, for a given pair of alternatives, the best alternative, the *closest* set of weights that equates their ranking. Watson and Buede (1987) illustrate a sensitivity analysis in a decision modeling strategy. Von Winterfeldt and Edwards (1986) cover the sensitivity analysis in the traditional way for those problems which can be approached by using a multi-attribute utility theory (MAUT) or a Bayesian model. They define the *Flat Maxima Principle* for MAUT problems, which states that the existence of dominance makes the sensitivity analysis almost unnecessary.

Evans (1984) investigates a linear programming-like sensitivity analysis in the decision theory. His approach is based on the geometric characteristics of optimal decision regions in the probability space. Also, in Triantaphyllou (1992) the sensitivity analysis approach is described for a class of inventory models. The methodology for the sensitivity analysis in multi-objective decision-making is described in Ríos (1990). That treatment introduced a general framework for the sensitivity analysis which expanded results of the traditional Bayesian approach to decision-making. Likewise, that work contains an analysis of why the flat maxima principle is not valid. Samson (1988) presents a whole new approach to the sensitivity analysis. He proposed that it should be part of the decision analysis process *thinking in real time*.

Triantaphyllou and Mann (1989) emphasize two criteria for MDM methods analysis. The first criterion refers to fulfillment of result consistency conditions in the case when the method is applied to a multi-dimensional problem while the second criterion refers to the stability conditions of the best ranked alternative. In their study, Triantaphyllou and Mann (1989) compare four methods (WSM-weighted sum model, WPM-weighted product model, AHP-analytic hierarchy process and Revised

AHP-revised hierarchy process). Those two authors conclude that none of the considered methods is completely effective in terms of both evaluative criteria. In 1996, Triantaphyllou and Lin examined five fuzzy multi-attribute decision-making methods (fuzzified WSM, WPM, AHP, revised AHP and TOPSIS) in terms of the same two evaluative criteria, adapted to fuzzy environment. Just like the previous study, when four crisp methods were compared, they came to same conclusions: that none of the examined fuzzy methods is perfectly effective in terms of both evaluative criteria and that precision methods decrease with increasing complexity of the decision-making problem.

In the last couple of years, there have been frequent comparative analyses by the authors who conduct comparison of the results gained through use of several different MDMM (Rodrigues et al., 2014; Anojkumar et al., 2014; Liu et al, 2013; Wang & Tzeng, 2012; Peng et al., 2011; Yang et al., 2008). However, the fact that there are multiple methods that recommend the same choice is not a satisfactory warranty of rationality and quality of the calculated solution (Pavličić, 1997).

Examples of analysis of ranking results accordance obtained through different methods can be seen in Rodrigues et al. (2014), Liu et al. (2013), Peng et al. (2011), Yang et al. (2008). It should be noted that the results of this kind of research depend on the observed method choice and characteristics of problems that those methods are being applied to. In accordance with that, there are different conclusions made by different authors. In the works in which robustness and stability analysis of obtained solution is conducted in MDM, besides comparison with the solutions gained thorough other methods and techniques, the analysis is often based on an appropriate sensitivity analysis of the results to changes of certain parameters in the decision-making model (Yu et al. (2012); Stevens-Navarro et al. (2012); Li et al. (2013a); Li et al. (2013b); Corrente et al. (2014); Kannan et al. (2014)).

As specified in the shown research studies, the selection of an optimal MCDMM is a very complex problem which without any prior sensitivity analysis of the solution can have a wrong selection. Therefore, it is necessary to define the model for the sensitivity analysis of MCDMM. This article presents a study of estimating the variation of alternatives according to the criteria for the results of ranking alternatives, and in connection with this, the approach to improving the reliability of decision-making (reduce the risk of making an unsound decision) is discussed in detail. The model was tested on the example of logistical center location selection and the results of are presented in section 4. It is necessary to emphasize that the results presented in section 4 refer only to the observed example of the logistical center location selection and cannot be generalized.

The remainder of this paper is structured as follows: Section 2 gives a brief idea of the research methodology. Section 3 proposes preliminary methods for multi-attribute decision-making and techniques. Sections 4 and 5 present an illustrative example and discussion of the sensitivity model results. Finally, Section 6 presents the conclusions, highlighting directions for further research.

2 Research Methodology

The MCDM problem is usually solved in a two phase process: (1) The rating, that is, the aggregation of the values of criteria for each alternative, and (2) The ranking or ordering between the alternatives, with respect to the global consensual degree of satisfaction. The step-by-step sequence of the problem of multi-criteria decision-making is defined as follows (Triantaphyllou, 2000; Tzeng & Huang, 2011):

(1) Choice of alternatives (A_i; $i=1,2,...,m$);

(2) Choice of evaluating criteria (C_j; $j=1,2,...,n$);

(3) Acceptance of scales of an estimation of alternatives on each criterion;

(4) Determination of priorities (weights) of criteria (w_j; $j=1,2,..,n$);

(5) Determination evaluation matrix, i.e. decision matrix $X=\left[a_{ij}\right]_{m\times n}$;

(6) Choosing a method for ranking alternatives.

Careful consideration of each step is the key to the success of the final choice. The first three and the last of the steps relate exclusively to a specific subject area and imply involvement of qualified specialists in the field under consideration. The remaining steps are formalized (partially or completely) and require involvement of specialists in applied mathematics. Accordingly, there are 5 main factors affecting the outcome for ranked decision-making methods for MCDMM for which variations in the form of a formalized procedure or method are possible. These are: (1) the choice of scales of criteria; (2) evaluation of the weights of the criteria; (3) evaluation of alternatives according to the criteria; (4) the method of normalizing the decision matrix and (5) method of ranking. Earlier, in Pamučar et al (2017), the sensitivity of the choice of criteria scales and the evaluation of the weights of the criteria on the results of the ranking of alternatives, convincingly confirming the above thesis, was investigated.

It seems obvious that for real decision-making tasks none of the alternatives can be accurately measured for each of the criteria. The reason for this is the fundamental uncertainty of nature. The correct wording shows how accurately the alternative is evaluated by the criterion. Therefore, $a_{ij}=a_{ij}\cdot(1\pm\delta_{ij})$, where $\delta_{ij}\in(0,1)$ is the relative error of the estimate. Taking this into account, if we use the linear algebraic transformations of the elements of the decision-making matrix (preliminary normalization of the elements a_{ij} is necessary) to obtain the final ranks of the alternatives, or the class of methods based on the quasi-arithmetic transformations of the decision matrix elements, it is obvious that the degree of reliability of the result depends on the degree of reliability of the elements of matrix D. In the absence of errors of other values, the error of the final ranking will not be less than $\max_{ij}(a_{ij}\cdot\delta_{ij})$. In the simplest case of the OWA (Ordered Weighted Averaging) criteria aggregation method, the reliability of the result is estimated by the order value $\max(\delta_{ij})$. Thus, the final ranks r_i ($i=1,2,...,m$) are calculated with an error and are stochastic values. Then the question of the priority of one alternative over another should be solved in a statistical way.

Let alternatives A_k and A_s have r_k and r_s ranks, respectively, and $r_k\approx r_s$. The question is whether they are significant. The answer can be obtained if we use the t-Test about the equality of two average normal populations. The lack of reliable information about δ_{ij} will not allow such a test to be performed. We consider the following method of partially solving the problem of estimating the error in calculating the ranks of alternatives.

Step 1 An approximate estimate of the maximum total error in the choice problem, for example, $\delta_{ij}=0.1$ (or 10%), which is similar to specifying the risk.

Step 2 Multiple simulation of r_i ranks (for example, 1000 simulations) for the variation of the elements of the decision matrix X : $a_{ij} = a_{ij} \cdot (1 \pm \delta_{ij} \cdot rnd())$ using the random number generator Rnd [0, 1].

Step 3 Calculate the mean and variance for r_i and test the performance of the paired t-Test for alternatives having 1, 2, and 3 ranks.

Calculations show that for different variants of calculations, the ranks of alternatives change. For example, suppose that in the 1000 decision matrix simulations the 1 rank of alternative A_k took 780 points, alternative A_s was 200, and alternative A_p was 20 points. The ratios are 3.9 and 39 times more in favor of alternative A_k. But this is only with a superficial (trivial) approach. After all, the first 20 ranks of alternative A_p are obtained for specific 20 implementations of the decision matrix. It is possible that the true values of the estimates of alternatives are according to the criteria from the same set. Then there is the possibility of not making the best decision although this chance (risk) is about 2%. Therefore, the value of the approach assuming statistical variations of estimates of the alternatives by the given criteria consists in additional information for the decision-maker regarding the magnitude of the risks.

Having a statistical picture of the assessment of ranks, the decision-making can be carried out not only on the statistics of alternatives having rank 1, but it can also use statistics of the alternatives having the largest total 1 and 2 rank, or 1, 2 and 3 ranks. This is especially true when the difference in rank values is not large and is distributed on an average evenly between the first three ranks. For example, suppose that for A_k the number of first places is 40%, the second 10%, and the third 5%; for A_s the number of first places is 36%, the second 25%, and the third 7%; for A_p the number of first places is 25%, the second 20%, and the third 20%. Then:

(1) A_k is better than A_s and A_p in the number of 1 ranks (40> 36> 25);

(2) A_k is worse than A_s and better than A_p by the amount of the sum of 1 and 2 ranks (50<51, 50>45);

(3) A_k is worse than A_s and worse than A_p in the amount of the sums of 1, 2 and 3 ranks (55<62<65).

The above example shows complexity (and subtlety) of the procedure for selecting alternatives for the decision-maker in this scenario.

3 Preliminary methods for used multi-attribute decision-making methods

Before any further explanation of the recommended model, we are going to explain the basic setup of methods used in this work. Five methods were used: SAW, MOORA, VIKOR, COPRAS, CODAS, TOPSIS, D'IDEAL, MABAC, PROMETHEE-I,II, ORESTE-II. Before a statistical analysis of the above presented multi-criteria methods we define some preliminary benchmarks important for this research:

(1) In this research alternatives A_i are unformalized linguistic variables and criteria (C_j) are non-formalized linguistic variables. For each criterion it is necessary

to determine the direction of growth, i.e. *max* (beneficial) = (+1) or *min* (cost)= (– 1) as $sg_j = signC_j = \{\pm 1\}_1^n;\ j = 1,\ldots,n.$

(2) The methods for normalizing the decision matrix:

(1) Max	(2) Sum	(3) Max-Min	(4) Vector
For benefit attributes			
(1) $x_{ij} = \dfrac{a_{ij}}{a_j^{\max}};$	(2) $x_{ij} = \dfrac{a_{ij}}{\sum_{i=1}^{m} a_{ij}};$	(3) $x_{ij} = \dfrac{a_{ij} - a_j^{\min}}{a_j^{\max} - a_j^{\min}};$	(4) $x_{ij} = \dfrac{a_{ij}}{\sqrt{\sum_{j=1}^{n} a_{ij}^2}}$
For cost attributes			
(1') $x_{ij} = 1 - \dfrac{a_{ij}}{a_j^{\max}};$	(2') $x_{ij} = 1 - \dfrac{a_{ij}}{\sum_{i=1}^{m} a_{ij}};$	(3') $x_{ij} = \dfrac{a_j^{\max} - a_{ij}}{a_j^{\max} - a_j^{\min}};$	(4') $x_{ij} = 1 - \dfrac{a_{ij}}{\sqrt{\sum_{j=1}^{n} a_{ij}^2}}$
Variations			
(1'') $x_{ij} = \dfrac{a_j^{\min}}{a_{ij}};$	(2'') $x_{ij} = \dfrac{1/a_{ij}}{(1/a_{ij}) / \sum_{i=1}^{m}(1/a_{ij})};$		
(1''') $x_{ij} = -\dfrac{a_{ij}}{a_j^{\max}};$			

(3) Selecting a metric to measure the remoteness of two m-dimensional objects *C* and *D*

$$L_p\left(C,D\right) = \left[\sum_{i=1}^{m}(c_i - d_i)^p\right]^{1/p},\ 1 \le p \le \infty; L_\infty\left(C,D\right) = \max_i\left|c_i - d_i\right| \qquad (1)$$

3.1 SAW (Simple Additive Weighting) method

Simple Additive Weighting (SAW) method is probably the best known and most widely used MADM method (Anupama et al, 2015). The SAW method also known as a scoring method is one of the best and simplest types of multiple attribute decision-making method. The basic logic of the SAW method is to obtain a weighted sum of performance ratings of each alternative over all attributes. An evaluation score is calculated for each alternative by multiplying the scaled value given to the alternative of that attribute with the weights of relative importance directly assigned by the decision maker followed by summing up of the products for all criteria. The advantage of this method is that it is proportional linear transformation of the raw data which means that the relative order of magnitude of the standardized scores remains equal. The step wise procedure is given below (Kaklauskas et al, 2006):

Step 1 Construct a decision matrix $X = \left[a_{ij} \right]_{m \times n}$ that includes m personnel and n criteria. Calculate the normalized decision matrix for benefit/cost criteria:

$$a_{ij} : norm(1-1' < or 1'' or 1''' >, 2-2', 3-3', or\ 4-4') \tag{2}$$

Step 2 Evaluate each alternative, A_i by the following formula:

$$A_i = \sum_{j=1}^{n} w_j a_{ij}; \quad \sum_{j=1}^{n} w_j = 1 \tag{3}$$

where a_{ij} is the normalized value of the *i*-th alternative with respect to the *j*-th criteria, w_j is the weighted criteria (Kaklauskas et al, 2006).

3.2 MOORA (MultiObjective Optimization on the basis of Ratio Analysis) method

The method starts with a matrix of responses of different alternatives on different objectives x_{ij}; where x_{ij} represents the response of alternative *i* on objective *j*.

MOORA goes for a ratio system in which each response of an alternative on an objective is compared to a denominator, which is representative for all alternatives concerning that objective. The step wise procedure is given below (Brauers & Zavadskas, 2006; Kalibatas & Turskis, 2008; Brauers, 2008; Brauers et al., 2008):

Step 1 Construct a decision matrix $X = \left[a_{ij} \right]_{m \times n}$ that includes m personnel and n criteria. Calculate the normalized decision matrix for benefit/cost criteria:

$$a_{ij} : norm(1\ or\ 2\ or\ 3\ or\ 4) \tag{4}$$

Step 2 Evaluate each alternative, A_i by the following formula:

$$Q_i = \sum_{j=1}^{n} sg_j \cdot w_j \cdot a_{ij}; \quad \sum_{j=1}^{n} w_j = 1 \tag{5}$$

where a_{ij} is the normalized value of the *i*-th alternative with respect to the *j*-th criteria, w_j is the weighted criteria. These normalized responses of the alternatives on the objectives belong to the interval [0,1].

Step 3 For optimization these responses are added in case of maximization and subtracted in case of minimization (Brauers, 2008):

$$Q_i = \max_j (v_{ij}); \ a_{ij} : norm(4); \ r_j = \left| \max_i \left(sg_j \cdot a_{ij} \right) \right|, \ v_{ij} = \omega_j \cdot \left| r_j - a_{ij} \right|; \ \max_i Q_i \tag{6}$$

where a_{ij} is the normalized value of the *i*-th alternative with respect to the *j*-th criteria, w_j is the weighted criteria.

3.3 VIKOR (VIsekriterijumsko KOmpromisno Rangiranje) method

VIKOR method represents an often used method for multicriteria ranking and suitable for solving different decision-making problems. It is especially suitable for those situations where the criteria of quantitative nature are prevalent. The VIKOR method was developed based on the elements of compromise programming. The method starts from the "border" forms of L_p metrics (Opricović & Tzeng, 2004). It seeks the solution that is the closest to the ideal. In order to find the distance from the ideal point it uses the following function:

$$L_p\left(F^*, F\right) = \left\{ \sum_{j=1}^{n} \left[f_j^* - f_j\left(x\right) \right]^p \right\}^{1/p}, 1 \le p \le \infty \qquad (7)$$

This function represents the distance between ideal point F^* and point $F\left(x\right)$ in space of criteria functions.

The essence of the VIKOR method is that for every action it finds the value of Q_i, and then it chooses the action which has the lowest listed value (the smallest distance from the "ideal" point). The step wise procedure is given below:

Step 1 Determine "ideal" and "anti-ideal" object

$$\begin{aligned} a_j^+ &= \{\max_i a_{ij} \left| if\ j \in C_j(\max);\ \min_i a_{ij} \right| if\ j \in C_j(\min)\}; \\ a_j^- &= \{\min_i a_{ij} \left| if\ j \in C_j(\max);\ \max_i a_{ij} \right| if\ j \in C_j(\min)\}. \end{aligned} \qquad (8)$$

where a_j^+ and a_j^-, respectively, present ideal and anti-ideal object.

Step 2 Weighted Normalization: *norm(3)*

$$w_j \cdot x_{ij} = \begin{cases} w_j \cdot \dfrac{a_{ij} - a_j^+}{a_j^+ - a_j^-} & if\ x_{ij} \in B; \\ w_j \cdot \dfrac{a_j^+ - a_{ij}}{a_j^+ - a_j^-} & if\ x_{ij} \in C. \end{cases} \qquad (9)$$

Where *B* and *C,* respectively, present beneficial and cost group of criteria.

Step 3 The strategies of maximal *R* and group utility *S*

$$\begin{aligned} S_i &= \sum_{j=1}^{n} x_{ij};\ S^* = \min_i S_i;\ S^- = \max_i S_i \\ R_i &= \max_j x_{ij};\ R^* = \min_i R_i;\ R^- = \max_i R_i \end{aligned} \qquad (10)$$

Step 4 Calculate the values of Q_i

$$Q_i = v \cdot \frac{S_i - S^*}{S^- - S^*} + \left(1 - v\right) \frac{R_i - R^*}{R^- - R^*} \qquad (11)$$

where *v* plays the role of the balancing factor between the overall benefit (*S*) and the maximum individual deviation (*R*). Smaller values of *v* emphasize group gain, while larger values increase the weight determined by individual deviations. "Voting by majority rule" (*v*> 0.5); or "by consensus" (for *v* = 0.5); or "with a veto" (for *v* <0.5).

Step 5 The result of the procedure comprises three rating lists: *S*, *R* and *Q*. The alternatives are evaluated by sorting values of *S*, *R* and *Q* by the criterion of the minimum value. The best alternatives:

$$\min_i \{Q_i, S_i, R_i\} \qquad (12)$$

Step 6 As a compromise solution, an alternative A_1 is proposed which is best estimated by Q (minimum) if the following two conditions are met:

Condition C1: "Allowable advantage": $Q(A_2) - Q(A_1) >= 1/(m-1)$, where A_2 is an alternative to the second position in the Q ranking list.

Condition C2: "Acceptable stability in decision-making": Alternative A_1 should also be best estimated by S or / and R.

Step 7 If one of the conditions - 1 or 2 - is not satisfied, then a set of compromise solutions is proposed, which consists of:

- alternatives A_1 and A_2, if condition C2 is not met, or,
- alternatives A_1, A_2, ..., A_k if condition C1 is not satisfied; A_k is determined by relation $Q(Ak-1)-Q(A1)<1/(m-1)$ & $Q(Ak)-Q(A1)\geq 1/(m-1)$.

3.4 COPRAS (COmplex PRoportional ASsessment) method

Ranking alternatives by the COPRAS method assumes direct and proportional dependence of significance and priority of the investigated alternatives on a system of criteria (Ustinovichius et al, 2007). The selection of significance and priorities of alternatives, by using the COPRAS method, can be expressed concisely using four stages (Viteikiene & Zavadskas, 2007). For normalization in the COPRAS method we use $x_{ij} : norm(1\ or\ 2 or\ 3\ or\ 4)$.

In the COPRAS method, each alternative is described with the sum of maximizing attributes S_{+i}. In order to simplify calculation of S_{+i} and S_{-i} in the decision-making matrix columns, the maximizing criteria are placed first, followed by the minimizing criteria. In such cases, S_{+i} and S_{-i} are calculated as follows (Viteikiene & Zavadskas, 2007):

$$S_{+i} = \sum_{j=1}^{n} x_{ij} \mid for\ j \in C_j (\max);$$
$$S_{-i} = \sum_{j=1}^{n} x_{ij} \mid for\ j \in C_j (\min). \tag{13}$$

Relative weight Q_i of the *i*-th alternative is calculated as follows:

$$Q_i = S_{+i} + \frac{\sum_{i=1}^{m} S_{-i}}{S_{-i} \sum_{i=1}^{m} \frac{1}{S_{-i}}} \tag{14}$$

The priority order of the compared alternatives is determined on the basis of their relative weight (higher relative weight higher priority/rank).

3.5 TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method

The basic principle of the TOPSIS method is that the best alternative should have the shortest distance from the ideal solution and the farthest distance from the anti-ideal solution. A relative distance of each alternative from ideal and anti-ideal solutions is obtained as (Chang et al, 2010)

$$Q_i = \frac{S_i^-}{S_i^+ + S_i^-}, i = 1, \ldots, n \tag{15}$$

where S_i^+ and S_i^- are separation measures of alternative i from the ideal and anti-ideal solution, respectively; Q_i is the relative distance of alternative i to the ideal solution, and $Q_i \in [0,1]$.

The largest value of criterion Q_i correlates with the best alternative. The best ranked, or the most preferable, alternative A_{TPS}^* can be determined as $A_{TPS}^* \left\{ A_i = \max_i Q_i \right\}$.

For normalization in the TOPSIS method we use $r_{ij} : norm(1\ or\ 2\ or\ 3\ or\ 4)$. The separation measures of each alternative, from the ideal and anti-ideal solutions, are computed using the following formulae (Chang et al, 2010):

$$S^+ = \left\{ \sum_{j=1}^{n} \left[w_j \left(r_{ij} - r_i^+ \right) \right]^2 \right\}^{1/2} \tag{16}$$

$$S^- = \left\{ \sum_{j=1}^{n} \left[w_j \left(r_{ij} - r_i^- \right) \right]^2 \right\}^{1/2} \tag{17}$$

where element r_{ij} represents the performance of alternative A_i in relation to criterion C_j. For m criteria ($C_1, C_2, \ldots, C_m$) and n alternatives ($A_1, A_2, \ldots, A_n$) matrix R has shape $R = \left[r_{ij} \right]_{nxm}$. Values ($w_1, w_2, \ldots, w_m$) represent weight values of the criteria that satisfy condition $\sum_{i=1}^{n} w_i$.

Ideal A^+ and anti-ideal A^- solution in the TOPSIS method can be determined using formulas (8) and (9), respectively.

$$A^+ = \left\{ (\max v_{ij} \mid j \in G), (\min v_{ij}, j \in G^{'}), i = 1,..,n \right\} = \left\{ v_1^+, v_2^+, \ldots, v_m^+ \right\} \tag{18}$$

$$A^- = \left\{ (\min v_{ij} \mid j \in G), (\max v_{ij}, j \in G^{'}), i = 1,..,n \right\} = \left\{ v_1^-, v_2^-, \ldots, v_m^- \right\} \tag{19}$$

It can be seen from equations (16) and (17) that the ordinary TOPSIS method is based on the Euclidean distance (Chang et al., 2010; Shanian & Savadogo, 2006).

3.6 D'IDEAL (Displaced Ideal Method)

An "ideal" object is formed from the most preferable values of the criteria and so are "anti-ideals" from the least preferred values. The distances of the objects from the original set to the "anti-ideal" are determined, on the basis of which the "worst" objects are allocated. After excluding the "worst" objects, we return to the stage of formation of the "ideal", and it changes, approaching the real objects. The procedure ends when there remain a small number of objects, which are considered to be the most preferable. The step wise procedure is given below:

Step 1 Determine an "ideal" object and an "anti-ideal" one

$$a_j^+ = \{ \max_i a_{ij} \left| if\ j \in C_j(\max); \ \min_i a_{ij} \right| if\ j \in C_j(\min) \}; \ j = 1, \ldots, n \tag{20}$$

$$a_j^- = \{ \min_i a_{ij} \left| if\ j \in C_j(\max); \ \max_i a_{ij} \right| if\ j \in C_j(\min) \}; \ j = 1, \ldots, n \tag{21}$$

$$w_j \cdot x_{ij} = \begin{cases} w_j \cdot \dfrac{a_{ij} - a_j^+}{a_j^+ - a_j^-} \ \ if \ \ x_{ij} \in B; \\ w_j \cdot \dfrac{a_j^+ - a_{ij}}{a_j^+ - a_j^-} \ \ if \ \ x_{ij} \in C. \end{cases} \tag{22}$$

Step 2 Calculate the distance of the objects to the "anti-ideal" using metrics for different values of *p*, for example, $p = \{1, 2, \infty\}$

$$L_i^p = \left\{ \sum_{j=1}^{n} x_{ij}{}^p \right\}^{1/p}, \ \ L_i^\infty = \max_j \left| x_{ij} \right| \tag{23}$$

Step 3 Exclude "hopeless" options. For this, for each *p*, all objects are ordered in proximity to the "ideal" in magnitude L_i^p. The more L_i^p, the further A_i is from the anti-ideal, and the higher the rank of the alternative A_i (rank 1 is higher).

$$Q_i = \sum_p (L_i^p / L_{\max}^p); L_{\max}^p = \max_i L_i^p \ ;$$
$$R_i = \sum_p r_i{}^p; \ r_i{}^p = rank(L_i^p \ |\{L_1^p, L_2^p, ..., L_m^p\}) \tag{24}$$

Exclude one (two or three, depending on the number of alternatives) of "unpromising" variants that have the greatest total rank R_i. These are objects that, at different metrics (different *p*), are at the end of the ordered series. The procedure ends when there remain a small number of objects, which are considered to be the most preferable. The best alternative is $\max_i Q_i$.

3.7 MABAC (Multi-Attributive Border Approximation area Comparison)

The MABAC method is developed by Pamucar & Cirovic (2015). The basic setting of the MABAC method consists in defining the distance of the criteria function of every observed alternative from the border approximate area. The step wise procedure is given below:

Step 1 Normalization of the initial matrix elements.

$$x_{ij} = \begin{cases} \dfrac{a_{ij} - a_j^+}{a_j^+ - a_j^-} \ \ if \ \ x_{ij} \in B; \\ \dfrac{a_j^+ - a_{ij}}{a_j^+ - a_j^-} \ \ if \ \ x_{ij} \in C. \end{cases} \tag{25}$$

where, a_j^+ and a_j^- represent the elements of the initial decision matrix.

Step 2 Calculation of the weighted matrix elements. The elements of the weighted matrix are calculated on the basis of the expression (26)

$$v_{ij} = (x_{ij} + 1) \cdot w_j \tag{26}$$

where v_{ij} represents the elements of the normalized matrix, w_j represents the weighted coefficients of the criterion.

Step 3 Determination of the approximate border area matrix. The border approximate area for every criterion is determined by expression (27):

$$g_j = \left(\prod_{i=1}^{m} v_{ij} \right)^{1/m}, \ i = 1, m; \ j = 1, n \tag{27}$$

where v_{ij} represents the elements of the weighted matrix, *m* represents total number of alternatives.

After calculating the value of g_j by criteria, a matrix of border approximate areas *G* is developed in the form *n* x 1.

Step 4 Ranking of alternatives. The calculation of the values of the criteria functions by alternatives is obtained as the sum of the distance of alternatives from the border approximate areas. The final values of the criteria function of alternatives are obtained as follows

$$Q_i = \sum_{j=1}^{n} (v_{ij} - g_j) \tag{28}$$

where *n* represents the number of criteria.

Step 5 The best alternative is $\max_i Q_i$.

3.8 ORESTE (Organisazion, RangEment ot SynTEze de donnecs relationnelles) method

The ORESTE method was developed by Roubens (1978). The aim of this method is to find a global preference structure of a set of alternatives by evaluating them by each criterion and the preference among the criteria. This method generally defines criteria and alternatives, constructs a global complete and partial preorder of the alternatives by performing indifference and conflict analyses. In this research normalization matrix is performed by using $r_{ij} : norm(3)$. The step wise procedure is given below (Roubens (1978)):

Step 1 Transition from matrix DM to matrix of ranks (the columns of the matrix are replaced by their ranks)

$$r_{ij} = rank(a_{ij} \,|\{a_{1j}, a_{2j}, ..., a_{mj}\}), \ \forall i, j \quad (i = 1, ..., m; j = 1, ..., n) \tag{29}$$

Step 2 Determine ranks of criteria

$$\begin{aligned} rc_j &= rank(C_j \,|\{C_1, C_2, ..., C_n\}), \ \forall j = 1, ..., n \ ; or \\ rc_j &= rank(w_j \,|\{w_1, w_2, ..., w_n\}) \end{aligned} \tag{30}$$

Step 3 Compute the projections of ranks

$$\begin{aligned} & d_{ij} = \left[(1-\alpha) \cdot r_{ij}{}^{p} - \alpha \cdot rc_j{}^{p} \right]^{1/p}, \ \alpha \in (0;1) \\ & p = 1, \ \ Average \ (Mean); \\ & p = -1, \ \ Medium \ Harmonic; \\ & p = 2, \ \ Mean \ Square \\ & p = \ \inf, \ \ \max(R, \ w); \\ & p = -\inf, \ \ \min(R, w) \end{aligned} \tag{31}$$

Step 4 Calculating ranks d_{ij}

$$Rd_{ij} = rank(d_{ij} \,|\, \{d_{ij}\}_{i=1:m; \, j=1:n}), \ \ R_i = \sum_{j=1}^{n} Rd_{ij} \tag{32}$$

Step 5 Calculate ranks R_i

$$OutR_i = rank(R_i \mid \{R_1, R_2, ..., R_m\}) \tag{33}$$

Step 6 Calculate preference factors C_{ik}

$$C_{ik} = \frac{1}{2 \cdot n^2 \cdot (m-1)} \cdot \sum_{j=1}^{n} (Rd_{ij} - Rd_{kj} + | Rd_{ij} - Rd_{kj} |)$$
$$r_{ij} = \underset{j}{rank}(a_{ij});\ R_{ij} = \underset{j}{sort}(a_{ij}, if\ sg_j = +1, \text{'descend'}, if\ sg_j = -1, \text{'ascend'},); \tag{34}$$

Step 7 The best alternative is $\min_i Q_i$.

3.9 PROMETHEE (Preference Ranking Organisation METHod for Enrichment Evaluations)

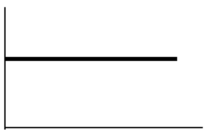
The PROMETHEE method was developed at the beginning of the 1980s and has been extensively studied and refined since then (Figueira et al., 2005). It has particular application in decision-making, and is used around the world in a wide variety of decision scenarios, in the fields such as business, governmental institutions, transportation, healthcare and education.

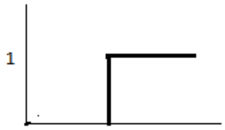
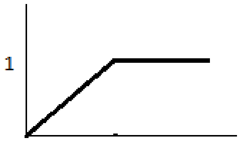
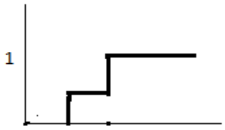
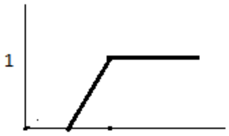
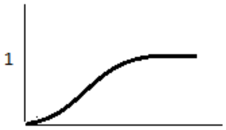
The PROMETHEE method helps the decision makers find the alternative that best suits their goal and their understanding of the problem. It provides a comprehensive and rational framework for structuring a decision problem, identifying and quantifying its conflicts and synergies, clusters of actions, and highlights the main alternatives and the structured reasoning behind them. The step wise procedure is given below:

Step 1 Set the preference function for two objects for each criterion $H_j = H(d_{is}, p, q)$. As a rule, they have two parameters: *p* - indifference threshold, it reflects the fact that if difference of d_{is} values of two alternatives *i* and *s* is unimportant, then objects by criterion j are equivalent. If the difference in threshold value *p* is exceeded, a preference relation is established between the objects. If the difference in threshold *q* is exceeded, the preference function corresponds to the "strong preference" of variant *i* with respect to variant *s* with respect to criterion *j*. With the difference of d_{is} in the interval from *p* to *q*, the preference function is less than 1, which corresponds to a "weak preference".

The choice of the preference function is determined by the decision-makers. Some types of functions are preferred *H*(*d*) are presented below (Table 1): 1) regular- 0 if *d*< =0, 1 if *d*>0; 2) U-Shape ([*p* 0] *p*>0); 3) V-Shape ([*p* 0] *p*>0); (*p* is indifference threshold); 4) Level criterion([*p* *g*]); *p*, *q*>0 (*q* is the preference threshold); 5) Linear criterion([*p* *g*]); *p*, *q*>0; 6) Gaus criterion([*p* *p*]) *p*=sigma (Table 1).

Table 1 Preference functions of PROMETHEE

Function	Shape	Threshold	Formula
Usual		No threshold	$f(x) = \begin{cases} 1, & x > 0 \\ 0, & x \le 0 \end{cases};$

Function	Shape	Threshold	Formula
U-shape		q threshold	$f(x)=\begin{cases}1, & x>q\\ 0, & x\le q\end{cases};$
V-shape		p threshold	$f(x)=\begin{cases}x/p, & x\le p\\ 1, & x>p\end{cases};$
Level		p and q threshold	$f(x)=\begin{cases}0, & x\le p\\ 0.5, & p<x<q;\\ 1, & x\ge q\end{cases}$
Linear		p and q threshold	$f(x)=\begin{cases}0, & x\le p\\ (x-p)/(q-p), & p<x<q;\\ 1, & x\ge q\end{cases}$
Gaussian		s threshold	$f(x)=1-\exp\left(-\frac{x^2}{2s^2}\right);$

Step 2 Calculate the difference in the values of the criteria for the two objects and calculate preference indexes V

$$d_{is}=a_{ij}-a_{sj};\ H_j=H_j(d_{is},p,q,);\ \ V_{is}=\sum_{j=1}^{n}w_j\cdot H_j \quad -[m\times m]-Matrix \tag{35}$$

Step 3 Determine the preference factors

$$\Phi_i^+=\sum_{s=1,s\ne i}^{m}V_{is};\ \Phi_i^-=\sum_{s=1,s\ne i}^{m}V_{si};\ \ Q_i=\Phi_i^+-\Phi_i^-. \tag{36}$$

Step 4 The best alternative is $\max_i Q_i$.

3.10 CODAS (COmbinative Distance-based ASsessment) method

The CODAS method is an efficient and updated decision-making methodology introduced by Keshavarz Ghorabaee et al. (2016). The desirability of alternatives in the CODAS is determined based on l^1-norm and l^2-norm indifference spaces for criteria. According to these spaces, in the procedure of this method, a combinative form of the Euclidean and Taxicab distances is utilized for calculation of the assessment score of alternatives. The step wise procedure is given below:

Step 1 Construct the Weighted Normalized Decision Matrix

$$x_{ij} = \begin{cases} w_j \cdot \dfrac{a_{ij}}{a_j^{\max}} & if \;\; x_{ij} \in B; \\ w_j \cdot \dfrac{a_j^{\min}}{a_{ij}} & if \;\; x_{ij} \in C. \end{cases} \tag{37}$$

Step 2 Determine the negative-ideal solution as given in equation. Construct *min* vector for criteria

$$r_j = \min_i x_{ij}; \;\; j = 1,\ldots,n; \;\; i = 1,\ldots,m \tag{38}$$

Step 3 Calculate the Euclidean and Taxicab distances of alternatives from the negative-ideal solution

$$E_i = \left[\sum_{j=1}^{n} (x_{ij} - r_j)^2 \right]^{1/2} \tag{39}$$

$$T_i = \sum_{j=1}^{n} | x_{ij} - r_j | \tag{40}$$

Step 5 Construct the relative assessment matrix

$$H_{ik} = (E_i - E_k) + \psi(E_i - E_k) \cdot (T_i - T_k), \quad i,k = 1,\ldots,m \tag{41}$$

where ψ denotes a threshold function

$$\psi(x) = \begin{cases} 1, & if \;\; |x| \geq \tau \\ 0, & if \;\; |x| \prec \tau \end{cases} \tag{42}$$

τ is the threshold parameter that can be set by the decision maker. It is suggested to set this parameter as a value between 0.01 and 0.05. If the difference between the Euclidean distances of two alternatives is less that τ, the two alternatives are also compared by the Taxicab distance.

Step 6 Calculate the assessment score of each alternative

$$H_i = \sum_{k=1}^{m} H_{ik} \tag{43}$$

Step 7 Rank the alternatives according to the decreasing values assessment score *H*. The alternative with the highest *H* is the best choice among the alternatives.

4 An illustrative example: the location selection of tri-modal LC and logistical flows

The sensitivity analysis model is tested on an example of the logistical center (LC) location selection (Pamučar et al, 2017). The goal is to find a location which generates lowest expenses, offers highest efficiency and at the same time fulfills operational and strategic needs.

3.1 Alternatives and criteria weighting

In our example the authors used 11 criteria which were identified in Pamučar et al (2017) based on which the location selection of tri-modal LC is going to be conducted (Table 2).

Table 2 Criteria for LC selection (Pamučar et al, 2017)

Criterion	Criterion name	w_i	Unit of Measurement
C_1	Connectivity to Multimodal Transport	0.109	Linguistic Variable
C_2	Infrastructure Development Evaluation	0.105	Infrastructure Development (%)
C_3	Environment effect	0.101	Linguistic Variable
C_4	Conformity with Spatial Plans and Strategy Of Economic Development	0.097	Linguistic Variable
C_5	Gravitating Intermodal Transport Unit - ITU	0.094	Number of Gravitating ITUs (ITU/year)
C_6	Reload capacity of an LC	0.094	Number of Reloaded ITUs (ITU/h)
C_7	Available Area For Future Development and Capacity Expansion Of Lcs	0.093	LC Development Area (m^2)
C_8	User's Distance from an LC	0.088	Linguistic Variable
C_9	Traffic Safety	0.084	Linguistic Variable
C_{10}	Length of Railroad Reload Front	0.071	Reload Front Length (m)
C_{11}	Evaluation of Quality of Traffic Approaches for Interpellant Means of Transportation	0.063	Linguistic Variable

A total of eight locations were considered. Table 3 shows characteristics of eight locations (alternatives) for the tri-modal LC development on the Danube River.

Table 3 A mixed data matrix corresponding to example (Pamučar et al, 2017)

Alternative	Criteria										
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}
LC 1	4	71	4	3	45000	150	1056	2	4	478	4
LC 2	4	85	4	4	58000	145	2680	2	5	564	4
LC 3	4	76	4	4	56000	135	1230	2	4	620	3
LC 4	3	74	3	4	42000	160	1480	4	3	448	5
LC 5	5	82	3	5	62000	183	1350	2	4	615	4
LC 6	4	81	3	5	60000	178	2065	2	3	580	4
LC 7	4	80	3	5	59000	160	1650	3	5	610	4
LC 8	3	82	4	4	54000	120	2135	3	4	462	5

The weight coefficients of the criteria are obtained based on the Sun (2012), Zare at al (2013) and Rahmaniani et al (2013):

$$w_j = (0.109; 0.105; 0.101; 0.097; 0.094; 0.094; 0.093; 0.088; 0.084; 0.071; 0.063)$$

with criteria $\text{sign}\, C_s = (1;1;-1;1;1;1;1;-1;1;1;1)$, where "1" marks criteria of the "benefit" type (bigger criterion value is preferable), whereas "-1" marks criteria of the "cost" type (lower criterion value is preferable).

Variations in the values of the alternatives of the presented example are carried out for the criteria C3, C5-C7, C10. For software implementation, it is sufficient to specify a vector-switch, according to the number of criteria. For the realized example, this is the vector [0 0 1 0 1 1 1 0 0 1 0], where 1- on, 0-off.

3.2 Statistical experiment

Statistics of effectiveness indicators of the alternatives for each criterion is made by the following calculation formula:

$$D_k = D_0 + (-1 + 2 \cdot rnd()) \cdot \delta \cdot D_0 \tag{44}$$

where D_0 is the initial evaluation of the decision matrix; the function $rnd()$ returns a uniformly distributed random number from [0,1]; δ is relative error of estimating alternatives for each criterion; k = 1, ..., N is the number of variations in decision matrix D_k.

For each variation of matrix D_k, a general evaluation of the alternatives' effectiveness for all the criteria was made by using one of the above described aggregation methods: SAW, MOORA, VIKOR, COPRAS, CODAS, TOPSIS, D'IDEAL, MABAC, PROMETHEE-I,II, ORESTE-II. The calculations are performed in the MATLAB system. The software protocols (m-files) and the user's manual are publicly available in the file exchange of website of the company MathWorks (Mukhametzyanov, 2018a, 2018b, 2018c, 2018d). The volume of the statistical experiment is N=1024. Relative error values δ varied from 5, to 25% {0.05, 0.10, 0.15, 0.20, 0.25}.

Thus, in statistical experiments, N values of the overall evaluation of the effectiveness of alternatives $\{C_i^*\}_k$ for all the criteria and the ranks (priorities) $\{r_i^*\}_k$ of alternatives A$_i$ (i = 1, m) corresponding to these values for each of the considered MCDM methods are obtained. For each sample of N values C_i^*, mean $\overline{C}_i^*$ and standard deviation $std(C_i^*)$ are calculated.

5 Results of sensitivity analysis of MDM methods

5.1 Distribution of the overall evaluation of the effectiveness of alternatives

In accordance with the central limit theorem (Lyapunov CLT) and considering that C_i^* aggregation is carried out additively for all alternatives, the distribution of random variable C^* obeys the normal distribution law. Figs. 1 and 2 show typical histograms of values C_i^* obtained for different values of the relative error of the computational experiment.

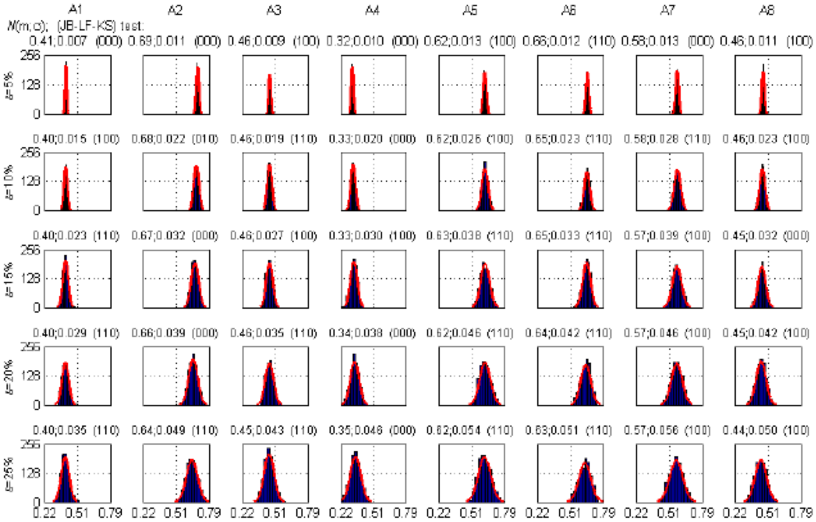


Fig. 1 Histogram of the relative closeness to the ideal solution depending on the relative error in the data (δ,%). (1000 Simulation of DM Matrix; m, σ- parameters of normal distribution)

Fig. 1 shows point estimates of unknown mean-variance parameters and also the logical values of three tests of normal distribution. This is Jarque-Bera test, Lilliefors test and Kolmogorov-Smirnov test. The null hypothesis that the sample is in vector *Q* comes from normal distribution with unknown mean and variance, with the alternative that it does not come from normal distribution. Three (JB-LF-KS): the figure is represented by a set of 0 and 1 for each of the tests. The test returns the logical value h = 1 if it rejects the null hypothesis at the 5% significance level, and h = 0 if it cannot.

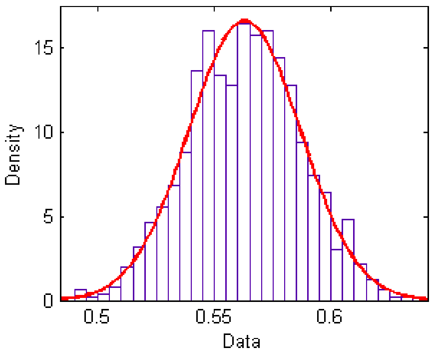


Fig. 2 Fit distributions to C_5^* (LC5, COPRAS, δ=20%, 1000 Simulation of DM Matrix)

For all the methods, a slight decrease $\overline{C}_i^*$ and increase $std(C_i^*)$ is observed with increasing values δ. The dynamics $\overline{C}_i^*$ and $std(C_i^*)$ is shown in Fig. 3.

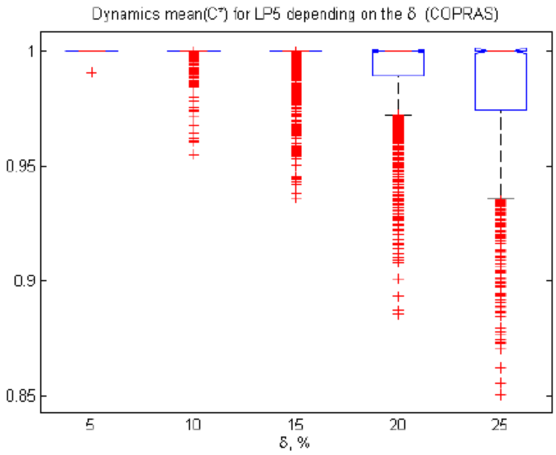


Fig. 3 Dynamics mean (C_5^*) depending on δ. (A_5, COPRAS, 1000 Simulation of DM Matrix).

To determine the distribution law, use the statistical function Statistics Toolbox MATLAB - dfittool - Interactive distribution fitting - opens a graphical user interface for displaying fit distributions to data.

Distribution parameters referring to Fig. 2 is: Distribution: Normal; Log likelihood: 2309.1; Domain: -Inf <y <Inf; Mean: 0.563; Variance: 0.0006; Parameter Estimate: mu 0.563, Std. Err. Mu 0.00076, Sigma 0.024, Std. Err. Sigma: 0.0005; 95% confidence intervals for mu: (0.5614; 0.5644). Similar statistical results hold for all A_i, all Methods, and all δ.

The distributions of statistics for the SAW, MOORA, ORESTE-2, TOPSIS, MABAC, PROMETHEE methods are described by the normal distribution law. The CODAS and VIKOR methods are not very stable to the variation of the initial data - multimodality, distribution asymmetry, or incomprehensible distribution laws are observed. For the COPRAS method, "leaders" alternatives A2, A5, A6 have deviations from normality due to strong asymmetry. For the D'Ideal method, distributions for alternatives A5 and A8 are not stable.

4.2 Ranking of alternatives

Changing the initial decision matrix at random in the calculations for a given value of the relative error (not more than δ) in a number of experiments, the priorities of the alternatives change. For example, Tables 4 and 5 show the results of the COPRAS calculations for various initial data. At δ = 10%, the first priority has alternatives LP5 in 91.8% simulations, LP2 in 5.2% simulations and LP6 in 3.0% simulations.

Table 4 COPRAS ranking C* for various initial data of the decision matrix for δ = 0.1; 1024 simulations (Fragment)

K	LC1	LC2	LC3	LC4	LC5	LC6	LC7	LC8
1	0.112	0.135	0.119	0.110	0.138	0.135	0.131	0.118
2	0.112	0.135	0.119	0.109	0.138	0.137	0.130	0.118
3	0.112	0.135	0.118	0.111	0.138	0.135	0.132	0.118
4	0.115	0.133	0.118	0.110	0.140	0.135	0.130	0.118
5	0.113	0.134	0.117	0.110	0.138	0.131	0.134	0.121
6	0.112	0.135	0.119	0.110	0.136	0.136	0.131	0.121
7	0.112	0.137	0.118	0.109	0.138	0.134	0.131	0.120
8	0.113	0.135	0.118	0.110	0.139	0.133	0.132	0.119
9	0.112	0.135	0.119	0.108	0.139	0.139	0.129	0.119
10	0.113	0.137	0.119	0.110	0.136	0.134	0.132	0.118
				…				
51	0.112	0.134	0.120	0.110	0.138	0.136	0.130	0.119
				…				
74	0.112	0.134	0.119	0.110	0.139	0.135	0.131	0.118
				…				
102	0.112	0.136	0.120	0.109	0.137	0.134	0.131	0.119
				…				
1023	0.113	0.137	0.120	0.110	0.138	0.134	0.131	0.118
1024	0.114	0.134	0.120	0.110	0.137	0.136	0.130	0.118
First rank (%)		8.6	-	-	79.3	12.1	-	-
Second rank (%)		-	-	-	-	44.2	-	-
Third rank (%)		48.4	-	-	-	-	-	-

Table 5 Summarized results of the COPRAS calculations for various initial data (δ = 0.1; N=1024)

Rank	Alternatives							
	LP1	LP2	LP3	LP4	LP5	LP6	LP7	LP8
I	0	88	0	0	812	124	0	0
II	0	391	0	0	172	453	8	0
III	0	496	0	0	40	410	78	0
IV	0	49	0	0	0	37	938	0
V	0	0	615	0	0	0	0	409
VI	1	0	409	0	0	0	0	614
VII	954	0	0	69	0	0	0	1
VIII	69	0	0	955	0	0	0	0
Total	1024	1024	1024	1024	1024	1024	1024	1024

In some cases, it may turn out that average efficiencies $\overline{C}_i^*$ for various alternatives are not statistically indistinguishable; hence, for the ranking it is necessary to consider alternatives having the largest number of the second and third ranks. We denote them as II(1) and III(1). Priorities of alternatives C_i^* are stochastic values. Therefore, when using the ranking procedure, the criterion for meaningful distinguishability of values C_i^* should be used. For example, the question is how much the value C_i^* is for the seventh experiment (refer to: Table 2). To correctly answer this question, it is necessary to construct interval estimates for C_i^* and to make a t-Test of the Student of significant difference between the two averages.

Thus, the problem of measuring the error of the result is current, provided that the error (error) in the initial data is known (estimated). Otherwise, we cannot guarantee the priority of any alternative, no matter what method we use.

Having a statistical picture of the ranks assessment, the decision-making can be carried out not only on the statistics of alternatives having rank I, but it can also use the statistics of alternatives having, for example, the largest total rank. The sums of the first three alternatives are relevant. The total rank of such alternatives is denoted by I+II(1) and I+II+III(1).

For various variants of calculations for a fixed δ, the ranks of alternatives change. Suppose that in the *N* simulation experiments DM, I the rank of alternative A_k took n_k points (times), alternative A_s took n_s, and alternative A_p took n_p ($n_k > n_s > n_p$). It seems that the choice is in favor of alternative A_k. But this holds for only when the approach is superficial (trivial). After all, n_p of the first ranks of alternative A_p are obtained for concrete n_p implementations of the decision matrix. It is possible that the true values of the estimates of alternatives are according to the criteria from the same set. Therefore, it is necessary to take into account such options. The following variations of the ranks I(2), I(3) - alternatives having rank I and, respectively, 2 and 3, the number (points) of realizations in *N* experiments are relevant. Alternatives I+II(2), I+II(3) and I+II+III(2) - alternatives having I, II and III rank are also relevant, and having respectively 2 and 3 the number of total realizations in *N* experiments.

Figs. 4 and 5 show the distribution of the points (number) of realizations of effective alternatives (%) to the total number of *N* experiments having ranks I, II, III, and the sums I+II, I+II+III ranks.

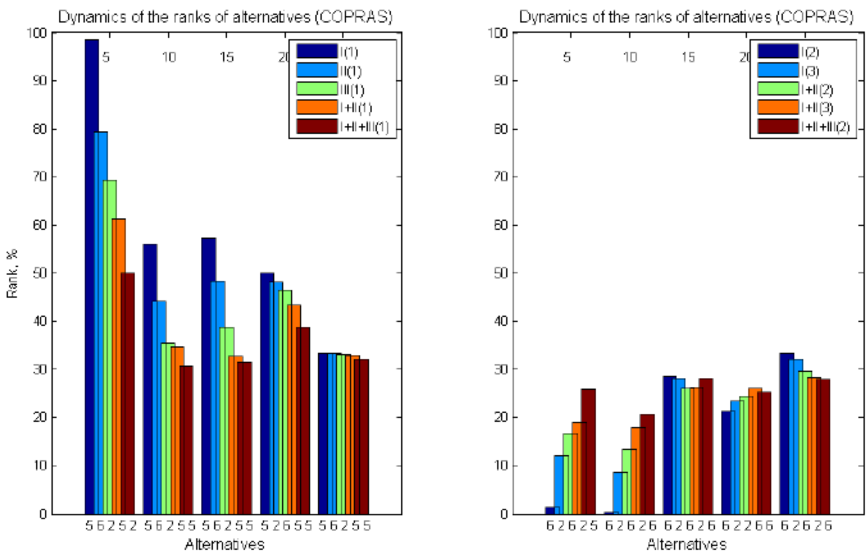


Fig. 4 Distribution of the point of realizations of effective alternatives in% to the total number of *N* experiments having ranks I, II, III, and the sums I+II, I+II+III ranks (LC5, COPRAS, 1024 Simulation of DM Matrix, δ = 5-25%)

The results show that in more options, the alternative is LC5. However, for a significant fraction of the total number of experiments = *N*, the alternatives are LC3 and LC6.

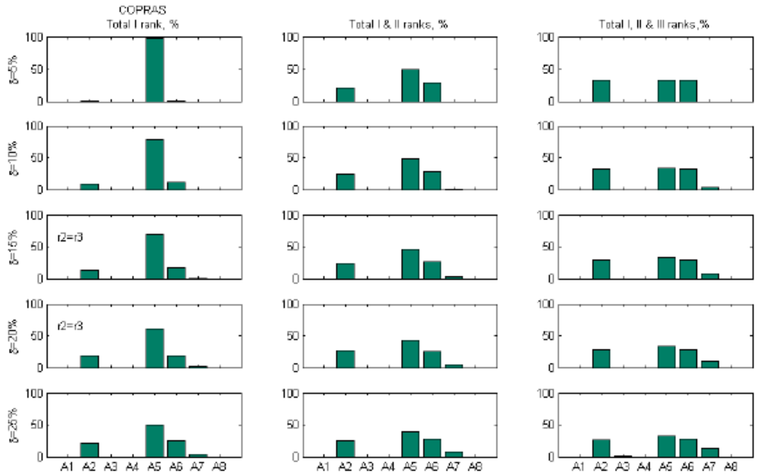


Fig. 5 Distribution of the point of realizations of effective alternatives in% to the total number of N experiments having ranks I(1) and the sums I + II(1), I + II + III(1) ranks. (COPRAS, 1024 Simulation of DM Matrix, δ = 5-25%)

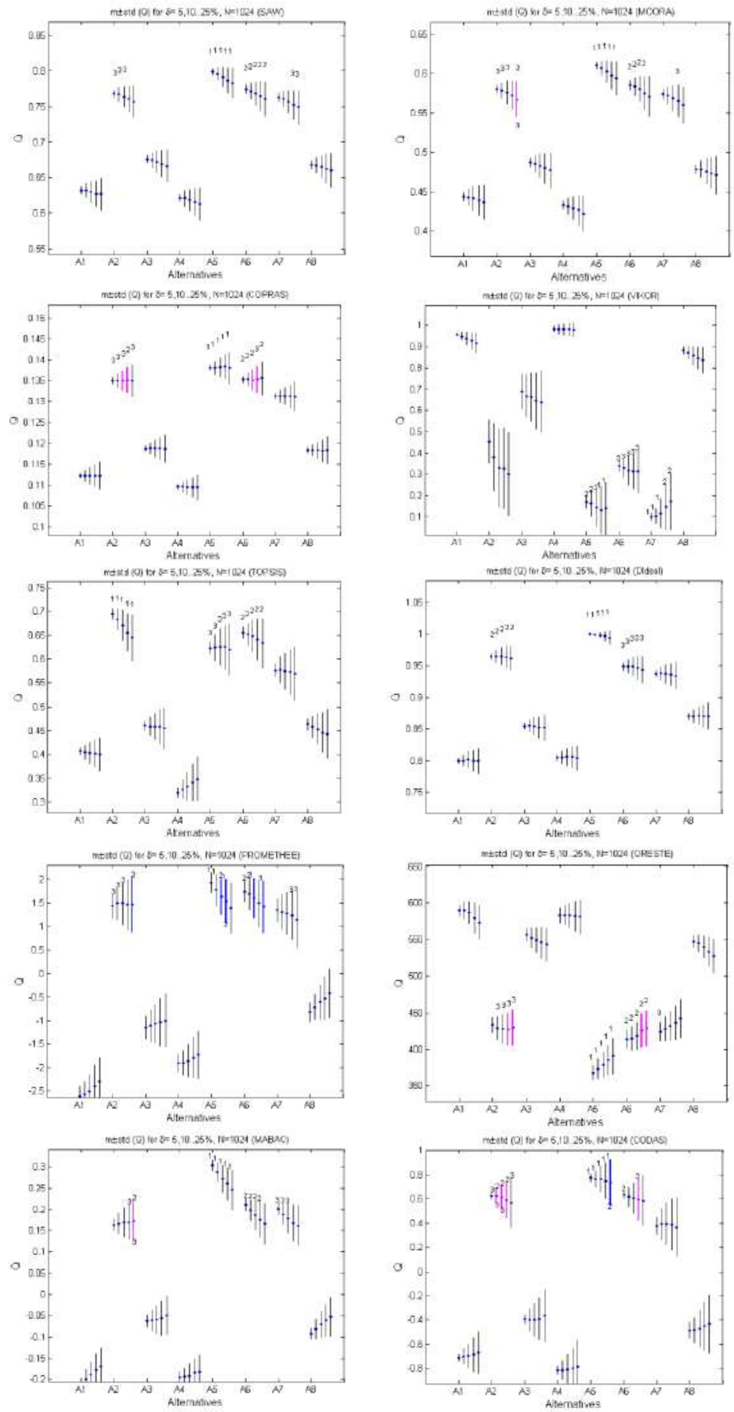


Fig. 6 Point and interval estimates of the integral index of alternatives for various rank methods and for different values of the random deviation of the elements of the decision matrix (δ = 5, 10, 15, 20 and 25%)

Figs. 1, 2 and 3 are marked, respectively, 1, 2 and 3 ranks. In blue, statistically indistinguishable values of the integral index of the 1st and 2nd rank are distinguished; in red, there are statistically indistinguishable values of the integral index of the 2nd and 3rd ranks.

4.3 Distribution of the overall effectiveness evaluation of alternatives for various MCDM methods

Table 6 shows the distribution of the overall effectiveness evaluation of alternatives for various MCDM methods for δ = 10% (similarly for the other δ). The results show a strong sensitivity of the selection procedure from the selected MCDM method and from the selection criterion.

Table 6 Distribution of the overall efficiency evaluation of alternatives for various MCDM methods for δ = 10% (N=1024)

			Rank(point)									
	δ,%		I(1)	II(1)	III(1)	I+II(1)	I+II+III(1)	I(2)	I(3)	I+II(2)	I+II(3)	I+II+III(2)
SAW	5	A:	5	6	2	5	5	6	1	6	2	6
		%	99.8	78.4	60.5	50.0	33.3	0.2	0.0	39.3	8.9	32.2
	10	A:	5	6	2	5	5	6	2	6	2	6
		%	95.0	53.5	39.3	49.8	33.3	3.2	1.7	28.4	15.8	29.1
	15	A:	5	6	2	5	5	6	2	6	2	6
		%	79.3	39.9	35.6	47.3	32.9	11.3	5.9	25.6	17.9	26.7
	20	A:	5	6	7	5	5	6	2	6	2	6
		%	66.7	31.3	32.4	45.0	32.6	17.0	11.4	24.1	20.6	25.7
	25	A:	5	6	7	5	5	6	2	6	2	6
		%	59.5	28.9	33.0	42.7	31.6	19.0	14.5	24.0	21.1	25.3
			I(1)	II(1)	III(1)	I+II(1)	I+II+III(1)	I(2)	I(3)	I+II(2)	I+II(3)	I+II+III(2)
MOORA	5	A:	5	6	2	5	5	1	1	6	2	6
		%	100.0	75.6	58.0	50.0	33.3	0.0	0.0	37.8	10.5	32.5
	10	A:	5	6	2	5	5	6	2	6	2	6
		%	93.9	51.7	42.8	49.7	33.3	3.9	1.6	27.8	16.5	28.3
	15	A:	5	6	2	5	5	6	2	6	2	6
		%	77.4	35.4	33.8	47.4	33.1	13.4	6.6	24.4	19.4	26.9
	20	A:	5	6	7	5	5	6	2	6	2	6
		%	68.0	30.4	34.0	44.8	32.6	15.7	11.3	23.0	20.8	24.7
	25	A:	5	2	2	5	5	6	2	6	2	6
		%	60.7	28.6	31.2	42.3	31.9	19.3	12.5	23.7	20.6	25.1
			I(1)	II(1)	III(1)	I+II(1)	I+II+III(1)	I(2)	I(3)	I+II(2)	I+II(3)	I+II+III(2)
COPRAS	5	A:	5	6	2	5	2	6	2	6	2	5
		%	98.4	56.1	57.3	50.0	33.3	1.3	0.3	28.7	21.3	33.3
	10	A:	5	6	2	5	5	6	2	6	2	6
		%	79.3	44.2	48.4	48.0	33.3	12.1	8.6	28.2	23.4	32.1
	15	A:	5	6	2	5	5	6	2	6	2	6
		%	69.2	35.5	38.8	46.5	33.2	16.8	13.5	26.2	24.4	29.6
	20	A:	5	2	6	5	5	6	2	2	6	6
		%	61.2	34.7	32.8	43.3	32.9	19.0	18.0	26.3	26.0	28.3
	25	A:	5	6	2	5	5	6	2	6	2	6
		%	49.9	30.7	31.4	38.8	32.1	25.8	20.7	28.2	25.3	27.9
			I(1)	II(1)	III(1)	I+II(1)	I+II+III(1)	I(2)	I(3)	I+II(2)	I+II(3)	I+II+III(2)
	5	A:	7	5	6	5	5	5	6	7	6	7
		%	100.0	1.5	1.4	50.0	33.3	98.5	84.6	50.0	42.3	33.3
	10	A:	7	5	6	7	7	5	6	5	6	5
		%	99.5	9.9	8.3	50.0	33.3	89.0	72.4	49.4	36.4	33.3
	15	A:	7	5	6	7	5	5	6	5	6	7
		%	90.4	11.4	13.1	48.6	33.0	84.3	59.7	47.9	30.9	33.0
	20	A:	5	7	6	5	5	7	6	7	6	7
		%	79.9	13.9	21.1	46.0	32.3	74.9	49.6	44.4	27.7	31.5
	25	A:	5	7	6	5	5	7	2	7	6	7
		%	76.3	12.5	18.4	43.8	31.7	67.7	45.1	40.1	26.9	29.8

			I(1)	II(1)	III(1)	I+II(1)	I+II+III(1)	I(2)	I(3)	I+II(2)	I+II(3)	I+II+III(2)
VIKOR	5	A:	2	6	5	2	2	6	1	6	5	5
		%	98.9	98.5	99.6	50.0	33.3	1.1	0.0	49.8	0.2	33.3
	10	A:	2	6	5	2	2	6	5	6	5	6
		%	80.8	71.7	80.7	47.6	33.3	16.1	3.1	43.9	8.5	33.3
	15	A:	2	6	5	2	6	6	5	6	5	2
		%	61.0	53.9	54.4	40.8	32.6	25.0	13.8	39.5	18.5	32.1
	20	A:	2	6	5	6	6	6	5	2	5	2
		%	50.8	44.6	41.8	36.5	31.2	28.4	19.1	36.0	23.5	30.6
	25	A:	2	6	5	6	6	6	5	2	5	2
		%	44.5	39.3	35.8	34.4	30.0	29.5	22.5	33.4	25.0	29.2
			I(1)	II(1)	III(1)	I+II(1)	I+II+III(1)	I(2)	I(3)	I+II(2)	I+II(3)	I+II+III(2)
TOPSIS	5	A:	5	2	6	5	2	1	1	2	6	5
		%	100.0	99.9	97.0	50.0	33.3	0.0	0.0	50.0	0.0	33.3
	10	A:	5	2	6	5	5	1	1	2	6	2
		%	100.0	92.6	75.9	50.0	33.3	0.0	0.0	46.3	3.5	33.2
	15	A:	5	2	6	5	5	2	6	2	6	2
		%	97.9	80.1	60.8	50.0	33.3	2.1	0.1	41.1	8.3	32.9
	20	A:	5	2	6	5	5	2	6	2	6	2
		%	94.1	70.7	49.8	49.7	33.3	4.7	0.9	37.7	10.1	31.8
	25	A:	5	2	6	5	5	2	6	2	6	2
		%	89.6	61.1	44.4	49.2	33.3	7.9	2.1	34.5	11.3	31.2
			I(1)	II(1)	III(1)	I+II(1)	I+II+III(1)	I(2)	I(3)	I+II(2)	I+II(3)	I+II+III(2)
D'Ideal	5	A:	5	6	7	5	5	1	1	6	7	6
		%	100.0	66.9	63.1	50.0	33.3	0.0	0.0	33.4	16.3	33.0
	10	A:	5	6	7	5	5	6	7	6	7	6
		%	98.2	51.2	41.0	50.0	33.3	1.3	0.4	26.2	18.2	28.5
	15	A:	5	6	7	5	5	6	7	6	7	6
		%	89.1	38.9	36.4	49.0	33.3	6.6	2.8	22.8	16.2	25.3
	20	A:	5	6	2	5	5	6	7	6	2	6
		%	82.8	32.5	33.5	47.9	33.2	7.0	5.7	19.8	16.4	23.6
	25	A:	5	2	2	5	5	2	6	2	6	2
		%	71.1	28.8	31.9	44.9	32.6	11.3	10.3	20.1	18.2	24.0
			I(1)	II(1)	III(1)	I+II(1)	I+II+III(1)	I(2)	I(3)	I+II(2)	I+II(3)	I+II+III(2)
MABAC	5	A:	5	6	7	5	5	6	7	6	7	6
		%	99.3	63.1	44.5	50.0	33.3	0.5	0.1	31.8	14.3	29.9
	10	A:	5	6	2	5	5	6	7	6	7	6
		%	93.2	52.8	36.5	49.7	33.3	4.8	1.2	28.8	11.4	27.9
	15	A:	5	6	2	5	5	6	2	6	2	6
		%	87.4	43.7	36.6	48.6	33.1	6.8	3.1	25.2	14.2	27.0
	20	A:	5	6	2	5	5	6	2	6	2	6
		%	79.5	35.3	33.8	47.0	32.9	8.6	6.5	21.9	18.8	24.9
	25	A:	5	6	2	5	5	6	2	6	2	2
		%	72.4	31.4	34.3	45.8	32.5	11.2	10.1	21.3	19.6	24.5
			I(1)	II(1)	III(1)	I+II(1)	I+II+III(1)	I(2)	I(3)	I+II(2)	I+II(3)	I+II+III(2)
ORESTE	5	A:	5	6	2	5	5	6	2	6	2	6
		%	67.7	47.9	36.0	46.4	32.9	24.2	6.2	36.0	12.2	31.9
	10	A:	5	6	2	5	5	6	2	6	2	6
		%	47.2	33.3	32.0	36.9	30.5	30.6	14.8	31.9	19.3	29.2
	15	A:	6	5	2	5	5	5	2	6	2	6
		%	33.6	31.3	27.0	31.1	28.6	30.8	23.0	30.1	23.7	28.0
	20	A:	5	5	7	5	5	6	2	6	2	6
		%	31.9	28.6	26.7	30.3	27.7	29.8	25.5	26.6	26.0	26.6
	25	A:	6	2	7	2	2	2	5	6	5	6
		%	28.6	27.0	26.3	27.7	26.9	28.4	27.8	27.3	27.2	26.4

			I(1)	II(1)	III(1)	I+II(1)	I+II+III(1)	I(2)	I(3)	I+II(2)	I+II(3)	I+II+III(2)
PROMETEE-II	5	A:	5	6	2	5	5	6	1	6	2	2
		%	99.8	56.2	56.3	50.0	33.3	0.2	0.0	28.2	21.8	33.3
	10	A:	5	2	2	5	5	6	2	6	2	2
		%	90.9	45.6	47.9	49.4	33.3	6.4	2.6	25.5	24.1	32.1
	15	A:	5	2	2	5	5	6	2	2	6	2
		%	74.7	39.7	40.2	47.6	33.1	14.0	10.4	25.1	24.1	30.1
	20	A:	5	2	6	5	5	6	2	2	6	6
		%	64.5	36.1	34.7	43.6	32.7	19.3	13.4	24.8	24.6	27.9
	25	A:	5	5	2	5	5	6	2	6	2	6
		%	54.7	29.5	34.5	42.1	31.9	22.4	17.8	25.7	23.3	27.2
			I(1)	II(1)	III(1)	I+II(1)	I+II+III(1)	I(2)	I(3)	I+II(2)	I+II(3)	I+II+III(2)
Total	5	A:	5	6	6	5	5	2	6	6	2	6
		%	86.4	54.3	30.7	44.7	33.3	12.2	11.2	32.7	18.7	32.0
	10	A:	5	6	6	5	5	6	2	6	2	6
		%	79.0	41.0	32.2	44.1	33.0	15.1	14.7	28.1	22.7	29.4
	15	A:	5	6	6	5	5	6	2	6	2	6
		%	70.4	32.7	31.3	43.4	32.4	18.7	17.2	25.7	24.2	27.6
	20	A:	5	2	6	5	5	6	2	2	6	6
		%	64.8	31.3	30.4	42.1	32.0	19.5	18.8	25.0	24.0	26.2
	25	A:	5	2	6	5	5	2	6	2	6	2
		%	58.4	29.0	28.2	40.2	31.2	21.3	21.2	25.2	24.1	25.7

5 Conclusion

Despite a significant number of developed and new methods, the problem of multicriteria choice is still not trivial. Following the obtained results, the evaluation of alternatives according to the criteria and the choice of the criterion for ranking alternatives using different ranks have a profound effect on the final choice.

Multiple simulation of the estimations of the decision matrix elements within a given error for calculating the ranks of alternatives allows one to obtain statistical estimates of ranks. Based on the simulations statistics, the decision-making can be carried out not only on the statistics of alternatives having rank 1, but also by using alternatives statistics having the largest total I and II rank or I, II and III ranks. This is especially true when the difference in rank values is not large and is distributed evenly among the first three ranks.

Apparently, a quantitative analysis can be used only to narrow the set of effective alternatives for the final decision-making. A statistical analysis makes an estimation of the number options possible in which an alternative has a priority. Additional criteria that take into account both aggregate priorities and the availability of possible priorities for other alternatives with small DM variations provide additional important information for the decision-maker.

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ANFIS MODEL FOR DETERMINING THE ECONOMIC ORDER QUANTITY

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Abstract: *The determination of the economic order quantity is important for the rational realization of the logistics process of transport, manipulation and storage in the supply chain. In this paper an expert model for the determination of the economic order quantity has been developed. The model has been developed using the hybrid method of artificial intelligence Adaptive neuro-fuzzy inference systems - ANFIS. It has been used for modeling a complex logistics process in which it is difficult to determine the interdependence of the presented variables applying classical methods. The hybrid method has been applied to take advantages of the individual methods of artificial intelligence: fuzzy logic and neural networks. Experience of an experts and information on the operations of the company for a certain group of items have been used to form the model. Analysis of the validity of the model results was performed on the basis of the average relative error and it has showed that the model imitates the work of the expert in the observed company with great accuracy. Sensitivity analysis has been applied which indicates that the model gives valid results. The proposed model is flexible and can be applied to various types of goods in supply chain management.*

Key words: *Adaptive neuro-fuzzy inference systems, economic order quantity, supply chain management, logistics processes.*

1. Introduction

The economy is largely in the phase of intense globalization. This does not mean only increasing the interdependence of regional economies and levels of technological integration, but also significant structural changes in the field of science, highly developed technique and its way of functioning. Scientific and technological progress, in coordination with economic development, covers all areas

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of the economy and its possibilities are used in the search for solutions for better organization and efficiency of flow of goods (Sremac, 2013).

The determination of the economic order quantity (EOQ) is a logistics process that has a significant influence on the successful operation of a company (Melis Teksan & Geunes, 2016). From the logical aspect, the determination of the EOQ requires an adequate attention, since inadequate purchase can additionally burden the company's business (Abraham, 2001). On the other hand, in order to achieve a high level of service for the client, all purchase should be realized independently of their value (Maddah & Noueihed, 2017).

Many phenomena in nature, society and the economy cannot be described and it is not possible to predict their behavior by traditional mathematical methods (Griffis et al., 2012). Due to the lack of flexibility of this approach, the human factor compensates for the uncertainty of mathematical model using knowledge based on experience (Negnevitsky, 2005) and make decisions based on data that are difficult to enter into a mathematical model (Efendigil, 2014). A modern approach to determining EOQ is the application of Adaptive neuro-fuzzy inference systems (ANFIS), as one of the hybrid methods of artificial intelligence.

The basic hypothesis of this paper is that it is possible to design a model on hybrid neuro-fuzzy approach of artificial intelligence to determine EOQ. The next goal is to effectively use such a system in the observed company in a highly dynamic and changing business environment. One of the objectives is that the proposed system shall be flexible and applicable in other companies for other types of goods in supply chain management (SCM). The basic motive for the design of such a decision support system is the development of the tool for EOQ that will be able to perform complex and real processes of SCM using a hybrid artificial intelligence technique.

The rest of this paper is organized as follows. The relevant literature review is classified and reviewed in Section 2. Section 3 describes ANFIS used in the proposed methodology. Section 4 presents proposed models and a sensitive analysis for different membership functions. Conclusion remarks are drawn in Section 5.

2. Literature review

The problem often arising and being examined is determining the amount of goods needed to meet customers' demands (Lagodimos et al., 2018). A century ago, Harris (1913) introduced EOQ inventory model. Most of the companies apply EOQ model to determine the maximum level of inventory or ordering lot size (Abdel-Aleem et al., 2017).

The application of classical methods for EOQ is based on limited assumptions that cannot cover the nature of modern complex logistics processes such as - demand is constant in unit time, lead time is deterministic and stationary, constant price etc. (Maddah & Noueihed, 2017). But, making decisions in SCM takes place in an environment where objectives and constraints are not and cannot often be precisely defined (Latif et al., 2014; Taleizadeh et al., 2016). Therefore a certain approximation is required in order to obtain a high quality model of a real system where the application of artificial intelligence has an important role. Consequently, individual methods of artificial intelligence (Keshavarz Ghorabaee et al., 2016) or their combination in the form of hybrid method are increasingly used in solving real and complex problems (Teksan & Geunes, 2016, Zavadskas et al., 2016).

Some researchers (Davis-Sramek & Fugate, 2007) interviewed a few visionaries in the field of SCM and recognized the irresistible call of these individuals for modeling and simulation to be involved in the research (Wallin et al., 2006). Modeling of the

SCM seeks for the best possible system configurations to minimize costs and increase operational efficiency in order to meet customer expectations (Bowersox et al., 2010). Important issue in SCM is the need to make the right decision, despite the occurrence of significant ambiguity (Giannoccaro et al., 2003). In addition to fluctuations in demand and delivery times, vagueness is associated with the lack of information from the production and distribution processes in SCM (Chatfield et al., 2013). Some authors expressed uncertainty of market demand and inventory costs in the model theory of fuzzy sets (Azizi et al., 2015).

Hereinafter, there is a review of some works from the field of SCM based on neuro-fuzzy approach. Jang (1993) first introduced the ANFIS method by embedding the Fuzzy Inference System into the framework of adaptive networks. Demand uncertainty is considered in the optimization model of Gupta and Maranas (2003) in which by a two-stage stochastic programming model they consider all production decisions in the first stage and all the supply chain decisions in the second. Yazdani-Chamzini et al. (2012) used ANFIS and artificial neural network (ANN) model for modeling the gold price.

Guneri et al. (2011) developed a new method using ANFIS for the supplier selection problem. Vahdani et al. (2012) presented numerous quantitative methods for supplier selection and evaluation in the literature, where the most current technique is Hybrid approaches. Later Ozkan and Inal (2014) employed ANFIS in supplier selection and evaluation process.

Several methods for EOQ in SCM have appeared in literature, including approaches based on a neuro-fuzzy (Yazdani-Chamzini et al., 2017). Paul et al. (2015) presents the application of ANFIS and ANN in inventory management problem to determine optimum inventory level. Abdel-Aleem et al. (2017) study and analyze the optimal lot size in a real production system to obtain the optimal production quantity.

ANFIS has a wide application in the fields of finance, marketing, distribution, business planning, information systems, production, logistics etc. (Ambukege et al., 2017; Mardani et al., 2017; Rajab & Sharma, 2017). The route guidance system developed by Pamučar & Ćirović (2018) is an Adaptive Neuro Fuzzy Inference Guidance System that provides instructions to drivers based upon "optimum" route solutions.

3. Description adaptive neuro-fuzzy inference systems

ANFIS are the modern class of hybrid systems of artificial intelligence. They are described as artificial neural networks characterized by fuzzy parameters. By combining two different concepts of artificial intelligence it is tried to exploit the individual strengths of fuzzy logistics and artificial neural networks in hybrid systems of homogeneous structure (Figure 1). Such engineered systems are increasingly used to solve everyday complex problems and with assistance of logistics experts and historical data, this approach can be designed on the basis of computer aided systems.

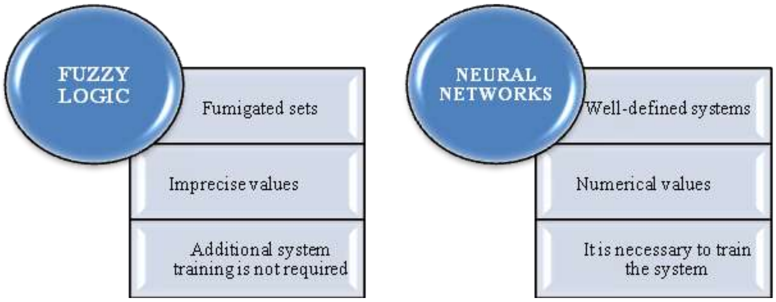

Figure 1. Basic characteristics of fuzzy logistics and neural networks

The possibility of displaying the fuzzy model in the form of a neural network is most often used in the methods of automatic determination of the parameters of the fuzzy model based on the available input-output data. The structure of Adaptive neuro-fuzzy inference systems is similar to the structure of neural networks. The membership functions of the input data are mapped to the input data of the neural networks and the input-output laws are defined through the output data of the neural networks (Figure 2).

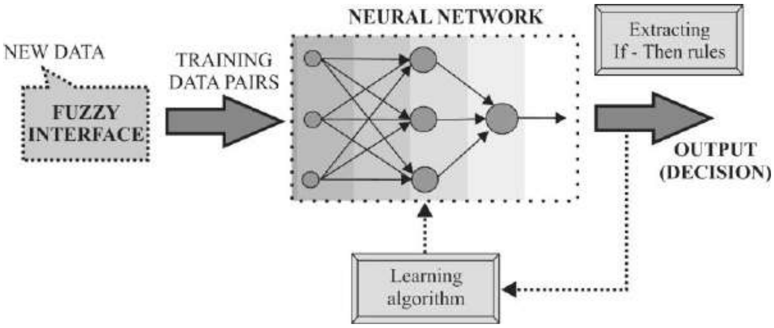

Figure 2. The basic structure of Adaptive Neuro-Fuzzy Inference Systems

Parameters characteristic of the corresponding membership functions change through the network learning process. Calculation of these parameters is usually done on the basis of the gradient of the vector, which is a measure of the accuracy of the transfer of the fuzzy inference system of the input set into the output set for the given set of verified parameters (Cetisli, 2010).

Basic idea of The Adaptive Neuro-Fuzzy Inference System is based on fuzzy modelling and learning methods according to the given dataset. Based on the input-output data set, an appropriate fuzzy inference system is formed and the parameters of the membership function are calculated. The parameters of the membership functions of the fuzzy system are set using the backpropagation algorithm or a combination of the algorithm and the method of least squares. This setting allows fuzzy systems to learn on the basis of input-output data set. This learning method is similar to the method of learning neural networks.

4. The development of ANFIS model for determining EOQ

4.1. Designing the model

This paper develops an adaptive neuro-fuzzy inference system model for determining the economic order quantity (ANFIS model EOQ) based on the input-output data in the observed company. The formation of the proposed model consists of the following steps:

- Determination of input-output data set in the form customized for training of the neuro-fuzzy inference system.
- The model structure with parameters is assumed, which by the rules reflects the input membership functions into output functions.

The model is trained on the training data. In doing so, the parameters of the membership functions are modified according to the selected error criterion in order to get the valid model results.

This way of modeling is appropriate if the training data are fully representative for all the properties that ANFIS model should have. In some cases, the data used to train the network contain measurement errors so they are not fully representative for all features that should be included in the model. Therefore, the model should be checked using the testing data. There are two ways of testing the model. The first way is to check the model when input data are those that are not used for training. This procedure shows how accurately the model predicts the output value set and it is implemented in the paper. Another way to test the model is a mathematical procedure when the data that were used for training are now used as a data set for testing and it is necessary to obtain the output with a minimal error.

The model presented here was developed in the MATLAB version R2007b using ANFIS Editor, included in the Fuzzy Logic Toolbox. ANFIS editors only support Sugeno-type fuzzy systems (Tahmasebi & Hezarkhani, 2010). Benefits of Sugeno type are that it is computationally more efficient, suitable for mathematical analysis, works well with linear, optimization and adaptive techniques. The course of the ANFIS model formation is presented in Figure 3.

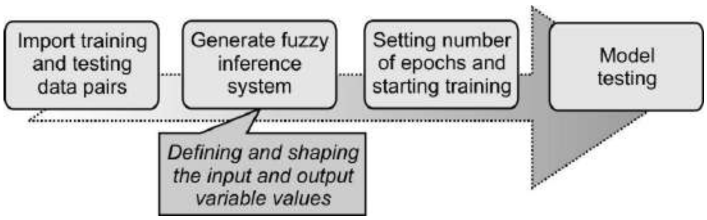

Figure 3. The model formation flowchart

The ANFIS model EOQ has the following structure. The input variables are: the size of demand, the level of inventory and price, while the output variable is EOQ. The number of membership functions of the input variables is three, except for the input variable the size of demand which has five values. Input membership functions are Gaussian. The structure of the neural network is shown in Figure 4.

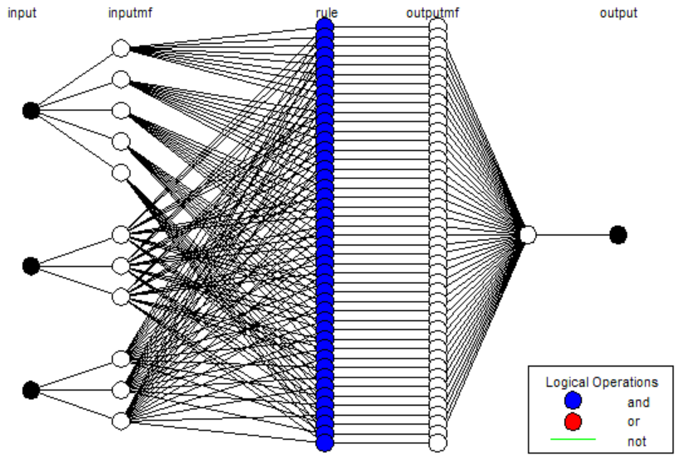

Figure 4. Fuzzy model mapped into a neural network

The developed model has the form of a multilayer neural network with the propagation of the signal forwards. The first layer represents the input variable, the hidden (middle) layer represents the fuzzy rule, and the third layer is the output variable. Fuzzy sets are defined in the form of link weights between nodes. Settings are performed in adaptive nodes to reduce the error that occurs at the exit of the model. The error is the difference between the known output values and the values obtained at the exit from the neuro-fuzzy network. The signals on the network are spreading forwards and the bugs are spreading backwards. Thus, the output numerical value approaches the optimal, i.e. the required value. The basic characteristics of the model are shown in Table 1.

Table 1. Basic characteristics of ANFIS model EOQ

The key model characteristics are:	
Number of nodes	118
Number of linear parameters	45
Number of nonlinear parameters	22
Total number of parameters	67
Number of training data pairs	50
Number of testing data pairs	10
Number of fuzzy rules	45

The data set for the training of the neural network was obtained on the basis of concrete data on business operations and the survey of the logistics expert in the observed company. For training (Figure 5), a hybrid optimization method was used consisting of:

- backpropagation algorithms, by which the errors of variables are determined recursively from the output layer to the input layers
- the methods of least squares for determining the optimal set of consequential parameters.

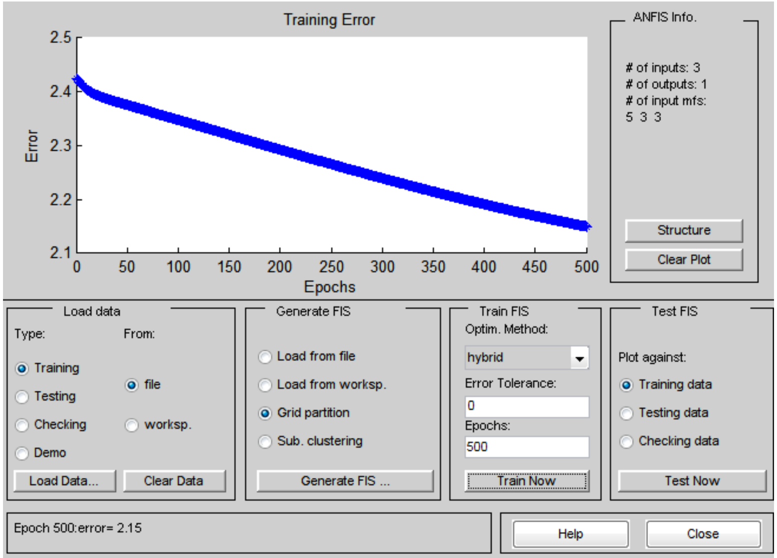

Figure 5. Training of the neural network

In order to train the network, 50 input-output procurement data sets were used in the observed company, while model testing was conducted on the basis of 10 input-output data sets. A grid partition technique was applied to generate one model output and a hybrid optimization method as well. It was assumed that the output membership functions are of a constant type.

The number of training cycles (epochs) is 500. At the output of the neural network, there is an error of 2.15 (Figure 6).

Figure 6. Results of training of ANFIS model EOQ

After the training phase, the ANFIS model EOQ was tested on the basis of 10 input-output datasets, which were not used in the training of the model. The average error in testing the model is 4.03 (Figure 7).

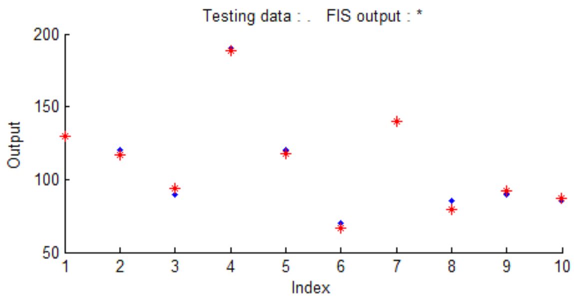

Figure 7. Results of testing of ANFIS model EOQ

Testing makes it possible to check the functioning of the model. Output data, generated by the network, are compared with known company data. The model is not expected to function without an error, but deviations must be within the limits of the predicted tolerance. If there are large deviations, a new training network needs to be done, or it is sometimes necessary to exclude problematic data.

The validity analysis of the model's results was carried out on the basis of the average relative error of the tested data (Figure 8). On the basis of the testing of 10 examples of EOQ determination, an average relative error of 3.28% was obtained. On the basis of this analysis it can be said that ANFIS model EOQ gives valid results.

Figure 8. Relative error of ANFIS model EOQ in %

4.2. Sensitive analysis

One of the basic requirements when modeling is to achieve a satisfactory sensitivity of the model. This means that with certain small changes in input variables, the output from the model must also have small changes in value.

The sensitive analysis of the ANFIS model EOQ was carried out by changing the shape of the membership functions of the input variables and the number of values of the input variables as well. Instead of the Gaussian curves applied in the basic model, triangular, trapezoidal and bell-shaped curves were tested (Table 2). In the analysis the "prod "(product of array elements) method was used for the operator "and" and "prob" (probably) method for the operator "or". Two cases were tested: first, where all input variables have three values, and the other one where the first input variable, size of demand, has five values, while the other two input variables, the level of inventory and price, have three values (Table 3).

Table 2. Sensitive analysis by changing the form of membership functions

	Membership function		
	Triangular	***Trapezoidal***	***Bell***
	120	124	125
	42	32	24
EOQ	220	225	228
	60	57	59
	132	133	135

Table 3. Sensitive analysis by changing the number of input values*

	Membership function					
	Triangular		***Trapezoidal***		***Bell***	
Number of the variable values	**3-3-3**	**5-3-3**	**3-3-3**	**5-3-3**	**3-3-3**	**5-3-3**
Training error	4,16	2,21	8,40	2,82	3,55	1,77
Testing error	7,02	6,58	8,56	6,99	6,36	2,83

** Number of epochs is set to 500.*

For defined cases of model sensitivity testing, the obtained results are the same or with negligible differences. This shows that the proposed ANFIS model EOQ gives valid results.

5. Conclusion

The applied concept of artificial intelligence is utilized for presenting, manipulating and implementing human knowledge on the efficient management for determining the economic order quantity. Adaptive neuro-fuzzy inference systems has proven to be a valuable artificial intelligence concept in determining EOQ that is designed using intuition and assessment of a logistics expert. Hybrid concept of artificial intelligence enabled the explanation of the system dynamics via a linguistic presentation of knowledge on a logistics process. It was used for modeling a complex linguistic system in which it is difficult to determine the interdependence of the presented variables applying other classical methods.

In the paper, ANFIS model EOQ for solving a concrete problem in a business practice was developed, following the tendency in contemporary scientific research. The model was tested and verified, and hence it can be practically applied. A sensational analysis was conducted and it gave the results of a model with negligible differences. The advantage of the proposed model is that with some minor modification, it can be applied in any company dealing with the flow of goods realization.

During the research it was observed that in addition to the advantages, the applied hybrid concept of artificial intelligence also had certain flaws, and that none of the tools was universally applicable. The observed flaws are that the selection and adjustment of the membership functions of the variables are very sensitive area that has a significant impact on the results of the model. Therefore, it is necessary to precisely and carefully form the logical base of the fuzzy rules. During development of the model, the neuro-fuzzy training time usually requires a large amount of data and can be very long, and therefore the need for frequent repetitions of training can make the application unusable. A small number of input parameters gives rough and inaccurate results, so the survey sample must be representative.

In further research, current methods of Multiple-criteria decision-making can be applied (Pamučar et al., 2018; Stević et al., 2017, Yazdani-Chamzini et al., 2017) and the flexibility of the proposed model can be used for determining the amount of procurement of other types of goods.

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DEMATEL-AHP MULTI-CRITERIA DECISION MAKING MODEL FOR THE DETERMINATION AND EVALUATION OF CRITERIA FOR SELECTING AN AIR TRAFFIC PROTECTION AIRCRAFT

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Abstract: *This paper describes an approach in the determination and evaluation of the criteria and attributes of criteria for selecting the air traffic protection aircraft. After collected initial criteria and attributes, the interaction between criteria and attributes of criteria for the selection of the aircraft especially for the protection of air traffic was evaluated by 45 respondents. Data processing and criteria and attributes determination were carried out by the DEMATEL method (by eliminating less significant criteria and attributes). Furthermore, the weight values of each criterion and attribute were determined by the AHP method. Prioritization was carried out using an eigenvector method. For determination reliability the consistency ratio was checked for each result. As a result the model for the selection of the aircraft was proposed.*

Key words*: Aircraft; Air Traffic; Attribute; Criterion;* Consistency; Protection.

1. Introduction

From an economic point of view air traffic can be one of the more profitable business activities of each country. The organization and implementation of air traffic is complex process, which includes the need for continuous improvement (Menon, Sweriduk & Bilimoria, 2004; Chen, Chen & Sun, 2017; Menon & Park, 2016; Steiner, Mihetec & Božičević, 2010; Durso & Manning, 2008; Abbass, Tang, Amin, Ellejmi & Kirby, 2014). But, the issue of improving the protection of air traffic from aircraft threats has become particularly important since 9/11 (Petrović, Kankaraš & Cvetković, 2015).

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There are many approaches to address air traffic protection issues. The basic way is in the existence of duty–aircrafts (it is essentially a fighter aircraft that provide a rapid reaction in the case of airspace violation and other situations of violation of air traffic safety).

Some of small countries (in quantitative and qualitative terms) (Gordić & Petrović, 2014) give another countries the jurisdiction for the conducting of this mission. In the case study of the Republic of Serbia, which is a synonym for the small country, it can be noticed what are the criteria and how to prioritize them for the needs of equipping the country with the aircraft whose main purpose is to protect air traffic and intercept the aircraft that violated the airspace.

The small area of the Republic of Serbia, and unusual, elongated form of territory allow for a short flight time over the territory and a simple and rapid airspace violation (Petrović, 2013). Therefore, it is necessary to determine which criteria and attributes of criteria are significant for the needs of equipping the country with the aircraft.

The general objective of this paper is: determination and evaluation of criteria and attributes within the determinated criteria for selecting the aircraft for the purpose of air traffic protection from the airspace violation and other aviation threats using the DEMATEL and AHP methods. This multi-criteria model consists of criteria and attributes that are significant for the selection of combat aircraft.

The above stated research objective gives rise to following general hypothesis:

Using the DEMATEL and AHP methods, it is possible to determinate and to evaluate the criteria for selecting the aircraft for the purpose of air traffic protection from the airspace violation and other aviation threats.

The scientific and methodological contribution of paper is reflected in the new approach of determinating significant and eliminating less significant criteria - attributes for the needs of selecting system with special role. Also, the scientific contribution is reflected in increase of theoretical fund, which refers to the systematization of previous knowledge by the method of content analysis, and the gathering of relevant data about the criteria and attributes of criteria for the selection of the aircraft for the needs of conducting the missions during peacetime.

The practical contribution is reflected in the fact that in the paper the model was created that could improve the process of equipping the System of Defence with new equipment. Also, modification of the model (by changing of criteria) enables its application in cases of procurement a wide range of equipment for the needs of realization of various forms of human activity.

2. Materials and methodes

The research was carried out in three phases: identification of initial criteria and attributes (for selection of combat aircraft), determination of significant criteria and attributes of criteria (for selection of aircraft), and prioritization of selected criteria and attributes (Figure 1).

In the first, all measures have been identified that enable selection of the combat aircraft by analyzing the contents of the relevant scientific fund (Čokorilo, Gvozdenović, Mirosavljević & Vasov, 2010; Kirby, 2001; Dagdeviren, Yavuz & Kilinc, 2009; Petrović, Cvetković, Kankaraš & Kapor, 2017). The selection and conceptual evaluation of military aircraft characteristics by applying the overall evaluation criterion (OEC) was done by Mavris & DeLaurentis (1995). The selection and evaluation of the criteria for equipping the Army with combat aircraft using the AHP method was done by Vlačić (2012). The identified measures are divided into general and specific measures using the classification method (based on the level of generality). The general measures represent criteria, and attributes are specific.

Taking into consideration the number and different significance of the identified criteria and attributes it was necessary to eliminate irrelevant and to evaluate significant criteria and attributes. It was carried out using the questionnaire, the DEMATEL and the AHP method.

Based on these results, the model that provides a multi-criteria analysis of the selection of the aircraft for the air traffic protection from the airspace violation and other aviation threats was developed.

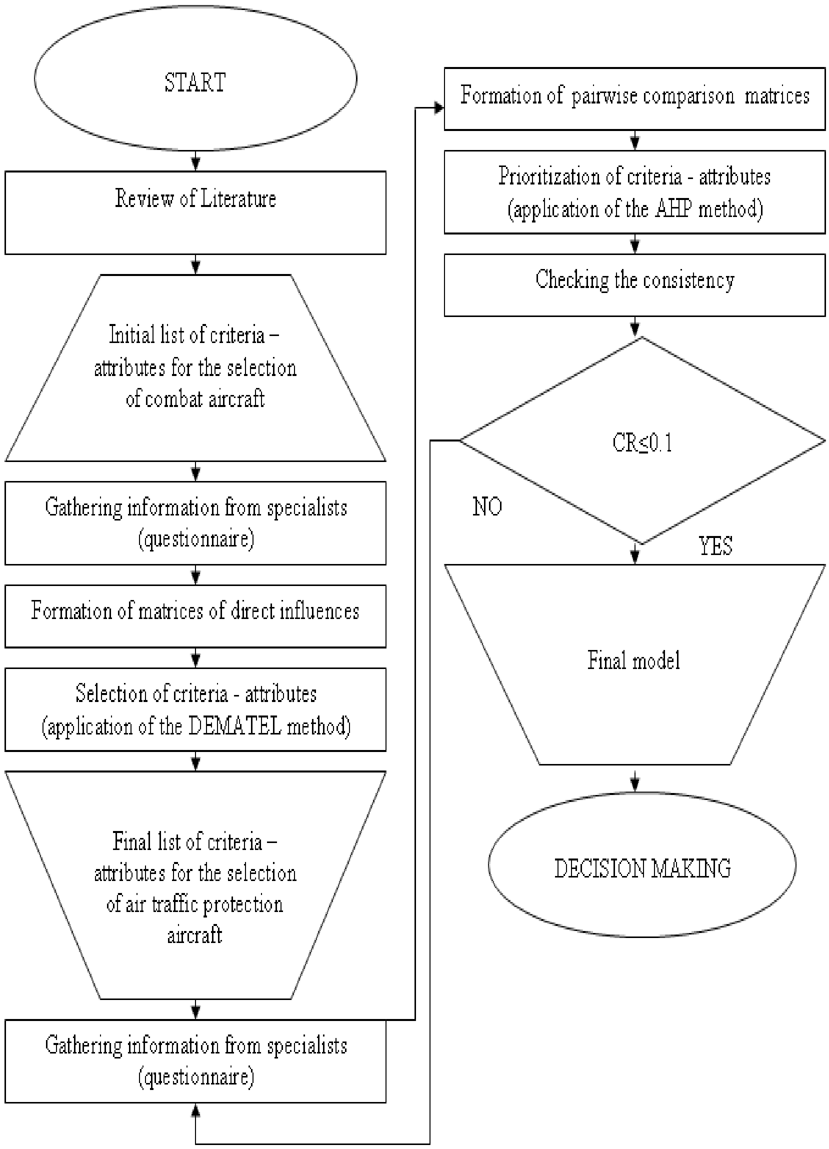

Figure 1. Algorithm of a multi-criteria selection of the aircraft

Using the questionnaire and contents analysis of literature, the criteria and the attributes of each criterion (initial criteria and attributes) for the combat aircraft were selected.

The following criteria are selected: A- aerodynamics and mechanics of the flight, B - construction and general systems, C - propulsion, D – avionics and sensors, E - integrated logistics support, F – armament, G – reconnaissance equipment, H – concept of pilot training and I – economy.

The initial attributes of criterion aerodynamics and mechanics of the flight are: A1 – weight, A2 - airspeed, A3 – acceleration performance, A4 – length of take off - landing, A5 - ceiling of flight, A6 – rate of climb, A7 – range of flight, A8 – maneuvering and stability performance, A9 – ability of supercruise and A10 – reaction time.

The initial attributes of criterion construction and general systems are: B1 - wing mechanization and flight control system, B2 – obstacle avoidance system, B3 – GPS terrain-following, B4 – voice command system, B5 – oxygen system, B6 – radar cross-section and infrared signature, B7 – potential for modernization, B8– durability, B9 – ability of aerial refueling and B10 – possibility of ejection of pilot's seat.

The initial attributes of criterion propulsion are: C1 – reliability and maintainability, C2 – maximum engine's thrust with afterburning, C3 – maximum engine's thrust without afterburning, C4 – thermal emission and C5 – maintenance system.

The initial attributes of criterion avionics and sensors are: D1 – radars and other sensors, D2 – communication equipment, D3 – fire-control radar, D4 – electronic warfare equipment, D5 – multi-function display, D6 – navigation equipment, D7 – multimedia link.

The initial attributes of criterion integrated logistics support are: E1 – reliability of aircraft, E2 - convenience of maintenance, E3 – maintenance of aircraft, E4 – maintainability, E5 – ability of maintenance staff, E6 – maintenance equipment and E7 – infrastructure.

The initial attributes of criterion armament are: F1 – capacity of locations for mounting armament, F2 – variety of armament, F3 – standardization of armament, F4 – number hardpoints of armament, F5 – under-fuselage hardpoints, F6 – possibility of using armament, F7 – safety work with armament on the ground, F8 – air – to – air missiles and rockets, F9 – bombs and other air - to - surface armament and F10 - guns (cannons).

The initial attributes of criterion reconnaissance equipment are: G1 - possibility of reconnaissance in different weather conditions, G2 - sensors range, G3 - data-processing of reconnaissance information, G4 - data-processing of reconnaissance photos and G5 - data-processing of reconnaissance video.

The initial attributes of criterion concept of pilot training are: H1 - pilot training abroad, H2 - individual training, H3 - collective training and H4 - simulators of flight.

The initial attributes of criterion economy are: I1 – acquisition cost, I2 – life cycle costs and I3 – aircraft disposal costs.

From initial criteria and attributes, the determination of criteria and attributes for the selection of the air traffic protection aircraft was preformed using the DEMATEL method (Moghaddam, Sahafzadeh, Alavijeh, Yousefdehi, & Hosseini, 2010; Sumrit & Anuntavoranich, 2013).

By applying this method (Decision – Making Trial and Evaluation Laboratory), based on the determination of direct and indirect influences between each criterion (attribute) on each citerion (attribute), criteria, which mutual impact on other criteria being less significant, were eliminated (Moghaddam et al, 2010).

Each of the respondents (45 specialists – military pilots and officers of the aviation - technical service) indicated the degree of direct and indirect influences between each criterion on each citerion and each attribute on each attribute of the criterion using the questionnarie. This step was done according to DEMATEL method (Sumrit & Anuntavoranich, 2013). Pairwise comparison was done as follows. The value of each pair is ranked by a number whose value is from 0 to 4 (0 – no influence; 1 – low influence; 2 – middle influence; 3 – high influence; 4 – very high influence) The assessment of each respondent is shown by a nonnegative matrix $n \times n$ (for criterion $n = 9$). Each element of the k-matrix which is calculated by the equation 1 is a non-negative number x_{ij}^{k}, where is $1 \le k \le m$.

$$X^{k} = \left[x_{ij}^{k} \right]_{n \times n} \tag{1}$$

Matrices $X^1, X^2, \ldots, X^m$ represent individual preference (pairwise comparison) matrices of the respondents. The diagonal values are 0 because there is no influence between same criterions (Sumrit & Anuntavoranich, 2013). By calculating the means of the individual gathered values, a matrix of direct influences was created (Table 1).

Table 1. Matrix of direct influences of criteria

K	A	B	C	D	E	F	G	H	I
A	0	3.85	3.92	3.45	3.73	3.68	0.45	0.54	3.9
B	2.17	0	2.04	3.12	1.45	1.72	0.53	0.34	1.14
C	2.94	1.11	0	1.73	1.14	0.94	0.52	0.32	0.85
D	3.65	3.2	3.91	0	3.17	3.2	0.61	0.29	3.23
E	3.42	3.17	2.12	1.92	0	2.73	0.45	0.34	2.45
F	3.18	2.57	3.14	3.22	2.72	0	0.32	0.35	2.74
G	0.51	0.42	0.37	0.32	0.41	0.38	0	0.42	0.39
H	0.33	0.42	0.44	0.41	0.37	0.39	0.51	0	0.19
I	3.92	3.17	2.93	3.45	3.15	3.08	0.28	0.32	0

In the second phase, the normalization of the matrix of direct influences is calculated using the following equation:

$$D = \frac{x}{\max\left(\max_{1 \le i \le} \sum_{j=1}^{n} x_{ij}, \max_{1 \le i \le n} \sum_{i=1}^{n} x_{ij} \right)} \tag{2}$$

D – Normalized matrix of direct influences,

X – Element of the mean value matrix of estimation of mutual influence.

Each element of the matrix of direct influences of criteria is divided with the maximum value of the sum of the columns and rows of the matrix of direct influence and new matrix is formed – normalized matrix of direct influence of criteria (Table 2).

Table 2: Normalized matrix of direct influence of criteria

K	A	B	C	D	E	F	G	H	I
A	0.000	0.164	0.167	0.147	0.159	0.156	0.019	0.023	0.166
B	0.092	0.000	0.087	0.133	0.062	0.073	0.023	0.014	0.048
C	0.125	0.047	0.000	0.074	0.048	0.040	0.022	0.014	0.036
D	0.155	0.136	0.166	0.000	0.135	0.136	0.026	0.012	0.137
E	0.145	0.135	0.090	0.082	0.000	0.116	0.019	0.014	0.104
F	0.135	0.109	0.134	0.137	0.116	0.000	0.014	0.015	0.116
G	0.022	0.018	0.016	0.014	0.017	0.016	0.000	0.018	0.017
H	0.014	0.018	0.019	0.017	0.016	0.017	0.022	0.000	0.008
I	0.167	0.135	0.125	0.147	0.134	0.131	0.012	0.014	0.000

In the next phase, all the relations between each pair of the criteria are expressed by the matrix of direct influences. Elements of matrix of full direct/indirect influence of criteria were derived by the equation 3 and the matrix is shown in Table 3.

$$T = D(I - D)^{-1} \text{ in} \tag{3}$$

$$T = \left[t_{ij}\right]_{nxn}, i, j = 1, 2, \ldots n$$

T – Matrix of full influence,

I – Unit matrix of influence,

t_{ij} - Element of the matrix of full influence.

Table 3: Matrix of full influence of criteria

K	A	B	C	D	E	F	G	H	I
A	0.383	0.486	0.509	0.470	0.451	0.448	0.083	0.072	0.436
B	0.299	0.194	0.288	0.310	0.236	0.244	0.059	0.042	0.214
C	0.279	0.200	0.164	0.220	0.188	0.180	0.050	0.037	0.170
D	0.484	0.435	0.479	0.313	0.406	0.405	0.083	0.058	0.389
E	0.409	0.376	0.353	0.331	0.233	0.336	0.066	0.051	0.313
F	0.429	0.378	0.416	0.398	0.359	0.254	0.066	0.056	0.343
G	0.070	0.062	0.063	0.058	0.057	0.056	0.009	0.025	0.055
H	0.058	0.057	0.060	0.056	0.051	0.052	0.030	0.006	0.042
I	0.490	0.433	0.443	0.439	0.404	0.401	0.070	0.059	0.268

By comparing the values in the matrix of full influence of criteria with the calculated threshold value it is determined whether the criteria are significant or not. Namely, if all the values of one criterion are less than the threshold value, this criterion is not significant for the selection of the aircraft.

The threshold value is calculated using the equation 4 and is 0.232.

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left[t_{ij}\right]}{N} \tag{4}$$

α - threshold value,

N – full number of elements of matrix T.

Table 4. Comparison of the elements of matrix of full influence of criteria with the threshold values of criteria

K	A	B	C	D	E	F	**G**	**H**	I
A	0.151	0.254	0.277	0.238	0.219	0.216	**-0.149**	**-0.160**	0.204
B	0.067	**-0.038**	0.056	0.078	0.004	0.012	**-0.173**	**-0.190**	**-0.018**
C	0.047	**-0.032**	**-0.068**	**-0.012**	**-0.044**	**-0.052**	**-0.182**	**-0.195**	**-0.062**
D	0.252	0.203	0.247	0.081	0.174	0.173	**-0.149**	**-0.174**	0.157
E	0.177	0.144	0.121	0.099	0.001	0.104	**-0.166**	**-0.181**	0.081
F	0.197	0.146	0.184	0.166	0.127	0.022	**-0.166**	**-0.176**	0.111
G	**-0.162**	**-0.170**	**-0.169**	**-0.174**	**-0.175**	**-0.176**	**-0.223**	**-0.207**	**-0.177**
H	**-0.174**	**-0.175**	**-0.172**	**-0.176**	**-0.181**	**-0.180**	**-0.202**	**-0.226**	**-0.190**
I	0.258	0.201	0.211	0.207	0.172	0.169	**-0.162**	**-0.173**	0.036

By observing the obtained results it is concluded that two criteria (G and H) are not significant for the selection of the aircraft (Table 4).

In the same way attributes of selected criteria that are not relevant for the selection of the aircraft were eliminated (Table 5-11).

Table 5. Comparison of the elements of matrix of full influence of attributes of criterion aerodynamics and mechanics of the flight with the threshold values

A	**A1**	A2	A3	**A4**	**A5**	A6	A7	A8	**A9**	A10
A1	**-0.236**	**-0.144**	**-0.145**	**-0.213**	**-0.201**	**-0.148**	**-0.135**	**-0.133**	**-0.209**	**-0.151**
A2	**-0.162**	0.225	0.363	**-0.150**	**-0.148**	0.159	0.371	0.421	**-0.156**	0.360
A3	**-0.153**	0.436	0.249	**-0.140**	**-0.141**	0.316	0.418	0.436	**-0.152**	0.401
A4	**-0.214**	**-0.134**	**-0.140**	**-0.234**	**-0.208**	**-0.155**	**-0.137**	**-0.128**	**-0.208**	**-0.128**
A5	**-0.224**	**-0.169**	**-0.169**	**-0.221**	**-0.239**	**-0.180**	**-0.166**	**-0.164**	**-0.217**	**-0.167**
A6	**-0.165**	0.383	0.360	**-0.149**	**-0.148**	0.135	0.364	0.399	**-0.159**	0.331
A7	**-0.179**	0.207	0.169	**-0.175**	**-0.174**	0.096	0.082	0.237	**-0.182**	0.069
A8	**-0.165**	0.248	0.181	**-0.163**	**-0.166**	0.172	0.282	0.160	**-0.171**	0.244
A9	**-0.211**	**-0.121**	**-0.120**	**-0.200**	**-0.210**	**-0.142**	**-0.116**	**-0.109**	**-0.233**	**-0.120**
A10	**-0.147**	0.443	0.425	**-0.138**	**-0.138**	0.346	0.445	0.456	**-0.147**	0.246

The attributes A1, A4, A5 and A9 are eliminated.

Table 6. Comparison of the elements of matrix of full influence of attributes of criterion construction and general systems with the threshold values

B	B1	**B2**	**B3**	**B4**	B5	B6	B7	**B8**	**B9**	B10
B1	0.303	**-0.111**	**-0.091**	**-0.092**	0.390	0.442	0.174	**-0.095**	**-0.072**	0.523
B2	**-0.073**	**-0.192**	**-0.162**	**-0.161**	**-0.086**	**-0.083**	**-0.106**	**-0.160**	**-0.157**	**-0.068**
B3	**-0.102**	**-0.174**	**-0.194**	**-0.163**	**-0.117**	**-0.114**	**-0.126**	**-0.166**	**-0.166**	**-0.097**
B4	**-0.085**	**-0.163**	**-0.157**	**-0.192**	**-0.103**	**-0.089**	**-0.127**	**-0.162**	**-0.171**	**-0.087**
B5	0.532	**-0.105**	**-0.084**	**-0.093**	0.220	0.394	0.269	**-0.093**	**-0.088**	0.517
B6	0.335	**-0.112**	**-0.099**	**-0.104**	0.285	0.189	0.223	**-0.114**	**-0.107**	0.427
B7	0.494	**-0.100**	**-0.078**	**-0.082**	0.389	0.379	0.143	**-0.091**	**-0.084**	0.498
B8	**-0.081**	**-0.162**	**-0.156**	**-0.156**	**-0.100**	**-0.099**	**-0.119**	**-0.191**	**-0.153**	**-0.078**
B9	**-0.090**	**-0.176**	**-0.171**	**-0.170**	**-0.106**	**-0.095**	**-0.111**	**-0.157**	**-0.192**	**-0.084**
B10	0.518	**-0.106**	**-0.089**	**-0.092**	0.281	0.435	0.314	**-0.094**	**-0.090**	0.330

The attributes B2, B3, B4, B8 and B9 are eliminated.

Table 7. Comparison of the elements of matrix of full influence of attributes of criterion propulsion with the threshold values

C	C1	C2	C3	C4	C5
C1	0.001	0.147	0.051	0.368	0.263
C2	0.056	**-0.218**	**-0.214**	0.082	**-0.140**
C3	0.123	0.002	-**0.172**	0.184	0.015
C4	**-0.070**	**-0.101**	**-0.053**	**-0.094**	**-0.009**
C5	**-0.051**	**-0.008**	**-0.047**	0.090	**-0.174**

All attributes are accepted.

Table 8. Comparison of the elements of matrix of full influence of attributes of criterion avionics and sensors with the threshold values

D	D1	D2	D3	D4	D5	D6	D7
D1	**-0.083**	0.030	**-0.001**	0.011	0.028	0.070	**-0.100**
D2	0.006	**-0.071**	**-0.015**	**-0.013**	0.028	0.070	**-0.048**
D3	0.140	0.147	**-0.034**	0.146	0.162	0.188	0.099
D4	**-0.065**	**-0.062**	**-0.095**	**-0.135**	**-0.088**	**-0.011**	**-0.106**
D5	**-0.099**	**-0.053**	**-0.134**	**-0.118**	**-0.144**	**-0.065**	**-0.111**
D6	0.099	0.115	0.060	0.080	0.097	0.008	0.037
D7	0.019	0.026	**-0.008**	**-0.006**	0.028	0.081	**-0.109**

All attributes are accepted.

Table 9. Comparison of the elements of matrix of full influence of attributes of criterion integrated logistics support with the threshold values

E	E1	**E2**	E3	E4	E5	E6	E7
E1	0.114	**-0.091**	0.360	0.375	0.305	0.348	0.279
E2	**-0.079**	**-0.212**	**-0.082**	**-0.085**	**-0.103**	**-0.088**	**-0.125**
E3	0.287	**-0.121**	0.127	0.280	0.206	0.270	0.214
E4	0.139	**-0.133**	0.117	0.021	0.085	0.077	0.037
E5	0.154	**-0.142**	0.053	0.113	-0.**020**	0.064	0.022
E6	0.219	**-0.134**	0.201	0.187	0.131	0.058	0.102
E7	0.360	**-0.102**	0.328	0.333	0.281	0.307	0.102

The attribute E2 is eliminated.

Table 10. Comparison of the elements of matrix of full influence of attributes of criterion armament with the threshold values

F	F1	F2	F3	F4	**F5**	F6	F7	F8	**F9**	F10
F1	-0.010	0.073	0.171	0.057	**-0.179**	0.163	0.132	0.029	**-0.155**	0.122
F2	0.021	**-0.023**	0.052	0.061	**-0.176**	0.037	0.094	0.087	**-0.174**	0.086
F3	**-0.052**	**-0.056**	**-0.087**	**-0.044**	**-0.200**	**-0.041**	**-0.036**	**-0.065**	**-0.192**	**-0.034**
F4	0.012	0.023	0.030	**-0.031**	**-0.178**	0.104	0.096	0.047	**-0.181**	0.134
F5	**-0.174**	**-0.175**	**-0.158**	**-0.173**	**-0.243**	**-0.154**	**-0.148**	**-0.180**	**-0.222**	**-0.168**
F6	0.089	0.125	0.193	0.158	**-0.164**	0.056	0.160	0.078	**-0.156**	0.217
F7	0.105	0.085	0.152	0.040	**-0.182**	0.088	0.009	0.014	**-0.166**	0.076
F8	0.251	0.256	0.298	0.237	**-0.141**	0.279	0.283	0.080	**-0.129**	0.253
F9	**-0.181**	**-0.175**	**-0.170**	**-0.182**	**-0.227**	**-0.170**	**-0.155**	**-0.176**	**-0.242**	**-0.165**
F10	0.189	0.214	0.218	0.151	**-0.140**	0.240	0.266	0.193	**-0.145**	0.113

The attributes F5 and F9 are eliminated.

Table 11. Comparison of the elements of matrix of full influence of attributes of criterion economy with the threshold values

I	I1	I2	I3
I1	0.075	0.275	0.317
I2	0.097	**-0.332**	**-0.041**
I3	0.055	**-0.108**	**-0.334**

All three attributes are accepted.

The evaluation of the selected criteria and attributes of criteria was performed by the AHP method (the Analytich Hierarchy Process). The gathering data was carried out using the questionnaire which was adapted to scale of relative importance (Saaty, 1980). Using the standard scale, each element of comparasion a_{ij} of matrix A can get one of 17 numerical values from a discrete interval [1/9, 9]. Prioritization is conducted using the eigenvector method – EV (Saaty, 1980). The criteria and attributes of criteria are pairwise compared by respondents. By calculating the mode of the individual gathered values, a pairwise comparison matrix was created (Table12).

Table 12. Pairwise comparison matrix (for criteria)

K	A	B	C	D	E	F	I
A	1	4	4	3	4	3	2
B	0.25	1	2	0.5	0.5	0.333	0.5
C	0.25	0.5	1	0.333	0.5	0.5	0.5
D	0.333	2	3	1	2	3	2
E	0.25	2	2	0.5	1	0.5	0.5
F	0.333	3	2	0.333	2	1	0.333
I	0.5	2	2	0.5	2	3	1

Based on values from the pairwise comparison matrix, a normalized pairwise comparison matrix was calculated by the equation 5 (Saaty, 1980).

$$a'_{ij} = {a_{ij}} \Big/ {\sum_{j=1}^{n} a_{ij}} \tag{5}$$

Table 13. Normalized pairwise comparison matrix (for criteria)

K	A	B	C	D	E	F	I
A	0.343	0.276	0.250	0.487	0.333	0.265	0.293
B	0.086	0.069	0.125	0.081	0.042	0.029	0.073
C	0.086	0.034	0.063	0.054	0.042	0.044	0.073
D	0.114	0.138	0.188	0.162	0.167	0.265	0.293
E	0.086	0.138	0.125	0.081	0.083	0.044	0.073
F	0.114	0.207	0.125	0.054	0.167	0.088	0.049
I	0.171	0.138	0.125	0.081	0.167	0.265	0.146

From the Table 13, the weight values W were calculated by the equation 6, which are shown in table 14.

$$w_i = {\sum_{j=1}^{n} a'_{ij}} \Big/ {n} \tag{6}$$

w_i - Weight value,

a'_{ij} - Element of normalized pairwise comparison matrix

Table 14. Weight values of criteria ($CR = 0.055$)

K	A	B	C	D	E	F	I	W	Rank
A	0.343	0.276	0.250	0.487	0.333	0.265	0.293	0.321	1
B	0.086	0.069	0.125	0.081	0.042	0.029	0.073	0.072	6
C	0.086	0.034	0.063	0.054	0.042	0.044	0.073	0.057	7
D	0.114	0.138	0.188	0.162	0.167	0.265	0.293	0.189	3
E	0.086	0.138	0.125	0.081	0.083	0.044	0.073	0.090	5
F	0.114	0.207	0.125	0.054	0.167	0.088	0.049	0.115	4
I	0.171	0.138	0.125	0.081	0.167	0.265	0.146	0.156	2

It can be noted (Table 14) that the highest weight value in the selection of the aircraft for air traffic protection has the criterion of aerodynamics and flight mechanics (A), while the lowest weight value has criterion propulsion (C).

Checking the consistency of the results was tested by the consistency ratio applying the following equation (Pamučar, 2017):

$$CR = {CI}/{RI} \quad (7)$$

Where is:

CI - Consistency index.

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (8)$$

$\lambda_{\max}$ - Maximum eigenvector of the matrix of comparison. This value was calculated as follows:

$$\lambda_{\max} = {1}/{n}\sum_{i=1}^{n}\lambda_i \quad (9)$$

$$\lambda_i = {b_i}/{w_i} \quad (10)$$

Value b_i was calcualted as follows:

$$\begin{bmatrix} b_1 \\ b_2 \\ b_n \end{bmatrix} = \begin{bmatrix} a_{11}a_{12}a_{1n} \\ a_{21}a_{22}a_{2n} \\ a_{n1}a_{n2}a_{nn} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ w_n \end{bmatrix} \quad (11)$$

a_{ij} - Represents the value of the element from the pairwise comparison matrix.

RI - Random index, which depends on the number of rows - columns of the matrix n (Pamučar, 2017). For example, if $n = 2$, than is $RI = 0$, if $n = 3 \Rightarrow RI = 0.52$, if $n = 4 \Rightarrow RI = 0.89$, if $n = 5 \Rightarrow RI = 1.11$, if $n = 6 \Rightarrow RI = 1.25$, if $n = 7 \Rightarrow RI = 1.35$, if $n = 8 \Rightarrow RI = 1.4$.

If $CR \le 0.10$ then the result is consistent. In this case, the consistency ratio is 0.055 and it is lower then 0.1, so the result is consistent (there is no need for corrections of the comparison).

The weight values for attributes are determined in the same way. Weight values for the attributes of each criterion are shown in the following tables.

Table 15. Weight values for attributes of criterion aerodynamics and mechanics of the flight ($CR = 0.03$)

A	A2	A3	A6	A7	A8	A10	W1	Rank
A2	0.185	0.222	0.273	0.222	0.254	0.147	0.217	2
A3	0.046	0.056	0.045	0.037	0.028	0.088	0.050	6
A6	0.092	0.167	0.136	0.148	0.169	0.147	0.143	3
A7	0.061	0.111	0.068	0.074	0.042	0.088	0.074	5
A8	0.061	0.167	0.068	0.148	0.085	0.088	0.103	4
A10	0.554	0.278	0.409	0.370	0.423	0.441	0.413	1

Table 16. Weight values for attributes of criterion construction and general systems ($CR = 0.01$)

B	B1	B5	B6	B7	B10	W2	Rank
B1	0.404	0.412	0.316	0.343	0.490	0.393	1
B5	0.058	0.059	0.053	0.057	0.061	0.057	5
B6	0.134	0.118	0.105	0.086	0.082	0.105	4
B7	0.202	0.176	0.211	0.171	0.122	0.177	3
B10	0.202	0.235	0.316	0.343	0.245	0.268	2

Table 17. Weight values for attributes of criterion propulsion ($CR = 0.02$)

C	C1	C2	C3	C4	C5	W3	Rank
C1	0.162	0.222	0.222	0.176	0.147	0.186	2
C2	0.081	0.111	0.148	0.118	0.117	0.115	3
C3	0.054	0.056	0.074	0.118	0.084	0.077	4
C4	0.054	0.056	0.037	0.059	0.065	0.054	5
C5	0.649	0.556	0.519	0.529	0.587	0.568	1

Table 18. Weight values for attributes of criterion avionics and sensors ($CR = 0.03$)

D	D1	D2	D3	D4	D5	D6	D7	W4	Rank
D1	0.152	0.133	0.170	0.190	0.194	0.100	0.218	0.165	3
D2	0.076	0.067	0.068	0.095	0.129	0.067	0.036	0.077	5
D3	0.304	0.333	0.339	0.286	0.258	0.400	0.327	0.321	1
D4	0.038	0.033	0.057	0.048	0.032	0.067	0.036	0.044	7
D5	0.051	0.033	0.085	0.095	0.065	0.067	0.055	0.064	6
D6	0.304	0.200	0.170	0.143	0.194	0.200	0.218	0.204	2
D7	0.076	0.200	0.113	0.143	0.129	0.100	0.109	0.124	4

Table 19. Weight values for attributes of criterion integrated logistics support ($CR = 0.03$)

E	E1	E3	E4	E5	E6	E7	W5	Rank
E1	0.374	0.261	0.357	0.350	0.329	0.462	0.355	1
E3	0.124	0.087	0.036	0.100	0.082	0.077	0.084	5
E4	0.075	0.174	0.071	0.100	0.055	0.058	0.089	4
E5	0.053	0.043	0.036	0.050	0.041	0.058	0.047	6
E6	0.187	0.174	0.214	0.200	0.164	0.115	0.176	3
E7	0.187	0.261	0.286	0.200	0.329	0.231	0.249	2

Table 20. Weight values for attributes of criterion armament ($CR = 0.04$)

F	F1	F2	F3	F4	F6	F7	F8	F10	W6	Rank
F1	0.032	0.024	0.031	0.029	0.025	0.023	0.053	0.024	0.030	8
F2	0.065	0.049	0.125	0.114	0.041	0.023	0.053	0.043	0.064	5
F3	0.065	0.024	0.063	0.114	0.062	0.034	0.074	0.071	0.063	6
F4	0.065	0.024	0.031	0.057	0.062	0.034	0.074	0.071	0.052	7
F6	0.161	0.146	0.125	0.114	0.124	0.136	0.122	0.107	0.130	3
F7	0.097	0.146	0.125	0.114	0.062	0.068	0.074	0.043	0.091	4
F8	0.226	0.341	0.313	0.286	0.373	0.341	0.368	0.428	0.334	1
F10	0.290	0.244	0.188	0.171	0.249	0.341	0.184	0.214	0.235	2

Table 21. Weight values for attributes of criterion economy ($CR = 0.02$)

I	I1	I2	I3	W7	Rank
I1	0.621	0.600	0.692	0.638	1
I2	0.310	0.300	0.231	0.280	2
I3	0.069	0.100	0.077	0.082	3

3. Results

On the basis of the first two phases of the research, less significant criteria and attributes are eliminated. These criteria are: reconnaissance equipment and concept of pilot training. In the same way attributes of criterion aerodynamics and mechanics of the flight are eliminated: weight, length of take off - landing, range and ceiling of flight and ability of supercruise. Eliminated attributes of criterion construction and general systems are: obstacle avoidance system, GPS terrain-following, voice command system, durability and ability of aerial refueling. Also, attribute convenience of maintenance of criterion integrated logistics support is eliminated. The following attributes of criterion armament are eliminated: under-fuselage hardpoints and bombs and other air - to - surface armament. Other attributes of selected criteria are significant for selection the air traffic protection aircraft. Their determination was the objective of the first part of the research.

Determining differences in significance between criteria and attributes of criteria was the objective of the second part of the research (using the AHP method). Prioritization of the criteria determined that the most significant criterion (Table 14 and Figure 2) is aerodynamics and mechanics of the flight (rank 1, weight 0.321), while the least significant is the criterion propulsion (rank 7; 0.057).

Attributes are also evaluated by prioritizing. The the most significant attribute of the criterion aerodynamics and mechanics of the flight (Table 15) is reaction time, and the least significant attribute is acceleration performance. Furthermore, for criterion construction and general systems the most significant attribute is wing mechanization and flight control system, and least significant is oxygen system.

The most significant attribute of the criterion propulsion (Table 17) is maintenance system and the least significant attribute is thermal emission. For the criterion avionics and sensors the highest weight value (Table 18) has fire-control radar and the lowest weight value has electronic warfare equipment. For the integrated logistics support the most significant is reliability of aircraft and the least significant is ability of maintenance staff (Table19). The air – to – air missiles and rockets are most significant for the criterion armament and the least significant attribute for the same criterion is capacity of locations for mounting armament (Table 20). Prioritization for the criterion economy is determined (Table 21) that highest weight value has acquisition cost, in the middle is life cycle costs and the lowest weight value has aircraft disposal costs.

For each weight value calculation, the consistency of the results was checked. Since all consistency ratio were less than 0.1, it is concluded that there is consistency for all results of prioritization.

Considering all aforementioned, it is concluded that the objective of the research is achieved and the general hypothesis is proven and the model is proposed (Figure 2).

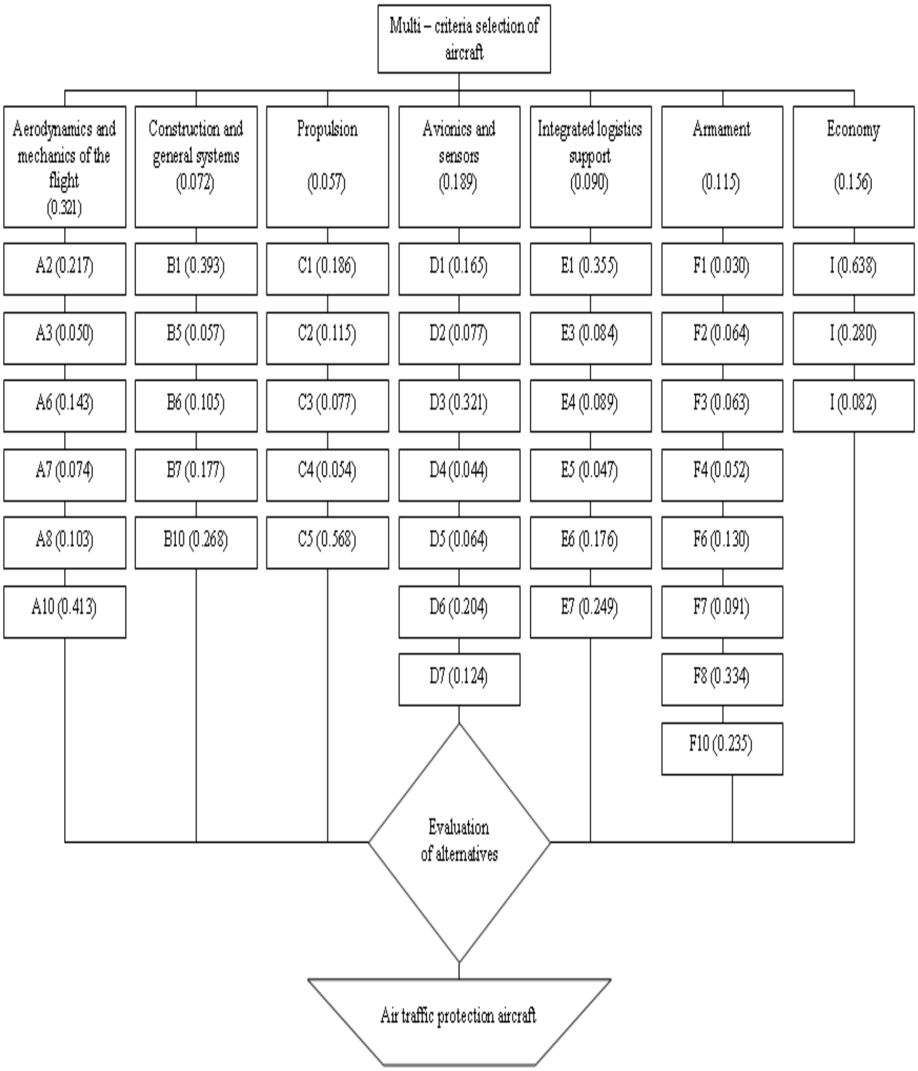

Figure 2. Proposed model for selection of the air traffic protection aircraft with weight values for criteria and attributes of criteria

4. Discussion

On the basis of the results it can be concluded that there are criteria and attributes which are significant for equipping the Army with the combat aircraft (Vlačić, 2012), but which are irrelevant in peacetime for the purpose of air traffic protection in the case of airspace violation.

For example, the most significant criterion for the combat aircraft is aerodynamics and mechanics of the flight, but also because of the multi roles, very significant is criterion reconnaissance equipment. The need for equipping two or three squadrons with the combat aircraft is the reason for the significance of the criterion concept of pilot training. Despite the aforementioned, the criterion economy is less significant for equipping with the combat aircraft than in the case of equipping with the air traffic protection aircraft (Vlačić, 2012). This difference as well as the difference in the significance of the selected criteria and attributes is a consequence of the overall picture of the organization and functioning of air traffic over the territory of the Republic of Serbia. Small area, elongated form of territory, high frequency of traffic, geostrategic position, number of air routes, financial capabilities of the country, availability and classes of airports are only several factors that have an impact on the determination and evaluation of criteria for selecting the aircraft (for example, it is easy to notice that due to the form of the territory and the area of the country, the reaction time is very significant for aircraft - the time required by duty - aircraft to take prescribed measures on the ground after receipt of an airspace endagering warning, to take off to be navigated and to intercept an aviation threat). The differences in the significance of the factors are also a consequence of the fact the combat aircraft conducts a wide range of tasks such as: air-to-air combat, aerial reconnaissance, forward air control, electronic warfare, air interdiction, suppression of enemy air defence and close air support. These missions would be conducted by aircraft in extremely specific conditions. Therefore, for selection of the aircraft are significant the following four overall evaluation criteria: affordability, mission capability, operational readiness and operational safety (Mavris & DeLaurentis, 1995).

It might be concluded that there are a lot of factors which impact on the determination and evaluation of criteria and attributes of criteria for selecting the air traffic protection aircraft. Also, those criteria are specific due to mission that is conducted by air traffic protection aircraft, although it is essentially the aircraft designed for use both in peacetime and wartime.

5. Conclusion

Air traffic is not immune to numerous security threats, including aviation threats. In the modern age, the possibility of occurrence of the airspace violation and other aviation threats is a reality. Therefore, the protection of air traffic from aviation threats is a very important security mission all around the world. In small countries, this task is conducted by their own aviation or aviation of some other countries. There is no doubt that for each country it is better to conduct this mission with its own aviation. It is also important to know that the aircrafts whose mission is to protect the air traffic from aviation threats have to meet the relevant international standards and technological criteria. Bearing in mind aforementioned and price of modern military aircrafts, the small countries usually make the decision to equip only a few aircrafts for the conducting of this mission. Therefore, it is necessary to determine very precisely according to the criteria of equipping, which depend on the set of factors mentioned in this paper and because of it precise determination and evaluation of the criteria for the selection of the air traffic protection aircraft on the example of the Republic of Serbia was the subject of this research.

For the purposes of this paper, traditional multi-criteria decision making methods are used and the model is proposed that can be applied in practice (and for the purpose of other countries that have simmilar teritorial characterics). By determining the mutual influence of the criteria (attributes) using the DEMATEL method, the final definition of the criteria (atributtes) and their weights are calculated by AHP. The applied methods, the obtained results and the proposed model make this research scientifically and methodologically justified.

Furthermore, it is possible to propose similar models for the needs of equipping the system of defence with other types of equippment. Above mentioned makes this research practical justified.

In the future research, it is possible to select a specific aircraft using some other the multi-criteria decision making methods (TOPSIS, MABAC, VIKOR, MAIRCA, etc.). Also, the models for designing certain technological solutions according to user requirements can be created. Furthermore, the application of similar models is possible for the purpose of implementing organizational changes in some organizational systems. Future research can also focus on the development of similar models using traditional methods in combination with methods that take into account uncertainty – fuzzy numbers tipe one-two or rough or interval-valued rough fuzzy numbers, intuitionistic fuzzy numbers, etc (Vahdani, Tavakkoli-Moghaddam, Meysam Mousavi & Ghodratnama, 2013; Sizong & Tao, 2016; Zywica, Stachowiak, & Wygralak, 2016, Pamučar, Petrović & Cirović, 2018), which would significantly improve the field of multi-criteria decision making.

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GENDER AND AGE STRUCTURE AS RISK FACTORS OF CAROTID ARTERY STENOSIS AND SPECIFIC THEMES AREAS OF CARTOGRAPHY

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Abstract: *The stroke prevention project was implemented in the period between 2012 –2017 in the Republic of Srpska when 38,863 patients of both genders were examined. Each of the patients underwent an ultrasound examination of the blood vessels of the neck on both sides. All the examinations were standardized and carried out by specially trained researchers. The presentation of the research results included descriptive statistics and a certain statistical test, which showed a statistically significant difference in carotid artery stenosis in male and female patients. The Geographic Information System was used for mapping carotid artery stenosis with the aim of determining the susceptibility of the population of a particular area, city and/or municipality to this disease and predicting it. The created epidemiological patterns show correlation between age structure and a particular area.*

Key Words: *Carotid Artery; GIS; Mapping; Prevention; Risk factors*

1 Introduction

Annually, about 4,5 million people die of a stroke, as one of the toughest and most common diseases of modern man. The stroke, regarding its consequences, is the first cause of disability of modern man and, therefore, its prevention is very important (Primatesta et al., 2007). It requires detection of the people with stroke risk factors (high blood pressure, diabetes, heart disease, high blood lipids, overweight people, smokers, people with a family history of stroke and people exposed to stress), as well as detection of pathological changes in the blood vessels of the neck and the head, whose treatment can lead to stroke prevention (Autret et al., 1987; Hennerici et al.,

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1987; O'Holleran et al., 1987; Norris et al., 1991; Inzitari et al., 2000; Thom et al., 2008; Đajić et al., 2015).

In the Republic of Srpska there is a great number of citizens with so-called stroke risk factors, who cannot afford an ultrasound examination. This project provides citizens with a free and fast ultrasound screening of the blood vessels in the neck and the head thus contributing to stroke prevention. The Geographic Information System (GIS) enables identification of epidemiological connection patterns between the risk factors and a particular area.

The aim of this research is to detect pathological changes in the blood vessels of the head and the neck in the people having stroke risk factors as well as to prevent a stroke in order to determine the asymptomatic carotid disease prevalence in general population on the basis of a random sample of patients who underwent an ultrasound examination of the blood vessels in the neck.

Therefore, the mapping is carried out of carotid artery stenosis by using the GIS with the aim of determining the susceptibility of the population of a particular area to a given disease and of predicting it.

2 Material and methods

In the period between 2012-2017, 38,863 patients were examined, i.e. 24,411 (62,8%) females and 14,452 (37,2%) males. All the examinees who had asymptomatic stroke (MU) and transient ischemic attack (TIA) were not included in the project. Before the examination, each patient filled in the standardized questionnaire asking for the following information: gender, age, height, weight, education, personal and family anamnesis of previous MU or TIA, heart disease, diabetes, hypertension, hyperlipidemia, smoking, alcoholism. After filling in the questionnaire each of them underwent an ultrasound examination of the blood vessels in the neck on both sides. All these examinations were standardized and carried out by specially trained researchers.

The stroke prevention project on the territory of the Republic of Srpska is carried out with the aim of determining the prevalence of the asymptomatic carotid disease in a representative sample of citizens in the Republic of Srpska. According to the last Census (published in 2017), 1,228,423 citizens live in the Republic of Srpska (Popis BiH, 2013), that is, 1,170,342 citizens (Rezultati popisa u BiH, 2013) (the difference in the number of citizens is due to different methodologies that were applied to conducting the Census). The previous Census was published in 1991, but, due to the war, there was a big migration of the population. This Census could not be used for calculating the number of patients who needed to be examined in certain municipalities; however, the sample was formed on the basis of the list of voters.

Local media and family doctors were previously informed about the project, as well as the local population, through a campaign which consisted of flyers, billboards, posters, media appearances, and so on. Each project participant was invited to come for an examination by a nurse or a family doctor, or he checked in at the local medical institution on his own.

Tabular presentation was carried out using descriptive statistics and the Mann-Whitney U test, by applying analytic-statistic tools of the SPPS (originally called: Statistical Package for the Social Sciences), version 20, while for conducting graphical presentation, the SPSS, version 20 and Microsoft Excel 2007 were used. Creating thematic maps was done in the software ArcMap 10.2. The statistical data, on the basis of which mapping was carried out, were prepared in Microsoft Excel 2007 (.csv format).

3 Research results

On the territory of the Republic of Srpska, starting from 2012, the stroke prevention project has been carried out, with 38,863 examined patients (Table 1).

Table 1 Examined patients in the period from 2012 – 2017

Year of examination	Gender of examinee		Total
	male	female	
2012	2284	4095	6379
2013	2 743	4281	7024
2014	2416	4421	6837
2015	3466	5931	9397
2016	2283	3957	6240
2017	1260	1726	2986
Total	14452	24411	38863

The degree of carotid artery stenosis (blockage) ranged from 0 to 100% (in patients of both genders). Median (Md) of stenosis for all patients is 17,00% (in female patients median is less by 5,00% as compared to male patients), Table 2.The average carotid artery stenosis for all patients is 19,03% (but in female patients average stenosis is less by 3,95% as compared to male patients).

Table 2 Degree of carotid artery stenosis

Gender of examinee	N	Minimum	Maximum	Median	Mean	Std. Dev.
Male	14452	0	100	20.00	21.51	15.008
Female	24411	0	100	15.00	17.56	12.556
Total	38863	0	100	17.00	19.03	13.654

Fig. 1 shows a degree of the carotid artery stenosis according to the gender of the patient.

By applying the Mann-Whitney U test, a statistically significant difference is calculated (z= -27,485, p = 0,000) between carotid artery stenosis in female patients (N = 24,411, Md = 15,00) and male patients (N = 14,452, Md = 20,00).

The carotid artery stenosis which is less than 20%, and, therefore, does not require any treatment was found in 21,408 (55,1%) patients (14,631 or 59,9% of all female patients and 6,777 or 46,9% of all male patients).

By observing the percentage of the carotid artery stenosis representation according to gender, one can notice a higher frequency of carotid artery stenosis in male patients (Table 3), as follows:

- stenosis ranging from 20 - 49%: 47,5% in male patients and 37,3% in female patients,
- stenosis ranging from 50 - 69%: 4,1% in male patients and 2,1% in female patients,
- stenosis ranging from 70 - 99%: 1,1% in male patients and 0,5% in female patients, and,

- stenosis of 100%: 0,4% in male patients and 0,2% in female patients.

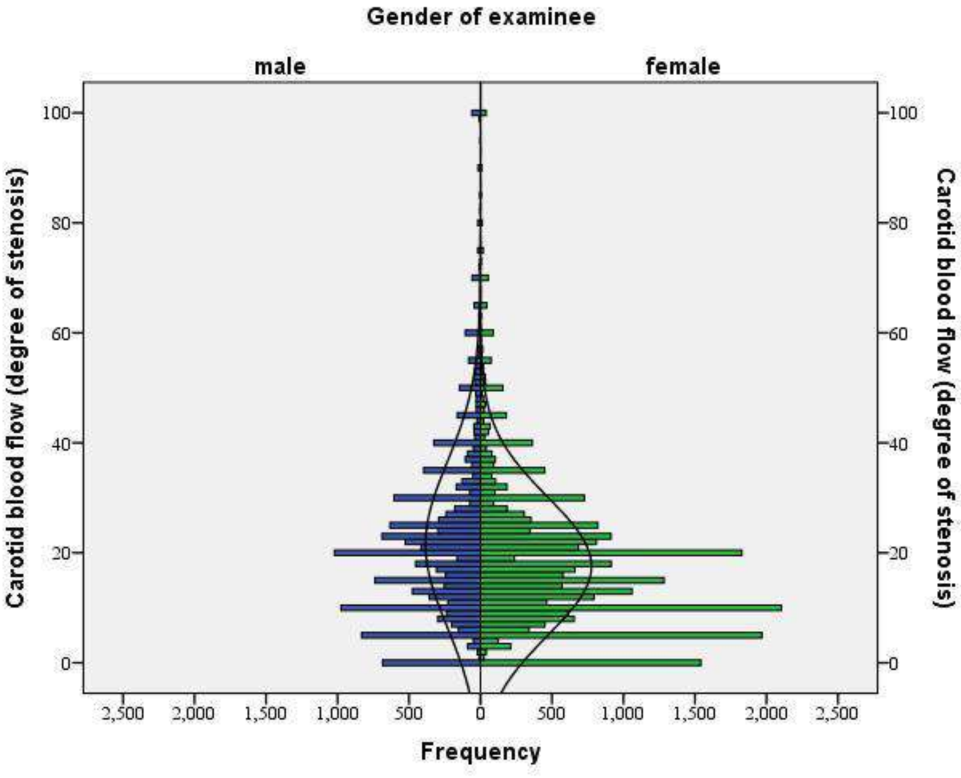


Fig.1 Degree of carotid artery stenosis according to the patient's gender

Table 3 Degree of carotid artery stenosis /groups/ according to the patient's gender

Carotid artery stenosis (%)		Gender of patient		Total
		male	female	
0-19	N	6777	14631	21408
	%	46.9%	59.9%	55.1%
20-49	N	6870	9109	15979
	%	47.5%	37.3%	41.1%
50-69	N	588	519	1107
	%	4.1%	2.1%	2.8%
70-99	N	157	113	270
	%	1.1%	0.5%	0.7%
100	N	60	39	99
	%	0.4%	0.2%	0.3%
Total	N	14452	24411	38863
	%	37.2%	62.8%	100.0%

Percentage of the presence of carotid artery stenosis /group/ according to the patients' gender is shown in Fig. 2.

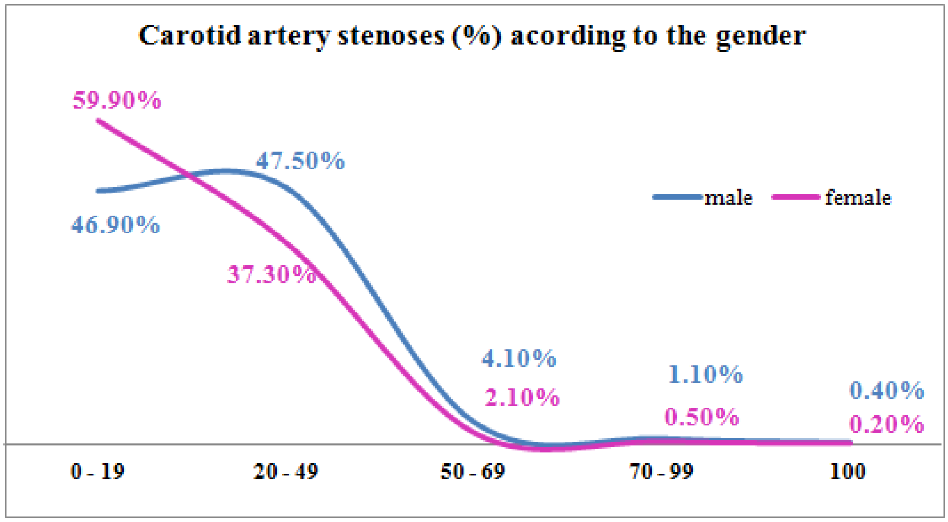


Fig. 2 Degree of stenosis of carotid artery /groups/ according to the patient's gender

The majority of patients, who underwent an examination, were between 55 and 64 years of age (13,642 or 35,1%); of these 6,679 had carotid artery stenosis ranging from 20 to 49%. Every fourth patient (10,207 or 26,3%) was older than 64, and 779 of them had carotid artery stenosis ranging from 50-69% (70,4% of all patients had carotid artery stenosis ranging from 50-69%); in 189 patients carotid artery stenosis was between 70-99% (70,0% of all patients had carotid artery stenosis between 70 and 99%), and 59 patients had complete blockage of the carotid artery (59,6% of all patients with complete blockage of the carotid artery). The patients who belonged to young age categories had smaller carotid artery stenosis (Table 4).

Table 4 Degree of carotid artery stenosis /groups/ according to the patients' age

Age group		Carotid artery stenosis (%)					Total
		0-19	20-49	50-69	70-99	100	
<= 24	N	264	2	0	0	0	266
	%	1.2%	0.0%	0.0%	0.0%	0.0%	0.7%
25 - 34	N	1638	6	0	0	0	1644
	%	7.7%	0.0%	0.0%	0.0%	0.0%	4.2%
35 - 44	N	3915	212	1	1	0	4129
	%	18.3%	1.3%	0.1%	0.4%	0.0%	10.6%
45 - 54	N	6895	2036	33	5	6	8975
	%	32.2%	12.7%	3.0%	1.9%	6.1%	23.1%
55 - 64	N	6560	6679	294	75	34	13642
	%	30.6%	41.8%	26.6%	27.8%	34.3%	35.1%
>= 65	N	2136	7044	779	189	59	10207
	%	10.0%	44.1%	70.4%	70.0%	59.6%	26.3%
Total	N	21408	15979	1107	270	99	38863
	%	55.1%	41.1%	2.8%	0.7%	0.3%	100.0%

Degree of carotid artery stenosis /groups/ according to the patients' age is shown in Fig. 3.

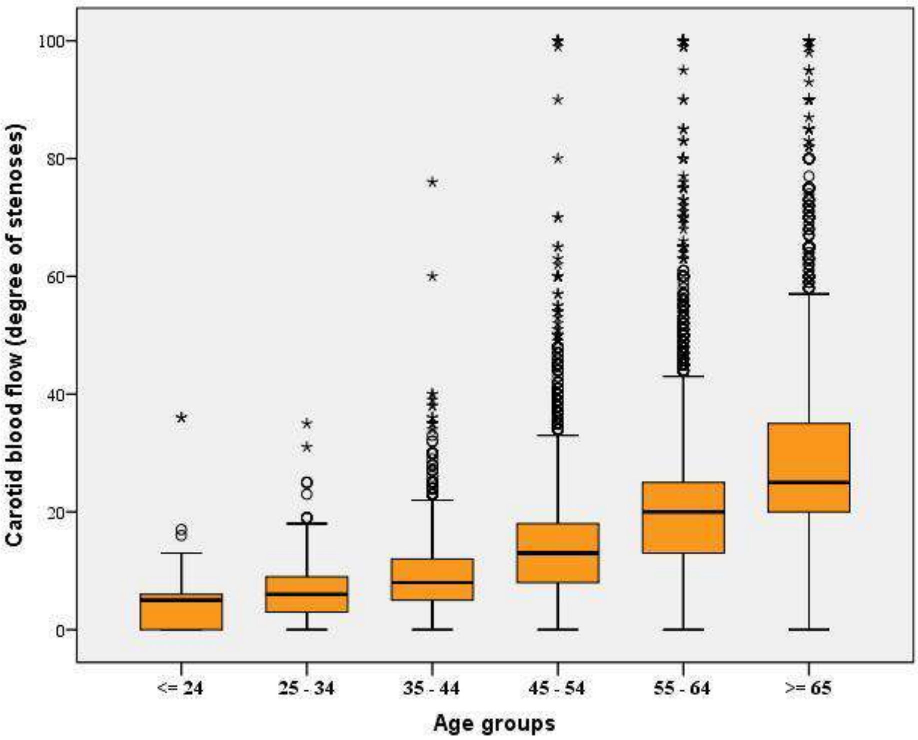


Fig. 3 Degree of carotid artery stenosis /groups/ according to the patients' age groups

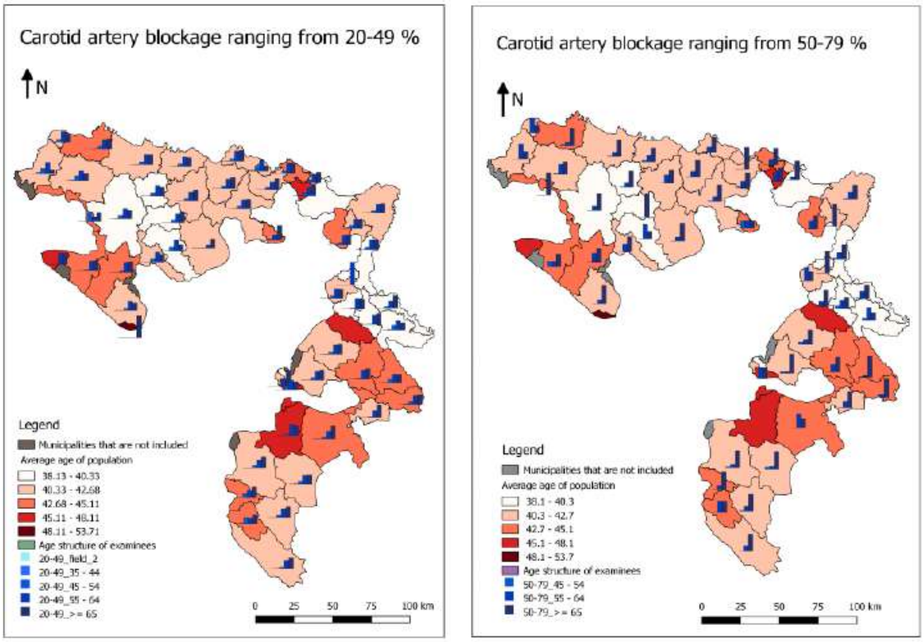
4 Creation of thematic maps of the carotid artery

Thematic cartography is a cartographic discipline that enables presentation of spatial arrangement of objects, phenomena and processes that are under study. The Geographic Information System development ensured simpler collecting, processing and visualizing of spatial and associated data. The Geographic Information Systems (GISs) and spatial analysis techniques are powerful tools for describing epidemiological patterns, as well as for detecting, explaining and predicting clusters of diseases in space and time (Grobusch et al., 2016). The GIS application to mapping anatomic features and clinical events has been infrequent in the GIS and medical literature (Garb et al., 2007). The greatest potential of the GIS is its ability to clearly show the results of complex analyses through maps (Mullner et al., 2004). Unlike tables and spreadsheets with seemingly endless numbers, maps produced by the GIS have the ability to transform data into information that can be quickly and easily communicated. Likewise, these systems also extend the range of problems that can this technology can help solving by allowing the users to more efficiently deal with complex problems (Melnick&Flemming, 1999; Preradović et al., 2017).

The creation of thematic maps of the carotid artery stenosis (blockage) is done using software of the company ERSI, ArcGIS 10.2. based on data basis. ArcGIS uses an object-relational data base. Simple tables and defined types of attributes allow the storage of spatial data, and SQL (Structural Query Language) enables creating, modifying and querying the tables. Data are saved in Shapefile format. Geometry of the object in .shp file can be presented by a dot, line or polygon. Apart from the data on geometry, .shp file also contains attributive table which stores descriptive information, such as: the name of municipality, postcode, etc.

Spatial objects (political borders of municipalities in the Republic of Srpska) were used as spatial references for the carotid artery blockage presentation. The borders of municipalities are presented by polygons in .shp format. The cartogram method is used to show prevalence of a certain degree of the carotid artery blockage by the patients' age groups while the average age of population is presented by the coloring method with the category borders defined by the method of natural borders. Data on patients' age and carotid artery blockage are downloaded in .xlsx format. The carotid artery blockage is shown by percentage and sorted in 5 categories (0-19, 20-49, 50-79, 80-99, 100). Average age of population is downloaded from the official site of the 2013 Census of population, households and dwellings in Bosnia and Herzegovina in .xlsx format [10]. As the data in their original form were not suitable for further processing, they were harmonized and sorted. Sorted data were saved in .csv format. .CSV format stores tabular data as plain text and ensures data exchange between different programs and, therefore, it is used in this paper. Connecting spatial and statistical data is carried out on the basis of mutual field (Name of the municipality), by using option *Join*.

Fig. 4 shows carotid artery blockages (separately for each category of carotid artery blockage and age group) by municipalities in the Republic of Srpska.



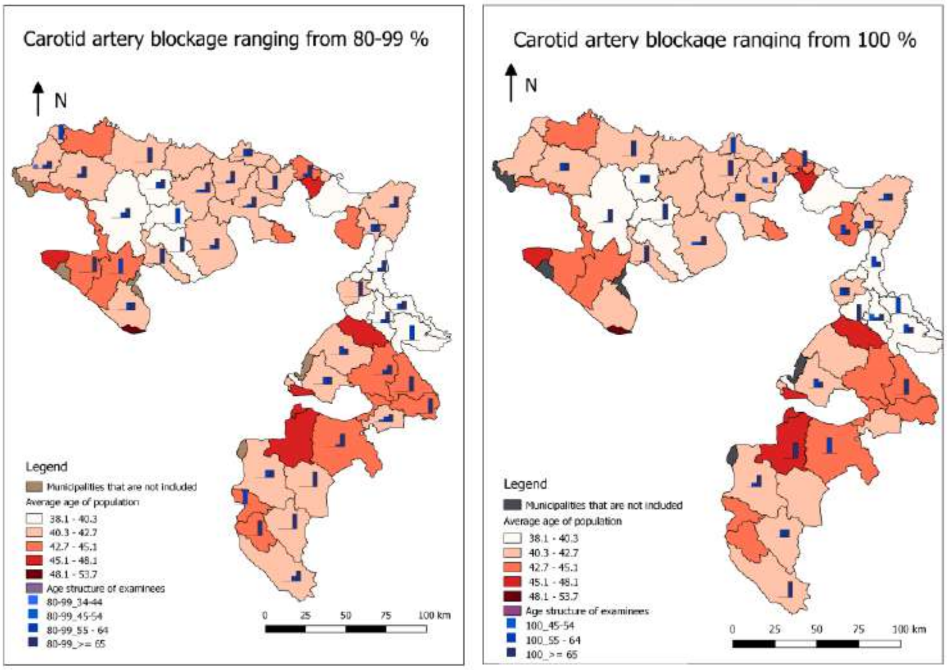


Fig. 4 Carotid artery blockage by municipalities in the Republic of Srpska

Fig. 5 shows percentages of patients with carotid artery stenosis higher than 50% by municipalities in the Republic of Srpska.

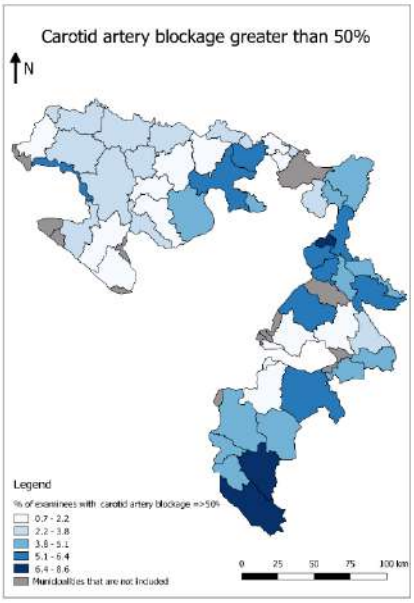


Fig. 5 Percentage of patients with carotid artery stenosis higher than 50% by municipalities in the Republic of Srpska

5 Conclusion

On the basis of these results, it is evident that the minimal (0 to 19%) carotid artery stenosis in percentage (in relation to the number of examined patients) is more prevalent in female patients, and while the carotid artery stenosis which needs to be treated (conservatively and/or surgically) is more prevalent in male patients. The created epidemiological patterns indicate that the examinees in certain regions (cities and municipalities) have a high risk of a stroke. In accordance with the obtained and presented research results, it is necessary to do an analysis of equipment of medical institutions in vulnerable regions, purchase additional medical equipment and educate health care workers and population, with the aim of reducing the risk of this, very common, disease, with a high mortality rate, whose consequences are very severe – for the patient, family and whole society.

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A MULTICRITERIA MODEL FOR THE SELECTION OF THE TRANSPORT SERVICE PROVIDER: A SINGLE VALUED NEUTROSOPHIC DEMATEL MULTICRITERIA MODEL

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Abstract: *The decision-making process requires, a priori, defining and considering certain factors, especially when it comes to complex areas such as transport management in companies. One of the most important items in the initial phase of the transport process that significantly influences its further flow is decision-making about the choice of the most favorable transport provider. In this paper a model for evaluating and selecting a transport service provider based on a single valued neutrosophic number (SVNN) is presented. The neutrosophic set concept represents a general platform that extends the concepts of classical sets, fuzzy sets, intuitionistic fuzzy sets, and an interval valued intuitionistic fuzzy sets. The application of the SVNN concept made a modification of the DEMATEL method (Decision-making Trial and Evaluation Laboratory Method) and proposed a model for ranking alternative solutions. The SVNN-DEMATEL model defines the mutual effects of the provider's evaluation criteria, while, in the second phase of the model, alternative providers are evaluated and ranked. The SVNN-DEMATEL model was tested on a hypothetical example of evaluation of five providers of transport services.*

Key Words: *Multicriteria Decision-making, DEMATEL, Single Valued Neutrosophic Numbers, Provider Selection*

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1. INTRODUCTION

Outsourcing approach is widely present in all logistic aspects of business, especially in the transport domain, which is distinguished by its significant and direct participation in overall logistics costs. After making a decision on accepting outsourcing for certain logistical activities of the organization, the management is facing the issue of selecting the provider that will implement these activities for the organization needs.

The problem of selecting a transport service provider is conceptually similar to the choice of providers in most other logistics activities. In that sense, when it comes to the models of selection of the transport service provider, of relevance are those research studies that are focused on the selection of carrier, suppliers, vendor, or independent logistics providers (third party logistics provider selection).

Regardless of differences in the views on the structuring of the providers selection problem (Ordoobadi & Wang, 2011; Shen Yu, 2012), as well as on the structure of the selection process itself (Snir & Hitt, 2004; Monczka et al., 2005; Cao & Wang, 2007), when it comes to the nature of this process, its multidimensional character is often mentioned (Vinodh et al., 2011; Senthil et al., 2014). In that sense, numerous multicriteria decision-making methods have been used to select providers.

Various examples of combining different approaches that treat uncertainty (fuzzy access, etc.) with traditional multicriteria techniques, such as TOPSIS (Zouggari & Benyoucef, 2011; Senthil et al., 2014), VIKOR (Sanayei et al., 2010), AHP (Singh & Sharma, 2011; Senthil et al., 2014), ANP (Nobar et al., 2011) etc. can be found in the literature. An example of the DEMATEL method application to the recognition of the relevant criteria as well as to the identification of their significance and causal relationships in the process of structuring a model for the supplier selection with carbon management competencies can be seen in (Hsu et al., 2011).

As can be seen in a review of the referential literature given here, most approaches prefer the use of traditional multicriteria decision-making (MCDM) models in combination with fuzzy techniques (Senthil et al., 2014). However, in the real world, the decision-maker may prefer attribute assessment by using linguistic variables instead of crisp values either due to his partial knowledge about attributes or the lack of information from the problem domain. The Fuzzy set presented by Zadeh (1965) is one of the tools used to present such imprecision in mathematical form. However, the fuzzy set can focus only on the degree of affiliation of unclear parameters or events. The Fuzzy set cannot represent the degree of non-affiliation and the degree of imprecision of uncertainty parameters. In order to partially overcome the difficulties in defining parameters that are imprecise, Atanassov (1986) introduced intuitionistic fuzzy sets (IFS) that are characterized by the degree of affiliation and non-affiliation simultaneously. However, in the IFS, the sum of the affiliation degree and non-affiliation degree of the unclear parameter is less than one (unity). In order to eliminate these shortcomings, Smarandache (1999) introduced a neutrosophic concept in order to deal with unspecified or inconsistent information that usually exists in reality. The concept of a neutrosophic set represents a general platform that extends the concepts of classical sets, fuzzy sets (Zadeh, 1965), intuitionistic fuzzy sets (Atanassov, 1986), and interval valued intuitionistic fuzzy sets (Atanassov & Gargov, 1989). Unlike intuitionistic fuzzy sets and interval valued intuitionistic fuzzy sets, in the neutrosophic set indeterminacy is explicitly characterized.

Using the advantages of the neutrosophic sets mentioned above, the original SVNN-DEMATEL model for the transport service provider evaluation was proposed in this paper. In the next section of work (section 2), the basic items of the SVNN are presented. Thereafter, in the third section of the paper, an original VKO model based on SVNN was presented. Testing of the presented model was performed in the fourth section of the work.

2. NEUTROSOPHIC SETS

According to the definition of a neutrosophic set, neutrosophic set A is a universal set X characterized by function of affiliation describing truth-membership function $T_A(x)$, indeterminacy-membership function $I_A(x)$ and the function of falsity-membership $F_A(x)$. Where $T_A(x)$, $I_A(x)$ and $F_A(x)$ are real standard or non-standard subsets of $[^-0,1^+]$, each of the three neutrosophic components satisfy the condition that $T_A(x)\rightarrow [^-0,1^+]$, $I_A(x)\rightarrow [^-0,1^+]$ and $F_A(x)\rightarrow [^-0,1^+]$.

Set $I_A(x)$ can be used to present not only indeterminacy, but also unclearness, uncertainties, inaccuracies, errors, contradictions, the undefined, the unknown, incompleteness, redundancy, etc. (Biswas et al, 2016). In order to cover all unclear information, the degree of affiliation to the indeterminacy-membership degree can be subdivided into sub-components, such as "contradiction," "uncertainty," and "unknown" (Smarandache, 1999).

The sum of these three neutrosophic set affiliation functions $T_A(x)$, $I_A(x)$ and $F_A(x)$ should satisfy the following condition $^-0 \le T_A(x)+I_A(x)+F_A(x) \le 3^+$ (Biswas et al, 2016). The component of neutrosophic set A for all values $x \in X$ is determined by A^C so that $T_A^c(x)=1^+ - T_A(x)$, $I_A^c(x)=1^+ - I_A(x)$ and $F_A^c(x)=1^+ - F_A(x)$. Neutrosophic set A is contained in another neutrosophic set B ($A \subseteq B$) if and only if for each value $x \in X$ the following conditions are satisfied $\inf T_A(x) \le \inf T_B(x)$, $\sup T_A(x) \le \sup T_B(x)$, $\inf I_A(x) \ge \inf I_B(x)$, $\sup I_A(x) \ge \sup I_B(x)$, $\inf F_A(x) \ge \inf F_B(x)$, and $\sup F_A(x) \ge \sup F_B(x)$.

Single valued neutrosophic sets (SVNS) are a special case of the neutrosophic set that can be used more successfully in modern scientific and engineering applications, compared to the classical neutrophic set. Basic arithmetic operations on SVNN that are significant for the mathematical background of the MCDM model can be looked in detail in (Wang et al., 2010; Deli & Şubaş, 2017).

3. SINGLE VALUED NEUTROSOPHIC DEMATEL METHOD

The DEMATEL method is a very suitable tool for designing and analyzing the structural model. And it can be achieved through the definition of cause-effect relationships between factors that are complex (Pamučar & Ćirović, 2015; Gigović et al., 2016). In order to comprehensively take into account the imprecision that exists in group decision-making, this paper performs a modification of the DEMATEL method by using the SVNS. In the next section the steps of the SVN-DEMATEL method are elaborated, namely:

Step 1: Factors expert analysis. Assuming that there are m experts and n factors (criteria) that are observed, each expert should determine the degree of influence of factor i on factor j. A comparative analysis of the pair of the i -th and j -th factor by the k-th expert is marked by d_{ij}^e, where $d_{ij}^e = \left\langle T_{ij}^e, I_{ij}^e, F_{ij}^e \right\rangle$, $(i=1,\dots,n;\ j=1,\dots,n)$ represents a neutrophic number that is being compared in the pairs of factors. The value of each pair d_{ij}^e takes the values from a previously defined single valued neutrosophic linguistic scale. The response of the e-th expert is displayed by a single valued neutrosophic matrix of $D^e = \left\langle d^e{}_{ij} \right\rangle_{n\times n} = \left\langle T_{ij}^e, I_{ij}^e, F_{ij}^e \right\rangle_{n\times n}$, $\left(1 \le e \le m\right)$ rank, where m represents the total number of experts.

$$D^e = \begin{bmatrix} 0 & \left\langle T_{12}^e, I_{12}^e, F_{12}^e \right\rangle & \cdots & \left\langle T_{1n}^e, I_{1n}^e, F_{1n}^e \right\rangle \\ \left\langle T_{21}^e, I_{21}^e, F_{21}^e \right\rangle & 0 & \cdots & \left\langle T_{2n}^e, I_{2n}^e, F_{2n}^e \right\rangle \\ \vdots & \vdots & \ddots & \vdots \\ \left\langle T_{n1}^e, I_{n1}^e, F_{n1}^e \right\rangle & \left\langle T_{n2}^e, I_{n2}^e, F_{n2}^e \right\rangle & \cdots & 0 \end{bmatrix}_{nxn} \tag{1}$$

Where $\left\langle T_{ij}^e, I_{ij}^e, F_{ij}^e \right\rangle$ represents single valued neutrosophic linguistic expressions from a predefined linguistic scale which the expert *e* uses to represent his comparison in the pairs of criteria. Thus we get matrices D^1, D^2, ..., D^m which represent the matrices of responses from each of the m experts.

Step 2: Determination of weight coefficients of experts. It starts from the assumption that m experts $\left\{E_1, E_2, ..., E_m\right\}$ with assigned weight coefficients $\{\varpi_1, \varpi_2, ..., \varpi_m\}$, $0 \le \varpi_e \le 1,\ (e = 1, 2, ..., m)$ participate in the decision-making process. Suppose that: (1) each expert from the group of *m* has his own weighting coefficient, (2) the weight coefficients of the experts differ in value, and (3) condition $\sum_{e=1}^{m} \varpi_e = 1$ is satisfied. Then we can present the significance of each expert using linguistic variables from a predefined single valued neutrosophic linguistic scale.

If we denote a single valued neutrosophic number with $E_e = \left\langle T_e(x), I_e(x), F_e(x) \right\rangle$ which evaluates the significance of the e-expert, then the weight coefficient of the e-th expert can be determined using the expression (2), [17]

$$\varpi_e = \frac{1 - \sqrt{\left\{\left(1 - T_e(x)\right)^2 + \left(I_e(x)\right)^2 + \left(F_e(x)\right)^2\right\} / 3}}{\sum_{e=1}^{m} \left(1 - \sqrt{\left\{\left(1 - T_e(x)\right)^2 + \left(I_e(x)\right)^2 + \left(F_e(x)\right)^2\right\} / 3}\right)} \tag{2}$$

where $\sum_{e=1}^{m} \varpi_e = 1$, $\left(1 \le e \le m\right)$.

Step 3: Determination of the average responses matrix of the experts. On the basis of individual matrices of the answer of the *m* experts, we obtain a matrix of aggregated sequences of experts $D^* = \left\langle d^e{}_{ij} \right\rangle_{n\times n} = \left\langle T_{ij}^e, I_{ij}^e, F_{ij}^e \right\rangle_{n\times n}$, $\left(1 \le e \le m\right)$, where $d^e{}_{ij} = \left\{\left\langle T_{ij}^1, I_{ij}^1, F_{ij}^1 \right\rangle, \left\langle T_{ij}^2, I_{ij}^2, F_{ij}^2 \right\rangle, ..., \left\langle T_{ij}^m, I_{ij}^m, F_{ij}^m \right\rangle\right\}$ represent sequences which describe the relative importance of criterion *i* in relation to criterion j.

Using the expression (3), an aggregation of values is made at each position of matrix D^*

$$\overline{d}_{ij} = \sum_{e=1}^{m}\left(\varpi_e \cdot d_{ij}^{e}\right) = \left(1-\prod_{e=1}^{m}\left(1-T_{ij}^{e}\right)^{\varpi_e}, \prod_{e=1}^{m}\left(I_{ij}^{e}\right)^{\varpi_e}, \prod_{e=1}^{m}\left(F_{ij}^{e}\right)^{\varpi_e}\right) \tag{3}$$

where $\overline{d}_{ij} = \left\langle \overline{T}_{ij}, \overline{I}_{ij}, \overline{F}_{ij} \right\rangle$ represents aggregated SVNN.

That is how we obtain an aggregated single valued neutrosophic matrix of the average response of the experts (4)

$$\overline{D} = \begin{bmatrix} 0 & \left\langle \overline{T}_{12}, \overline{I}_{12}, \overline{F}_{12} \right\rangle & \cdots & \left\langle \overline{T}_{1n}, \overline{I}_{1n}, \overline{F}_{1n} \right\rangle \\ \left\langle \overline{T}_{21}, \overline{I}_{21}, \overline{F}_{21} \right\rangle & 0 & \cdots & \left\langle \overline{T}_{2n}, \overline{I}_{2n}, \overline{F}_{2n} \right\rangle \\ \vdots & \vdots & \ddots & \vdots \\ \left\langle \overline{T}_{n1}, \overline{I}_{n1}, \overline{F}_{n1} \right\rangle & \left\langle \overline{T}_{n2}, \overline{I}_{n2}, \overline{F}_{n2} \right\rangle & \cdots & 0 \end{bmatrix} \tag{4}$$

Matrix $\overline{D}$ shows the initial effects that factor *j* causes, as well as the initial effects that factor *j* receives from the other factors. The sum of each *i*-th row of matrix $\overline{D}$ represents the total direct effects that factor *i* handed over to the other factors, and the sum of each *i j*--th column of matrix $\overline{D}$ represents the total direct effects that factor *j* receives from the other factors.

Step 4: Determine the SVN total relation matrix. Using expression (5) we calculate a single valued neutrosophic total relation matrix $T = \left\langle t_{ij} \right\rangle_{n\times n} = \left\langle T_{ij}(t), I_{ij}(t), F_{ij}(t) \right\rangle_{n\times n}$. Element $t_{ij} = \left\langle T_{ij}(t), I_{ij}(t), F_{ij}(t) \right\rangle$ represents the direct effect of factor *i* on factor j, while matrix T reflects the overall relationship between each pair of factors.

Since each single valued neutrosophic number consists of three sequences $T_{ij}(t)$, $I_{ij}(t)$ and $F_{ij}(t)$ then the SVN matrix can be divided into three submatrices, i.e. $\overline{D} = \left\langle \overline{T}, \overline{I}, \overline{F} \right\rangle_{n\times n}$, where, $\overline{T} = \left[\overline{T}_{ij}\right]_{n\times n}$, $\overline{I} = \left[\overline{I}_{ij}\right]_{n\times n}$ and $\overline{F} = \left[\overline{F}_{ij}\right]_{n\times n}$. Furthermore, $\lim_{m\to\infty}\left(\overline{T}\right)^m = O$, $\lim_{m\to\infty}\left(\overline{I}\right)^m = O$ and $\lim_{m\to\infty}\left(\overline{F}\right)^m = O$, where 0 represents zero matrix. Based on the defined settings, we obtain the SVN matrix of total T effects by calculating the following elements

$$\left.\begin{aligned} & T(t) = \lim_{m\to\infty}\left(I + \overline{T} + \overline{T}^2 + \ldots + \overline{T}^m\right) = \left(I - \overline{T}\right)^{-1} = \left[T_{ij}(t)\right]_{n\times n} \\ & I(t) = \lim_{m\to\infty}\left(I + \overline{I} + \overline{I}^2 + \ldots + \overline{I}^m\right) = \left(I - \overline{I}\right)^{-1} = \left[I_{ij}(t)\right]_{n\times n} \\ & \textit{and} \\ & F(t) = \lim_{m\to\infty}\left(I + \overline{F} + \overline{F}^2 + \ldots + \overline{F}^m\right) = \left(I - \overline{F}\right)^{-1} = \left[F_{ij}(t)\right]_{n\times n} \end{aligned}\right\} \tag{5}$$

Sub-matrices $T(t)$, $I(t)$ and $F(t)$ together represent a SVN matrix of total impact $T = \left\langle T(t), I(t), F(t) \right\rangle_{n\times n}$. Based on expression (5) the SVN matrix of total impacts is obtained

$$T = \begin{bmatrix} \langle T_{11}(t), I_{11}(t), F_{11}(t) \rangle & \langle T_{12}(t), I_{12}(t), F_{12}(t) \rangle & \cdots & \langle T_{1n}(t), I_{1n}(t), F_{1n}(t) \rangle \\ \langle T_{21}(t), I_{21}(t), F_{21}(t) \rangle & \langle T_{22}(t), I_{22}(t), F_{22}(t) \rangle & \cdots & \langle T_{2n}(t), I_{2n}(t), F_{2n}(t) \rangle \\ \vdots & \vdots & \ddots & \vdots \\ \langle T_{n1}(t), I_{n1}(t), F_{n1}(t) \rangle & \langle T_{n2}(t), I_{n2}(t), F_{n2}(t) \rangle & \cdots & \langle T_{nn}(t), I_{nn}(t), F_{nn}(t) \rangle \end{bmatrix} \tag{6}$$

where $t_{ij} = \langle T_{ij}(t), I_{ij}(t), F_{ij}(t) \rangle$ is a single valued neutrosophic number which expresses indirect effects of factors i on factor j. Then matrix T reflects the interdependence of each pair of factors.

Step 5: Calculating the sum of the rows and columns of the total impact T matrix. In the total impact T matrix the sum of rows and that of columns is represented by vectors R and C of $n \times 1$:

$$R_i = \left[\sum_{j=1}^{n} t_{ij} \right]_{n \times 1} = \left[\sum_{j=1}^{n} \langle T_{ij}(t), I_{ij}(t), F_{ij}(t) \rangle \right]_{n \times 1} \tag{7}$$

$$C_i = \left[\sum_{i=1}^{n} t_{ij} \right]_{1 \times n} = \left[\sum_{i=1}^{n} \langle T_{ij}(t), I_{ij}(t), F_{ij}(t) \rangle \right]_{1 \times n} \tag{8}$$

Step 6: Determination of the weighting coefficients of the criteria. The weighting coefficients of the criteria are determined using the expression

$$W_j = \sqrt{\begin{pmatrix} 2 - \sqrt{\left\{ (1 - T(R_i))^2 + (I(R_i))^2 + (F(R_i))^2 \right\} / 3} \\ -\sqrt{\left\{ (1 - T(C_i))^2 + (I(C_i))^2 + (F(C_i))^2 \right\} / 3} \end{pmatrix}^2 + \begin{pmatrix} \sqrt{\left\{ (1 - T(R_i))^2 + (I(R_i))^2 + (F(R_i))^2 \right\} / 3} \\ +\sqrt{\left\{ (1 - T(C_i))^2 + (I(C_i))^2 + (F(C_i))^2 \right\} / 3} \end{pmatrix}^2} \tag{9}$$

Step 7: Forming the initial decision matrix (N). As in DEMATEL method, the evaluation of alternatives by the criteria is being done by m experts $\{E_1, E_2, ..., E_m\}$ with assigned weighting coefficients $\{\varpi_1, \varpi_2, ..., \varpi_m\}$, $\sum_{e=1}^{m} \varpi_e = 1$. In order to make a final ranking of alternatives $a_i \in A$ ($i = 1,2,..,b$), each expert E_e ($e = 1,2,...,m$) evaluates alternatives by a defined set of criteria $C = \{c_1, c_2, ... c_n\}$. In that way, correspondent initial decision matrix $N^{(e)} = \left[\eta_{ij}^{(e)} \right]_{b \times n}$ is being constructed for each expert where elements of matrix $N^{(e)}$ ($\eta_{ij}^{(e)}$) represent SVN numbers from a predefined neutrosophic linguistic scale. Final aggregated decision matrix N is obtained by centering matrix elements $\eta_{ij}^{(e)} = \langle T_{\eta ij}^{(e)}, I_{\eta ij}^{(e)}, F_{\eta ij}^{(e)} \rangle$ of matrix $N^{(e)}$. That is how we obtain matrix $N = \left[\eta_{ij} \right]_{b \times n}$, where elements $\eta_{ij} = \langle T_{\eta ij}, I_{\eta ij}, F_{\eta ij} \rangle$ are obtained by applying the SWNSWAA operator, the expression (10)

$$\eta_{ij} = SVNSWAA(\eta_{ij}^{(1)}, \eta_{ij}^{(2)}, .., \eta_{ij}^{(m)}) = \sum_{b=1}^{m} \varpi_e \eta_{ij}^{(1)} = \\ = \left\langle 1 - \prod_{b=1}^{m} \left(1 - T_{\eta ij}^{(e)}\right)^{\varpi_e}, \prod_{b=1}^{m} \left(I_{\eta ij}^{(e)}\right)^{\varpi_e}, \prod_{b=1}^{m} \left(F_{\eta ij}^{(e)}\right)^{\varpi_e} \right\rangle \tag{10}$$

where ϖ_e is weighting coefficient, $0 \le \varpi_e \le 1,\ (e = 1, 2, ..., m)$, $\sum_{e=1}^{m} \varpi_e = 1$.

Step 8: Calculation of the elements of the difficult matrix (D). The elements of difficult matrix $D = \left[d_{ij}\right]_{b \times n} = \left[\left\langle T_{dij}, I_{dij}, F_{dij} \right\rangle\right]_{b \times n}$ are obtained by applying the expression (11)

$$d_{ij} = \left\langle T_{dij}, I_{dij}, F_{dij} \right\rangle = w_j \cdot \eta_{ij} = \left\langle 1 - \left(1 - T_{\eta ij}\right)^{w_j}, I_{\eta ij}{}^{w_j}, F_{\eta ij}{}^{w_j} \right\rangle \tag{11}$$

Step 9: Ranking alternatives. On the basis of the value of criterion functions Q_i ($i = 1, 2, ..., b$) ranking of alternatives is carried out. The criteria functions are obtained by applying expression (12),

$$Q_i = \sum_{j=1}^{n} d_j, \ \ i = 1, 2, ..., b;\ j = 1, 2, ..., n. \tag{12}$$

4. NUMERICAL EXAMPLE

The SVNN-DEMATEL VKO model for selecting providers was tested on a hypothetical example of the selection of five providers of transport services. As a result of the use of the model, the weighting coefficients of the evaluation criteria were determined and the ranking of the transport providers was performed. Four experts in the field of transport participated in the testing of the model; they got weighting coefficients assigned by using the expression (2) E_1=0.2864, E_2=0.2741, E_3=0.2170 and E_4=0.1673. Experts evaluated the criteria using a linguistic scale: Very important – VI (0.90,0.10,0.10); Important – I (0.75,0.25,0.20); Medium – M (0.50,0.50,0.50); Unimportant – UI (0.35,0.75,0.80); Very unimportant – VU (0.10,0.90,0.90). Five criteria were used to evaluate the provider: C_1 – *Reliability*, C_2 – *Business excellence*, C_3 – *Total cost,* C_4 – *Customer service,* C_5 – *Green image*. Expert evaluations of the criteria are shown in Table 1.

Table 1 Expert analysis of the criteria

Criteria	C_1	C_2	C_3	C_4	C_5
C_1	0	VI;VI;VI;I	I;M;M;I	VI;VI;IVI	I;I;M;UI
C_2	I;M;M;I	0	M;M;VI;VI	M;M;M;M	VI;I;I;VI
C_3	M;M;M;M	M;M;I;I	0	M;I;M;M	VI;VI;VI;VI
C_4	I;I;IVI	M;M;M;M	M;M;M;M	0	M;M;M;M
C_5	M;VU;VU;UI	I;I;I;I	M;M;M;M	I;M;M;I	0

By summing up the elements of the total relation matrix (6) by rows, equation (7), and by columns, equation (8), the values of the total direct and indirect effects of criterion *j* on the other criteria and the other criteria on criterion *j* are obtained.

These values together with the threshold value (α) of the total relation matrix are used for defining the cause-and-effect relationship diagram. The cause and effect relationship (CER) diagram (Fig. 1) is formed to visualize the complicated causal relationship of criteria in a visible structural model.

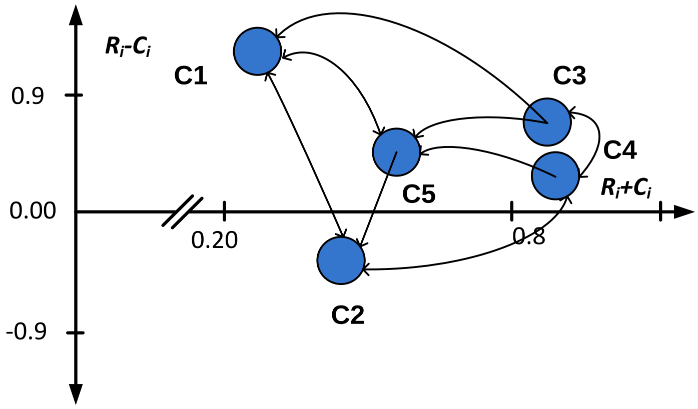

Figure 1 CERD diagram

The elements in matrix T with a value higher than the threshold value α will be identified and mapped on the diagram (Fig. 1) where the x-axis denotes (R_i+C_i), and y-axis denotes (R_i-C_i). These values will be used for demonstrating the relationship between two factors. In the course of the demonstration, the arrow denoting the cause-effect membership is directed from the element with a value lower than α towards the element characterized by a higher value than α.

Using the expression (9), we obtain the weight coefficients of the criteria: C_1 (0.828,0.156,0.145), C_2 (0.606,0.381,0.364), C_3 (0.873,0.129,0.147), C_4 (0.641,0.372,0.329) and C_5 (0.709,0.307,0.318).

Expert evaluation of providers by the criteria (Table 2) was carried out using a linguistic scale: Extremely good/high – EG/EH (1,0,0); Very very good/high – VVG/VVH (0.9,0.1,0.1); Very good/high – VG/VH (0.8,0.15,0.2); Good/high – G/H (0.7,0.25,0.3); Medium good/high – MG/MH (0.6,0.35,0.4); Medium /fair – M/F (0.5,0.5,0.5); Medium bad/low – MB/ML (0.4,0.65,0.6); Bad/low – B/L (0.3,0.75,0.7); Very bad/low – VB/VL (0.2,0.85,0.8).

Table 2 Expert evaluation of providers according to the evaluation criteria

Alternative/ criteria	C_1	C_2	C_3	C_4	C_5
A1	VG;MG;VG;G	G;G;MG;G	MG;MG;M;M	G;M;MG;M	M;MH;VH;M
A2	G;VG;MG;MG	VG;MG;M;MG	VG;G;VG;VG	VG;VG;M;G	VH;M;H;H
A3	M;GMG;M	M;VG;G;G	M;G;MG;MG	MG;MG;MG;MG	H;H;M;MH
A4	G;MG;G;MG	MG;M;VG;M	G;MG;G;MG	M;MB;MG;VG	M;M;MH;H
A5	G;G;MG;VG	G;G;MG;VG	MG;G;VG;G	MG;G;VG;G	H;VH;VH;VH

Applying expressions (10) - (12) we get the final rank of the provider: A1 (0.622,0.330,0.374)> A2 (0.571,0.384,0.425)> A3> (0.504,0.457,0.497)>A4 (0.499,0.457,0.497)> A5(0.344,0.643,0.637). The ranking of providers was based on the value of score functions of that time $S(A_i)$ [15].

5. CONCLUSION

In this paper, a new SVNN-DEMATEL multicriteria model of the selection of the transport service provider is presented. This model uses a new neutrosophic number based approach in dealing with uncertainties. Since unambiguous and precise determination of the relative importance of the criteria is not necessary, this model uses, in the process of evaluation, neutrophic linguistic expressions. Therefore, the areas of possible application of the model are numerous: from logistical problems, problems of industrial management, environmental management, education, and health to various other fields of expertise. Also, the model is open for upgrading and expanding by implementing the results of various techniques of group or expert thinking.

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OPTIMIZATION OF DANGEROUS GOODS TRANSPORT IN URBAN ZONE

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Abstract: *Due to the specificity of the transport of dangerous goods, as well as the obligations arising from the legislation regulating this field, all the actors of this process are obliged to take special measures in order to avoid undesired consequences. Special attention is paid to the planning of the transport of dangerous goods. One of the most important planning elements is choosing a route for the transport of dangerous goods in urban areas. In order to take preventive measures, risk assessment is carried out on the routes and the minimum risk route is defined. In this paper, a new model for selection of the routes for the transport of dangerous goods (hazmat) on the network of urban roads is proposed. The model is based on a multi-criteria risk analysis and the traditional Dijkstra algorithm (D-R model). The D-R model is a new approach for minimizing the cost and a variety of risk criteria in hazmat routing, which adequately takes into account and minimizes a number of risks on potential routes. The model is based on route selection based on the absolute risk size. The proposed routing model was tested in a real case and in a real urban hazmat routing problem, in Serbia.*

Key Words: *Multi-criteria Decision-making, Hazardous Materials Routing, Risk, Dijkstra's Algorithm.*

1 Introduction

In transport management, mitigation of the negative consequences of transport, especially those related to safety and environmental impact, is often emphasized. Due to the harmfulness and the extent of the possible consequences, managing the transport of dangerous goods, especially in urban areas, is an issue gaining more and more attention. One of the main problems in managing the transport of dangerous goods is the problem of route selection. The problem of dangerous goods routing is manifested in numerous variations. The formulation of the problem depends on

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whether the selected is one route (between two nodes in the network) or multiple ones (in general, among multiple destinations), whether the parameters of the network are of a static or dynamic character, whether they are stochastic or deterministic, whether choosing the route is from a local or global perspective, etc. A large number of factors are involved in the process of solving this problem, and, consequently, solutions require numerous compromises. The essence of the compromise is reflected in the set of criteria for route selection that are present in the decision-making model. Also, a major problem for decision-makers is the availability and reliability of the data that are needed for decision-making, as well as models of risk assessment in transport hazmat.

The main objective of this paper is to propose a model that can serve as a useful tool for decision-making in planning hazmat transport routes in urban areas. With the model proposal that deals with the problem of hazmat rutting in a comprehensive way, with respect to both cost aspects and various risk aspects, as well as numerous uncertainties in the decision-making process, it is shown that academic research models can be more practical and useful for real hazmat routes planning. The rest of the paper is organized as follows. In addition to the introduction and conclusion, the paper is structured through three more chapters. In second chapter, a review of the literature with an emphasis on the application of the rutting models used for the transport of dangerous goods is given, while the third unit is a description of the model used in this paper. In the third chapter the Dijkstra-Risk (D-R) routing model algorithm is presented in detail. The fourth chapter presents the implementation of the D-R routing model in the real case of transporting dangerous goods in the Ministry of Defense.

2 Literature review

A large number of international studies have shown that the risk originating from mobile sources (vehicles transporting dangerous goods) has the same significance as the risk originating from fixed sources - (Ormsby& Le, 1988; Brockoff, 1992; Vilchez et al., 1995; Bonvicini and Spadoni, 2005), so that it is necessary to reduce the size of the risk originating from mobile sources and keep it within the limits of acceptable values. A number of different methodologies have been developed in the literature for the selection of routes for the movement of vehicles transporting dangerous goods: from case studies that include risk analysis (Bubbico at al., 2000; Rao Madala, 2000; Milazzo et al., 2002; Scenna& Santa Cruz, 2005; Govan, 2005; Wang et al., 2015), through studies where the choice of route is based on the data obtained from statistical analysis and research of a number of incident situations (Fabiano et al., 2002; Anderson &Barkan, 2004; Hamouda, 2004; Ohtani& Kobayashi, 2005), to solving the choice of a route through algorithms for routing vehicles (Fu, 2001; Bonvicini et al., 2002; Akshay&Prozz, 2004; Zografos and Androutsopoulos, 2004; Bahar&Verter, 2004; Godoy, 2007; Zografos, 2008; Batarlienė, 2008; Wang et al., 2015; Androutsopoulos & Zografos, 2010;Pamučar et al., 2016). The methods that are very easy to use, that are understandable and with a high level of reliability of risk level determination have been developed by (Rao et al., 2004; Bubbico et al., 2004; Huang, 2005; Ghazinoory&Kheirkhah, 2008): also, there are methods that are adapted to support decision-making process and are intended for spatial planning (Spadoni et al., 2000; Lin, 2001; Gheorghe et al., 2005;Jovanović, 2009). In the last ten years, special attention has been devoted to developing methodologies for determining the level of risk of transporting dangerous goods in tunnels; these methodologies have been developed by (OECD, 2001; Saccomanno and Haastrup, 2002; Knoflacher, 2002; Van den Horn et al., 2006; Kohl et al., 2006).

From the above, it can be concluded that there are numerous methodologies developed with the aim of selecting a route for the movement of vehicles transporting dangerous goods from the aspect of risk management. The hybrid methodologies, which represent the application of a multi-criteria analysis in combination with the conventional routing models, in spite of their simplicity, have not been considered in the literature so far. This paper presents a new model named a D-R model for hazmat vehicle routing problem (HVRP) in urban zones based on the application of the Dijkstra algorithm and the multi-criteria minimization of risk. One of the advantages of this model comparing to the existing ones lies in its complex consideration of a number of parameters which affect the risk of dangerous goods transport in urban areas. In this sense, in addition to the carrier's operating costs, as criteria for the convenience of routes for the transport of dangerous goods on the network of urban roads, six parameters which define the level of risk are considered: Emergency response, Environmental risk, Risk of an accident, Consequences of an accident, Risk associated with infrastructure and Risks of terror attack / hijack. A risk (R) value is introduced as a convenience measure for the transport of dangerous goods.

By optimizing the routes for the transport of dangerous goods in urban areas with the help of the proposed model the safety of residents in urban areas is improved and the risk of accidents is reduced. In general, since in most models for solving the hazmat routing problem as criterion functions there are cost and / or risk functions that are related to randomness and uncertainty, here a soft computing approach is desirable, as it is desirable to use a more comprehensive set when selecting a route criteria. A comprehensive approach to the risk analysis when planning the route for the transport of dangerous goods adds a new value to the decision-making process and evaluates the problems associated with the urban hazmat routing.

The second advantage of this model is its processing of group knowledge in the process of selecting vehicle routes since this model was formed on the basis of an expert knowledge base which stems from the heuristic management experience. The third advantage is the adaptability of the model, which is reflected in the possibility of adjusting the model depending on the specificity of a concrete problem, thus achieving risk management in an uncertain environment.

3 D-R routing model

The D-R model is realized through two phases. In the first phase of the D-R model, a transport network is formed in the urban area and the input parameters (criteria) are identified, based on which the R values of the branch network are determined. Defining R values of the branch network is done using the term (1)

$$f_{\min} = \sum_{j=1}^{n} Y_j w_j \tag{1}$$

Where Y_j represents the value of the criterion for the observed network branch, w_j represents the weighting coefficient of the optimization criteria, while n represents the total number of optimization criteria.

The input parameters in expression (1) are presented through seven criteria that influence the definition of the R value of the transport network branch: The Carrier's Operating Costs, Emergency Response, Environment Risk, Risk of an Accident, The

Consequences of an Accident, Risk associated with Infrastructure and Risks of Terror attack / hijack. As the output from the I phase of the D-R model, R values are obtained for each specific link of the transport network.

After defining the R values on the network, in the second phase, using the Dijkstra algorithm, the routes for the transport of dangerous goods are defined. The criterion function minimized by means of the Dijkstra algorithm is the sum of the R values of the branch network that are on the routes. The routing model in urban zones is realized through the following steps:

Step 1 A network of roads is defined. Within the network of roads, network nodes containing the customers to which dangerous goods are delivered are defined.

Step 2 Input parameters of the adaptive neural network that influence the determination of R values on the branches of the transport network are identified. In the D-R model, seven parameters are set, representing the aggregated value of costs and risks during the transport of dangerous goods in urban areas.

Step 3 Input parameters are calculated (, j = 1, 2,…7), expression (1), for each branch of the transport network. This defines R values for all branches of the observed transport network.

Step 4 Using the Dijkstra algorithm, the routes for the transport of dangerous goods in urban areas are designed.

3.1 Criteria for minimizing risk in the D-R model

As stated in the previous chapter, seven criteria are identified on the basis of which R values are determined on the observed transport network (Table 1). The selection of criteria and their indicators was carried out on the basis of the recommendations of Pamučar et al., (2016) research and expert recommendations.

Table 1. Criteria for defining R values on the transport network of urban roads

No.	Criteria	Criterion description
C1	Costs of transport	Transport costs are proportional to the values of the variables: travel time, distance, fuel costs, etc. The value of the criterion is presented as the length of the branch expressed in kilometers (km).
C2	Emergency response in the event of an accident	Emergency response is the time for which city services (fire services and emergency services) react in the event of an accident. The average response time is taken as an input parameter, which is determined based on the distance of these services from the middle of the branch network. The value of this criterion is expressed in minutes (min).
C3	Environment Risk	It is determined based on the number of sensitive areas of the environment (water surfaces, green areas) located in the branch belt. The branch belt is defined as a critical area that can be contaminated in the event of an accident. The width of the branch belt depends on the type of dangerous goods and covers an area of 800 meters from the branch. The value of this criterion is determined on a scale of 1-10, where the value 1 represents a very small number of

No.	Criteria	Criterion description
		sensitive areas, and the value of 10 is a very large number of sensitive areas.
C4	Risk of traffic accidents	The risk of a traffic accident is defined based on the number of traffic accidents (*f1*) at the branch in the last 10 years, the number of traffic lanes (*f2*), the percentage of freight vehicles in the traffic flow (*f3*) and the signaling (*f4*). The total risk of an accident (*X*) is obtained using the expression X = 0.3 *f1* + 0.2 *f2* + 0.2 *f3* + 0.3 *f4*. The values of *f1, f2*, and *f3* are presented with quantitative indicators, while the quantification of indicators *f4* is done using the scale: 1 - traffic rules, 2 - traffic signal regulation, 3 –light signals regulation. The value of this criterion is determined on a scale of 1-10, where value 1 represents a very small risk of a traffic accident, and the value of 10 is a very high risk of a traffic accident.
C5	Implications for the population in the event of an accident	It is represented by the number of inhabitants (affected population) living in the belt of the branch. The belt of the branch is space of 800 meters from the branch. The value of this criterion is determined on a scale of 1-10, where value 1 represents a very small number of affected population, and the value of 10 is a very large number of affected population.
C6	Infrastructure and important facilities risk	Infrastructure and important facilities risk is the number of important infrastructure facilities in the branch belt (railways, electrical installations, industry, business and transport facilities, schools, hospitals, historic buildings, official buildings). The value of this criterion is determined on a scale of 1-10, where the value 1 represents a very small number of infrastructure objects, and the value of 10 a very large number of infrastructure objects.
C7	The risk of a terrorist attack	The risk of a terrorist attack is an assessment of the threat to the branch as a potential site of a terrorist attack, with the aim of endangering the population, significant infrastructure facilities and vulnerable areas of the environment. The risk is proportional to the significance of potential objectives in the branch belt. The value of this criterion is determined on a scale of 1-10, where value 1 represents a very small risk of a terrorist attack, and the value of 10 is a very high risk of a terrorist attack.

Weight coefficients (w_j). The weight criteria of these criteria are defined by interviewing experts. In the next section of the paper, a model for estimating the reliability of the results and its application in this study is presented. The significance of the criteria was determined using the 1-10 scale, where 1 is a little important and

10 is a very important criterion. The results of the survey of experts are shown in Table 2.

Table 2. Weight coefficients of the criteria

No.	Criterion	Middle value	Weight coefficient
1.	Costs of transport	6.2	0.109
2.	Emergency response in the event of an accident	8.7	0.153
3.	Environmental risk	9.1	0.160
4.	Risk of traffic accidents	9.2	0.162
5.	Implications for the population in the event of an accident	9.5	0.168
6.	Infrastructure and important facilities risk	8.1	0.143
7.	The risk of a terrorist attack	5.9	0.105

The final values of weight coefficients have been normalized using additive normalization. An example of the calculation of the final value of the weight coefficient for the criteria "Transport Costs" is shown in the following expression

$$w_1 = \frac{\bar{x}_1}{\sum_{j=1}^{7} \bar{x}_j} = \frac{6.2}{6.2+8.7+9.1+9.2+9.5+8.1+5.9} = 0.109$$

where $\bar{x}_1$ represents the mean value of the criteria *Transport Costs*, while the $\sum_{j=1}^{7} \bar{x}_j$ represents the sum of the median value of all the criteria obtained by interviewing the experts.

Similarly the weight criteria for the remaining criteria were obtained, Table 2.

3.2 Dijkstra algorithm

Dijkstra (1959) has developed one of the most efficient and most used algorithms for determining the shortest paths from one node to all other nodes in the network. This algorithm presents a special case of the exposed generic algorithm. In the Dijkstra's algorithm, a node i corresponding to the minimum value of the shortest known path is removed from the list of candidates V in each iteration.

Step 1 In the first step it is necessary to determine the initial node in the network. In the model presented in this paper, the initial node in the network is defined in advance and represents the location of the CLC. We begin the process from node L. Since G_p from node L to node L is equal to zero we assign the initial node with $G_{pL} = 0$. We give predecessor node L the symbol +, and so $q_L = +$ (where q_i is the node in front of node *i*, at the shortest distance from node L to node *i*).

Step 2 Since the paths from node L to all of the remaining nodes are for now undiscovered, we designate them temporarily as $G_{p,Li} = \infty$ for $i \neq L$. Since *i* precursor nodes to nodes $i \neq L$ are unknown on the shortest paths we designate them $q_i = -$ for all $i \neq L$. The only node currently in a closed state is node L. Therefore, we can say that $c = L$.

Step 3 In order to transform some of the temporary designations into actual ones, it is necessary to examine all of the branches (*c,i*) coming out of the last node that is in a closed state (node *c*). If node *i* is in a closed state, then examination of the next node begins. If node *j* is in an open state, we obtain its designation as an EUF vehicle on the basis of the relation

$$G_{p,cj} = \max\left\{G_{p,j},\ G_{p,ac} + G_p\left(c, j\right)\right\} \tag{2}$$

If node *j* is in an open state, we obtain its designation on the basis of the relation

$$G_{p,cj} = \min\left\{G_{p,j},\ G_{p,ac} + G_p\left(c, j\right)\right\} \tag{3}$$

Step 4 To determine which node is next to move from an open to a closed state, the size of all of the nodes in an open state is compared.

We choose the node with the lowest size value G_p. Let it be node *j*. Node *j* passes from an open to a closed state, since there is no value of G_p from *a* to *j* that is less than $G_{p,aj}$ (4). The link performance through any other node would be higher.

$$G_{p,aj} = \max\left\{G_{p,aj}\right\} \tag{4}$$

Step 5 Since the next node which passes from an open to a closed state is node *j* we determine the predecessor node for node *j*, on the shortest path which leads from node *a* to node *j*. The performances of the links of all of the branches (*i,j*) which lead from the nodes in a closed state to node *j* are tested until we determine that the relation is fulfilled (5)

$$G_{p,ai} = G_{p,aj} - G_p\left(i, j\right) \tag{5}$$

Let this relation be fulfilled for node *t*. This means that node *t*, the predecessor node to node *j,* is on the shortest path that leads from node *a* to node *j*. This means that we can say that $q_i = t$.

Step 6 If all the nodes in the network are in a closed state, then we have finished with the process of finding the optimal routes for vehicles. If there are still any nodes that are in an open state, then we go back to *Step 3*.

4 Testing of the D-R model for dangerous goods routing in urban zones

The model has been tested in the case of the transport of dangerous goods for the needs of the Ministry of Defense of the Republic of Serbia. The transport of dangerous goods was considered on the route: The Vasa Čarapić Barracks Warehouse – Knic warehouse of propulsion assets (Leskovac) and return to the Knic warehouse of propulsion assets (Leskovac) – The Vasa Čarapić Barracks. The transport of dangerous goods is carried out in both directions, which additionally complicates the set task. By looking at the road networks and determining possible road directions for the realization of the assigned task, it comes to the road network that is shown in Figure1.

Figure 1. Display of the road network for the realization of the task

Display of the road network for realization based on Figure1, important knots and branches related to the city zones of the cities of Kragujevac and Belgrade cannot be seen, so these zones need to be shown separately. Figure 2 shows the road network for the city of Kragujevac.

Figure 2. Display of the road network of the city of Kragujevac

The same thing has to be done for the city zone of Belgrade. The enlarged view is shown in Figure 3.

Figure 3. Display of road network of the city of Belgrade

For a simpler view of the transport network, a schematic representation of all nodes and branches of the road network shown in Figures 1, 2 and 3 is shown in Figure 4. The schema is not in ratio but only shows the transport network and the connection of the nodes on it. The transport network in Figure 4 was used to solve the Dijkstra algorithm.

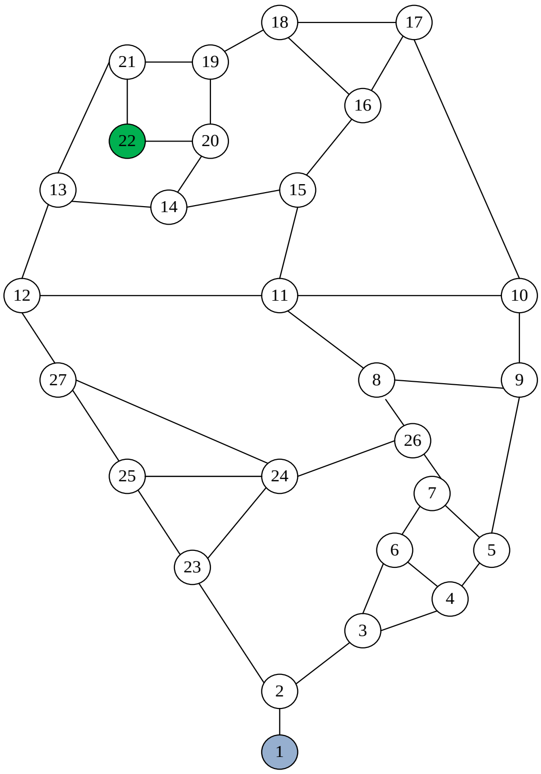

Figure 4. The network where it is necessary to determine the optimal route for the transport of dangerous goods

4.1 Evaluation of the transport network branch

Determination of the value of the branch was made on the basis of the criteria described in the previous chapter. For each branch, the values of the criteria are individually determined in the following way:

- Criterion K1 (transport costs) is determined on the basis of the length of the branch and is expressed in kilometers.

- The K2 criterion (emergency response in the event of an accident) was determined on the basis of the proximity of the branch from the emergency services and is expressed in minutes.

-The criterion K3 (environmental risk) was determined on the 1-9 scale in the following way: the values 1 and 2 were assigned to city zones in which there are few green areas, 3, 4, and 5 were assigned to urban and populated areas in which there are green areas, 6 and 7 were assigned to zones in which the branch of large length stretches along the agricultural land or next to a protected property, 8 and 9 were assigned to zones in which the branch passes by or across rivers and lakes, and often in combination with green areas and agricultural land.

- The K4 criterion (risk of a traffic accident) is determined on the basis of road characteristics that directly affect the safety of traffic and the possibility of a traffic accident. It was determined on the 1-9 scale in the following way: the values 1, 2, and 3 were assigned to freeways and roads without curves, the values 4, 5, and 6 were assigned to roads with multiple crossing points, traffic roundabouts, curves and intensive traffic, value 7, 8 and 9 were assigned to road directions with many curves, poor road transparency, high-intensity traffic and travel loops.

- The K5 criterion (consequences for the population in the case of an accident) is determined based on the number of inhabitants living near the branch. It is determined on the 1-9 scale in the following way: the values 1, 2, and 3 were assigned to branches that pass through uninhabited and poorly populated places, the values 4, 5, and 6 were assigned to the branches that pass through villages and suburban zones, values 7, 8 and 9 were assigned to branches that pass through urban settlements.

- Criterion K6 (infrastructure and important facilities risk) is determined based on the number of infrastructure and important facilities located near the branch. It was set on the 1-9 scale in the following way: the values 1, 2, and 3 were assigned to branches in the vicinity of not many important objects, the values 4, 5, and 6 were assigned to the branches in the vicinity of infrastructural objects of minor importance (smaller factories, ambulances), values 7, 8 and 9 were assigned to branches in the vicinity of large plants, factories, schools, hospitals, embassies, state facilities.

- The K7 criterion (the risk of a terrorist attack) is directly related to the number of infrastructure and important facilities. It was set on the 1-9 scale in the following way: the values 1, 2 and 3 were assigned to branches that go through smaller urban areas, the values 4, 5, and 6 were assigned to the branches in the vicinity of tourist sites, police stations, hospitals, schools, the values 7, 8 and 9 were assigned to branches in the vicinity of tourist sites, embassies, state buildings, factory plants, military facilities, institutions, etc.

The values of the criteria by branches are shown in Table 3.

Table 3. Displaying the value of the criteria by branch network

Branch	K1(km)	K2(min)	K3-(1-9)	K4-(1-9)	K5-(1-9)	K6-(1-9)	K7-(1-9)
(1,2)	10.90	12	2	5	3	1	2
(2,3)	13.70	9	3	3	6	6	4
(3,4)	4.30	5	5	6	9	8	8
(3,6)	3.90	5	6	7	9	8	8
(4,6)	1.50	3	5	6	9	9	8
(6,7)	1.20	5	5	4	8	6	5
(4,5)	1.10	8	7	3	7	6	4
(5,7)	2.00	10	4	3	6	5	3
(5,9)	102.00	18	2	2	2	2	2
(24,26)	27.00	17	4	5	6	4	4
(8,9)	9.50	15	4	5	5	3	2
(9,10)	22.40	10	3	3	5	4	3
(8,11)	35.80	14	4	7	6	4	4
(10,11)	3.80	10	3	3	3	3	2
(10,17)	10.90	10	4	5	8	6	6
(17,18)	5.70	8	6	6	9	9	9
(16,17)	1.70	8	5	7	8	8	8
(16,18)	1.20	7	6	6	9	9	8
(18,19)	0.28	6	6	6	9	9	8
(15,16)	2.30	10	7	4	9	6	6
(14,15)	0.55	6	5	5	9	5	5
(14,20)	0.29	3	3	4	8	8	8
(19,20)	0.60	2	4	4	7	9	9
(19,21)	0.45	5	5	4	9	9	9
(21,22)	0.60	5	5	4	9	9	9
(20,22)	0.45	4	4	4	7	9	9
(11,15)	7.20	10	4	5	7	5	5
(11,12)	7.10	14	5	7	7	6	6
(12,13)	3.00	14	5	8	9	6	5
(13,21)	1.60	8	6	9	9	8	8
(13,14)	2.20	9	4	7	9	7	6
(2,23)	36	20	9	9	7	7	9
(23,25)	38	20	9	8	7	6	4
(25,27)	31	20	9	9	6	5	5
(12,27)	45.3	19	7	8	9	6	4
(23,24)	28.1	20	9	9	6	5	3
(24,25)	21.5	20	8	7	9	6	4
(24,27)	47.9	20	9	9	6	5	3
(7,26)	36.6	20	7	5	7	6	4
(8,26)	31.8	20	9	7	6	4	5

By normalizing the values shown in Table 3 the values of the comparable non-dimensional size on the basis of which they are calculated are obtained, the expression (1), the final value of the branches, and the total value of the risk. The normalization of the value of the criterion was made using the percentage normalization, i.e. by dividing the values of the criteria with the highest value of the observed criterion. Table 4 shows the normalized values of the criteria and the value of each branch is determined using the expression (1), $f_{\min} = w_1Y_1 + w_2Y_2 + ... + w_7Y_7$; where $f_{\min}$ represents the final value of risk on the branch, $w_1, w_2...w_7$ represent the weight coefficients of the criteria, while Y_j represent the normalized values of the criteria for the observed network branch.

Table 4. Normalized branch network values

Branch mark	Criterions							
	K1 (0.109)	K2 (0.153)	K3 (0.160)	K4 (0.162)	K5 (0.168)	K6 (0.143)	K7 (0.105)	Σ
(1,2)	0.107	0.600	0.222	0.556	0.333	0.111	0.222	0.32
(2,3)	0.134	0.450	0.333	0.333	0.667	0.667	0.444	0.48
(3,4)	0.042	0.250	0.556	0.667	1.000	0.889	0.889	0.57
(3,6)	0.038	0.250	0.667	0.778	1.000	0.889	0.889	0.65
(4,6)	0.015	0.150	0.556	0.667	1.000	1.000	0.889	0.64
(6,7)	0.012	0.250	0.556	0.444	0.889	0.667	0.556	0.54
(4,5)	0.011	0.400	0.778	0.333	0.778	0.667	0.444	0.53
(5,7)	0.020	0.500	0.444	0.333	0.667	0.556	0.333	0.43
(5,9)	1.000	0.900	0.222	0.222	0.222	0.222	0.222	0.43
(24,26)	0.265	0.850	0.444	0.556	0.667	0.444	0.444	0.49
(8,9)	0.093	0.750	0.444	0.556	0.556	0.333	0.222	0.45
(9,10)	0.220	0.500	0.333	0.333	0.556	0.444	0.333	0.44
(8,11)	0.351	0.700	0.444	0.778	0.667	0.444	0.444	0.49
(10,11)	0.037	0.500	0.333	0.333	0.333	0.333	0.222	0.39
(10,17)	0.107	0.500	0.444	0.556	0.889	0.667	0.667	0.53
(17,18)	0.056	0.400	0.667	0.667	1.000	1.000	1.000	0.68
(16,17)	0.017	0.400	0.556	0.778	0.889	0.889	0.889	0.63
(16,18)	0.012	0.350	0.667	0.667	1.000	1.000	0.889	0.69
(18,19)	0.003	0.300	0.667	0.667	1.000	1.000	0.889	0.67
(15,16)	0.023	0.500	0.778	0.444	1.000	0.667	0.667	0.64
(14,15)	0.005	0.300	0.556	0.556	1.000	0.556	0.556	0.51
(14,20)	0.003	0.150	0.333	0.444	0.889	0.889	0.889	0.54
(19,20)	0.006	0.100	0.444	0.444	0.778	1.000	1.000	0.54
(19,21)	0.004	0.250	0.556	0.444	1.000	1.000	1.000	0.62
(21,22)	0.006	0.250	0.556	0.444	1.000	1.000	1.000	0.62
(20,22)	0.004	0.200	0.444	0.444	0.778	1.000	1.000	0.55
(11,15)	0.071	0.500	0.444	0.556	0.778	0.556	0.556	0.50
(11,12)	0.070	0.700	0.556	0.778	0.778	0.667	0.667	0.59
(12,13)	0.029	0.700	0.556	0.889	1.000	0.667	0.556	0.65
(13,21)	0.016	0.400	0.667	1.000	1.000	0.889	0.889	0.70
(13,14)	0.022	0.450	0.444	0.778	1.000	0.778	0.667	0.65

Branch mark	Criterions							
	K1 (0.109)	K2 (0.153)	K3 (0.160)	K4 (0.162)	K5 (0.168)	K6 (0.143)	K7 (0.105)	Σ
(2,23)	0.353	1.000	1.000	1.000	0.778	0.778	1.000	0.82
(23,25)	0.373	1.000	1.000	0.889	0.778	0.667	0.444	0.79
(25,27)	0.304	1.000	1.000	1.000	0.667	0.556	0.556	0.74
(12,27)	0.444	0.950	0.778	0.889	1.000	0.667	0.444	0.79
(23,24)	0.275	1.000	1.000	1.000	0.667	0.556	0.333	0.71
(24,25)	0.211	1.000	0.889	0.778	1.000	0.667	0.444	0.79
(24,27)	0.470	1.000	1.000	1.000	0.667	0.556	0.333	0.72
(7,26)	0.359	1.000	0.778	0.556	0.778	0.667	0.444	0.75
(8,26)	0.312	1.000	1.000	0.778	0.667	0.444	0.556	0.67

A schematic representation of the transport network with the previously calculated values is shown in Figure 5.

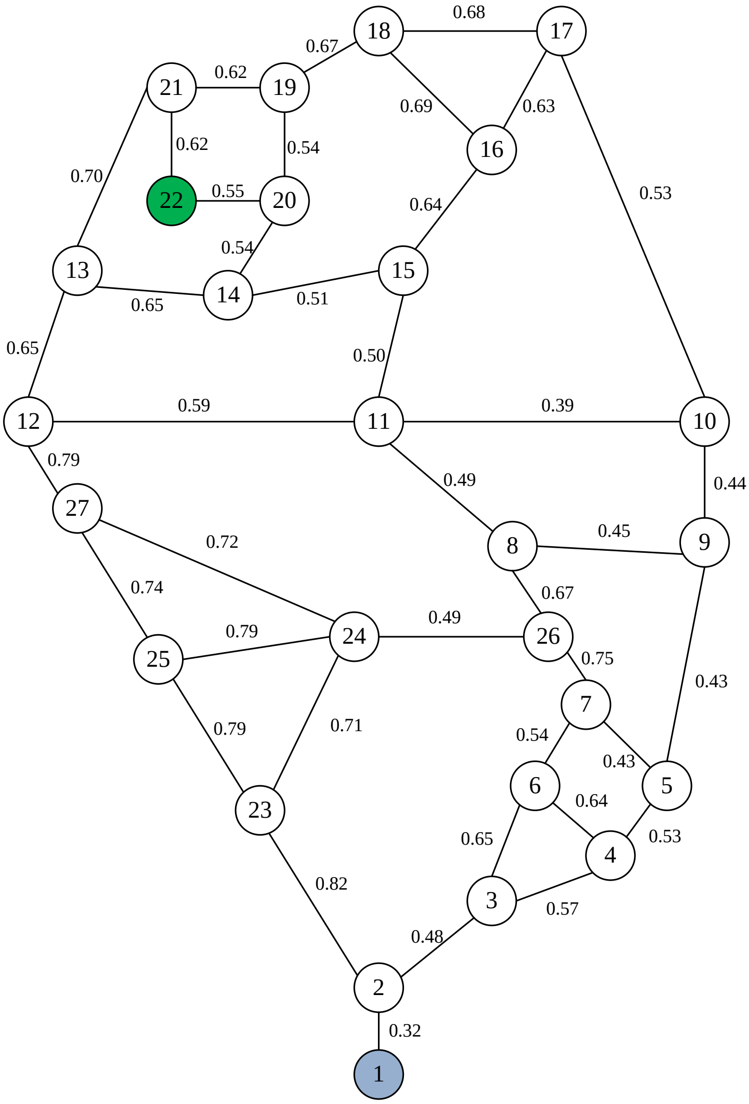

Figure 5. Display of transport network with branch values

4.2 Application of the Dijkstra's algorithm to calculating the optimal route

Using the Dijkstra algorithm described in section 3.4 of this paper the shortest paths from node 1 to all other nodes in the network are calculated. Since the values of the transport network branch are the risk calculated using the criteria determining the shortest paths from node 1 to all other nodes, an optimal route (the safest) for the transport of dangerous goods will be obtained.

On the given transport network, node 1 is the warehouse of propulsion assets of CLoB "Knic" (Leskovac), and node 22 is the barrack Vasa Čarapić. By determining the shortest route between these two nodes, an optimum route for the transport of dangerous goods is obtained.

The process of searching for the shortest paths starts from node 1. Since the length of the shortest path from node 1 to node 1 is equal to 0, that is $d_{1,1}=0$. The precursor to the starting node 1 is indicated by the + symbol, therefore $q_1=+$. The lengths of all the shortest paths from node 1 to all other nodes $i \neq 1$ for now are unexplored, and that is why it is for all other nodes $i \neq 1$ putted that $d_{1,i}=\propto$. Since the nodes are the precursors to the nodes $i \neq 1$ on the shortest paths it is putted $q_i=-$ for all $i \neq 1$. The only node that is currently closed is node 1. That's why it is $c=1$. In addition to the labels of the node 1 - the sign $(0,+)$ the sign‘ is placed to indicate that node 1 is in a closed state. This completes the first step of the algorithm.

In the second step of the algorithm, the lengths of all branches that come out of node 1 that is in a closed state are examined. It follows that: $d_{1,2}=\min\{\propto, 0+0{,}32\}$, i.e. $d_{1,2}=0{,}32$.

In the third step, since the branch (1, 2) is the only branch leaving node 1, this means that the next node that goes into the closed state is node 2. Since it is $d_{1,2}-d(1,2)=0{,}32-0{,}32=0=d_{1,1}$, it follows that in the fourth step, node 1 is precursor to node 2 on the shortest path, that is, $q_2=1$.

In the fifth step, it can be noticed that there are still nodes in the transport network that are in an open state, so the second step is repeated according to the algorithm.

The last node that is in a closed state is node 2, which means that $c=2$. By examining all branches that go from node 2 to nodes in the open state, it follows that:

$$d_{1,3}=\min\left\{\propto, d_{1,2}+d(2,3)\right\}=\min\left\{\propto, 0{,}32+0{,}48\right\}=\min\left\{\propto, 0{,}8\right\}=0{,}8$$

$$d_{1,23}=\min\left\{\propto, d_{12}+d(2,23)\right\}=\min\left\{\propto, 0{,}32+0{,}82\right\}=\min\left\{\propto, 1{,}14\right\}=1{,}14$$

Since it is $d_{1,3}<d_{1,23}$, this means that node 3 goes from an open to a closed state.

Also, since it is:

$$d_{1,3}-d(2,3)=0{,}8-0{,}48=0{,}32=d_{1,2},$$

this means that node 2 is the node-precursor of node 3, i.e. that $q_3=2$.

In the fifth step after the second pass through the algorithm, it is determined that there are still open nodes on the transport network and, therefore, the algorithm is repeated.

In the third pass through the algorithm follows:

$$d_{1,4}=\min\left\{\propto, d_{1,3}+d(3,4)\right\}=\min\left\{\propto, 0{,}8+0{,}57\right\}=\min\left\{\propto, 1{,}37\right\}=1{,}37$$

$$d_{1,6}=\min\left\{\propto, d_{1,3}+d(3,6)\right\}=\min\left\{\propto, 0{,}8+0{,}65\right\}=\min\left\{\propto, 1{,}45\right\}=1{,}45$$

$$d_{1,23}=1{,}14,$$

So it is $d_{1,23}=\min\left\{d_{1,23}, d_{1,4}, d_{1,6}\right\}=1{,}14$, and $d_{1,23}-d(2,23)=1{,}14-0{,}82=0{,}32=d_{1,2}$; then it follows that node 2 is the node precursor for node 23 in the shortest path, so it is $q_{1,2}=2$, which means that the next node that goes to the closed state is node 23. In the last 26th pass, we got the following results:

$$d_{1,20}=\min\left\{\propto, d_{1,14}+d(14,20)\right\}=\min\left\{\propto, 4{,}17+0{,}54\right\}=\min\left\{\propto, 4{,}71\right\}=4{,}71,$$

$$d_{1,21}=\min\left\{\propto, d_{1,13}+d(13,21)\right\}=\min\left\{\propto, 4{,}01+0{,}7\right\}=\min\left\{\propto, 4{,}71\right\}=4{,}71,$$

$$d_{1,22} = \min\{d_{1,21} + d(21,22), d_{1,20} + d(20,22)\} = \min\{4,71 + 0,62, 4,71 + 0,55\}$$
$$= \min\{5,33, 5,26\} = 5,26$$

So it is $d_{1,22} - d(20,22) = 5,26 - 0,55 = 4,71 = d_{1,20}$, and from this it follows that node 20 is the node-precursor of node 22 on the shortest path, so it is $q_{1,20} = 22$, which means that the next node that goes into the closed state is node 22. After 26 passes it can be determined that there are no open nodes on the network, which means that the algorithm is finished. The shortest paths are displayed in Figure 6.

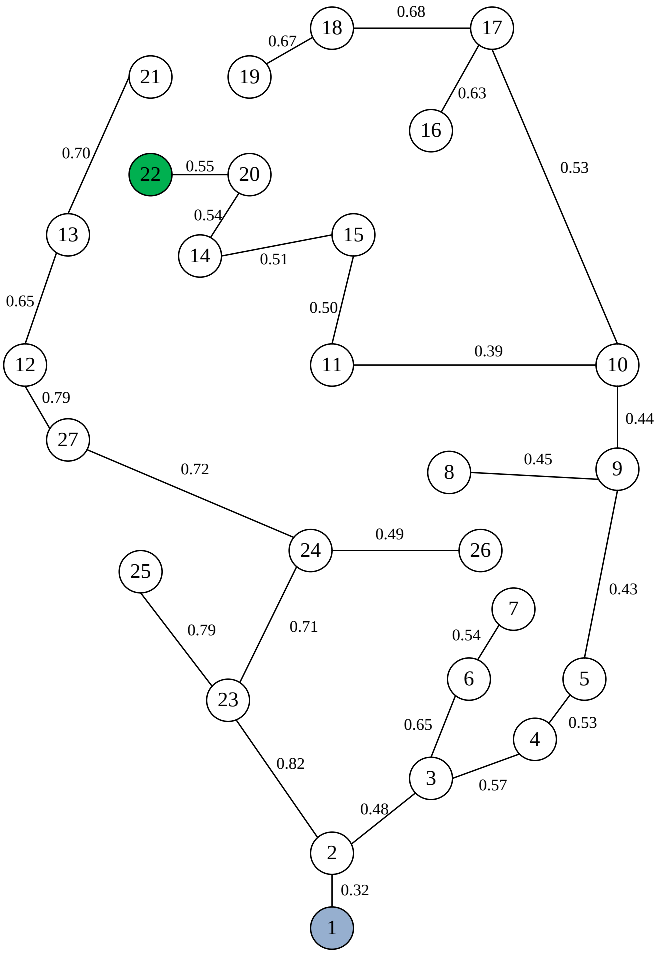

Figure 6. Display of the shortest paths from node 1 to all other nodes

The optimal route for the transport of dangerous goods is: 1-2-3-4-5-9-10-11-15-14-20-22. The total value of the risk on the optimal route is obtained using the following expression:

$$d_{1,22} = \min\{d_{1,21} + d(21,22), d_{1,20} + d(20,22)\} = \min\{4.71 + 0.62, 4.71 + 0.55\}$$
$$= \min\{5.33, 5.26\} = 5.26$$

4.3 Analysis of the obtained result

The D-R model sets the minimum risk values for transporting dangerous goods from node 1 to all other nodes. The optimal route for the transport of dangerous goods is: The barrack Vasa Čarapić - Bulevar JNA - Jajinaci – Bubanj Potok - E-75 – Batoččina - Kragujevac - Leskovac. In return, the same route was used. In the Ministry of Defense this task has been solved in a different way. The route for transporting dangerous goods in the rural areas is the same as the optimal route obtained in the operation. The difference between the routes is in the city zone of Belgrade. In the urban zone, the criteria that are either not considered in practice or are not given enough importance come to the fore. For these reasons, in practice, most often there are mistakes when choosing a route for the transport of dangerous goods.

The difference between the route obtained by the DR model and the route used in practice is best seen in the schematic representation, Figure 7. In Figure 7, the red color indicates the route in which the transport of dangerous goods is carried out in practice, while the blue color presents the optimal route for transport dangerous goods obtained by the DR model. The risk on the route used for the transport of dangerous goods in the Ministry of Defense is:

$$\begin{aligned} f_{\min} &= d(1,2)+d(2,3)+d(3,4)+d(4,5)+d(5,9)+d(9,10)+d(10,17) \\ &+d(17,18)+d(18,19)+d(19,21)+d(21,22)= \\ &=0.32+0.48+0.57+0.53+0.43+0.44+0.53+0.68+0.67 \\ &+0.62+0.62=5.89 \end{aligned}$$

While the risk in the D-R model is represented by the following term

$$\begin{aligned} f_{\min} &= d(1,2)+d(2,3)+d(3,4)+d(4,5)+d(5,9)+d(9,10)+d(10,11) \\ &+d(11,15)+d(15,14)+d(14,20)+d(20,22) \\ &=0.32+0.48+0.57+0.53+0.43+0.44+0.39+0.50 \\ &+0.51+0.54+0.55=5.26 \end{aligned}$$

It is evident that the risk of the route used in practice is higher than that of the route obtained by applying a routing model for $\Delta X = 100\left[1-\left(X_{Dijk}/X_{VS}\right)\right]=10.7\ \%$

This means that the solution obtained by the D-R model is significantly safer for the transport of dangerous goods than the one used in practice.

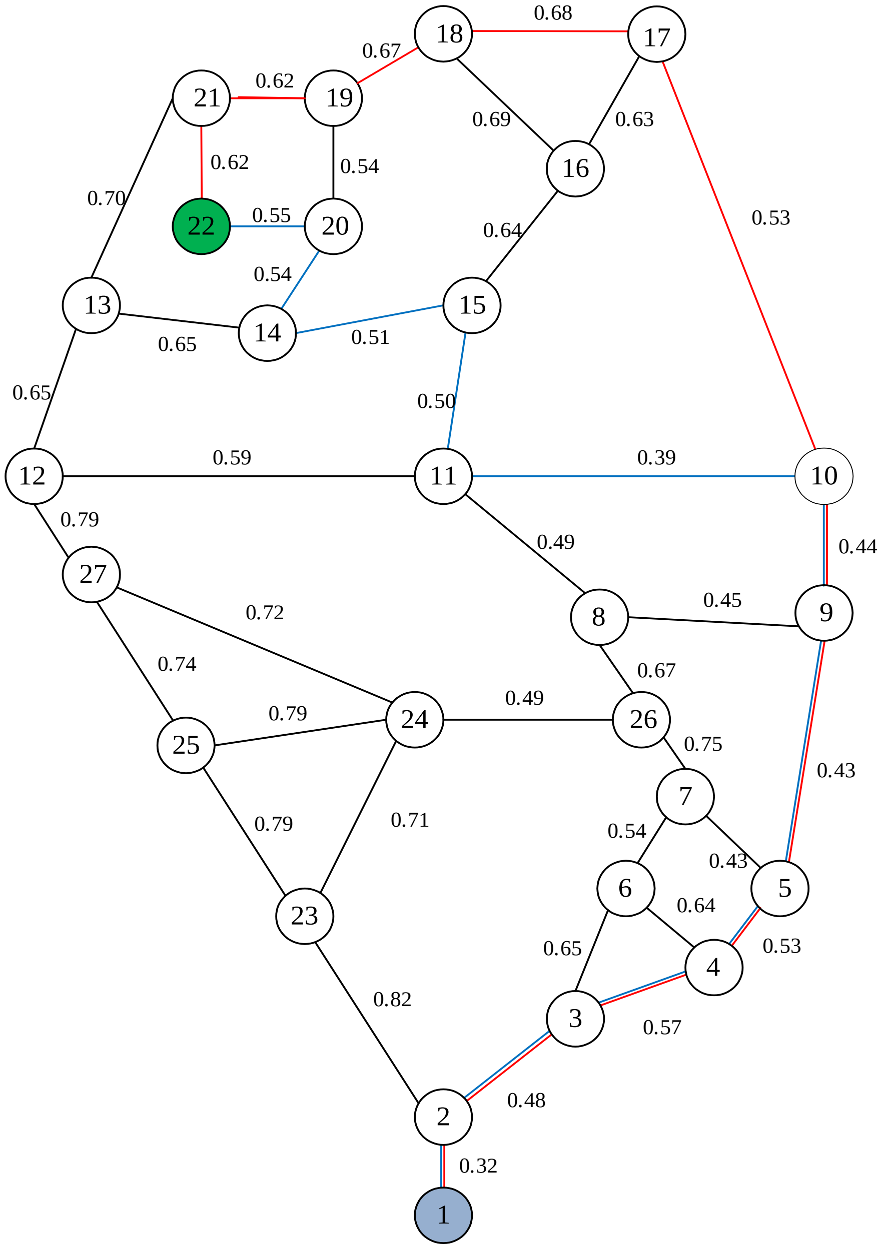

Figure 7. Comparing the used and the optimal transport routes

5 Conclusions

The paper presents a new approach to the application of the Dijkstra algorithm and the multi-criteria model in solving urban HVRP. The multi-criteria model was used to determine R values when transporting dangerous goods on urban roads. The authors' opinion is that this new approach to hazmat routing (D-R model) represents a qualitative move towards improving the methodology of routing dangerous goods in urban zones.

The proposed D-R model extends the theoretical framework of knowledge in the field of dangerous goods routing. The problem of routing dangerous goods is considered by the new methodology and thus forms the basis for further theoretical and practical upgrading. Also, the presented model highlights the multiple aspects of the risk assessment on the network of roads that have not been unified in the models so far, and they are important for this issue. By introducing and combining those with the criterion of operational transport costs, what is stressed is the need for a more versatile approach in further analysis of hazmat vehicle routing and similar problems.

The proposed D-R model has three main advantages over other methods. Firstly, it can reflect a variety of decision-making criteria in times of need. The system has the ability of adaptability, which is reflected in the ability to adjust the weight of the criteria depending on the problem under consideration. Secondly, it can be implemented as a computer-based system and, therefore, it supports a dynamic decision-making process in hazmat routing. Thirdly, the proposed model allows for relatively fast and objective estimations of cost and risk factors in hazmat transport under the conditions of a changing environment.

The direction of future research should move towards the identification of additional parameters that influence the identification of risks on the network of urban roads and the implementation of additional decision criteria in the proposed model. In this sense, the methods of fuzzy linear and dynamic programming in combination with heuristic and metaheuristic methods find their place of application. One of the recommendations is the consideration of the strategy of scheduling vehicles that transport different quantities of dangerous goods to selected routes, using genetic algorithms, while defining the limits that are considered with fuzzy linear programming and visualizing the solutions obtained using the geographic information system.

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A COMPARATIVE EMPIRICAL STUDY OF ANALYTIC HIERARCHY PROCESS AND CONJOINT ANALYSIS: LITERATURE REVIEW

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Abstract: *This paper is based on the main difference between conceptual and theoretical frameworks as well as literature review of comparative studies of two multi-criteria decision making methods (MCDM): Analytic Hierarchy Process (AHP) and Conjoint analysis. The AHP method represents a formal framework for solving complex multiatributive decision making problems, as well as a systemic procedure for ranking multiple alternatives and/or for selecting the best from a set of available ones. Conjoint analysis is an experimental approach used for measuring individual's preferences regarding the attributes of a product or a service. It is based on a simple premise that individuals evaluate alternatives, with these alternatives being composed of a combination of attributes whose part-worth utilities are estimated by researchers. Bearing in mind the quality of desired results, it must be dependent on the problems and aspects of research: knowledge of the MCDM methods, level of complexity (number of criteria), order effects, level of consistency, chooses the appropriate method.*

Key words: *Analytic Hierarchy Process, Conjoint analysis, multi-criteria decision making (MCDM) methods, literature review.*

1. Introduction

Decision making refers to the process of selecting an alternative, from a set of available ones, which resolves a given problem. The following elements can be distinguished in the decision-making issue: goals to be achieved by making a decision, criteria that measure the achievement of the goals, weights of the criteria that reflect their importance and alternatives within which the most desirable is to be selected (Anderson et al., 2012). A goal is to understand as the state of the system that is to be reached by making a decision. Criteria are the attributes describing alternatives and usually in the given decision-making issue not all the criteria are

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equally important. Their relative importance stems from the preferences of a decision maker, respectively, a respondent.

Decision making has increasingly been present in scientific research projects around the world recently, as it has become clear that the success of companies largely depends on the decisions made. When we say that a manager makes quality decisions, this means that these decisions are well thought out, made at the right time, and the realization of such decisions is precisely planned, all in order to maximize the effects that the decisions need to achieve.

Generally, a decision maker is exposed to an environment that is extremely complex and dynamic, being burdened with his paradigms and a series of influences which he, sometimes knowingly and sometimes unconsciously, includes into the decision-making process. The situation changes when a decision maker disposes with enough information about the problem and when the events related to the problem are certain, which implies full knowledge of the event or knowledge of the probability of the occurrence of an event.

The methods used in decision making can be classified into the two basic groups:

1. Single-criterion optimization methods
2. Multi-criteria optimization methods

Multi-criteria decision making can be divided into (Figueira et al., 2005):

1. MADM (Multiple Attribute Decision Making), and
2. MODM (Multiple Objective Decision Making).

Basic difference between the multiple attribute and the multiple objective decision making is reflected in the fact that in the multiple attribute decision making the best action is selected from the final set of previously defined actions described by explicit attributes, while in the multiple objective decision making the final set of objectives is defined on the basis of which the action which will fulfill defined objectives is selected.

Primarily because of their similarity, but also because of the wide applicability in the last years, in this paper, two techniques of multi attribute valuation are selected: the AHP method and the Conjoint analysis.

The AHP method is designed for a subjective assessment of multiple alternatives compared to multiple criteria, organized into a hierarchical structure. At the upper level the criteria are assessed, and alternatives based on the criteria are evaluated at the lower level. A decision maker gives its subjective assessment separately for each level and sub-level. According to these estimates pair comparison matrices are formed, which are based exclusively on subjective assessments. The AHP is a technique used to rank more alternatives and/or to select the best one from a set of available ones. Ranking/selection is performed in relation to the overall goal which is described through multiple criteria.

Conjoint analysis is based on the assumption that complex decisions are made not based on a single attribute, but on several attributes and their levels CONsidered JOINTly, hence the term conjoint. The technique can establish the relative values of particular attributes and identify the trade-offs the customers are likely to make in choosing a product and service and the price they are willing to pay for it.

The paper is organized as follows: the sections 2 and 3 describe Conjoint analysis and the AHP method, basic concepts, goals and the methodology of performance. Conceptual comparison and overview of the applications of the selected methods will be described in chapters 4 and 5. Finally, the main conclusions are summarized in section 6.

2. Conjoint analysis

Conjoint analysis is a multivariate technique used specifically to understand how a respondent's preferences are developed (Hair et al., 1995). More precisely the technique is used to gain insights into how individuals evaluate the total worth of a profile by combining the separate amounts of utility for each attribute level.

There are three basic major phases for conducting a Conjoint study. The first phase involves determining relevant attributes and the levels of each attribute. Lists of attributes describing single alternatives are called profiles (real or hypothetical) being presented to respondents who are invited to express their preference by rating or ranking these profiles.

The second phase involves design data collection of measuring individual preference and estimating respondent's utility functions. To determine the relative importance of different attributes to respondents, a relationship between the attributes' utility and the rated responses must be specified. The most commonly used model is the linear additive model. This model assumes that the overall utility derived from any combination of attributes of a given good or service is obtained from the sum of the separate part-worths of the attributes. Thus, respondent *i*'s (i= 1,…, I) predicted conjoint utility for profile j (j = 1 ,…, J)can be specified as follows (Kuzmanović et al., 2013a):

$$U_{ij}=\sum_{k=1}^{K}\sum_{l=1}^{L_k}\beta_{ikl}x_{jkl}+\varepsilon_{ij} \tag{1}$$

where:

xjkl is a (0,1) variable that it equals 1 if profile j has attribute k at level l, otherwise it equals 0

βikl– respondent *i*'s utility with respect to level l (L_k – the number of levels of attribute k)of attribute k (K – the number of attributes)

ε_{ij} – stochastic error term.

The parameters *βikl* (also known as part-worth utilities) are estimated by a regression analysis. The value of beta coefficients can be used: to indicates the amount of any effect that an attribute has on overall utility of the profiles; for preference-based segmentation; to calculate the relative importance of each attribute (importance value). Importance values are calculated by taking the utility range for each attribute separately, and then dividing it by the sum of the utility ranges for all of the factors (2). The results are then averaged to include all of the respondents (Kuzmanović et al., 2013).

Error! Objects cannot be created from editing field codes. (2)

where FI_{ik} is the relative importance that ith respondent assigned to the factor k. The results are then averaged to include all the respondents:

$$FI_k=\sum_{i=1}^{I}FI_{ik}\Big/I,\quad k=1,\dots,K \tag{3}$$

If the market is characterized by heterogeneous customer preferences, it is possible to determine the importance of each attribute for each isolated market segment.

The last (third) phase involves market simulation to predict how buyers will choose among competing products and how their choices are expected to change as product features and/or price are varied.

3. The Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process – AHP is a multi-criteria decision making method that was developed by Saaty (1980). This method considers a given set of qualitative and/or quantitative criteria combines them through the decomposition of complex problems into a model that has the form of a hierarchy (goal, criteria, sub-criteria and alternatives). The main objective of AHP is ranking/selection of several alternatives made in relation to the set goal, as well as the choice of the best one from a set of available ones, in situations where decision-making involves a larger number of experts and criteria (Popovic et al., 2018).

The generalized method can be simply described as follows (Bhushan & Rai, 2007): Data are collected from decision makers in the pairwise comparison of alternatives on a qualitative scale. Decision makers can rate the comparison as equal, marginally strong, strong, very strong, and extremely strong. The pairwise comparisons of various criteria are organized into a square matrix. The diagonal elements of the matrix are 1. The criterion in the *i*-th row is better than criterion in the *j*-th column if the value of element (*i, j*) is more than 1; otherwise the criterion in the *j*-th column is better than that in the *i*-th row. The (*j, i*) element of the matrix is the reciprocal of the (*i, j*) element.

The principal eigenvalue and the corresponding normalized right eigenvector of the comparison matrix give the relative importance of the various criteria being compared. The elements of the normalised eigenvector are termed weights with respect to the criteria or sub-criteria and ratings with respect to the alternatives.

Therefore a comparisons made by AHP are subjective this method tolerates inconsistency through the amount of redundancy in the approach. If this consistency index (*CI*) fails to reach a required level then answers to comparisons may be re-examined (4) (Sener et al., 2010).

$$CI = (\lambda_{\max} - n) / (n-1) \tag{4}$$

where λ_{max} max is the maximum eigenvalue of the judgment matrix. AHP calculates a consistency ratio (*CR*) comparing the consistency index (*CI*) with a random matrix (*RI*). Saaty (1980) suggests the value of *CR* should be less than 0.1.

Finaly, the rating of each alternative is multiplied by the weights of the sub-criteria and aggregated to get local ratings with respect to each criterion. The local ratings are then multiplied by the weights of the criteria and aggregated to get global ratings.

It should be noted that AHP is a method that orders the priorities in a given situation, incorporating the element of subjectivity and intuition so that a final decision can be reached by experts for part-issues in a consistent way and gradually move up levels to deal with the given situation have clear idea of what it entails (Al-Harbi, 2001).

4. Conceptual comparison of AHP and Conjoint analysis

Both the Conjoint analysis and the AHP method can be used to measure preferences of respondents and determine relative importance of attributes (criteria), but having in mind the quality of the desired results, a more appropriate method should be selected based on the specific problem and the research conditions. Basic theoretical differences between the Traditional Conjoint analysis and the AHP method are provided in the Table 1.

Table 1. Conceptual comparison of AHP and Conjoint analysis (Mulye, 1998; Helm et al., 2004; Scholl et al., 2005; Kallas et al., 2011)

	Conjoint analysis	**AHP**
Pre-condition	Preferential independence of the attributes	Preferential independence of the attributes
Survey form	Decompositional	Compositional
Scale used	Ordinal or interval scale	Ratio scale
Utility model	Additive part-worth model	Weighted additive utility model
Applicability	Up to six attributes with two to four levels	Many attributes possible with up to seven to eight attribute-levels
Respondents	Market segment on basis of individual customers	Individual decision makers
Interview expense	Ranking, rating or paired comparisons	Paired comparisons
The basic aim of application	Measuring preferences	Decision making
Application range	Design problems	Selection problems and/or design problems
Results	Part-worths of all attribute-levels	Relative preferences of attribute-levels and attributes

Although both techniques were developed with a different aim, they can be used in the same study. Fundamental assumption on which both methods are based is the preferential independence of the attributes, i.e., one level of attributes (for example, a brand) has no influence on the characteristics of another level of attributes (for example, on color). Conjoint analysis can function also in some cases of mutual interaction of attributes, but at least basic preferential independence is required.

Considering the AHP evaluation task is based on direct paired comparisons of single attributes and attribute levels, it is possible to survey tasks consisting of many attributes and their levels. But, Conjoint analysis asks the respondents to evaluate complete profiles. Therefore, the number of profiles and the number of attributes and their levels are limited as cognitive resources of the respondents are restricted. The differences in the scales used to evaluate the criteria cause differences in the evaluation steps. Both the AHP method and the Conjoint analysis are based on comparative analysis, but in the Conjoint analysis other evaluation steps are also possible.

Both methods are applicable for studies which use ‘pen and paper’ method, however, in the case of application of the AHP method, it is recommended the use of commercial softwares (www.expertchoice.com) which, during the evaluation process itself, determine consistency level of the responses and require that the responses to the same questions are repeated in case of too large inconsistencies. The number of respondents is not limited, and the only difference is that the target group in the AHP method are the respondents representing individual decision makers (most often they are experts in a given field of research), and in the Conjoint analysis, these are arbitrarily chosen market segment.

There are several factors - such as the motivation of respondents, the scope of information that a questionnaire contains, the clarity of a questionnaire, the knowledge of the method - which can influence the results of empirical research using the AHP method and the Conjoint analysis. These factors determine practical applicability of the method; so for example, the questionnaires that are difficult to answer can reduce the validity of the results (Hartmann & Sattler, 2004). Likewise, the time needed to complete the questionnaire affects the results obtained. Longer questionnaires can exhaust the respondents, cause response distortion or provoke deviations in the study. Time is also a factor that affects total costs, as the total costs of conducting research increase by increasing the time required. The question arises as to what was the influence of the factors, such as the knowledge of the methods by the respondents, the complexity of the study (number of criteria) and the problem of research, to the result of the comparison of these methods.

5. Overview of the research projects based on the comparison of the AHP method and the Conjoint analysis

In the research projects based on the comparison of the Conjoint analysis and the AHP method are obtained contradictory conclusions regarding the conditions of application of these methods. Therefore, in order to compare them (during the application procedure), it is necessary to control all the factors that can favor one against the other method. Further in the paper, comparative overview of basic concepts of eight studies aimed at comparing the results of the Conjoint analysis and the AHP method (Table 2) will be presented.

Table 2. Overview of basic concepts of the research of comparison of the Conjoint analysis and the AHP

	Decision problem	**Number of attributes and attribute levels**	**Respondents**	**Complexity of the decision problem**
Tscheulin (1991)	Ship travels	5 attributes (4 with 3 and 1 with 4 levels)	No knowledge of the methods	Relatively complex
Mulye (1998) I study	Running shoes	4 attributes (2 with 3 and 2 with 4 levels)	Knowledge of the methods (students)	Relatively simple
Mulye (1998) II study	Rental accomodation	8 attributes (each consisting 3 levels)	Knowledge of the methods (students)	Relatively complex
Helm et al. (2004)	Universities	6 attributes (5 with 3 and 1 with 2 levels)	Knowledge of the methods (students)	Relatively complex
Helm et al. (2008)	Mountain bikes	4 attributes (po 3 levels)	Two groups– with/without	Relatively simple

	Decision problem	Number of attributes and attribute levels	Respondents	Complexity of the decision problem
			knowledge of the methods	
Ijzerman et al. (2008)	Treatment preferences in people with neurological disorders	7 attributes (2-4 levels)	No knowledge of the methods	Relatively complex
Kallas et al. (2011)	Rabbit meat in menus in Spain	4 attributes (each consisting 3 levels)	No knowledge of the methods	Relatively simple
Ijzerman et al. (2012)	Stroke rehabilitation	8 attributes (2-4 levels)	No knowledge of the methods	Relatively complex
Danner et al. (2017)	Age-Related Macular Degeneration	5 attributes (1 with 4, 2 with 3 and 2 with 2 levels)	No knowledge of the methods	Relatively complex

Danner et al., (2017) claim that common application of the AHP method and the Conjoint analysis is the broadest in the field of health care system. However, on the basis of comparative overview of fundamental concepts of the research carried out so far, as shown in the Table 3.6, it can be noted that the spectrum of the decision making issues is broad. According to the research issue, the studies conducted differ in complexity of the decision-making issue. Authors use four to eight attributes with two, three, four, or even five levels to describe their research issue. Taking into consideration the limitations of the application of the Conjoint analysis based on the number of attributes, certain decision-making issues can be characterized as relatively complex.

Although the study conducted by Kallas et al., (2011) did not have as the primary goal determining which method was better, the results obtained allowed them to see the advantages and disadvantages of each of the method. The AHP method proved to be easier in this study, while the Conjoint analysis allowed combining the obtained preferences with socio-demographic variables.

An important prerequisite for the quality of the obtained empirical results, stated by the authors in their papers, is the knowledge of the method (procedure) of the research by the respondents. In the Table 3 is provided an overview of the effects of comparison of the Conjoint analysis and the AHP based on the knowledge of the research methods and the complexity of the questionnaires found in the previous studies (Table 2).

As can be seen from the Table 3, the studies showed that different results were obtained if respondents knew the methods and understood the procedure: the Conjoint analysis appeared to be better when the respondents were not familiar with the research methodology, while the AHP should be opted for when respondents understand the steps of the method. Tscheulin (1991) suggests explaining some of the relevant methodological aspects of the AHP and the Conjoint analysis before the interview itself. This can be performed as a "pre-research" through several minor and simpler common decision-making issues.

Table 3. Influence of knowledge of methods and complexity of questionnaires on the results of research (Helm et al., 2008; Ijzerman et al., 2012)

		Complexity of the evaluation task	
		HIGH/MEDIUM	LOW
Knowledge in preference measurement	YES	AHP better (II study -Mulye, 1998; Helm et.al., 2004)	Similar results (I study - Mulye, 1998) Conjoint analysis slightly better (Helm et.al., 2008)
	NO	Conjoint analysis better (Tscheulin, 1991; Ijzerman et al. 2012)	Conjoint analysis remarkably better (Helm et.al., 2008)

Given the consistency level achieved with the Conjoint analysis and the AHP method in all studies, the lower levels are less preferred. If sensitivity and consistency level are observed, the obtained results disagree. Although Helm et al., (2004) found in the first study that the AHP was less sensitive compared to the Conjoint analysis, in the second study (Helm et al., 2008) they came to the opposite conclusion. The Conjoint analysis proved to be less sensitive to changes and required a lower minimum level of consistency than the AHP, hence a large number of insufficiently consistent respondents in the study. The explanation of this difference is not obvious, but it may again result from a change in the complexity of the decision-making issues, because the inconsistency in the Conjoint analysis has much more direct impact on the final result than the local inconsistency in the AHP, which only applies to one attribute.

Considering other factors that influence the result of the comparison, it can be said that the Conjoint analysis leads to better results when applied after the AHP (Mulye, 1998). Helm et al., (2004), in contrast to Mulye, obtains opposite results, which is probably the consequence of the complexity of the problem, in the first study, however, in the second study based on somewhat simpler issues, slightly better effects can be observed when the Conjoint analysis is applied after the AHP (Helm et al., 2008).

The conclusion of a former research summarize the four aspects may influence the quality of the results of Conjoint analysis and AHP as technique for measuring preferences:

- knowledge of the MCDM methods,
- level of complexity (number of criteria),
- order effects,
- level of consistency.

It can be said that Conjoint analysis is a better choice in relatively simple decision-making issues. In case of complex decision-making problems and/or respondents with prior knowledge of the method of research, the AHP seems to be more convenient method. Having in mind practical applicability, the AHP method has a potential advantage because it requires less time to complete the survey and achieve a higher level of satisfaction of the respondents (Helm et al., 2008; Ijzerman et al., 2012). Both methods require certain level of consistency in respondents' responses, with the Conjoint analysis being more resistant in simple, and the AHP in more complex issues. In any case, any "pre-research" performed before starting evaluation could have positive effects.

These findings could have an influence on future practice of measuring preferences, since more than 65% of all Conjoint analysis surveys include more than six attributes. Therefore, researchers need a new method that supports operating with multiple attributes. Many of the newly developed variants of the Conjoint analysis have failed in practice because there have been no commercial softwares to support them. Today, currently available Adaptive Conjoint analysis softwares are so far the most dominant commercial softwares that can compensate these deficiencies of the Traditional Conjoint analysis. Additionally, with the professional AHP-based softwares, more advanced options for measuring preferences appear in practice. Another advantage of the Conjoint analysis in relation to the AHP is that it offers the possibility of segmentation based on the results obtained, as well as the prediction of market share, which has not been taken into account by the authors of the previous studies.

6. Conclusions

The findings of this paper are significant on both a theoretical and an applied level. On a theoretical level, both methods can be applied in the measurement of the preferences of respondents and determining relative importance of attributes (criteria), but considering the quality of the required results, it is necessary based on the specific issue and the aspect of research (knowledge of the MCDM methods, level of complexity (number of criteria), order effects, level of consistency) to choose the adequate method. On the applied level, the results provide information to policy makers to help them make decisions more effectively. In fact, although these two methods were originally developed with different objectives, they can still be used independently in similar or the same research projects.

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