Sustainable supplier selection using combined FUCOM – Rough SAW model

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Article Info

Article history:

Received March 1, 2020
Revised May 10, 2020
Accepted May 25, 2020

Keywords:

sustainable supplier
FUCOM
Rough SAW
evaluation

ABSTRACT

In recent decades, due to the rapid consumption of natural resources and the need for environmental protection, sustainability in supply chain management has emerged as an increasingly important issue. Therefore, in this study, supplier selection has been performed in order to achieve sustainability, taking into account all aspects: economic, social and environmental criteria. For this purpose, combined FUCOM - Rough SAW approach has been used. The evaluation of criteria grouped at two levels has been carried out by decision makers according to the needs of the company whose main activity is lime production. To obtain the criterion weight values, the FUCOM (FUll COnsistency Method) has been used.. In order to avoid uncertainty and imprecision in the supplier evaluation process, combination with the Rough SAW method, which is used for ranking and supplier selection, has been performed. In order to control the stability of the used model, a sensitivity analysis has been performed. The first phase involves changing the weights of the criteria, while the second phase involves a comparative analysis using other MCDM methods.

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1. Introduction

In response to the changes caused by globalization, businesses are increasingly paying attention to logistics. With the development of logistics, supply chains are developed and their importance strengthened. Christopher (2016) defines the supply chain as upstream and downstream relationships with suppliers and customers in order to deliver superior customer value at less cost to the supply chain as a whole.

A well-designed system of supply chain management is important for improving a competitive advantage in an era of international economy and accelerated development of information technologies Liu and Wang, (2007). Procurement of materials as a separate logistics subsystem plays an important role in achieving the efficiency of a sustainable supply chain. In a procurement process, it is necessary to take into account the adequate selection of suppliers, which will greatly increase competitiveness in the market. Sustainable supplier selection is an continuous process that requires consideration of a number of criteria needed to reach the decisions on the selection of the most appropriate supplier (Luthra et al. 2017; Stević et al. 2020; 3,8,1]. Supplier evaluation also takes into account tangible and intangible factors, which are not always very clearly defined (Bai and Sarkis, 2019). Suppliers have to meet a number of requirements and be prepared to adapt their business policies to their customers at all times. In order to do this, it is necessary to take into account all three aspects of sustainability: environmental, economic and social. In fact, it is claimed that the long-term profitability and existence of a company is best if it is based on a balance between economic, environmental and social goals (Dao et al. 2011). Accordingly, in this paper, the evaluation of suppliers has been performed, taking into account 21 criteria from the aspect of all sustainability factors.

This study examined the problem of sustainable evaluation of supplier performance and selection in supply chains by presenting an integrated FUCOM – Rough SAW model. The assessment and selection of suppliers has been performed on the basis of an equal number of criteria by all aspects of sustainability.

This paper has several goals. The first refers to the consideration of the theory of multi-criteria problems that are largely dominated by uncertainties and dilemmas. This goal is achieved by applying the Rough SAW method. The second goal is to reduce subjectivity in group decision-making and to allow more precise identification of the preferences of decision-makers. This is achieved by integrating the FUCOM method and the Rough SAW algorithm. The third goal is to optimize the procurement process, i.e. to evaluate and select a sustainable supplier in a lime company. These goals reflect the contribution of this research.

After the introductory part, the paper is written throughout four other sections. The second section presents the proposed model in this study. The FUCOM algorithm is briefly presented, as well as the operations with rough numbers. The Rough SAW method is given at the end of this section. The third section consists of the results with the calculation presented in detail using the proposed integrated model. A sensitivity analysis, which includes changing the weight of the criteria throughout a total of 12 scenarios and applying other methods to compare the proposed model, is performed in the fourth section. Finally, the fifth section is the conclusion and discussion of the results obtained.

2. Methods

2.1. FUCOM method

The FUCOM (Bad and Abdulshahed, 2019; Nunić, 2019). method was developed by Pamučar et al. (2019) for determining the weights of criteria. It represents a new method that according to the authors is a better method than AHP (Analytic Hierarchy Process) and BWM (Best Worst Method). The following section presents a procedure for obtaining the weighting coefficients of criteria using FUCOM:

Step 1. The first step is to rank the criteria from a predefined set of evaluation criteria $C = \{C_1, C_2, \ldots, C_n\}$. Ranking is performed according to the significance of the criteria, i.e. from the criterion that we expect to have the highest weighting coefficient towards the criterion of the least significance. Thus, we obtain ranked criteria according to the expected values of the weighting coefficients

$$C_{j_{(1)}} > C_{j_{(2)}} > \cdots > C_{j_{(k)}} \quad (1)$$

where k represents the rank of the observed criterion. If there are estimates that two or more criteria have the same significance, a sign of equality is placed between the criteria instead of ">" in Expression (1).

Step 2. In the second step, a mutual comparison of ranked criteria is made and comparative significance $(\varphi_{k/(k+1)})$, $= 1,2,\ldots,n$, is determined, where k represents the ranking of the evaluation criteria. The comparative significance of the evaluation criteria $(\varphi_{k/(k+1)})$ presents the advantage that the criterion of rank has over the criterion of rank $C_{j_{(k+1)}}$. Thus, we obtain vectors of the comparative significance of the evaluation criteria

$$\Phi = (\varphi_{1/2}, \varphi_{2/3}, \ldots, \varphi_{k/(k+1)}) \quad (2)$$

Step 3. In the third step, the final values of the weighting coefficients of the evaluation criteria $(w_1, w_2, \ldots, w_n)^T$ are calculated. The final values of the weighting coefficients should satisfy two conditions: (1) The ratio of the weighting coefficients is equal to the comparative significance among the observed criteria $(\varphi_{k/(k+1)})$, which is defined in Step 2, i.e. that the following condition is fulfilled

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} \quad (3)$$

(2) In addition to condition (3), the final values of the weighting coefficients should satisfy the condition of mathematical transitivity, i.e. that $\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$. Since $\varphi_{k/(k+1)} = \frac{w_k}{w_{k+1}}$ and $\varphi_{(k+1)/(k+2)} = \frac{w_{k+1}}{w_{k+2}}$, we obtain that $\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$. Thus, we gain a second condition that should be satisfied by the final values of the weighting coefficients of the evaluation criteria

$$\frac{w_k}{w_{k+2}} = \varphi_{\frac{k}{k+1}} \otimes \varphi_{\frac{k+1}{k+2}} \quad (4)$$

Based on the defined settings, we can define a final model for determining the final values of the weighting coefficients of the evaluation criteria

$$\begin{aligned} &\min \chi \\ &s.t. \\ &\left| \frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)} \right| = \chi,\ \forall j \\ &\left| \frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \right| = \chi,\ \forall j \qquad (5) \\ &\sum_{j=1}^{n} w_j = 1,\ \forall j \\ &w_j \geq 0,\ \forall j \end{aligned}$$

2.2. Rough set theory

In rough set theory, any vague idea can be presented as a pair of exact concepts based on the lower and upper approximation as shown in Figure 1.

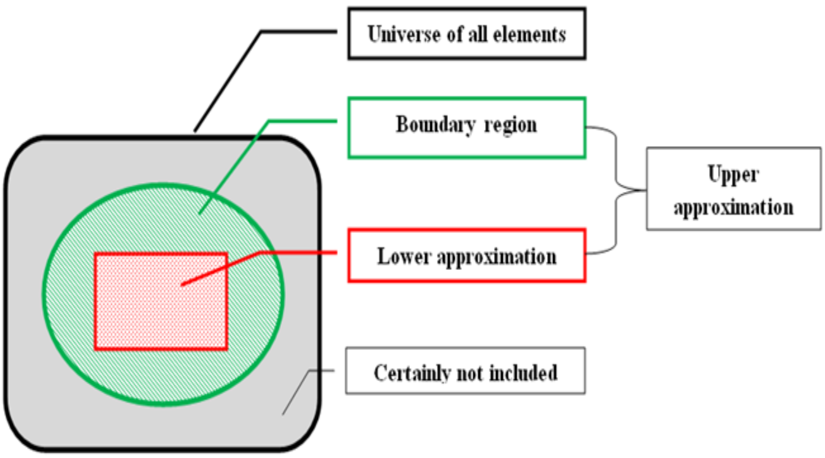

Figure. 1 *Basic concept of rough set theory*

Assume that U is a universe consisting of all objects, Y is an arbitrary object of U, R is a set of t classes ($G_1;G_2;\ldots;G_t$) that include all objects in U, R ($G_1;G_2;\ldots;G_t$). If these classes are determined as $G_1<G_2<\ldots<G_t$, then $\forall Y \in U, G_q \in R, 1 \leq q \leq t$ lower approximation $\left(\underline{Apr}(G_q)\right)$, upper approximation $\left(\overline{Apr}(G_q)\right)$ and the boundary region $\left(Bnd(G_q)\right)$ of class G_q according to (Zhu et al. 2015) is defined as:

$$\underline{Apr}(G_q) = \cup \left\{ Y \in \frac{U}{R(Y)} \leq G_q \right\} \quad (6)$$

$$\overline{Apr}(G_q) = \cup \left\{ Y \in \frac{U}{R(Y)} \geq G_q \right\} \quad (7)$$

$$Bnd(G_q) = \cup \left\{ Y \in \frac{U}{R(Y)} \neq G_q \right\} = \left\{ Y \in \frac{U}{R(Y)} \geq G_q \right\} = \cup \left\{ Y \in \frac{U}{R(Y)} \leq G_q \right\} (8)$$

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

$$\underline{Lim}(G_q) = \frac{1}{M_L}\sum R(Y)|Y \in \underline{Apr}(G_q) \quad (9)$$

$$\overline{Lim}(G_q) = \frac{1}{M_U}\sum R(Y)|Y \in (\overline{Apr}(G_q) \quad (10)$$

$$RN(G_q) = [\underline{Lim}(G_q), \overline{Lim}(G_q)] \quad (11)$$

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

The differences between them are expressed as a rough boundary interval

$$IRBnd(G_q) = \overline{Lim}(G_q) - \underline{Lim}(G_q) \quad (12)$$

Operations for two rough numbers

$RN(\alpha) = [\underline{Lim}(\alpha), \overline{Lim}(\alpha)]$ and $RN(\beta) = [\underline{Lim}(\beta), \overline{Lim}(\beta)]$ according to (Đalić et al. 2020) are:

Adding (+) two rough numbers (α) and (β)

$$RN(\alpha) + RN(\beta) = [\underline{Lim}(\alpha) + \underline{Lim}(\beta), \overline{Lim}(\alpha) + \overline{Lim}(\beta)] \quad (13)$$

Subtracting (-) two rough numbers (α) and (β)

$$RN(\alpha) - RN(\beta) = [\underline{Lim}(\alpha) - \overline{Lim}(\beta), \overline{Lim}(\alpha) - \underline{Lim}(\beta)] \quad (14)$$

Multiplying (×) two rough numbers (α) and (β)

$$RN(\alpha) \times RN(\beta) = [\underline{Lim}(\alpha) \times \underline{Lim}(\beta), \overline{Lim}(\alpha) \times \overline{Lim}(\beta)] \quad (15)$$

Dividing (÷) two rough numbers (a) and (b)

$$RN(\alpha) \div RN(\beta) = [\underline{Lim}(\alpha) \div \overline{Lim}(\beta), \overline{Lim}(\alpha) \div \underline{Lim}(\beta)] \quad (16)$$

The scalar multiplication of two rough numbers (α), where μ is a non-zero value.

$$\mu \times RN(\alpha) = [\underline{\mu \times Lim}(\alpha), \mu \times \overline{Lim}(\alpha)] \quad (17)$$

2.3. Rough SAW method

The SAW method represents a simple and easily applicable multi-criteria decision-making method. However, using only crisp numbers, it is impossible to obtain results that treat uncertainties and objectivity appropriately. Therefore, a new approach combining the SAW method and rough numbers is presented below. The Rough SAW method consists of the following steps (Stević et al. 2017):

Step 1: Defining a problem that needs to be solved and that consists of *m* alternatives and *n* criteria.

Step 2: Forming a group of experts who evaluate alternatives by all criteria using the linguistic scale shown in (Stević et al. 2017). Based on the linguistic scale, the expert group evaluates the alternatives taking into account a type of criteria (benefit or cost). It is very important for this kind of solving engineering problems that the evaluation of potential solutions be carried out adequately, which involves the application of the above or some other similar scales.

Step 3: Converting individual matrices into a group rough matrix. Each individual expert matrix *k1*, *k2*, ..., *kn* have to be converted into a rough group matrix by applying Equations (6) - (18):

$$RGM = \begin{bmatrix} [x_{11}^L, x_{11}^U] & [x_{12}^L, x_{12}^U] & \cdots & [x_{1m}^L, x_{1m}^U] \\ [x_{21}^L, x_{21}^U] & [x_{22}^L, x_{22}^U] & \cdots & [x_{2m}^L, x_{2m}^U] \\ \vdots & \vdots & \ddots & \vdots \\ [x_{m1}^L, x_{m1}^U] & [x_{m2}^L, x_{m2}^U] & \cdots & [x_{mm}^L, x_{mm}^U] \end{bmatrix} \quad (18)$$

Step 4: Group matrix normalization applying Equations (19) and (20):

$$r_{ij} = \frac{[x_{ij}^L; x_{ij}^U]}{max[x_{ij}^{+L}; x_{ij}^{+U}]} for C_{1,} C_{2,} \dots, C_n \epsilon B \quad (19)$$

$$r_{ij} = \frac{min[x_{ij}^{-L}; x_{ij}^{-U}]}{[x_{ij}^L; x_{ij}^U]} for C_{1,} C_{2,} \dots, C_n \epsilon C \quad (20)$$

The values are marked with $^+$ and $^-$ in order to facilitate the identification of the values that belong to different types of criteria. The previously written equations can be expressed in a simpler way as:

$$r_{ij} = \left[\frac{x_{ij}^L}{x_{ij}^{+U}}; \frac{x_{ij}^U}{x_{ij}^{+L}}\right] for C_{1,} C_{2,} \dots, C_n \epsilon B \quad (21)$$

$$r_{ij} = \left[\frac{x_{ij}^{-L}}{x_{ij}^{U}}; \frac{x_{ij}^{-U}}{x_{ij}^{L}}\right] for C_{1,} C_{2,} \dots, C_n \epsilon C \quad (22)$$

and a normalized matrix is obtained, as follows:

$$Rn = \begin{bmatrix} [r_{11}^L, r_{11}^U] & [r_{12}^L, r_{12}^U] & \cdots & [r_{1m}^L, r_{1m}^U] \\ [r_{21}^L, r_{21}^U] & [r_{22}^L, r_{22}^U] & \cdots & [r_{2m}^L, r_{2m}^U] \\ \vdots & \vdots & \ddots & \vdots \\ [r_{m1}^L, r_{m1}^U] & [r_{m2}^L, r_{m2}^U] & \cdots & [r_{mm}^L, r_{mm}^U] \end{bmatrix} \quad (23)$$

Step 5: Weighting the normalized matrix:

$$Vn = \left[v_{ij}^L; v_{ij}^U\right]_{mxn}$$
$$v_{ij}^L = w_J^L \times r_{ij}^L, i = 1,2, \dots m, j \quad (24)$$
$$v_{ij}^U = w_J^U \times r_{ij}^U, i = 1,2, \dots m, j$$

where w_j^L is the lower limit, and w_j^U is the upper limit of criterion weight expressed as a rough number obtained by applying a rough AHP or a rough BWM as is the case in this paper.

Step 6: Summing up all the values of the alternatives obtained (summing by rows):

$$S = \left[s_{ij}^L; s_{ij}^U\right] \quad (25)$$

Step 7: Ranking alternatives by decreasing values, i.e. the highest value represents the best solution. To facilitate ranking of potential solutions, a rough number can be converted to crisp.

3. RESULTS

The selection of a sustainable supplier depends on the precise determination and selection of appropriate criteria and their evaluation. The criteria and alternatives were evaluated by a group of employed experts with regards to the needs of Carmeuse (Bosnia and Herzegovina), a company for lime production. This group consists of three decision-makers. The criteria for selecting a sustainable supplier are as follows:

- Sub-criteria of the economic criteria group C_1:
    - C_{11} - cost/price,
    - C_{12} - quality,
    - C_{13} - flexibility,
    - C_{14} - productivity,
    - C_{15} - financial capacity,
    - C_{16} - partnerships and
    - C_{17} - eco-innovation.
- Sub-criteria of the social criteria group C_2:
    - C_{21} - reputation,
    - C_{22} - safety at work,
    - C_{23} - workers' rights,
    - C_{24} - local community influence,
    - C_{25} - employee training,
    - C_{26} - respect for rights and policies and
    - C_{27} - release of information.
- Sub-criteria of the environmental criteria group C_3:
    - C_{31} - ecological image,
    - C_{32} - recycling,
    - C_{33} - pollution control,
    - C_{34} - environmental management system,
    - C_{35} - ecological products,

- C_{36} - resource consumption and
- C_{37} - green competencies.

A complete calculation of the criteria is presented in (Durmić, 2019), obtaining the following values of the criteria, which are further used in the calculation with the Rough SAW method:

$$w_{11} = 0.084, w_{12} = 0.135, w_{13} = 0.058, w_{14} = 0.083,$$
$$w_{15} = 0.055, w_{16} = 0.060, w_{17} = 0.045,$$
$$w_{21} = 0.044, w_{22} = 0.060, w_{23} = 0.031, w_{24} = 0.024,$$
$$w_{25} = 0.033, w_{26} = 0.040, w_{27} = 0.037,$$
$$w_{31} = 0.029, w_{32} = 0.037, w_{33} = 0.046, w_{34} = 0.027,$$
$$w_{35} = 0.030, w_{36} = 0.019, w_{37} = 0.023$$

The evaluation of the alternatives by three decision-makers is shown in Table 1. Since the selection of suppliers is influenced by three decision-makers, it is necessary to convert the individual matrices of each decision-maker into a group rough matrix by applying Equations (6) - (11).

Table 1 *Evaluation of the alternatives by three decision-makers*

	A_1			A_2			A_3			A_4		
	DM_1	DM_2	DM_3	DM_1	DM_2	DM_3	DM_1	DM_2	DM_3	DM_1	DM_2	DM_3
C_{11}	1	2	1	1	3	3	1	2	2	1	3	2
C_{12}	7	7	7	7	6	6	7	7	6	7	6	6
C_{13}	5	4	5	5	4	4	7	6	5	7	6	6
C_{14}	7	6	6	6	5	6	7	6	5	7	6	6
C_{15}	5	4	5	6	5	5	6	6	6	7	7	6
C_{16}	7	7	7	6	5	5	6	6	6	6	6	7
C_{17}	6	5	5	6	5	4	6	5	5	7	6	5
C_{21}	5	5	4	6	6	5	7	7	6	7	7	6
C_{22}	5	4	5	6	5	4	7	6	4	7	6	5
C_{23}	5	5	5	3	6	5	6	6	4	6	5	4
C_{24}	3	3	2	3	3	3	4	4	3	4	4	4
C_{25}	3	3	3	6	5	4	6	4	3	6	5	5
C_{26}	5	4	4	6	5	5	6	6	5	6	6	6
C_{27}	3	3	2	5	4	3	6	6	4	6	6	4
C_{31}	4	4	5	4	4	5	5	5	4	6	6	5
C_{32}	6	6	5	5	5	5	6	6	5	6	6	4
C_{33}	4	4	6	5	5	5	6	5	4	5	6	4
C_{34}	3	3	4	4	4	4	6	5	2	6	5	3
C_{35}	5	4	4	4	3	4	6	5	3	5	4	5
C_{36}	4	5	5	4	5	5	4	5	6	3	4	3
C_{37}	3	4	3	4	3	4	5	4	3	5	5	4

Converting individual matrices into a group rough matrix is performed as follows:

$\tilde{x}_{11} = \{1,2,1\};\ \underline{Lim}(1) = 1, \overline{Lim}(1) = \frac{1}{3}(1+2+1) = 1.33; \underline{Lim}(2) = \frac{1}{3}(1+2+1) = 1.33, \overline{Lim}(2) = 2;$

$RN(x_{11}^1) = [1; 1.33]; RN(x_{11}^2) = [1.33; 2];$

$$x_{11}^L = \frac{x_{11}^1 + x_{11}^2 + x_{11}^1}{S} = \frac{1 + 1.33 + 1}{3} = 1.11$$

$$x_{11}^U = \frac{x_{11}^1 + x_{11}^2 + x_{11}^1}{S} = \frac{1.33 + 2 + 1.33}{3} = 1.55$$

After obtaining the group rough matrix, its normalization has to be performed using Equations (18) - (21) in order to obtain the normalized matrix shown in Table 2, while the weighted normalized matrix obtained in the following step, is achieved by applying Equation (23). The normalization of group matrix elements for benefit criteria is performed as follows:

$$\tilde{r}_{12} = \left[\frac{x_{ij}^L}{x_{ij}^{+U}}; \frac{x_{ij}^U}{x_{ij}^{+L}}\right] = \left[\frac{7.00}{7.00}; \frac{7.00}{7.00}\right] \rightarrow \tilde{r}_{12} = [1.000;\ 1.00]$$

and for cost criteria as follows:

$$\tilde{r}_{11} = \left[\frac{x_{ij}^{-L}}{x_{ij}^{U}}; \frac{x_{ij}^{-U}}{x_{ij}^{L}}\right] = \left[\frac{1.11}{1.55}; \frac{1.55}{1.11}\right] \rightarrow \tilde{r}_{11} = [0.176; 1.396]$$

Table 2 *The normalized matrix*

	A1	A2	A3	A4
C_{11}	[0.716, 1.396]	[0.399, 0.82]	[0.587, 1.069]	[0.444, 1.033]
C_{12}	[1, 1]	[0.873, 0.936]	[0.921, 0.984]	[0.873, 0.936]
C_{13}	[0.679, 0.8]	[0.627, 0.745]	[0.84, 1.064]	[0.933, 1.072]
C_{14}	[0.933, 1.072]	[0.832, 0.964]	[0.84, 1.064]	[0.933, 1.072]
C_{15}	[0.646, 0.758]	[0.742, 0.86]	[0.871, 0.930]	[0.936, 1.068]
C_{16}	[1, 1]	[0.73, 0.793]	[0.857, 0.857]	[0.873, 0.936]
C_{17}	[0.789, 1.009]	[0.692, 1]	[0.786, 1.009]	[0.846, 1.182]
C_{21}	[0.646, 0.7]	[0.791, 0.913]	[0.936, 1.068]	[0.936, 1.068]
C_{22}	[0.685, 0.889]	[0.692, 1]	[0.752, 1.162]	[0.846, 1.182]
C_{23}	[0.849, 0.917]	[0.925, 1.081]	[0.830, 1.061]	[0.764, 1.009]
C_{24}	[0.613, 0,745]	[0.75, 0.75]	[0.863, 0.973]	[1, 1]
C_{25}	[0.541, 0.587]	[0.811, 1.076]	[0.76, 1]	[0.921, 1.086]
C_{26}	[0.685, 0.758]	[0.852, 0.982]	[0.908, 0.982]	[1, 1]
C_{27}	[0.424, 0.591]	[0.606, 0.92]	[0. 846, 1.182]	[0.846, 1.182]
C_{31}	[0.698, 0.835]	[0.698, 0.835]	[0.756, 0.897]	[0.925, 1.081]
C_{32}	[0.925, 1.081]	[0.849, 0.917]	[0.925, 1.081]	[0.83, 1.061]
C_{33}	[0.767, 1.022]	[0.909, 1]	[0.818, 1.1]	[0.818, 1.1]
C_{34}	[0.577, 0.888]	[0.742, 1]	[0.609, 1.32]	[0.722, 1.348]
C_{35}	[0.763, 1.022]	[0.640, 0.874]	[0.722, 1.211]	[0.826, 1.099]
C_{36}	[0.636, 0.798]	[0.636, 0.798]	[0.565, 0.789]	[0.876, 1.141]
C_{37}	[0.636, 0.798]	[0.706, 0.874]	[0.716, 1.011]	[0.91, 1.099]

The normalization matrix is weighted as follows: $v_{13}^{L} = [\, w_{13}^{L} \times r_{13}^{L}] = [0.679 \times 0.058] \rightarrow v_{13}^{L} = [0.039]$
$v_{13}^{U} = [\, w_{13}^{U} \times r_{13}^{U}] = [0.800 \times 0.058] \rightarrow v_{13}^{U} = [0.046]$
V_{13} =[0.039, 0.046]

After weighting the normalized matrix, the values for all alternatives are summarized by rows and the final ranking of the alternatives is obtained, which is shown in Table 6. The ranking is made in decreasing order, where the highest value represents the best solution and the lowest worst. The table also shows the conversion of a rough number into crisp by applying the average value of the lower and upper limits of the rough number.

Table 6 *Results and ranking of alternatives*

	s_{ij}^{L}	s_{ij}^{U}	**AV**	**Rank**
A_1	0.769	0.939	0.854	3
A_2	0.740	0.909	0.825	4
A_3	0.811	1.036	0.924	2
A_4	0.847	1.063	0.955	1

Alternative 4 is the most acceptable solution according to the results obtained.

4. SENSITIVITY ANALYSIS

4.1. Changing the weights of criteria

The aim of sensitivity analysis by changing the weights of the criteria is to determine the sensitivity of the model to changes in the weights. For this purpose, 12 scenarios have been formed in which the weights of the criteria have been modeled. The rankings of the alternatives in the formed scenarios are shown in Figure 2. The first ($C_{11}, C_{12}, C_{13}, C_{14}, C_{15}, C_{16}, C_{22}$) scenario implies reduction of the seven most important criteria by 4% and increase of the others by 2%, while, in the second scenario, the economic criteria have increased by 3%, while the others have decreased by 1.5%. In the third set, the criteria belonging to the economic group have reduced by 4%, while the criteria of the social group have increased proportionally, and the value of environmental criteria remains unchanged. The fourth scenario presents a reverse situation from the third, where economic criteria have reduced by 3%, environmental criteria have increased proportionally, and the social criteria remain unchanged. The fifth scenario involves the reduction of the economic criteria by 4% and increase of the social and environmental criteria by 2%, while, in the sixth set, the seven least significant criteria ($C_{23}, C_{24}, C_{31}, C_{34}, C_{35}, C_{36}, C_{37}$) have increased by 4% and the others have decreased by 2%. In the seventh scenario, the value of social criteria has decreased by 2% and the values of environmental criteria have increased proportionally, while economic criteria remain the same. In the eighth scenario, decision-making is based only on economic criteria, in the ninth, it is based on social criteria and, in the tenth, it is based on environmental criteria. The eleventh scenario represents the elimination of the seven most significant criteria, while the seven least significant criteria are eliminated in the twelfth scenario.

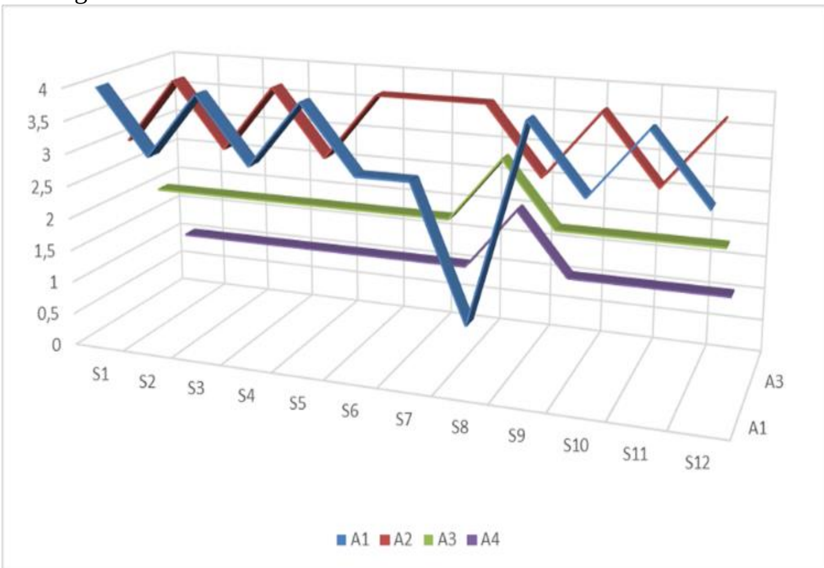

Figure 2 *A sensitivity analysis by changing the weights of criteria*

The results show that the model is sensitive to changes in the weights of the criteria. The rankings of alternatives change in the first, third, fifth, eighth, ninth and eleventh scenarios, which means that the most significant criteria play a very important role in a decision-making process. This is confirmed by the fact that there are rank changes in the first scenario, when the seven most significant criteria are reduced, and in the eleventh scenario, when the seven most significant criteria are eliminated. The initial scenario of this study has a complete correlation with six scenarios (2, 4, 6, 7, 10, 12), which means that the rankings of the alternatives remain the same completely. The reason for this result is that there is no major change in the values of the most important economic criteria. The initial scenario has the lowest correlation with the eighth scenario in which the selection of suppliers is made only on the basis of economic criteria, whereby the ranking of three alternatives changes. The only alternative that does not change its rank is Alternative 2, which ranks last in the ranking as the worst solution. In other scenarios, as noted above, the rankings of two alternatives A_1 and A_2 change, where they replace their positions.

Changes in the rankings in the third and fifth scenarios are due to the fact that the values of economic criteria have decreased, which, as already stated, have the greatest influence on the first level of decision-making, and the values of less significant environmental and social criteria have increased. The change also occurs in the first and eleventh scenarios, where the reason for changing the rank is the reduction and elimination of the seven most significant criteria. In the ninth section, the change of rank occurs because the selection of suppliers is made only on the basis of the social criteria, which have the least impact. It is important to emphasize that the two alternatives A_4 and A_3, which represent the best solution, do not change the rankings in either scenario, which means that they are insensitive to changes in the significance of the criteria.

4.2. A comparative analysis

The stability of the obtained results of the applied methodology has been examined by a comparative analysis throughout the application of other methods. The proposed model has been compared with other approaches developed more recently: Rough ARAS (Radović et al. 2018), Rough WASPAS (Stojić et al. 2018) and Rough (Roy et al. 2018). The obtained results show that the developed integrated FUCOM-RSAW model is in complete correlation with the applied R-ARAS, R-WASPAS and R-MABAC models, which means that the applied model is stable. The ranks of the alternatives remain the same in all models (Table 7), i.e. Alternative

4 is the best solution, followed by Alternative 3, then Alternative 1 and ultimately the worst solution is Alternative 2.

Table 7. *Results of comparative analysis*

	RSAW		RARAS		RWASPAS		RMABAC	
A1	0.859	4	0.764	4	0.774	4	-0.050	4
A2	0.875	3	0.967	2	0.978	2	0.111	1
A3	0.957	2	0.999	1	1.006	1	0.051	2
A4	0.979	1	0.770	3	0.784	3	0.024	3

5. CONCLUSION

As a logistics subsystem, procurement plays an essential role in achieving a sustainable supply chain, and suppliers play a key role in a procurement process. Efficiency in day-to-day business requires decision-making that will save costs but also meet customer needs, so every business should strive to provide good and high quality suppliers in order for their business to achieve its goals and operate profitably in the environment and thereby satisfy the wishes and needs of existing and potential customers. Since manufacturing processes are complex and numerous, so are the requirements of manufacturers towards suppliers. The number of criteria (requirements) is constantly increasing, leading decision-makers to a situation where they can no longer compare the growing number of suppliers with the increasing number of criteria. Therefore, in this study, a multi-criteria decision-making methodology has been applied to overcome this problem.

An integrated FUCOM - Rough SAW model was used for supplier evaluation. The evaluation was performed on the basis of 21 criteria classified into a two-level hierarchical structure. The FUCOM method was applied to determine the significance of the criteria. First, the values of the main criteria, economic, social and environmental, were determined. Then, the weights of all sub-criteria were calculated for each major group of the criteria. The Rough SAW method was applied to rank and select suppliers from a potential set. The results obtained show that the fourth supplier is the best solution. The validity of the final results was determined through a sensitivity analysis. In the sensitivity analysis, 12 scenarios that imply a change in the weight of the criteria were formed first. After that, the results were compared using R-ARAS, R-WASPAS and R-MABAC methods, which also confirmed the previous results, which means that the applied FUCOM-RSAW model allows obtaining stable solutions to the problem of selecting a sustainable supplier.

Future research related to this paper refers to the integration of other MCDM methods with rough numbers when it comes to the applied methodology. In addition, it is possible to define an extension of the set of supplier evaluation criteria from a practical aspect.

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