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A Novel Multicriteria Approach – Rough Step-Wise Weight Assessment Ratio Analysis Method (R-SWARA) and Its Application in Logistics

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Abstract: A decision-making process often requires knowledge of numerous parameters and their interaction in order to make valid decisions that will result in meeting the objectives set. Multi-criteria decision-making is an area that helps in decision-making processes considering a set of criteria and alternatives. A new MCDM approach has been developed in this paper with a view to better managing the uncertainties and the subjectivity of real decision problems. In the last few years, the integration of Rough numbers and multi-criteria decision-making methods has enjoyed a great popularity, so in this paper, the Rough Step-wise Weight Assessment Ratio Analysis (SWARA) approach has been developed. The developed approach has been verified throughout a sensitivity analysis, which involves the comparison of the obtained results with two other methods for determining the weight values, the Rough Best Worst method (BWM) and Rough Analytic Hierarchy Process (AHP). The correlation of obtained ranks using the Rough SWARA approach with the ranks of Rough BWM and Rough AHP is complete, i.e. the ranks are identical, which confirms the stability and credibility of the developed approach.

Keywords: Rough SWARA, Criteria, Weights of criteria, Multi-criteria Decision Making, Logistics.

1. Introduction

The theory of multi-criteria decision-making holds a special place in the field of science, as the everyday application of the methods from this field is inevitable. It contributes to solving real life problems, as well as solving very complicated and complex problems in the field of science. This area confirms its special position in science throughout the expansion it has experienced only in the last ten years. It is constantly striving to create a better and simpler tool that will help decision-makers. Taking into account only the period from 2010 to present, it is impossible not to notice the expansion and popularity that this area has been achieving. This is also evidenced by the following publications in which new methods have been developed: ARAS method [40] developed for the evaluation of microclimate in office rooms, MULTIMOORA [1] for project management, EDAS [18] for inventory classification, MABAC [20] for decision-making on the choice of forklifts at a logistics center. All the above methods are used to rank alternatives, except for the EDAS method that, in its steps, has a proposed way for determining the weight values of criteria. The inviolability of the AHP method for determining the weight values of criteria had not been questioned until the SWARA method was developed in [16]. However, there is a notable lack of methods for calculating the weights of criteria compared to methods for ranking alternatives. Therefore, the BWM [27] was developed, which also found its application in different areas.

The main goal and contribution of this paper is the development of a novel Rough SWARA approach for defining relative weight values of the criteria. The integration of Rough numbers and SWARA methods reduces the uncertainty and subjectivity of decision-makers. Its improvement contributes to the entire area of multi-criteria decision-making, especially in the area of calculating the weight values of criteria. The developed approach is characterized by a small number of steps, easy data collection and simplicity in access creation.

In addition to the introductory considerations, there are five more sections. In the second section, a brief overview of the literature related to the application of the SWARA method and of the development of new approaches in the integration

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with Rough numbers is given. The third section describe used methods and consists of three parts. The first part presents the basic information and operations of rough set theory. Afterwards, the steps of the crisp SWARA method are presented, followed by a Novel Rough SWARA approach in the last part of the third section, with its all seven steps shown in detail. The fourth section contains an illustrative example of evaluating the criteria for the selection of wagons in a logistics company. The fifth section includes a sensitivity analysis in which the developed approach is compared to the Rough BWM and Rough AHP methods. The sixth section includes the conclusion which explaines advantages of the developed approach and the guidelines for future research.

2. Literature review

Based on [7] and [8], the SWARA method is suitable for a high level of decision-making and also instead of policy-making. Its convenience in a decision-making process is reflected throughout 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 in the possibility to evaluate the opinions of experts on the significance of criteria in a process of determining their weights. Over the last few past years, this method has been used in a number of publications to determine the weight values of criteria. The SWARA was used to assess the relation between the floods and influencing parameters in [11], while the ANFIS model was applied for flood spatial modelling and zonation, and it was used for the R&D project evaluation in [9]. Using the SWARA method in [10], it was concluded that subject competency is the main criteria in IT personnel selection. In [17], it is used to determine the significance of criteria in a process of evaluating construction equipment in sustainable conditions, while Ruzgys et al. (2014) in [29] applied it to the evaluation of external wall insulation in residential buildings. It was successfully applied to risk assessment [38], for selection of a basic shape of single-family residential house's plan [14], while Karabašević et al. (2017) in [15] used adapted SWARA with Delphi method for selection of personnel.

The combination of SWARA and WASPAS was used for solar power plant site selection in [37], as well as in [4] where the combination of these two methods was applied to the nanotechnology industry. This combination was also integrated in [36] where it was used for the selection of personnel in tourism. The integration of SWARA, Fuzzy Kano Model and ROV methods was proposed in [13] to solve the supplier selection. The Fuzzy SWARA was used to determine the significance of criteria, and Fuzzy COPRAS for rank and to select the sustainable 3PRLPs in the presence risk factors. The suggested model was applied to a case study from automotive industry [39]. The combination of Fuzzy SWARA and Fuzzy MOORA was used for sustainable third-party reverse logistic provider selection in plastic industry [19]. Authors in [26] used SWARA method for prospecting copper in the Anarak region, central Iran, while authors in [12] used for sustenance of zero-loss on production lines from a cement plant.

The popularization of rough sets has been evident lately and increasingly used to make decisions in different areas. In their paper [31], Song et al. (2014) used a rough TOPSIS approach for failure mode and effects analysis in uncertain environments. The integration of rough AHP and MABAC [6,24] were proposed in [28] for selection of medical tourism sites, while the integration of interval rough AHP and GIS was proposed for flood hazard mapping [5]. The Rough AHP and rough TOPSIS approach were also used in [30]. The application of rough numbers together with MCDM methods, according to Stević et al. (2017) [34], provides good results, and, as such, popularization of rough numbers has recently been noticed [2,3,21,32,35]. In addition to the AHP method and its rough form, it is also possible to apply the Rough BWM (Best Worst Method). Until now, the Rough BWM has been applied in several publications. The Rough BWM model in [22] was used to determine weight coefficients of the criteria for location selection for wind farms, while in [33] it was applied to determine the significance of the criteria for the selection of wagons for a logistics company. The interval Rough fuzzy BWM was applied in [23], in a study of the optimal selection of fire fighting helicopters.

3. Methods

3.1 The Rough set theory

In the rough set theory, any vague idea can be represented as a couple of exact concepts based on the lower and upper approximations. This is shown in Figure 1. Detailed explanation of the rough set theory can be find in [25].

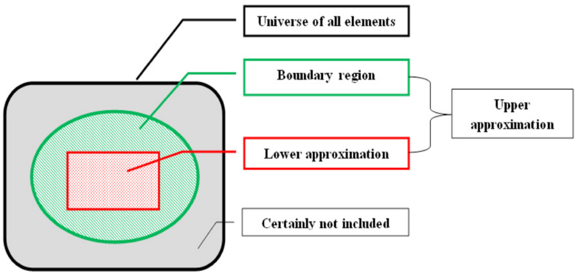


Figure 1. Elementary concept of rough set theory

Suppose U is the universe which contains all the objects, Y is an arbitrary object of U, R is a set of t classes $\{G_1, G_2, ..., G_t\}$ that cover all the objects in U, $R = \{G_1, G_2, ..., G_t\}$. If these classes are ordered as $G_1 < G_2 < ... < G_t\}$, then $\forall Y \in U, G_q \in R, 1 \le q \le t$, by R (Y) meaning the class to which the object belongs. The lower approximation $(\underline{Apr}(G_q))$, upper approximation $(\overline{Apr}(G_q))$ and boundary region $(Bnd(G_q))$ of class G_q are defined as:

$$\underline{Apr}(G_q) = \{Y \in U / R(Y) \le G_q\}, \tag{1}$$

$$\overline{Apr}(G_q) = \{Y \in U / R(Y) \ge G_q\}, \tag{2}$$

$$\begin{gathered} Bnd(G_q) = \{Y \in U / R(Y) \ne G_q\} = \\ \{Y \in U / R(Y) > G_q\} \cup \{Y \in U / R(Y) < G_q\}, \end{gathered} \tag{3}$$

Then G_q can be shown as a rough number $(RN(G_q))$, which is determined by its corresponding lower limit $(\underline{Lim}(G_q))$ and upper limit $(\overline{Lim}(G_q))$ where:

$$\underline{Lim}(G_q) = \frac{1}{M_L} \sum_{Y \in \underline{Apr}(G_q)} R(Y), \tag{4}$$

$$\overline{Lim}(G_q) = \frac{1}{M_U} \sum_{Y \in \overline{Apr}(G_q)} R(Y), \tag{5}$$

$$RN(G_q) = \left[\underline{Lim}(G_q), \overline{Lim}(G_q)\right], \tag{6}$$

where M_L, M_U are the numbers of objects contained in $\underline{Apr}(G_q)$ and $\overline{Apr}(G_q)$, respectively.

The difference between them is expressed as a rough boundary interval $(IRBnd(G_q))$:

$$IRBnd(G_q) = \overline{Lim}(G_q) - \underline{Lim}(G_q), \tag{7}$$

The operations for two rough numbers

$RN(\alpha) = \left[\underline{Lim}(\alpha), \overline{Lim}(\alpha)\right]$ and $RN(\beta) = \left[\underline{Lim}(\beta), \overline{Lim}(\beta)\right]$, are:

Addition (+) of two rough numbers $RN(\alpha)$ and $RN(\beta)$:

$$RN(\alpha) + RN(\beta) = \begin{bmatrix} \underline{Lim}(\alpha) + \underline{Lim}(\beta), \\ \overline{Lim}(\alpha) + \overline{Lim}(\beta) \end{bmatrix}, \tag{8}$$

Subtraction (-) of two rough numbers $RN(\alpha)$ and $RN(\beta)$:

$$RN(\alpha) - RN(\beta) = \begin{bmatrix} \underline{Lim}(\alpha) - \overline{Lim}(\beta), \\ \overline{Lim}(\alpha) - \underline{Lim}(\beta) \end{bmatrix}, \tag{9}$$

Multiplication (×) of two rough numbers $RN(\alpha)$ and $RN(\beta)$:

$$RN(\alpha) \times RN(\beta) = \begin{bmatrix} \underline{Lim}(\alpha) \times \underline{Lim}(\beta), \\ \overline{Lim}(\alpha) \times \overline{Lim}(\beta) \end{bmatrix}, \tag{10}$$

Division (/) of two rough numbers $RN(\alpha)$ and $RN(\beta)$:

$$RN(\alpha) / RN(\beta) = \begin{bmatrix} \underline{Lim}(\alpha) / \overline{Lim}(\beta), \\ \overline{Lim}(\alpha) / \underline{Lim}(\beta) \end{bmatrix}, \tag{11}$$

Scalar multiplication of rough number $RN(\alpha)$, where μ is a nonzero constant:

$$\mu \times RN(\alpha) = \left[\mu \times \underline{Lim}(\alpha), \mu \times \overline{Lim}(\alpha)\right]. \tag{12}$$

3.2 The 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) [16] and, according to them, 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 the 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, experts perform the ranking of 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 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 in the following way. It is determined how much the criterion c_j is more important than the criterion c_{j+1}.

Step 3: Calculate the coefficient k_j as follows:

$$k_j = \begin{cases} 1 & j = 1 \\ s_{j+1} & j > 1 \end{cases} \quad (13)$$

Step 4: Determine the recalculated weight q_j as follows:

$$q_j = \begin{cases} 1 & j = 1 \\ \dfrac{q_{j-1}}{k_j} & j > 1 \end{cases} \quad (14)$$

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

$$w_j = \frac{q_j}{\sum_{k=1}^{m} q_k} \quad (15)$$

where w_j represents the relative weight value of criteria.

3.3 A novel Rough SWARA method

The popularization of rough numbers, as it has already been emphasized, has been noticed lately and there are a large number of publications that address the problems by applying integrated models which involve the application of multi-criteria decision-making methods and rough sets. In this paper, a new Rough SWARA approach has been developed, precisely based on the above-mentioned integration. The aim of this paper is to take advantages of rough numbers (reduction of subjectivity, uncertainty, etc.) and the advantages of SWARA method (small number of comparisons of criteria among themselves), and, in some way, clearer determination of weight values compared to other methods.

The Rough SWARA method consists of the following steps:

Step 1: Define a set of criteria that participate in a decision-making process.

Step 2: Form a team of k experts who will assess the significance of criteria. First, it is necessary to rank the criteria according to their importance, from the most significant to the least significant. Subsequently, sj - is determined in such a way, starting from the second criterion, to determine significances of how much the criterion c_1 is more important than the criteria c_{1-n}.

Step 3: Converting individual responses of experts into a group rough matrix c_j. Each individual response of the experts $k_1, k_2, \ldots, k_n$ should be converted into a rough group matrix using the equations (1) - (6):

$$RN(C_j) = \left[c_j^L, c_j^U\right]_{1\times m} \quad (16)$$

Step 4: Normalization of the matrix $RN(C_j)$ in order to obtain the matrix $RN(S_j)$ (17):

$$RN(S_j) = \left[s_j^L, s_j^U\right]_{1\times m} \quad (17)$$

The elements of matrix $RN(S_j)$ are obtained by applying the equation (18):

$$RN\left(S_j\right) = \frac{\left[c_j^L, c_j^U\right]}{\max_r \left[c_r^L, c_r^U\right]} \quad (18)$$

The first element of matrix $RN(S_j)$, i.e. $\left[s_j^L, s_j^U\right]$ $=\left[1.00, 1.00\right]$, because $j = 1$. For other elements $j > 1$, the equation (18) can be calculated using the equation (19):

$$RN\left(S_j\right) = \left[\frac{c_j^L}{\max\left(c_r^L\right)}; \frac{c_j^U}{\max\left(c_r^U\right)}\right]_{1\times m} \quad j = 2,3,\ldots,m \quad (19)$$

Step 5: Calculate the matrix $RN(K_j)$ (20):

$$RN(K_j) = \left[k_j^L, k_j^U\right]_{1\times m} \tag{20}$$

by applying the equation (21):

$$RN\left(K_j\right) = \left[s_j^L + 1, s_j^U + 1\right]_{1\times m} \; j = 2,3,...,m \tag{21}$$

Step 6: Determine the matrix of recalculated weights $RN(Q_j)$ (22):

$$RN(Q_j) = \left[q_j^L, q_j^U\right]_{1\times m} \tag{22}$$

The elements of matrix $RN(Q_j)$ are obtained by applying the equation (23):

$$RN(Q_j)\left[q_j^L = \begin{cases} 1.00 & j=1 \\ \dfrac{q_{j-1}^L}{k_j^U} & j>1 \end{cases}, q_j^U = \begin{cases} 1.00 & j=1 \\ \dfrac{q_{j-1}^U}{k_j^L} & j>1 \end{cases} \right] \tag{23}$$

Step 7: The calculation of the matrix of relative weight values $RN(W_j)$ (24):

$$RN(W_j) = \left[w_j^L, w_j^U\right]_{1\times m} \tag{24}$$

Individual weight values of criteria are obtained by applying the equation (25):

$$\left[w_j^L, w_j^U\right] = \left[\frac{\left[q_j^L, q_j^U\right]}{\sum_{j=1}^{m}\left[q_j^L, q_j^U\right]} \right] \tag{25}$$

4. Illustrative example

The verification of the proposed novel Rough SWARA approach was carried out by determining the significance of the criteria for selection of railway wagons for the needs of internal transport. The model in [33] was based on eight criteria in total: the price of the wagon, the maintenance conditions, the exploitation time, the load capacity, the manipulative convenience, the time of last revision, the state of the bandages and the flanges of the wheels and ecological factor. Seven experts took part in the assessment of criteria. The data represent the first two steps of the Rough SWARA approach. In the third step, it is necessary to convert the individual responses of the experts into the group rough matrix c_j. The assessment performed by the experts is shown in Table 1.

Table 1. Assessment of criteria by seven experts

Crit./ Ex.	E_1	E_2	E_3	E_4	E_5	E_6	E_7
C_4	1	1	1	1	1	1	1
C_2	2	3	3	2	2	3	3
C_1	2	2	2	2	2	2	3
C_5	5	4	5	5	4	4	5
C_3	6	5	6	5	5	6	5
C_6	6	7	6	7	7	6	6
C_7	7	8	8	8	7	8	7
C_8	8	9	9	9	8	9	8

Using the equations (1) - (6), a group rough matrix c_j is obtained as follows:

$$\tilde{c}_3 = \{6,5,6,5,5,6,5\}$$

$$\underline{Lim}(5) = 5, \overline{Lim}(5) = \frac{1}{7}(6+5+6+5+5+6+5) = 5.428$$

$$\underline{Lim}(6) = \frac{1}{7}(6+5+6+5+5+6+5) = 5.43, \overline{Lim}(6) = 6$$

$$RN(c_3^1) = RN(c_3^3) = RN(c_3^6) = [5.428, 6]; RN(c_3^2) = RN(c_3^4) = RN(c_3^5) = RN(c_3^7) = [5, 5.428]$$

$$c_3^L = \frac{c_3^1 + c_3^2 + c_3^3 + c_3^4 + c_3^5 + c_3^6}{n} = \frac{5.428+5+5.428+5+5+5.428+5}{7} = 5.17$$

$$c_3^U = \frac{c_3^1 + c_3^2 + c_3^3 + c_3^4 + c_3^5 + c_3^6}{n} = \frac{6+5.428+6+5.428+5.428+6+5.428}{7} = 5.59$$

The complete matrix c_j obtained on the basis of previous calculations is:

$$RN(c_4) = [1.00,\ 1.00],$$
$$RN(c_2) = [2.30,\ 2.79],$$
$$RN(c_1) = [2.02,\ 2.28],$$
$$RN(c_5) = [4.29,\ 4.76],$$
$$RN(c_3) = [5.17,\ 5.59],$$
$$RN(c_6) = [6.17,\ 6.60],$$
$$RN(c_7) = [7.30,\ 7.75],$$
$$RN(c_8) = [8.30,\ 8.75].$$

In the fourth step, it is necessary to normalize the previous matrix by applying the equations (17) - (19) in the following way.

The worst ranked criterion has the maximum value, which is the eighth criterion in this case. It has been said that the first element $RN(S_j)$ is equal to one, while the other elements of the same matrix are obtained by dividing them with the maximum values, in this case, with the values of c_8 criterion.

$$RN(s_2)=\left[\frac{c_2^L}{c_8^U},\frac{c_2^U}{c_8^L}\right]=\left[\frac{2.30}{8.75},\frac{2.79}{8.30}\right]=\left[0.262,0.337\right]$$

$$RN(s_3)=\left[\frac{c_3^L}{c_8^U},\frac{c_3^U}{c_8^L}\right]=\left[\frac{5.17}{8.75},\frac{5.59}{8.30}\right]=\left[0.590,0.674\right]$$

In the same way, it is necessary to calculate the other elements in order to obtain the matrix:

$$\begin{aligned}
RN(s_4)&=[1.000,\ 1.000],\\
RN(s_2)&=[0.262,\ 0.337],\\
RN(s_1)&=[0.231,\ 0.274],\\
RN(s_5)&=[0.491,\ 0.574],\\
RN(s_3)&=[0.590,\ 0.674],\\
RN(s_6)&=[0.705,\ 0.795],\\
RN(s_7)&=[0.834,\ 0.934],\\
RN(s_8)&=[0.948,\ 1.055].
\end{aligned}$$

In the fifth step, by applying the equation (21), all the elements of the previous matrix, except the first one that does not change the value, should be added to the number one and the following matrix is obtained:

$$\begin{aligned}
RN(k_4)&=[1.000,\ 1.000],\\
RN(k_2)&=[1.262,\ 1.337],\\
RN(k_1)&=[1.231,\ 1.274],\\
RN(k_5)&=[1.491,\ 1.574],\\
RN(k_3)&=[1.590,\ 1.674],\\
RN(k_6)&=[1.705,\ 1.795],\\
RN(k_7)&=[1.834,\ 1.934],\\
RN(k_8)&=[1.948,\ 2.055].
\end{aligned}$$

In the sixth step, the elements of the matrix of the recalculated weight are calculated by applying the equation (23) as follows:

$$q_2^L=\frac{q_{j-1}^L}{k_j^U}=\frac{q_1^L}{k_2^U}=\frac{1}{1.337}=0.748,$$

$$q_2^U=\frac{q_{j-1}^U}{k_j^L}=\frac{q_1^U}{k_2^L}=\frac{1}{1.262}=0.792$$

$$q_1^L=\frac{q_{j-1}^L}{k_j^U}=\frac{q_2^L}{k_1^U}=\frac{0.748}{1.274}=0.587,$$

$$q_1^U=\frac{q_{j-1}^U}{k_j^L}=\frac{q_2^U}{k_1^L}=\frac{0.792}{1.231}=0.643$$

It is important to note that *j-1* denotes the previous criterion in relation to *j*. The rank of criteria from Step 3 is taken into account, which means that if, e.g. the value of the third criterion is calculated, *j-1* represents the fifth criterion because it is the previous one according to ranking. The complete matrix $RN(Q_j)$ is:

$$\begin{aligned}
RN(q_4)&=[1.000,\ 1.000],\\
RN(q_2)&=[0.748,\ 0.792],\\
RN(q_1)&=[0.587,\ 0.643],\\
RN(q_5)&=[0.373,\ 0.432],\\
RN(q_3)&=[0.223,\ 0.271],\\
RN(q_6)&=[0.124,\ 0.159],\\
RN(q_7)&=[0.064,\ 0.087],\\
RN(q_8)&=[0.031,\ 0.045].
\end{aligned}$$

Using the equation (25) from Step 7, relative weight values of criteria are obtained. The example of calculation w_j is:

$$\left[w_2^L,w_2^U\right]=\left[\frac{0.748}{3.429},\frac{0.792}{3,150}\right]=\left[0.218,0.251\right]$$

$$\begin{aligned}
RN(w_4)&=[0.292,\ 0.317],\\
RN(w_2)&=[0.218,\ 0.251],\\
RN(w_1)&=[0.171,\ 0.204],\\
RN(w_5)&=[0.109,\ 0.137],\\
RN(w_3)&=[0.065,\ 0.086],\\
RN(w_6)&=[0.036,\ 0.051],\\
RN(w_7)&=[0.019,\ 0.028],\\
RN(w_8)&=[0.009,\ 0.014].
\end{aligned}$$

5. Sensitivity analysis

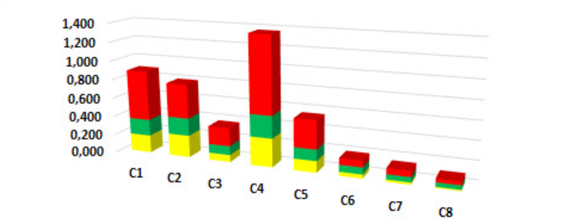
The weight values of criteria obtained by applying the other two methods for determining the weight values of criteria - Rough BWM and Rough AHP method – have been shown in order to determine the stability of the developed approach and the results obtained through the sensitivity analysis. The process of obtaining the weight values by applying the Rough BWM is explained in detail in [27] and their values are presented in the following matrix:

$$BMW-RN(w_1)=[0.171,\ 0.178],$$
$$BMW-RN(w_2)=[0.186,\ 0.190],$$
$$BMW-RN(w_3)=[0.094,\ 0.099],$$
$$BMW-RN(w_4)=[0.236,\ 0.239],$$
$$BMW-RN(w_5)=[0.119,\ 0.120],$$
$$BMW-RN(w_6)=[0.063,\ 0.081],$$
$$BMW-RN(w_7)=[0.053,\ 0.055],$$
$$BMW-RN(w_8)=[0.043,\ 0.047].$$

The weight values of criteria obtained by applying the Rough AHP are presented in the following matrix:

$$AHP-RN(w_1)=[0.425,\ 0.629],$$
$$AHP-RN(w_2)=[0.241,\ 0.485],$$
$$AHP-RN(w_3)=[0.147,\ 0.239],$$
$$AHP-RN(w_4)=[0.646,\ 1.000],$$
$$AHP-RN(w_5)=[0.209,\ 0.396],$$
$$AHP-RN(w_6)=[0.063,\ 0.077],$$
$$AHP-RN(w_7)=[0.055,\ 0.070],$$
$$AHP-RN(w_8)=[0.035,\ 0.041].$$

Figure 2 shows the crisp weight values of criteria according to all the applied methods. It can be noticed that the results obtained by the developed Rough SWARA approach provide stable results that are very close to the values obtained using the Rough BWM method.



	C1	C2	C3	C4	C5	C6	C7	C8
Rough AHP	0,527	0,363	0,193	0,823	0,302	0,070	0,063	0,038
Rough BWM	0,174	0,188	0,096	0,237	0,120	0,072	0,054	0,045
Rough SWARA	0,188	0,235	0,076	0,305	0,123	0,043	0,023	0,012

Figure 2. Crisp weight values of the criteria obtained by different approaches

By observing the obtained values from the aspect of criterion ranks, it can be noted that the ranks are in complete correlation, which is confirmed by the stability of the results and of the proposed Rough SWARA approach. The results obtained by using the Rough SWARA approach are closer to those obtained by the Rough BWM in comparison to the Rough AHP, which can also be seen in Figure 2.

6. Conclusion

The developed approach presented in this research refers to the integration of Rough numbers and Step-wise Weight Assessment Ratio Analysis (SWARA) method. The model has been verified during the process of evaluating the criteria for the selection of wagons for internal transport. Seven experts determined the significance of criteria and their assessment in relation to the best ranked criterion. The main goal of the paper is to take the advantages of the rough numbers and of the SWARA method. These are initially reflected in a small number of comparisons of criteria among themselves, and, in a certain way, in a clearer determination of weight values compared to other methods.

The algorithm of Rough SWARA method consists of seven steps and in each step, the calculation has been explained in detail throughout a verification model.

In order to determine the stability of the obtained results, a sensitivity analysis has been performed in which two other methods for obtaining the weight values of criteria have been applied: Rough BWM and Rough AHP method. The results obtained in the sensitivity analysis show that the developed Rough SWARA approach provides good and valid results when determining the significance of criteria. Analyzing the results obtained throughout the calculation of Spearman's correlation coefficient, it has been found that the obtained criterion ranks of the Rough SWARA approach are in complete correlation with the ranks of other approaches. The main contribution of this paper lies in the development of the novel Rough SWARA approach that ensures an objective aggregation of expert decisions with absolute respect for inaccuracies and subjectivity that prevail in group decision-making. The novel approach development contributes to the improvement of literature in which the theoretical and practical application of multi-criteria methods is considered. The developed approach enables the evaluation of criteria and the ascertainment of their significance regardless of the inaccuracies and the lack of quantitative information in a decision-making process.

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