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A ROUGH MULTICRITERIA APPROACH FOR EVALUATION OF THE SUPPLIER CRITERIA IN AUTOMOTIVE INDUSTRY

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Abstract. *Ensuring costs reduction and increasing competitiveness and satisfaction of end users are the goals of each participant in the supply chain. Taking into account these goals, the paper proposes methodology for defining the most important criteria for suppliers' evaluation. From a set of twenty established criteria, i.e. four sets of criteria: finances, logistics, quality and communication and business including its sub-criteria, we have allocated the most important ones for supplier selection. Analytic Hierarchy Process (AHP) based on rough numbers is presented to determine the weight of each evaluation criterion. For the criteria evaluation we have used knowledge from the expert in this field. The efficacy of the proposed evaluation methodology is demonstrated through its application to the company producing metal washers for the automotive industry. Next a sensitivity analysis is carried out in order to show the stability of the model. For checking stability the AHP method in conventional form is used in combination with fuzzy logic.*

Key words: *Rough AHP, Supplier Criteria, Fuzzy AHP, Logistics, Quality.*

1. Introduction

One of the most important strategic issues in logistics procurement according to Stević, (2017c) is a correct and optimal supplier selection, which enables an increase of market competitiveness. The importance of an adequate supplier selection was recognized at the beginning of the last decade of the 20th century when Davis (1993) emphasized that the failure of suppliers to fulfill the promises and expectations regarding delivery is one of the three main sources of uncertainty plaguing the

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supply chain. Kagnicioglu (2016) considers that the supplier selection is a critical procurement activity in the supply chain management because of the crucial role that the supplier characteristics play regarding price, quality, delivery and service in achieving the objectives of the supply chain. Van Weele (2009) points out that a healthy relationship with the suppliers can improve the financial position in a short term and so can a competitive strategy over a long period of time.

Today the company must strive to enlarge the quality of product itself so that the end user is satisfied with provided services, which would make him a loyal user. Due to the above mentioned, it is necessary, during the first phase of logistics, i.e. purchasing logistics, to commit good evaluation and choice of the supplier, which can largely influence the forming of the product’s final price; thus, it can, in this way, accomplish a significant effect in the complete supply chain. It is possible to accomplish the above mentioned if the evaluation is done on the basis of a multi-criteria decision-making that includes a large number of criteria as well as an expert’s estimation of their relative significance (Stević et al. 2016).

This paper is structured as follows. Section 2 shows the fundamentals of a rough set theory, operations with rough numbers and rough Analytic Hierarchy Process. Section 3 makes up the body of the paper: it gives a practical example besides showing results of the proposed model. Section 4 presents a sensitivity analysis. This section also gives discussion and model stability. Section 5 presents conclusions before the paper ends with a list of references.

2. Methods

2.1. A rough set theory

Due to the complexity and uncertainty of numerous real indicators in the process of multi-criteria decision-making, as well as the occurrence of the ambiguity of human thinking, there are difficulties in presenting information about the attributes of decisions through accurate (precise) numerical values. These uncertainties and ambiguities are commonly exploited through application of rough numbers (Song et al., 2014; Zhu et al., 2015).

In addition to the fuzzy theory, a very suitable tool for the treatment of uncertainty without any impact of subjectivism is a rough set theory, which was first introduced in (Pawlak, 1982). From the beginning until today, the theory of rough sets has evolved through solving many problems by using rough sets (Khoo & Chai, 2001; Chai & Liu, 2014; Nauman et al. 2016; Liang et al. 2017; Pamučar et al. 2017a) and through the use of rough numbers as in (Tiwari et al., 2016; Shidpour et al., 2016; Stević et al., 2017b; 2017d; 2017e).

In the theory of rough sets only the internal knowledge is used, i.e. operational data, and there is no need to rely on the models of assumptions. In other words, in the application of rough sets, instead of various additional/external parameters, we use exclusively the structure of the data provided (Duntsch et al., 1997). In rough sets the measurement of uncertainty is based on the uncertainty that is already contained in the data (Khoo & Chai, 2001). This leads to objective indicators that are contained in the data. In addition, the theory of rough sets is suitable for application in the sets that are characterized by a small number of data, and for which statistical methods are not suitable (Pawlak, 1991).

2.2. Operations with rough numbers

In the rough set theory, any vague concept can be represented as a pair of precise concepts based on the lower and upper approximations (Pawlak, 1991) as shown in Figure 1.

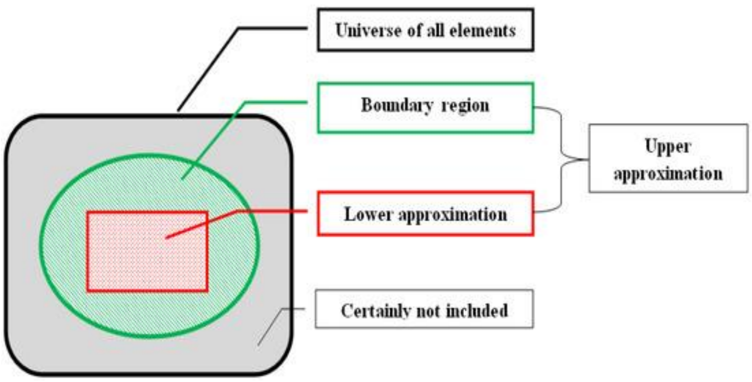

Figure 1. Basic notions of the rough set theory (Stević et al., 2017a)

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

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

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

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

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:

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

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

where M_L and M_U represent the sum of objects contained in the lower and upper object approximation of J_q, respectively. Obviously, the lower limit and upper limit denote the mean value of elements included in the lower approximation and upper approximation, respectively. Their difference is defined as rough boundary interval ($IRBnd(G_q)$):

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

Operation for two rough numbers $RN(\alpha) = \left[\underline{Lim}(\alpha), \overline{Lim}(\alpha)\right]$ and $RN(\beta) = \left[\underline{Lim}(\beta), \overline{Lim}(\beta)\right]$ according to (Zhai et al., 2009) are:

Addition (+) of two rough numbers (α) and (β)

$$RN(\alpha) + RN(\beta) = \left[\underline{Lim}(\alpha) + \underline{Lim}(\beta), \overline{Lim}(\alpha) + \overline{Lim}(\beta)\right] \tag{8}$$

Subtraction (-) of two rough numbers (α) and (β)

$$RN(\alpha) - RN(\beta) = \left[\underline{Lim}(\alpha) - \overline{Lim}(\beta), \overline{Lim}(\alpha) - \underline{Lim}(\beta)\right] \tag{9}$$

Multiplication (×) of two rough numbers (α) and (β)

$$RN(\alpha) \times RN(\beta) = \left[\underline{Lim}(\alpha) \times \underline{Lim}(\beta), \overline{Lim}(\alpha) \times \overline{Lim}(\beta)\right] \tag{10}$$

Division (÷) of two rough numbers $RN(a)$ and $RN(b)$

$$RN(\alpha) \div RN(\beta) = \left[\underline{Lim}(\alpha) \div \overline{Lim}(\beta), \overline{Lim}(\alpha) \div \underline{Lim}(\beta)\right] \tag{11}$$

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

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

2.3. Rough Analytic Hierarchy Process

The procedure of the rough AHP is described as follows (Zhu et al., 2015):

Step 1: Identify the evaluation objective, criteria and alternatives. Construct a hierarchical structure with the evaluation objective at the top layer, criteria in the middle and alternatives at the bottom.

Step 2: Conduct AHP survey and construct a group of pair-wise comparison matrices. The pair-wise comparison matrix of the eth expert is described as:

$$B_e = \begin{bmatrix} 1 & x_{12}^e & \cdots & x_{1m}^e \\ x_{21}^e & 1 & \cdots & x_{2m}^e \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1}^e & x_{m2}^e & \cdots & 1 \end{bmatrix} \tag{13}$$

where $x_{gh}^e (1 \le g \le m, 1 \le h \le m, 1 \le e \le s)$is the relative importance of criterion g on criterion h given by expert e, m is the number of criteria, s is the number of experts.

Calculate maximum eigenvalue λ_{max}^e of Be, then compute consistency index $CI = (\lambda_{max}^e - n)/(n-1)$.

Determine random consistency index (RI) in Table 1 according to n. Compute consistency ratio CR=CI/RI.

Table 1. Value of random index depending on the rank of matrix (Saaty & Vargas, 2012)

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Conduct consistency test. If CR<0.1, the comparison matrix is acceptable. Otherwise, experts' judgments should be adjusted until CR < 0.1

Then, integrated comparison matrix $\tilde{B}$ is built as:

$$\tilde{B} = \begin{bmatrix} 1 & \tilde{x}_{12}^e & \cdots & \tilde{x}_{1m}^e \\ \tilde{x}_{21}^e & 1 & \cdots & \tilde{x}_{2m}^e \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1}^e & \tilde{x}_{m2}^e & \cdots & 1 \end{bmatrix} \tag{14}$$

where $\tilde{x}_{gh}\{x_{gh}^1, x_{gh}^2, \dots, x_{gh}^s\}$, $\tilde{x}_{gh}$ is the sequence of relative importance of criterion g on criterion h.

Step 3: Construct a rough comparison matrix.

Translate element x_{gh}^e in $\tilde{B}$ into rough number $RN(x_{gh}^e)$ using Eqs. (1) - (6):

$$RN(x_{gh}^e) = [x_{gh}^{eL}, x_{gh}^{eU}] \tag{15}$$

where x_{gh}^{eL} is the lower limit of $RN(x_{gh}^e)$ while x_{gh}^{eU} is the upper limit.

Then rough sequence $RN(\tilde{x}_{gh})$ is represented as:

$$RN(\tilde{x}_{gh}) = \{[x_{gh}^{1L}, x_{gh}^{1U}], [x_{gh}^{2L}, x_{gh}^{2U}], \dots, [x_{gh}^{sL}, x_{gh}^{sU}]\} \tag{16}$$

It is further translated into an average rough number $RN(x_{gh})$ by rough arithmetic Eqs. (8) - (12):

$$RN(x_{gh}) = [x_{gh}^L, x_{gh}^U] \tag{17}$$

$$x_{gh}^L = \frac{x_{gh}^{1L} + x_{gh}^{2L} + \dots + x_{gh}^{sL}}{s} \tag{18}$$

$$x_{gh}^U = \frac{x_{gh}^{1U} + x_{gh}^{2U} + \dots + x_{gh}^{sU}}{s} \tag{19}$$

where x_{gh}^L is the lower limit of $RN(x_{gh})$ and x_{gh}^U is the upper limit.

Then rough comparison matrix M is formed as:

$$M = \begin{bmatrix} [1,1] & [x_{12}^L, x_{12}^U] & \cdots & [x_{1m}^L, x_{1m}^U] \\ [x_{21}^L, x_{21}^U] & [1,1] & \cdots & [x_{2m}^L, x_{2m}^U] \\ \vdots & \vdots & \ddots & \vdots \\ [x_{m1}^L, x_{m1}^U] & [x_{m2}^L, x_{m2}^U] & \cdots & [1,1] \end{bmatrix} \tag{20}$$

Step 4: Calculate rough weight *wg* of each criterion:

$$w_g = \left[\sqrt[m]{\prod_{h=1}^m x_{gh}^L}, \sqrt[m]{\prod_{h=1}^m x_{gh}^U},\right] \tag{21}$$

$$w_g' = w_g / \max(w_g^U) \tag{22}$$

where w_g' is the normalization form.

Finally, the criteria weights are obtained.

3. Numerical example

The main activity of the company which is the subject of research is the production of metal washers for the automotive industry. Its product range covers up over 3000 types of metal washers, and the largest part of it is used for mechanical transmissions in heavy machinery, cranes, trucks, and the like. The company is focused on the production and sale of flat and elastic washers. The ability of production is over 3500 tons of finished products.

The aim of this paper is to determine the most important criteria for suppliers' evaluation in the mentioned company. Figure 2 presents criteria finance, logistics, quality and communications and business, and each of these criteria contains five subcriteria which are also shown in the figure below each criterion. A review of the given criteria for suppliers' evaluation through literature is presented in the paper (Stević, 2017c).

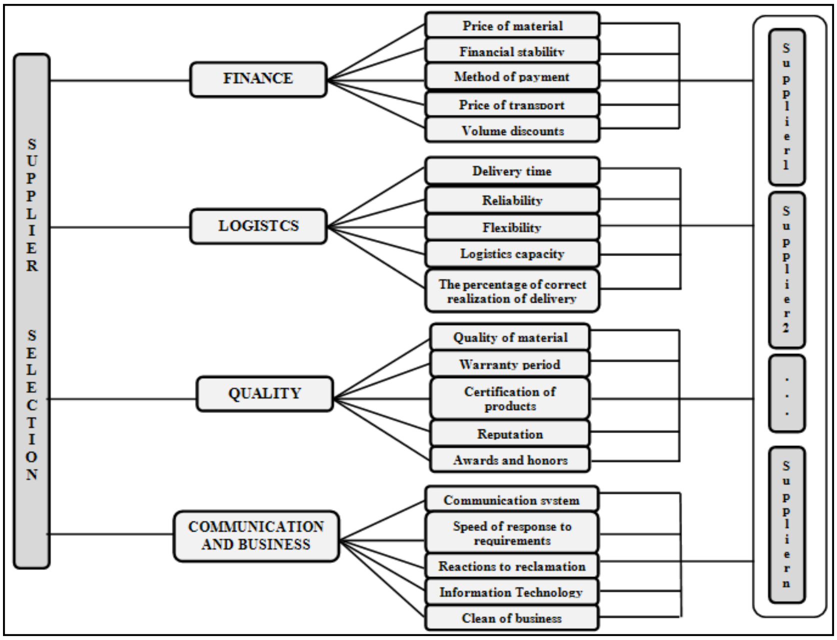

Figure 2. Criteria for supplier selection (Stević, 2017b)

Collect individual judgments and construct a group of pairwise comparison matrices. Take the consistency examination until all the comparison matrices can pass through. Integrate individual comparison matrices to generate an integrated comparison matrix. The individual pair-wise comparison matrices are as follows:

$$B_1 = \begin{bmatrix} 1 & 1/4 & 1/3 & 3 \\ 4 & 1 & 3 & 5 \\ 3 & 1/3 & 1 & 4 \\ 1/3 & 1/5 & 1/4 & 1 \end{bmatrix}, CR = 0{,}068 < 0{,}10$$

$$B_2 = \begin{bmatrix} 1 & 4 & 1 & 3 \\ 1/4 & 1 & 1/4 & 1/3 \\ 1 & 4 & 1 & 4 \\ 1/3 & 3 & 1/3 & 1 \end{bmatrix}, CR = 0{,}047 < 0{,}10$$

$$B_3 = \begin{bmatrix} 1 & 4 & 1 & 4 \\ 1/4 & 1 & 1/4 & 3 \\ 1 & 4 & 1 & 5 \\ 1/4 & 1/3 & 1/5 & 1 \end{bmatrix}, CR = 0{,}049 < 0{,}10$$

Obviously CRe < 0.1 (e= 1, 2, 3), all the comparison matrices are acceptable. Then integrated comparison matrix $\tilde{B}$ is generated by combining with the above three individual comparison matrices.

$$\tilde{B} = \begin{bmatrix} 1,1,1 & 1/4,4,4 & 1/3,1,1 & 3,3,4 \\ 4,1/4,1/4 & 1,1,1 & 3,1/4,1/4 & 5,1/3,3 \\ 3,1,1 & 1/3,4,4 & 1,1,1 & 4,4,5 \\ 1/3,1/4,1/4 & 1/5,3,1/3 & 1/4,1/3,1/5 & 1,1,1 \end{bmatrix}$$

Translate the elements in $\tilde{B}$ into rough numbers and correspondingly original integrated comparison matrix $\tilde{B}$ is converted into a rough comparison matrix.

Take as an example $\tilde{x}_{24} = \{5,1/3,3\}$

$$\underline{Lim}\left(\frac{1}{3}\right) = \frac{1}{3}, \quad \overline{Lim}\left(\frac{1}{3}\right) = \frac{1}{3}\left(5 + \frac{1}{3} + 3\right) = 2{,}78$$

$$\underline{Lim}(3) = \frac{1}{2}\left(\frac{1}{3} + 3\right) = 1{,}67, \quad \overline{Lim}(3) = \frac{1}{2}(3 + 5) = 4$$

$$\underline{Lim}(5) = \frac{1}{3}\left(5 + \frac{1}{3} + 3\right) = 2{,}78, \quad \overline{Lim}(5) = 5$$

Thus, x_{24}^{e} can be expressed in rough number:

$$RN(x_{24}^{1}) = RN(5) = [2{,}78; 5]$$

$$RN(x_{24}^{2}) = RN\left(\frac{1}{3}\right) = [0{,}33; 2{,}78]$$

$$RN(x_{24}^{3}) = RN(3) = [1{,}67; 4]$$

According to Eqs. (17) - (19)

$$x_{24}^{L} = \frac{x_{24}^{1} + x_{24}^{2} + x_{24}^{s}}{S} = \frac{2{,}78 + 0{,}33 + 1{,}67}{3} = 1{,}59$$

$$x_{24}^{U} = \frac{x_{24}^{1} + x_{24}^{2} + x_{24}^{s}}{S} = \frac{5 + 2{,}78 + 4}{3} = 3{,}93$$

Thus rough sequence $\tilde{x}_{24}$ in $\tilde{B}$ is transformed into rough number $RN(x_{24}) = [1{,}59; 3{,}93]$. The transformation of other elements in $\tilde{B}$ is implemented in the same way.

Then, the rough comparison matrix is obtained:

$$M = \begin{bmatrix} [1; 1] & [1{,}92; 3{,}58] & [0{,}63; 0{,}93] & [3{,}11; 3{,}55] \\ [0{,}67; 2{,}33] & [1; 1] & [0{,}56; 1{,}78] & [1{,}59; 3{,}93] \\ [1{,}22; 2{,}11] & [1{,}96; 3{,}59] & [1; 1] & [4{,}11; 4{,}55] \\ [0{,}28; 0{,}32] & [0{,}57; 1{,}95] & [0{,}22; 0{,}24] & [1; 1] \end{bmatrix}$$

Calculate rough weights of the criteria using Eqs. (21) and (22).

$$w = \{[1{,}39; 1{,}85]; [0{,}88; 2{,}01]; [1{,}77; 2{,}42]; [0{,}43; 0{,}62]\}$$

$$w' = \{[0{,}57; 0{,}76]; [0{,}36; 0{,}83]; [0{,}73; 1]; [0{,}18; 0{,}26]\}$$

According to the obtained results, the third criterion quality is the most important in the target company. Observing the obtained values of the upper and lower limits of the rough number in all, except for the second criterion, shows that they have relatively approximate values. The cause of a large difference between the lower and the upper limit of logistics criteria are the different attitudes of decision-makers when this criterion is concerned. That is why the decision-makers gave different assessments of their preferences, for example, 1/3 and 5, etc.

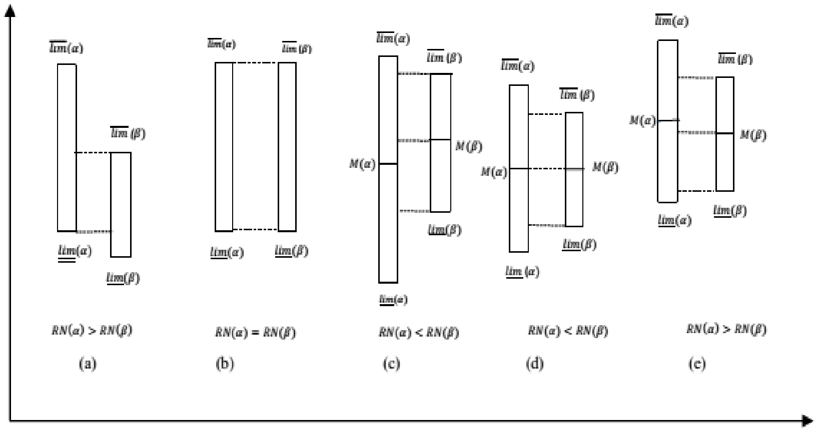

Figure 3. Comparison of rough numbers (Zhai et al., 2008)

Figure 3 shows a comparison of rough numbers on the basis of which the criteria or alternatives are ranked. A comparison of the two rough numbers is clearly defined, depending on the lower and upper limits.

After obtaining the values that mark the weight of the criteria in the same way it is necessary to make calculation for sub-criterion; so, the following is an example of the calculation for the subcriteria that belong to the logistics.

The individual pair-wise comparison matrices are as follows:

$$B_1 = \begin{bmatrix} 1 & 4 & 4 & 1/4 & 1/4 \\ 1/4 & 1 & 3 & 1/5 & 1/5 \\ 1/4 & 1/3 & 1 & 1/5 & 1/5 \\ 4 & 5 & 5 & 1 & 1 \\ 4 & 5 & 5 & 1 & 1 \end{bmatrix}, CR = 0{,}088 < 0{,}10$$

$$B_2 = \begin{bmatrix} 1 & 4 & 1/3 & 1 & 1/3 \\ 1/4 & 1 & 1/5 & 1/4 & 1/5 \\ 3 & 5 & 1 & 3 & 1 \\ 1 & 4 & 1/3 & 1 & 1/3 \\ 3 & 5 & 1 & 3 & 1 \end{bmatrix}, CR = 0{,}028 < 0{,}10$$

$$B_3 = \begin{bmatrix} 1 & 1/3 & 4 & 5 & 7 \\ 3 & 1 & 5 & 7 & 9 \\ 1/4 & 1/5 & 1 & 3 & 4 \\ 1/5 & 1/7 & 1/3 & 1 & 3 \\ 1/7 & 1/9 & 1/4 & 1/3 & 1 \end{bmatrix}, CR = 0{,}062 < 0{,}10$$

Obviously CRe < 0.1 (e= 1, 2, 3), all the comparison matrices are acceptable. Then integrated comparison matrix $\tilde{B}$ is generated by combining with the above three individual comparison matrices.

$$\tilde{B} = \begin{bmatrix} 1,1,1 & 4,4,1/3 & 4,1/3,4 & 1/4,1,5 & 1/4,1/3,7 \\ 1/4,1/4,3 & 1,1,1 & 3,1/5,5 & 1/5,1/4,7 & 1/5,1/5,9 \\ 1/4,3,1/4 & 1/3,5,1/5 & 1,1,1 & 1/5,3,3 & 1/5,1,4, \\ 4,1,1/5 & 5,4,1/7 & 5,1/3,1/3 & 1,1,1 & 1,1/3,3 \\ 4,3,1/7 & 5,5,1/9 & 5,1,1/4 & 1,3,1/3 & 1,1,1 \end{bmatrix}$$

Translate the elements in $\tilde{B}$ into rough numbers and correspondingly original integrated comparison matrix $\tilde{B}$ is converted into a rough comparison matrix.

Take as an example $\tilde{x}_{45} = \{1,1/3,3\}$

$$\underline{Lim}\left(\frac{1}{3}\right) = \frac{1}{3}, \quad \overline{Lim}\left(\frac{1}{3}\right) = \frac{1}{3}\left(1 + \frac{1}{3} + 3\right) = 1{,}44$$

$$\underline{Lim}(1) = \frac{1}{2}\left(1 + \frac{1}{3}\right) = 0{,}66, \quad \overline{Lim}(1) = \frac{1}{2}(1 + 3) = 2$$

$$\underline{Lim}(3) = \frac{1}{3}\left(1 + \frac{1}{3} + 3\right) = 1{,}44, \quad \overline{Lim}(3) = 3$$

Thus, x_{45}^{e} can be expressed in rough number:

$$RN(x_{45}^{1}) = RN(1) = [0{,}66; 2]$$

$$RN(x_{45}^{2}) = RN\left(\frac{1}{3}\right) = [0{,}33; 1{,}44]$$

$$RN(x_{45}^{3}) = RN(3) = [1{,}44; 3]$$

According to Eqs. (17) - (19)

$$x_{45}^{L} = \frac{x_{45}^{1} + x_{45}^{2} + x_{45}^{s}}{S} = \frac{0{,}66 + 0{,}33 + 1{,}44}{3} = 0{,}81$$

$$x_{45}^{U} = \frac{x_{45}^{1} + x_{45}^{2} + x_{45}^{s}}{S} = \frac{2 + 1{,}44 + 3}{3} = 2{,}15$$

Thus rough sequence $\tilde{x}_{245}$ in $\tilde{B}$ is transformed into rough number $RN(x_{45}) = [0{,}81; 2{,}15]$. The transformation of other elements in $\tilde{B}$ is implemented in the same way.

Then, the rough comparison matrix is obtained:

$$M = \begin{bmatrix} [1; 1] & [1{,}96; 3{,}59] & [1{,}96; 3{,}59] & [0{,}98; 3{,}36] & [1{,}02; 4{,}40] \\ [0{,}56; 1{,}78] & [1; 1] & [1{,}51; 3{,}91] & [0{,}97; 4{,}37] & [1{,}18; 5{,}09] \\ [0{,}56; 1{,}78] & [0{,}77; 3{,}17] & [1; 1] & [1{,}45; 2{,}69] & [0{,}84; 2{,}74] \\ [0{,}84; 2{,}74] & [1{,}75; 4{,}18] & [0{,}85; 2{,}93] & [1; 1] & [0{,}81; 2{,}15] \\ [1{,}36; 3{,}29] & [2{,}28; 4{,}46] & [0{,}98; 3{,}36] & [0{,}81; 2{,}15] & [1; 1] \end{bmatrix}$$

Calculate rough weights of the criteria using Eqs. (21) and (22).

$$w = \{[1{,}31; 2{,}86]; [0{,}99; 2{,}74]; [0{,}88; 2{,}11]; [1{,}00; 2{,}35]; [1{,}20; 2{,}54]\}$$

$$w' = \{[0{,}46; 1{,}00]; [0{,}35; 0{,}96]; [0{,}31; 0{,}74]; [0{,}35; 0{,}82]; [0{,}42; 0{,}89]\}$$

In order to obtain the final values of the subcriteria belonging to the logistics group, the following values are needed:

$$w' = \{[0{,}46; 1{,}00]; [0{,}35; 0{,}96]; [0{,}31; 0{,}74]; [0{,}35; 0{,}82]; [0{,}42; 0{,}89]\}$$

Multiplying with the values of the main criterion-logistics $[0{,}36; 0{,}83]$ gives the following values:

$$w'' = \{[0{,}17; 0{,}83]; [0{,}13; 0{,}80]; [0{,}11; 0{,}61]; [0{,}13; 0{,}68]; [0{,}15; 0{,}74]\}$$

The most important logistics sub-criteria are delivery and reliability, which in the overall ranking occupy high positions, which can be seen in Table 2.

Following the above described methodology, the values for all the twenty criteria are obtained and shown in Figure 4.

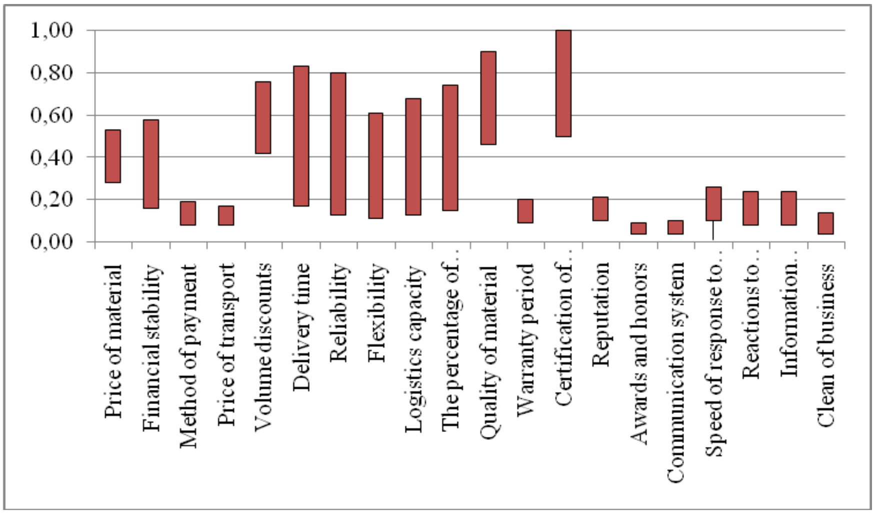

Figure 4 Values of all criteria in rough numbers

Figure 4 shows that the certification of products which is used in (Birgün Barla, 2003; Jamil et al., 2013; Ting & Cho, 2008; Uygun et al., 2013) and quality (Fallahpour et al., 2017; Kilic, 2013; Özbek, 2015; Stević et al., 2016; Wang et al., 2017) are of utmost importance in the company which is the subject of our research. These two criteria are very important because the company exports its products to the international market. The third place is taken by the criterion of volume discounts (Jamil et al., 2013; Wang, 2010) because the company is located on the territory of Bosnia and Herzegovina which is a very poor country; thus, additional discounts in business are very popular. The next most important criterion is that of delivery time (Chan & Kumar, 2007; Sawik, 2010; Yücenur et al., 2011; Rezaei et al., 2014) and reliability (Gencer & Gürpinar, 2007; Muralidharan et al., 2002; Büyüközkan & Göçer, 2017).

4. Comparison and discussion

Once the results are obtained, a sensitivity analysis including comparison of the values of the criteria using three different forms of the AHP method is carried out.

Figure 5 presents the values of the main criteria obtained using conventional AHP, Fuzzy AHP and Rough AHP, while in Table 2 presented are all the results of the sensitivity analysis including all the twenty criteria. The sensitivity analysis is very important for all types of research; a very studious example of the sensitivity analysis in the multicriteria decision-making can found in the paper (Pamučar et al., 2017b) in which the authors use different methods for ranking solution.

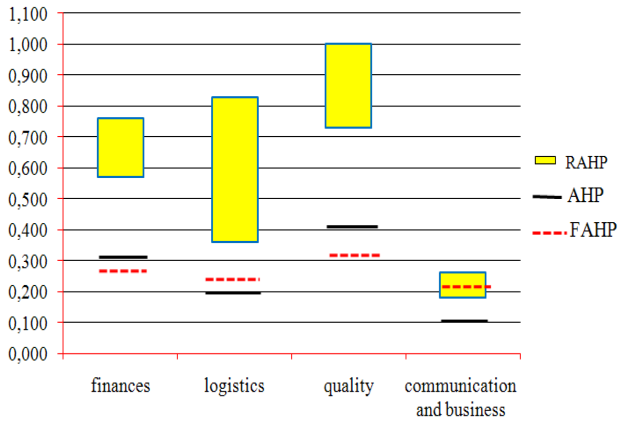

Figure 5. Values of main criteria using AHP, FAHP and RAHP

Certification of products is the most important criterion using AHP and rough AHP, while quality is the most important one using fuzzy AHP. Of equal rank by all the methods is volume discount which thus occupies the third position. The results show that the rough AHP has more similarity with the conventional AHP for this research.

Table 2. Results of sensitivity analysis

Criteria	AHP		FAHP		RAHP	
	Values	Rank	Values	Rank	Values	Rank
Price of material	0,084	4	0,068	4	(0,28;0,53)	7
Financial stability	0,047	5	0,052	6	(0,16;0,58)	8
Method of payment	0,025	14	0,039	13	(0,08;0,19)	14
Price of transport	0,025	14	0,026	18	(0,08;0,17)	15
Volume discounts	0,122	3	0,074	3	(0,42;0,76)	3
Delivery time	0,047	5	0,056	5	(0,17;0,83)	4
Reliability	0,033	10	0,043	11	(0,13;0,80)	5
Flexibility	0,034	9	0,042	12	(0,11;0,61)	9
Logistics capacity	0,039	7	0,050	7	(0,13;0,68)	10
The percentage of correct realization of delivery	0,043	6	0,047	10	(0,15;0,74)	6
Quality of material	0,149	2	0,114	1	(0,46;0,90)	2
Warranty period	0,032	11	0,037	14	(0,09;0,20)	13
Certification of products	0,164	1	0,102	2	(0,50;1,00)	1
Reputation	0,037	8	0,033	15	(0,10;0,21)	12
Awards and honors	0,017	16	0,021	19	(0,04;0,09)	18
Communication system	0,012	17	0,032	16	(0,04;0,10)	17
Speed of response to requirements	0,029	12	0,048	8	(0,10;0,26)	11
Reactions to reclamation	0,027	13	0,044	9	(0,08;0,24)	11
Information Technology	0,021	15	0,043	11	(0,08;0,24)	11
Clean of business	0,011	18	0,031	17	(0,04;0,14)	16

Ranking all criteria from the first to the twentieth place is also shown in Figure 6.

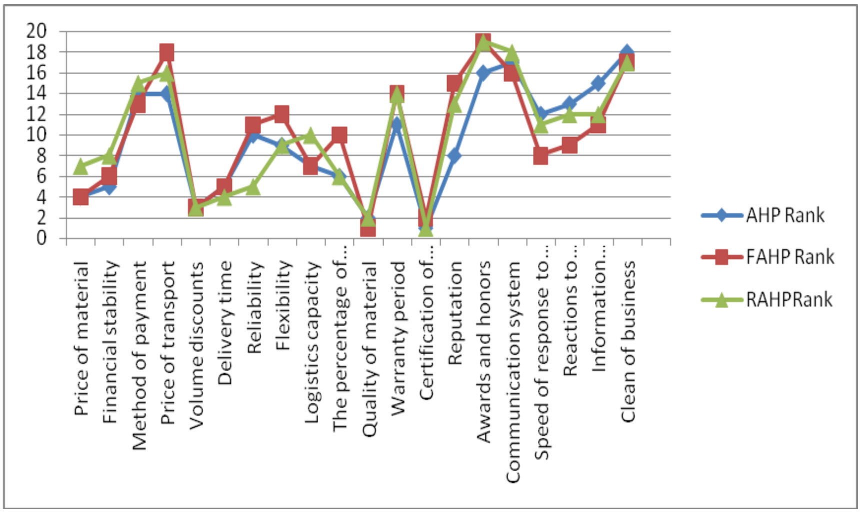

Figure 6. Ranking criteria by the three forms of the AHP method

The consequence of different results using different methods is reflected in different scales for evaluating criteria, which according to Mukhametzyanov & Pamučar (2017) is one of the five main reasons that influence the obtaining of results and their ranking.

Rough AHP according to (Roy et al., 2016) enables us to measure consistency of preferences, manipulate multiple decision-makers and calculate relative importance for each criterion. The rough AHP according to (Song et al., 2013) combines the strength of rough sets in handling subjectivity and the advantage of AHP in hierarchy evaluation.

5. Conclusion

This study proposes a rough group AHP approach to the evaluation supplier criteria in the company for producing metal washers for the automotive industry. According to the methodology applied in this paper the conclusion is that decision-making based on the rough AHP can be very helpful in production companies. The proposed models allow the evaluation of alternatives despite the imprecision and lack of quantitative information in the decision-making process. Future research related to this work based on the most important criteria represents the application of some of the multicriteria methods based on the rough theory, for example the rough TOPSIS for suppliers evaluation and their ranking.

References

Birgün Barla, S. (2003). A case study of supplier selection for lean supply by using a mathematical model. *Logistics Information Management*, *16*(6), 451-459.

Büyüközkan, G., & Göçer, F. (2017). Application of a new combined intuitionistic fuzzy MCDM approach based on axiomatic design methodology for the supplier selection problem. Applied Soft Computing, 52, 1222-1238.

Chai, J., & Liu, J. N. (2014). A novel believable rough set approach for supplier selection. Expert Systems with Applications, 41 (1), 92-104

Chan, F. T., & Kumar, N. (2007). Global supplier development considering risk factors using fuzzy extended AHP-based approach. Omega, 35 (4), 417-431.

Davis, T. (1993). Effective supply chain management. Sloan management review, 34 (4), 35.

Duntsch, I., Gediga, G. (1997). The rough set engine GROBIAN. In: A. Sydow (ed.), Proceedings 15th IMACS World Congress, Berlin, Wissenschaft und Technik Verlag, Berlin 4, 613-618.

Fallahpour, A., Olugu, E. U., & Musa, S. N. (2017). A hybrid model for supplier selection: integration of AHP and multi expression programming (MEP). Neural Computing and Applications, 28(3), 499-504.

Fazlollahtabar, H., Vasiljević, M., Stević, Ž., & Vesković, S. (2017). Evaluation of supplier criteria in automotive industry using rough AHP. The 1st International Conference on Management, Engineering and Environment ICMNEE, 186-197.

Gencer, C., & Gürpinar, D. (2007). Analytic network process in supplier selection: A case study in an electronic firm. Applied mathematical modelling, 31 (11), 2475-2486.

Jamil, N., Besar, R., & Sim, H. K. (2013). A study of multicriteria decision making for supplier selection in automotive industry. Journal of Industrial Engineering, 2013, Article ID 841584, 1-22.

Kagnicioglu, C. H. (2006). A fuzzy multiobjective programming approach for supplier selection in a supply chain. The Business Review, 6(1), 107-115.

Khoo, L.-P., & Zhai, L.-Y. (2001). A prototype genetic algorithm enhanced rough set-based rule induction system. Computers in Industry, 46 (1), 95–106.

Kilic, H. S. (2013). An integrated approach for supplier selection in multi-item/multi-supplier environment. Applied Mathematical Modelling, 37 (14), 7752-7763.

Liang, D., Xu, Y., Liu, D. (2017). Three-way decisions with intuitionistic fuzzy decision-theoretic rough sets based on point operators. Information Sciences 375, 183–201.

Mukhametzyanov, I., & Pamučar, D. (2017). Multi-criteria decision making methods: Sensivity of results in variation of estimaons of alternatives by criteria. The 1st International Conference on Management, Engineering and Environment ICMNEE, 2-24

Muralidharan, C., Anantharaman, N., & Deshmukh, S. G. (2002). A multi-criteria group decision making model for supplier rating. Journal of supply chain management, 38 (3), 22-33.

Nauman, M., Nouman, A., & Yao, J.T. (2016). A three-way decision making approach to malware analysis using probabilistic rough sets. Information Sciences, 374, 193–209.

Özbek, A. (2015). Supplier Selection with Fuzzy TOPSIS. Journal of Economics and Sustainable Development, 6 (18), 114-125.

Pamučar, D., Mihajlović, M., Obradović, R., & Atanasković, P. (2017a). Novel approach to group multi-criteria decision making based on interval rough numbers: Hybrid DEMATEL-ANP-MAIRCA model. Expert Systems with Applications, 88, 58-80

Pamučar, D., Božanić, D., & Ranđelović, A. (2017b). Multi-criteria decision making: An example of sensitivity analysis. Serbian Journal of Management, 12 (1), 1-27.

Pawlak, Z. (1991). Rough sets: Theoretical aspects of reasoning about data. Kluwer Academic Publishing: Dordrecht.

Pawlak, Z. (1982). Rough sets. International Journal of Computer & Information Sciences, 11(5), 341–356

Rezaei, J., Fahim, P. B., & Tavasszy, L. (2014). Supplier selection in the airline retail industry using a funnel methodology: Conjunctive screening method and fuzzy AHP. Expert Systems with Applications, 41(18), 8165-8179.

Roy, J., Chatterjee, K., Bandhopadhyay, A., & Kar, S. (2016). Evaluation and selection of Medical Tourism sites: A rough AHP based MABAC approach. arXiv:1606.08962.

Saaty, T.L., & Vargas, L.G. (2012). Models, methods, concepts & applications of the analytic hierarchy process. Springer Science & Business Media, 175 (2), 1-346.

Sawik, T. (2010). Single vs. multiple objective supplier selection in a make to order environment. Omega, 38 (3), 203-212.

Shidpour, H., Da Cunha, C., & Bernard, A. (2016). Group multi-criteria design concept evaluation using combined rough set theory and fuzzy set theory. Expert Systems with Applications, 64, 633-644.

Song, W., Ming, X., Wu, Z., & Zhu, B.A. (2014). Rough TOPSIS approach for failure mode and effects analysis in uncertain environments. Quality and Reliability Engineering International, 30(4), 473-486.

Song, W., Ming, X., & Wu, Z. (2013). An integrated rough number-based approach to design concept evaluation under subjective environments. Journal of Engineering Design, 24 (5), 320-341.

Stević, Ž. (2017a). Criteria for supplier selection: A literature review. International Journal of Engineering, Business and Enterprise Applications, 19(1), 23-27.

Stević, Ž. (2017b). Evaluation of supplier selection criteria in agricultural company using fuzzy AHP method, 22th International Scientific Conference Strategic Management and Decision Support Systems in Strategic Management, 607-612.

Stević, Ž. (2017c). Modeling performance of logistics subsystems using fuzzy approach. Transport & Logistics: The International Journal, 17 (42), 30-39.

Stević, Ž., Pamučar, D., Zavadskas, K.E., Ćirović, G., & Prentkovskis, O. (2017d). The Selection of Wagons for the Internal Transport of a Logistics Company: A Novel Approach Based on Rough BWM and Rough SAW Methods. Symmetry, 9 (11), 1-25.

Stević, Ž., Pamučar, D., Vasiljević, M., Stojić, G., & Korica, S. (2017e). Novel Integrated Multi-Criteria Model for Supplier Selection: Case Study Construction Company. Symmetry, *9*(11), 1-25.

Stević, Ž., Tanackov, I., Vasiljević, M., Novarlić, B., & Stojić, G. (2016). An integrated fuzzy AHP and TOPSIS model for supplier evaluation. Serbian Journal of Management, 11(1), 15-27.

Ting, S.C., & Cho, D.I. (2008). An integrated approach for supplier selection and purchasing decisions. Supply Chain Management: An International Journal, 13(2), 116-127.

Tiwari, V., Jain, P.K., Tandon, P. (2016). Product design concept evaluation using rough sets and VIKOR method, Advanced Engineering Informatics, 30, 16-25.

Uygun, Ö., Kaçamak, H., Ayşim, G., & Şimşir, F. (2013). Supplier Selection for Automotive Industry Using Multi-Criteria Decision Making Techniques. Turkish Online Journal of Science & Technology, 3(4), 25-38.

Van Weele, A. J. (2009). Purchasing and supply chain management: Analysis, strategy, planning and practice. Cengage Learning EMEA.

Wang, T. K., Zhang, Q., Chong, H. Y., & Wang, X. (2017). Integrated supplier selection framework in a resilient construction supply chain: An approach via analytic hierarchy process (AHP) and grey relational analysis (GRA). Sustainability, *9*(2), 28-39.

Wang, W. P. (2010). A fuzzy linguistic computing approach to supplier evaluation. Applied Mathematical Modelling, 34 (10), 3130-3141.

Yücenur, G. N., Vayvay, Ö., & Demirel, N. Ç. (2011). Supplier selection problem in global supply chains by AHP and ANP approaches under fuzzy environment. The International Journal of Advanced Manufacturing Technology, 56(5), 823-833.

Zhai, L. Y., Khoo, L. P., & Zhong, Z. W. (2008). A rough set enhanced fuzzy approach to quality function deployment. The International Journal of Advanced Manufacturing Technology, 37 (5), 613-624.

Zhai, L.-Y., Khoo, L.-P., & Zhong, Z.-W. (2009). A rough set based QFD approach to the management of imprecise design information in product development. Advanced Engineering Informatics, 23 (2), 222-228.

Zhu, G. N., Hu, J., Qi, J., Gu, C. C., & Peng, Y. H. (2015). An integrated AHP and VIKOR for design concept evaluation based on rough number. Advanced Engineering Informatics, 29(3), 408-418.