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A NEW WAY OF APPLYING INTERVAL FUZZY LOGIC IN GROUP DECISION MAKING FOR SUPPLIER SELECTION

Abstract: Today, there is strong competition in the market, and therefore an adequate process of selecting suppliers, as one of the key activities in the supply chain management, can contribute to the company's overall business. In an empirical research that dealt with the selection of suppliers for a paper manufacturing company, it was necessary to select a supplier that would contribute to improving the environmental awareness of this company. The selection of suppliers in this paper is based on the application of the interval fuzzy logic and the group decision making model. Interval fuzzy logic was applied to the AHP and TOPSIS methods. The AHP method has determined the weights of the criteria, while TOPSIS method ranks the supplier based on the distance from an ideally positive and negative solution. Linguistic values were used to meet the criteria of supplier. Based on a practical example conducted on real suppliers, it has been established that supplier A_6 shows the best results in relation to other suppliers. These results were confirmed by sensitivity analysis.

Keywords: supplier selection, interval fuzzy logic, AHP, TOPSIS, sensitivity analysis.

JEL Classification: C02, C44, L67

1. Introduction

The selection of suppliers is one of the most important elements in supply chain management and logistics in a single company. In order to start production, it is necessary to procure materials, raw materials and machines. Based on this, the choice of suppliers is one of the most important aspects of planning production and its control with the company (Tamošaitienė et al, 2017). Choosing the wrong supplier violates the financial position of the company (Önüt et al, 2009), and the competitiveness of the company is undermined. In order to make this section, it is necessary to include different suppliers in the decision making, which are

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evaluated based on a number of criteria using different methods. This process is a fundamental problem in multi-criteria decision making (MCDM). There are many ways in which this deciding problem can be solved, and various methods such as linear programming models, stochastic methods, statistical and other methods can be used.

In addition to qualitative and quantitative criteria, it is possible to evaluate individual suppliers according to certain criteria through linguistic values. The application of linguistic values instead of traditional quantitative expressions is a useful concept for solving situations that are too complex or insufficiently determined (Yazdani et al, 2011). Linguistic values are represented in the form of a scale that needs to be transformed into numerical values in order to perform the process of selecting a supplier. In order to transform linguistic values into numerical, it is possible to use fuzzy logic. According to Zadeh (1965), fuzzy logic can be used as a narrow approach in which the fuzzy logic is an extension of classical logic and a wider approach where fuzzy logic is used in sets that do not have clear boundaries. Fuzzy approach is closer to human thinking because in the real world there are situations that are not defined and it is difficult to determine the boundaries of the set. This is particularly present when it comes to qualitative criteria. Therefore, it is best to use linguistic values in the form of a scale in these criteria. In this paper fuzzy logic will be used when choosing a supplier. In this case, the interval fuzzy logic will be used. When choosing a supplier, subjective assessments of the importance of particular criteria will be used and will be evaluated by individual vendors according to these criteria. In order to determine the weights of the supplier selection criteria, the interval fuzzy AHP (IVFS AHP) method is selected, which performs the subjective determination of the weight of the criterion. The IVFS AHP method works on comparing pairs of criteria and alternatives. Due to the fact that there would be too many pairs to compare each of the alternative suppliers according to the individual criterion with the IVFS AHP method, the interval fuzzy TOPSIS (IVFS TOPSIS) method will also be used. IVFS TOPSIS is based on the concept that a particular alternative should have the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution (Lu et al, 2007). In doing so, the best alternative is closest to the ideal positive solution, that is, the longest of the ideal negative solution. Since this study uses fuzzy logic when choosing a supplier, it is necessary to look at similar works that deal with this topic. Zeydan et al, (2011) used fuzzy AHP (FAHP), fuzzy TOPSIS (FTOPSIS) and DEA method for selecting suppliers in the automotive industry. Using the FAHP method they determined the weights of the criteria, with the FTOPSIS method they ranged the criteria while the DEA method was used to establish compliance with the criteria of individual suppliers. Kabir (2012) used FAHP to determine the weights of the criteria while with TOPSIS method he was assessing and selecting a logistics service provider, using three-fold fuzzy numbers. Kannan et al, (2013) ranked suppliers in the Green Supply Chain System. In doing so, they used FAHP to determine the weights of the criteria, FTOPSIS for determining the rank of the supplier's rankings and with the multi-

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point programming methods performed the verification of meeting the criteria for
certain suppliers. Junior et al, (2014) carried out the ranking of suppliers in the
automotive industry by applying FAHP to determine the weights of the criteria,
and the FTOPSIS method was used to determine the ranking order. Stević et al,
(2016) used the FAHP and TOPSIS method in the selection of suppliers. FAHP
was used to determine the weight of the criteria and the TOPSIS method for
ranking suppliers. In this paper FAHP method will be used to determine the
weights of the criteria, using interval fuzzy logic, while the FTOPSIS method will
be used to rank the suppliers. Expert judgment will also be used to determine the
weights of the criteria and for evaluating suppliers according to given criteria
through linguistic values. In order to explain on a practical example a new
approach to using interval fuzzy logic, it is first necessary to treat the concept of
interval fuzzy logic theoretically and to explain the methods used. In order to make
it easier to apply this methodology, the simplification of the IVFS AHP method, as
well as the IVFS TOPSIS method, has been carried out in this paper. Therefore, the
second part of the paper explains the interval fuzzy logic. The third part explains
the IVFS AHP method, and in the fourth part, the IVFS TOPSIS method is
explained. The fifth part is in charge of a new approach of applying interval logic
on a real example of supplier selection. In the sixth part, the sensitivity analysis
was carried out and the most important conclusions were derived.

2. Interval fuzzy logic

When we use the theory of fuzzy sets it is very difficult for the decision maker
(DM) to precisely define his opinion in the interval [0, 1]. For this reason, it is
better to form the opinion using linguistic value, and through the fuzzy logic to
transform it into an interval [0, 1]. Interval-valued fuzzy (IVFS) was first used in
Gorzalczany (1987). After that, this approach is used in other papers. The
application of this approach is very diverse and it is increasingly used in practice
(Ghorabaee et al, 2016), so it is necessary to define the interval fuzzy logic.

Based on the Gorzalczany's approach (1987), the basics of interval fuzzy logic
were derived. The use of IVFS is defined in the interval (-∞, + ∞) and the
following relations are given:

$$
\begin{aligned}
&A = \left\{ \left(x, \left[\mu_A^L(x), \mu_A^U(x) \right] \right) \right\} \\
&\mu_A^L, \mu_A^U : X \rightarrow [0,1] \forall x \in X, \mu_A^L \leq \mu_A^U \\
&\overline{\mu}_A(x) = \left[\mu_A^L(x), \mu_A^U(x) \right] \\
&A = \left\{ \left(x, \overline{\mu}_A(x) \right) \right\}, x \in (-\infty, \infty)
\end{aligned}
\tag{1}
$$

Where is μ_A^L the lower limit of membership degree and μ_A^U the upper limit of
membership degree to the fuzzy function.

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Bearing in mind the two boundaries of the interval fuzzy logic $N_x = \left[N_x^-; N_x^+\right]$ and $M_y = \left[M_y^-; M_y^+\right]$ the following definitions are set:

Definition 1 The basic mathematical operations between these sets in the interval fuzzy logic are:

Addition and Subtraction of IVFN numbers:

$$\tilde{N} \pm \tilde{M} = \left[\left(N_1, N_1^*\right); N_2; \left(N_3^*, N_3\right)\right] \pm \left[\left(M_1, M_1^*\right); M_2; \left(M_3^*, M_3\right)\right] = \\ \left[\left(N_1 \pm M_1, N_1^* \pm M_1^*\right), N_2 \pm M_2; \left(N_3^* \pm M_3^*, N_3 \pm M_3\right)\right] \tag{2}$$

Multiplication of fuzzy numbers:

$$\tilde{N} \times \tilde{M} = \left[\left(N_1, N_1^*\right); N_2; \left(N_3^*, N_3\right)\right] \times \left[\left(M_1, M_1^*\right); M_2; \left(M_3^*, M_3\right)\right] = \\ \left[\left(N_1 \times M_1, N_1^* \times M_1^*\right), N_2 \times M_2; \left(N_3^* \times M_3^*, N_3 \times M_3\right)\right] \tag{3}$$

Division of fuzzy numbers:

$$\tilde{N} \div \tilde{M} = \left[\left(N_1, N_1^*\right); N_2; \left(N_3^*, N_3\right)\right] \div \left[\left(M_1, M_1^*\right); M_2; \left(M_3^*, M_3\right)\right] = \\ \left[\left(N_1 \div M_3, N_1^* \div M_3^*\right), N_2 \div M_2; \left(N_3^* \div M_1^*, N_3 \div M_1\right)\right] \tag{4}$$

Multiplication by plain number

$$q \times \tilde{N} = q \times \left[\left(N_1, N_1^*\right); N_2; \left(N_3^*, N_3\right)\right] = \left[\left(q \times N_1, q \times N_1^*\right); q \times N_2; \left(q \times N_3^*, q \times N_3\right)\right] \tag{5}$$

Division by plain number

$$\tilde{N} \div q = \left[\left(N_1, N_1^*\right); N_2; \left(N_3^*, N_3\right)\right] \div q, = \left[\left(\frac{N_1}{q}, \frac{N_1^*}{q}\right); \frac{N_2}{q}; \left(\frac{N_3^*}{q}, \frac{N_3}{q}\right)\right] \tag{6}$$

Definition 2 The average of two IVFS (Gorzalczany, 1987) is defined as the minimum of the lower and upper limits of the interval. Two intervals [0, 1] and $M_y = \left[M_y^-; M_y^+\right] \subset [0,1]$ are given, the minimum value for both these intervals is: $K = Min\left(N_x, M_y\right) = \left[Min\left(N_x^-, M_y^-\right), Min\left(N_x^+, M_y^+\right)\right]$.

Definition 3 The average of two IVFS (Mousavi et al, 2013) is defined as the maximum of the lower and upper limits of the interval. Two intervals are given: [0,1] and $M_y = \left[M_y^-; M_y^+\right] \subset [0,1]$, where the maximum value for both these intervals is: $K = Max\left(N_x, M_y\right) = \left[Max\left(N_x^-, M_y^-\right), Max\left(N_x^+, M_y^+\right)\right]$.

Definition 4 Absolute value: $\left|N_x\right| = Max\left\{\left|N_x^-\right|, \left|N_x^+\right|\right\}$

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Definition 5 Let the $\tilde{N}$ and $\tilde{M}$ be two triangles IVFS where it is
$\tilde{N} = \left[\left(N_1, N_1^*\right); N_2; \left(N_3^*, N_3\right)\right]$ and $\tilde{M} = \left[\left(M_1, M_1^*\right); M_2; \left(M_3^*, M_3\right)\right]$. These IVFS
can be represented as follows:

$$h(\tilde{N}) = \frac{N_1 + N_1^* + 2N_2 + N_3^* + N_3}{6} \qquad (7)$$

i $h(\tilde{M}) = \frac{M_1 + M_1^* + 2M_2 + M_3^* + M_3}{6} \qquad (8)$

It can be said that it is $\tilde{N} > \tilde{M}$ if it is $h(\tilde{N}) > h(\tilde{M})$.

In this paper, the following linguistic values of IVFS will be used to determine the
importance of alternatives for individual criteria (Table 1) and for determining the
weights of the criteria (Table 2).

Table 1. Definitions of linguistic variables for the ratings

Very Poor (VP)	[(0, 0); 0; (1, 1.5)]
Poor (P)	[(0, 0.5); 1; (2.5, 3.5)]
Medium Poor (MP)	[(0, 1.5); 3; (4.5, 5.5)]
Medium (F)	[(2.5, 3.5); 5; (6.5, 7.5)]
Medium Good (MG)	[(4.5, 5.5); 7; (8, 9.5)]
Good (G)	[(5.5, 7.5); 9; (9.5, 10)]
Very Good (VG)	[(8.5, 9.5); 10; (10, 10)]

Table 2. Definitions of linguistic variables for the importance of each criterion

Equally (E)	[(1, 1); 1; (1, 1)]
Very Low Strong (LS)	[(1, 1.5); 2; (2.5, 3)]
Slightly Strong (SS)	[(2, 2.5); 3; (3.5 , 4)]
Medium Strong (MS)	[(3, 3.5); 4; (4.5, 5)]
Fairly Strong (FS)	[(4, 4.5); 5; (5.5, 6)]
Preferred Strong (PS)	[(5, 5.5); 6; (6.5, 7)]
Very Strong (VS)	[(6, 6.5); 7; (7.5, 8)]
Very High Strong (VH)	[(7, 7.5); 8; (8.5, 9)]
Absolutely Strong (AS)	[(8, 8.5); 9; (9, 9)]

3. IVF AHP method

The AHP method was developed by Saaty in 1980. It is based on the comparison
of pairs of alternatives, where the decision maker expresses the intensity, weight of
the preferences of one alternative relative to the other, within the essential criteria
(Puška, 2011). In the same way, the criteria are compared according to their own
preferences and their intensity. Making a decision using the AHP method is
applied using assessment of the weight of the criterion (Turskis and Zavadskas,
2010). In order to better contribute to solving the uncertainty and undetermined in
decision-making, the AHP method has been integrated with an interactive fuzzy
logic. Kahraman et al, (2012) and Sari et al, (2013) were the first studies that

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focused on the use of interval fuzzy logic with the AHP method. In this paper presented the application of the IVFS AHP method that will be used in decision making in the group. The procedure for applying the IVFS AHP method consists of the following steps:

Steps 1 Defining a problem and setting a goal.

Step 2 Structuring the problem, setting the target to the top, the criteria in the middle and alternatives to the bottom of the structure.

Step 3 Comparison of criteria or alternatives in pairs and the assignment of linguistic values presented in Table 2. Based on these comparisons, fuzzy pairwise comparison matrices are formed as following (Oztaysi, 2015):

$$\tilde{\tilde{A}} = \begin{bmatrix} 1 & \tilde{\tilde{a}}_{12} & \Lambda & \tilde{\tilde{a}}_{1n} \\ \tilde{\tilde{a}}_{21} & 1 & \Lambda & \tilde{\tilde{a}}_{2n} \\ M & M & O & M \\ \tilde{\tilde{a}}_{n1} & \tilde{\tilde{a}}_{n2} & \Lambda & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{\tilde{a}}_{12} & \Lambda & \tilde{\tilde{a}}_{1n} \\ 1/\tilde{\tilde{a}}_{12} & 1 & \Lambda & \tilde{\tilde{a}}_{2n} \\ M & M & O & M \\ 1/\tilde{\tilde{a}}_{1n} & 1/\tilde{\tilde{a}}_{2n} & \Lambda & 1 \end{bmatrix} \quad (9)$$

Where:

$$1/a = \left(\left(\frac{1}{a_{13}^u}, \frac{1}{a_{12}^u}, \frac{1}{a_{11}^u}; H_1\left(a_{12}^u\right), H_2\left(a_{13}^u\right) \right), \left(\frac{1}{a_{23}^u}, \frac{1}{a_{22}^u}, \frac{1}{a_{21}^u}; H_1\left(a_{22}^u\right), H_2\left(a_{23}^u\right) \right) \right)$$

Step 4 Transformation of linguistic values into fuzzy numbers. Since this is an interval fuzzy logic in the transformation of linguistic values of the weights of the criteria, two matrices of decision are formed for each of the intervals:

$$A = \begin{bmatrix} 1 & a_{12}, b_{12}, c_{12}^* & \Lambda & a_{1n}, b_{1n}, c_{1n}^* \\ 1/c_{12}^*, 1/b_{12}, 1/a_{12} & 1 & \Lambda & a_{2n}, b_{2n}, c_{2n}^* \\ M & M & O & M \\ 1/c_{1n}^*, 1/b_{1n}, 1/a_{1n} & 1/c_{2n}^*, 1/b_{2n}, 1/a_{2n} & \Lambda & 1 \end{bmatrix} \quad (10)$$

$$A' = \begin{bmatrix} 1 & a_{12}^*, b_{12}, c_{12} & \Lambda & a_{1n}^*, b_{1n}, c_{1n} \\ 1/c_{12}, 1/b_{12}, 1/a_{12}^* & 1 & \Lambda & a_{2n}^*, b_{2n}, c_{2n} \\ M & M & O & M \\ 1/c_{1n}, 1/b_{1n}, 1/a_{1n}^* & 1/c_{2n}, 1/b_{2n}, 1/a_{2n}^* & \Lambda & 1 \end{bmatrix} \quad (11)$$

Formed matrices show that in the case of reciprocal values, the order of fuzzy numbers changes, because if the fuzzy number function does not change, the first fuzzy number would be the largest and the third the smallest. In this way, a membership function is formed which on the following example looks like this: $1/c_{12} \le 1/b_{12} \le 1/a_{12}^*$.

Step 5 Normalization of the matrix.

In this step, the normalization of the decision matrices is carried out, which can be done in different ways, and in this example, the classic normalization used by Saaty (1980), when presenting this method, will be taken.

$$r_{ij} = \frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}, \frac{b_{ij}}{\sum_{j=1}^{n} b_{ij}}, \frac{c_{ij}}{\sum_{j=1}^{n} c_{ij}} \tag{12}$$

Step 6 Calculating the weight of a criterion or an alternative.

After that, the geometric mean for the rows representing individual criteria, or alternatives, is calculated. The geometric mean is done as follows:

$$w_{ia} = \sqrt[n]{a_{i1} \cdot a_{i2} \cdot \mathrm{K} \cdot a_{in}} \tag{13}$$

Using this formula, we calculate the weight values for all fuzzy numbers. After that, the denazification of weights is done using the following formula, and a crisp number is obtained (Kahraman et al, 2014):

$$A = \frac{g_{ij} + 4h_{ij} + l_{ij}}{6} \tag{14}$$

The next step is to calculate the total weight that is obtained as the average weights of intervals:

$$w = \frac{wA + wA^{*}}{2} \tag{15}$$

4. IVFS TOPSIS method

The TOPSIS method was first applied by Hwang and Yoon (1981). The basis of this method is the principle that the best alternative is the one with the shortest distance from the Positive Ideal Solution (PIS), i.e. the greatest distance from the Negative-Ideal Solution (NIS). The PIS is the ideal solution where are the smallest costs but the biggest benefit, while NIS is the worst solution where are the highest costs but least benefit. Based on this approach, Chen and Hwang (1992) developed the approach to applying the TOPSIS method in a fuzzy set.

In this paper the following steps will be applied when using the TOPSIS method in IVFS.

Steps 1 Normalization of decision matrix. This is the first step of each method for multi-criteria analysis (MCA). In this paper, the normalization of TYPE 1 or 'the free linear normalization' will be used. With this method, the criteria of benefits are shared with the maximum value of the membership function, while the criteria of costs are divided with a minimum value. Based on this, the following membership function was given: $\tilde{x} = \left[\left(a_{ij}, a_{ij}^{*} \right), b_{ij}; \left(c_{ij}^{*}; c_{ij} \right) \right]$.

Using the normalization proposed by Chen (2000), it can be calculated as:

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$$\tilde{r}_{ij} = \left[\left(\frac{a_{ij}}{c_j^+}, \frac{a_{ij}^*}{c_j^+} \right); \frac{b_{ij}}{c_j^+}; \left(\frac{c_{ij}^*}{c_j^+}, \frac{c_{ij}}{c_j^+} \right) \right], i = 1,...,n, \; j \in \Omega_b$$

$$\tilde{r}_{ij} = \left[\left(\frac{a_j^-}{c_{ij}^*}, \frac{a_j^-}{c_{ij}} \right); \frac{a_j^-}{b_{ij}}; \left(\frac{a_j^-}{a_{ij}}, \frac{a_j^-}{a_{ij}^*} \right) \right], i = 1,...,n, \; j \in \Omega_c$$

(16)

Where it is

$$c_j^+ = \underset{i}{Max} c_{ij}, j \in \Omega_b$$

$$a_j^- = \underset{i}{Min} a_{ij}, j \in \Omega_c$$

(17)

Further steps will be explained on the basis of a corrected approach from Ashtiani et al, (2009).

Step 2 Multiplication of a normalized matrix.

In this step, the normalized values of the decision matrix with weighted values are multiplied and the following form is made:

$$\tilde{v}_{ij} = \left[\left(\tilde{r}_{1ij} \times \tilde{w}_{1j}, \tilde{r}_{1ij}^* \times \tilde{w}_{1j}^{*'} \right); \tilde{r}_{2ij} \times \tilde{w}_{2j}; \left(\tilde{r}_{3ij}^* \times \tilde{w}_{3j}^{*'}, r_{31ij} \times \tilde{w}_{3j} \right) \right] =$$

$$= \left[\left(g_{ij}, g_{ij}^* \right); h_{ij}; \left(l_{ij}^*, l_{ij} \right) \right]$$

(18)

Step 3 Defining an ideally positive and negative solution.

The PIS can be defined as:

$$A^+ = \left\{ v_1^+, K, v_n^+ \right\} = \left\{ \left(\underset{j}{max} \, v_{ij} \middle| i \in I \right), \left(\underset{j}{min} \, v_{ij} \middle| i \in J \right) \right\}$$

(19)

NIS can be defined as:

$$A^- = \left\{ v_1^-, K, v_n^- \right\} = \left\{ \left(\underset{j}{min} \, v_{ij} \middle| i \in I \right), \left(\underset{j}{max} \, v_{ij} \middle| i \in J \right) \right\}$$

(20)

Step 4 Determining the distance of alternatives from ideal solutions.
In this step the n-dimensional Euclidean distances of all alternatives of an ideally positive and ideally negative solution are calculated by means of relations.

$$D^- \left(\tilde{N}, \tilde{M} \right) = \sqrt{ \frac{1}{3} \sum_{i=1}^{3} \left[\left(N_{xi}^- - M_{yi}^- \right)^2 \right] }$$

(21)

$$D^+ \left(\tilde{N}, \tilde{M} \right) = \sqrt{ \frac{1}{3} \sum_{i=1}^{3} \left[\left(N_{xi}^+ - M_{yi}^+ \right)^2 \right] }$$

(22)

Where $D^- \left(\tilde{N}, \tilde{M} \right)$ and $D^+ \left(\tilde{N}, \tilde{M} \right)$ are the primary and secondary distant measure, respectively. Thereby, distance of each alternative from the ideal alternative $\left[D_{i1}^+, D_{i2}^+ \right]$ can be currently calculated, where (Ashtiani et al, 2009):

$$D_{i1}^+ = \sum_{j=1}^{m} \sqrt{\frac{1}{3}\left[\left(g_{ij} - g_j^+\right)^2 + \left(h_{ij} - h_j^+\right)^2 + \left(l_{ij}^* - l_j^{*+}\right)^2\right]}$$

$$D_{i2}^+ = \sum_{j=1}^{m} \sqrt{\frac{1}{3}\left[\left(g_{ij}^* - g_j^{*+}\right)^2 + \left(h_{ij} - h_j^+\right)^2 + \left(l_{ij} - l_j^+\right)^2\right]}$$

(23)

Simultaneously, for negative ideal solutions the following terms are followed:

$$D_{i1}^- = \sum_{j=1}^{m} \sqrt{\frac{1}{3}\left[\left(g_{ij} - g_j^-\right)^2 + \left(h_{ij} - h_j^-\right)^2 + \left(l_{ij}^* - l_j^{*-}\right)^2\right]}$$

$$D_{i2}^- = \sum_{j=1}^{m} \sqrt{\frac{1}{3}\left[\left(g_{ij}^* - g_j^{*-}\right)^2 + \left(h_{ij} - h_j^-\right)^2 + \left(l_{ij} - l_j^-\right)^2\right]}$$

(24)

Applying this principle, less data is lost than combining these two formulas into one.

Step 5 Determining the relative proximity of an alternative to an ideal solution.

Since in this example we have two intervals and two solutions, it is necessary to calculate the average value of the solution of the relative proximity of the alternative to the ideal solution for both intervals. Relative proximity calculations are calculated as follows:

$$CC_1 = \frac{D_{i1}^-}{D_{i1}^+ + D_{i1}^-}, CC_2 = \frac{D_{i2}^-}{D_{i2}^+ + D_{i2}^-}$$

(25)

And the final solution is calculated by finding the average of these two solutions:

$$CC_i^* = \frac{CC_1 + CC_2}{2}$$

(26)

5. Integrated model to the supplier selection problem

The integrated model of the supplier selection problem will be done on the example from the practice. For example, a paper manufacturing company will be used. The biggest problem with paper production is of ecological nature. Therefore, it is necessary to pay attention to suppliers during the production of paper and try to reduce ecological problems. Suppliers can supply materials, equipment and services that will reduce the occurrence of environmental risks in the production of paper. Since these decisions require long-term investment of the company, it is important to select a supplier who will help him in solving these production problems. The proposed supplier selection model was implemented in the mentioned company. The basic task of this model is to use a group decision to select a supplier with which the company could establish long-term partnership relations. This is why a detailed survey was conducted through the distribution of questionnaires to the managers of this company. On the basis of the obtained data, the criteria for the selection of the supplier were

reduced. After comparing all the criteria and alternatives, a comparative questionnaire was developed to determine the weights of the criteria used for the AHP method and the determination of the linguistic values of each supplier for individual criteria was made. Certain criteria are presented in Table 3. The goal of this model is to select a supplier that best meets the set decision goals. The proposed model is presented in Figure 1.
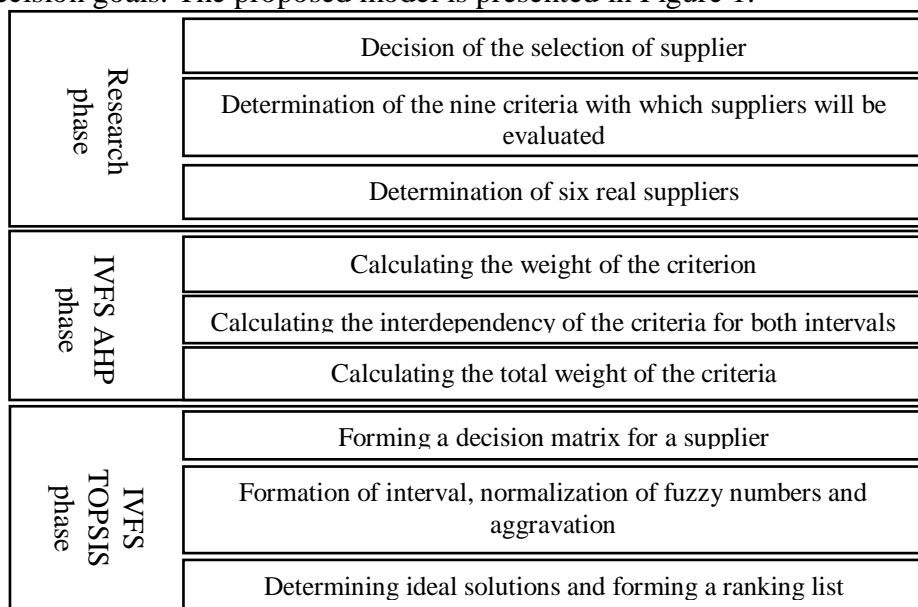
Research phase	Decision of the selection of supplier
	Determination of the nine criteria with which suppliers will be evaluated
	Determination of six real suppliers
IVFS AHP phase	Calculating the weight of the criterion
	Calculating the interdependency of the criteria for both intervals
	Calculating the total weight of the criteria
IVFS TOPSIS phase	Forming a decision matrix for a supplier
	Formation of interval, normalization of fuzzy numbers and aggravation
	Determining ideal solutions and forming a ranking list

Figure 1. Proposed approach of supplier selection

Table 3. Criteria for the selection of suppliers

Id	Criteria	Definition
C_1	Additional discount on quantity	Possibility to obtain a lower price per unit of production if a larger quantity is purchased.
C_2	Certification of the product	The certification implies confirmation by an independent organization that the products conform to certain normative documents.
C_3	Price	Price is the value of a product, goods, or service.
C_4	Quality	Quality is the degree to which a set of product characteristics meets customer requirements.
C_5	Warranty period	The warranty period is the time for which the manufacturer guarantees the value of the warranty on the products.
C_6	Method of payment	Methods in which the payment to the supplier can be made.
C_7	Reputations	Reputation marks the general opinion of the supplier, which relates to his reputation.
C_8	Delivery time	It represents the deadline for when the supplier is going to deliver his products or services.
C_9	Reliability	Reliability is the probability that the supplier will perform all the tasks envisaged within a specified period of time.

Based on the established criteria, it can be concluded that C_3 - price and C_8 - delivery time, are the cost criteria and it is desirable that these values be as low as possible, while other criteria are benefit criteria, i.e. it is desirable that their value be as high as possible. All calculations were done in MS Excel. Since the first phase has been completed and criteria and suppliers were selected, it is necessary to determine the weights of the criteria using the IVFS AHP method. Since the opinions of the three decision makers were taken (DMs), in Table 4 are presented their preference values of the criteria by means of the linguistic variables which are presented in Table 2.

Table 4. Comparison of criteria by pairs for each decision maker

DM1	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	E	SS	1/SS	1/MS	MS	PS	MS	SS	FS
C_2	1/SS	E	1/MS	1/FS	SS	FS	SS	E	MS
C_3	SS	MS	E	1/SS	FS	VS	FS	SS	PS
C_4	MS	FS	SS	E	PS	VH	PS	FS	VS
C_5	1/MS	1/SS	1/FS	1/PS	E	MS	E	1/SS	SS
C_6	1/PS	1/FS	1/VS	1/VH	1/MS	E	1/MS	1/FS	1/SS
C_7	1/MS	1/SS	1/FS	1/PS	E	MS	E	1/SS	SS
C_8	1/SS	E	1/SS	1/FS	SS	FS	SS	E	MS
C_9	1/FS	1/MS	1/PS	1/VS	1/SS	SS	1/SS	1/MS	E
DM2	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	E	SS	1/VS	1/VH	MS	FS	MS	SS	FS
C_2	1/SS	E	1/VS	1/VH	SS	MS	SS	1/MS	MS
C_3	VS	VS	E	1/MS	MS	PS	FS	MS	FS
C_4	VH	VH	MS	E	FS	VS	PS	FS	PS
C_5	1/MS	1/SS	1/MS	1/FS	E	SS	SS	1/FS	VL
C_6	1/FS	1/MS	1/PS	1/VS	1/SS	E	1/FS	1/PS	1/MS
C_7	1/MS	1/SS	1/FS	1/PS	1/SS	FS	E	1/FS	SS
C_8	1/SS	MS	1/MS	1/FS	FS	PS	FS	E	MS
C_9	1/FS	1/MS	1/FS	1/PS	1/VL	MS	1/SS	1/MS	E
DM3	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	E	MS	1/MS	1/MS	FS	VS	FS	MS	PS
C_2	1/MS	E	1/FS	1/FS	SS	FS	SS	1/VS	MS
C_3	MS	FS	E	E	PS	VH	PS	FS	VS
C_4	MS	FS	E	E	PS	VH	PS	FS	VS
C_5	1/FS	1/SS	1/PS	1/PS	E	MS	VL	1/SS	SS
C_6	1/VS	1/FS	1/VH	1/VH	1/MS	E	1/MS	1/FS	1/SS
C_7	1/FS	1/SS	1/PS	1/PS	1/VL	MS	E	1/SS	SS
C_8	1/MS	VS	1/FS	1/FS	SS	FS	SS	E	MS
C_9	1/PS	1/MS	1/VS	1/VS	1/SS	SS	1/SS	1/MS	E

Since there are three DMs, the DM1 example will present the methodology for implementing the IVFS AHP method. Based on linguistic values, the transformation of linguistic values into fuzzy numbers in the form of an interval is made. Therefore, two matrices for each of the intervals are formed. After the matrix of criteria is established for both intervals, normalization is performed, and

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the geometric mean for each fuzzy number is calculated. The same procedure is carried out with all DMs. By applying this procedure, the weights of the criteria for each DMs was determined (Table 5).

Table 5. The weights of the criteria for the decision maker

DM1	Fuzzy weight for the interval A			wA	Fuzzy weight for the interval A '			wA'	w
C_1	0.14	0.14	0.15	0.144	0.14	0.15	0.15	0.146	0.145
C_2	0.09	0.09	0.09	0.086	0.08	0.09	0.09	0.085	0.085
C_3	0.21	0.21	0.21	0.214	0.22	0.22	0.22	0.217	0.215
C_4	0.33	0.33	0.31	0.328	0.34	0.33	0.33	0.334	0.331
C_5	0.05	0.05	0.05	0.047	0.04	0.05	0.04	0.045	0.046
C_6	0.02	0.02	0.02	0.019	0.02	0.02	0.02	0.018	0.018
C_7	0.05	0.05	0.05	0.047	0.06	0.06	0.06	0.058	0.052
C_8	0.09	0.09	0.09	0.089	0.07	0.07	0.07	0.069	0.079
C_9	0.03	0.03	0.03	0.029	0.03	0.03	0.03	0.027	0.028
DM2	Fuzzy weight for the interval A			wA	Fuzzy weight for the interval A '			wA'	w
C_1	0.15	0.15	0.15	0.151	0.15	0.15	0.15	0.153	0.152
C_2	0.08	0.08	0.08	0.077	0.07	0.08	0.08	0.076	0.076
C_3	0.23	0.23	0.23	0.231	0.24	0.23	0.23	0.233	0.232
C_4	0.30	0.31	0.29	0.302	0.32	0.31	0.31	0.310	0.306
C_5	0.05	0.05	0.06	0.052	0.05	0.05	0.05	0.052	0.052
C_6	0.03	0.02	0.03	0.024	0.02	0.02	0.02	0.023	0.023
C_7	0.04	0.04	0.04	0.041	0.05	0.05	0.05	0.051	0.046
C_8	0.09	0.09	0.09	0.092	0.07	0.07	0.07	0.073	0.082
C_9	0.03	0.03	0.03	0.031	0.03	0.03	0.03	0.029	0.030
DM3	Fuzzy weight for the interval A			wA	Fuzzy weight for the interval A '			wA'	w
C_1	0.15	0.16	0.15	0.156	0.16	0.16	0.16	0.158	0.157
C_2	0.07	0.07	0.07	0.072	0.07	0.07	0.08	0.073	0.072
C_3	0.29	0.28	0.29	0.280	0.29	0.28	0.28	0.284	0.282
C_4	0.29	0.28	0.29	0.280	0.29	0.28	0.28	0.284	0.282
C_5	0.04	0.05	0.04	0.046	0.04	0.05	0.05	0.045	0.046
C_6	0.02	0.02	0.02	0.017	0.02	0.02	0.02	0.017	0.017
C_7	0.04	0.04	0.04	0.040	0.05	0.05	0.05	0.051	0.046
C_8	0.08	0.08	0.08	0.083	0.06	0.06	0.06	0.063	0.073
C_9	0.03	0.03	0.03	0.026	0.02	0.03	0.02	0.025	0.026

Based on DM preference, it can be concluded that the most important criterion for choosing supplier C_4 is the quality of products, then C_3 - the price that is particularly different from other criteria. The least importance for all DMs was C_6 - payment method, then criterion C_9 - reliability. It can be concluded that DMs equitably assigned criteria preferences and obtained similar weights. After calculating the weights of the criteria, it is necessary to evaluate suppliers with

linguistic values for each of the criteria. The evaluation of the suppliers is
presented in Table 6.

Table 6. Decision matrix for alternatives of every DM

DM1	C_1	C_2	C_3	C_4	C_5	C6	C_7	C_8	C_9
A_1	P	F	P	G	MG	MG	F	MP	P
A_2	F	MP	F	MG	MG	F	P	F	MP
A_3	G	G	G	G	MG	VG	VG	G	G
A_4	VP	MG	MG	F	MP	MP	MP	MG	MP
A_5	MP	P	MP	F	F	F	MG	MP	F
A_6	F	G	MG	G	MG	VG	G	VG	G
DM2	C_1	C_2	C_3	C_4	C_5	C6	C_7	C_8	C_9
A1	MP	MG	F	F	MG	G	F	F	P
A2	F	G	F	P	F	MG	MP	F	MP
A3	G	VG	MG	G	MG	G	G	G	VG
A4	P	MP	MG	F	MP	MP	MP	MG	F
A5	F	MP	F	P	F	F	MG	MP	MG
A6	MG	G	MG	MG	MG	VG	VG	VG	G
DM3	C_1	C_2	C_3	C_4	C_5	C6	C_7	C_8	C_9
A1	MP	G	MP	F	G	MG	F	MP	MP
A2	MG	G	MP	P	F	F	MP	MP	P
A3	F	MP	F	MP	MP	G	G	P	MG
A4	MP	F	MG	F	MP	P	F	MG	F
A5	VG	VG	MG	VG	G	VG	G	MG	VG
A6	MG	MG	G	G	G	VG	VG	G	G

By defining the membership function, linguistic values are transformed into the
corresponding fuzzy numbers, and two intervals are formed. To solve a group
decision model, it is calculated the average values for each supplier according to
certain criteria. The average values of the alternatives and weights are presented in
Tables 7 and 8.

Table 7. Average values for alternatives at the first interval

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.00, 2.33, 3.83	4.17, 7.00, 8.00	0.83, 3.00, 4.50	3.50, 6.33, 7.50	4.83, 7.67, 8.50	4.83, 7.67, 8.50	2.50, 5.00, 6.50	0.83, 3.67, 5.17	0.00, 1.67, 3.17
A_2	3.17, 5.67, 7.00	3.67, 7.00, 7.83	1.67, 4.33, 5.83	1.50, 3.00, 4.33	3.17, 5.67, 7.00	3.17, 5.67, 7.00	0.00, 2.33, 3.83	1.67, 4.33, 5.83	0.00, 2.33, 3.83
A_3	4.50, 7.67, 8.50	4.67, 7.33, 8.00	4.17, 7.00, 8.00	3.67, 7.00, 7.83	3.00, 5.67, 6.83	6.50, 9.33, 9.67	6.50, 9.33, 9.67	3.67, 6.33, 7.17	6.17, 8.67, 9.17
A_4	0.00, 1.33, 2.67	2.33, 5.00, 6.33	4.50, 7.00, 8.00	2.50, 5.00, 6.50	0.00, 3.00, 4.50	0.00, 2.33, 3.83	0.83, 3.67, 5.17	4.50, 7.00, 8.00	1.67, 4.33, 5.83
A_5	3.67, 6.00, 7.00	2.83, 4.67, 5.67	2.33, 5.00, 6.33	3.67, 5.33, 6.33	3.50, 6.33, 7.50	4.50, 6.67, 7.67	4.83, 7.67, 8.50	1.50, 4.33, 5.67	5.17, 7.33, 8.17
A_6	3.83, 6.33, 7.50	5.17, 8.33, 9.00	4.83, 7.67, 8.50	5.17, 8.33, 9.00	4.83, 7.67, 8.50	8.50, 10, 10	7.50, 9.67, 9.83	7.50, 9.67, 9.83	5.50, 9.00, 9.50
w	0.15	0.08	0.24	0.31	0.05	0.02	0.05	0.08	0.03

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Table 8. Average values for alternatives at the second interval

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	1.17, 2.33, 4.83	5.50, 7.00, 9.00	1.8, 3.00, 5.50	4.83, 6.33, 8.33	6.17, 7.67, 9.67	6.17, 7.67, 9.67	3.50, 5.00, 7.50	2.17, 3.67, 6.17	0.83, 1.67, 4.17
A_2	4.17, 5.67, 8.17	5.50, 7.00, 8.50	2.83, 4.33, 6.83	2.17, 3.00, 5.50	4.17, 5.67, 8.17	4.17, 5.67, 8.17	1.17, 2.33, 4.83	2.83, 4.33, 6.83	1.17, 2.33, 4.83
A_3	6.17, 7.67, 9.17	6.17, 7.33, 8.50	5.50, 7.00, 9.00	5.50, 7.00, 8.50	4.17, 5.67, 8.17	8.17, 9.33, 10	8.17, 9.33, 10	5.17, 6.33, 7.83	7.50, 8.67, 9.83
A_4	0.67, 1.33, 3.50	3.50, 5.00, 7.50	5.50, 7.00, 9.50	3.50, 5.00, 7.50	1.50, 3.00, 5.50	1.17, 2.33, 4.83	2.17, 3.67, 6.17	5.50, 7.00, 9.50	2.83, 4.33, 6.83
A_5	4.83, 6.00, 7.67	3.83, 4.67, 6.33	3.50, 5.00, 7.50	4.50, 5.33, 7.00	4.83, 6.33, 8.33	5.50, 6.67, 8.33	6.17, 7.67, 9.67	2.83, 4.33, 6.83	6.17, 7.33, 9.00
A_6	4.83, 6.33, 8.83	6.83, 8.33, 9.83	6.17, 7.67, 9.67	6.83, 8.33, 9.83	6.17, 7.67, 9.67	9.50, 10, 10	8.83, 9.67, 10	8.83, 9.67, 10	7.50, 9.00, 10
w	0.15	0.08	0.24	0.31	0.05	0.02	0.05	0.08	0.03

After a decision matrix has been formed for both intervals, data normalization is performed. The next step of the IVFS TOPSIS method is the multiplication of the normalized values with the corresponding weights of the criteria, and forming a weighted decision matrix.

Table 9. A weighted decision matrix for the first interval

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.00, 0.04, 0.06	0.03, 0.05, 0.06	0.02, 0.07, 0.11	0.11, 0.19, 0.23	0.02, 0.04, 0.04	0.01, 0.01, 0.02	0.01, 0.02, 0.03	0.01, 0.03, 0.04	0.00, 0.00, 0.01
A_2	0.05, 0.09, 0.11	0.03, 0.05, 0.06	0.04, 0.11, 0.14	0.05, 0.09, 0.13	0.02, 0.03, 0.03	0.01, 0.01, 0.01	0.00, 0.01, 0.02	0.01, 0.03, 0.05	0.00, 0.01, 0.01
A_3	0.07, 0.12, 0.13	0.04, 0.06, 0.06	0.10, 0.17, 0.19	0.11, 0.21, 0.24	0.01, 0.03, 0.03	0.01, 0.02, 0.02	0.03, 0.04, 0.05	0.03, 0.05, 0.06	0.02, 0.02, 0.03
A_4	0.00, 0.02, 0.04	0.02, 0.04, 0.05	0.11, 0.17, 0.19	0.08, 0.15, 0.20	0.00, 0.01, 0.02	0.00, 0.00, 0.01	0.00, 0.02, 0.02	0.04, 0.05, 0.06	0.00, 0.01, 0.02
A_5	0.06, 0.09, 0.11	0.02, 0.04, 0.04	0.06, 0.12, 0.15	0.11, 0.16, 0.19	0.02, 0.03, 0.04	0.01, 0.01, 0.01	0.02, 0.04, 0.04	0.01, 0.03, 0.04	0.01, 0.02, 0.02
A_6	0.06, 0.10, 0.11	0.04, 0.07, 0.07	0.12, 0.19, 0.21	0.16, 0.26, 0.28	0.02, 0.04, 0.04	0.02, 0.02, 0.02	0.04, 0.05, 0.05	0.06, 0.08, 0.08	0.02, 0.03, 0.03

Table 10. A weighted decision matrix for the second interval

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.02, 0.04, 0.07	0.04, 0.05, 0.07	0.04, 0.07, 0.13	0.15, 0.19, 0.26	0.03, 0.04, 0.05	0.01, 0.01, 0.02	0.02, 0.02, 0.04	0.02, 0.03, 0.05	0.00, 0.00, 0.01
A_2	0.06, 0.09, 0.12	0.04, 0.05, 0.07	0.07, 0.11, 0.17	0.07, 0.09, 0.17	0.02, 0.03, 0.04	0.01, 0.01, 0.02	0.01, 0.01, 0.02	0.02, 0.03, 0.05	0.00, 0.01, 0.01
A_3	0.09, 0.12, 0.14	0.05, 0.06, 0.07	0.13, 0.17, 0.22	0.17, 0.21, 0.26	0.02, 0.03, 0.04	0.02, 0.02, 0.02	0.04, 0.04, 0.05	0.04, 0.05, 0.06	0.02, 0.02, 0.03
A_4	0.01, 0.02, 0.05	0.03, 0.04, 0.06	0.13, 0.17, 0.23	0.11, 0.15, 0.23	0.01, 0.01, 0.03	0.00, 0.00, 0.01	0.01, 0.02, 0.03	0.04, 0.05, 0.07	0.01, 0.01, 0.02
A_5	0.07, 0.09, 0.12	0.03, 0.04, 0.05	0.09, 0.12, 0.18	0.14, 0.16, 0.21	0.02, 0.03, 0.04	0.01, 0.01, 0.02	0.03, 0.04, 0.05	0.02, 0.03, 0.05	0.02, 0.02, 0.03
A_6	0.07, 0.10, 0.13	0.05, 0.07, 0.08	0.15, 0.19, 0.24	0.21, 0.26, 0.30	0.03, 0.04, 0.05	0.02, 0.02, 0.02	0.04, 0.05, 0.05	0.07, 0.08, 0.08	0.02, 0.03, 0.03

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Since a weighted matrix of decision-making is formed, it is necessary for each of
the criteria to determine a positive and negative ideal point and to determine the
relative proximity of the alternatives to the ideal results using formulas 24 and 25.

Table 11. Results and ranking alternatives

	First interval			Second interval			CC^*	Rank
	D_{i1}^+	D_{i1}^-	CC_1	D_{i2}^+	D_{i1}^-	CC_2		
A_1	0.328	0.163	0.332	0.335	0.168	0.334	0.333	5
A_2	0.358	0.132	0.268	0.366	0.136	0.271	0.270	6
A_3	0.104	0.388	0.789	0.103	0.399	0.795	0.792	2
A_4	0.304	0.187	0.381	0.312	0.194	0.383	0.382	4
A_5	0.248	0.244	0.496	0.259	0.245	0.486	0.491	3
A_6	0.017	0.472	0.966	0.017	0.485	0.967	0.966	1

Table 11 gives aggregate results and shows that A_6 is the best ranked supplier
while the worst ranked supplier is A_2.

6. Sensitivity analysis

When performing the sensitivity analysis, a change in the weights of the criteria is
made, and the effect on the result of the analysis is examined. When conducting the
sensitivity analysis in this paper, the change in the strength of the criteria was
applied so that to all DMs the biggest strength was given to one criterion, while the
importance of the other criteria remained unchanged. Using this principle, 9
different calculations were obtained. The weight changes according to each
criterion are presented in Table 12. In the first calculation, in all DM, the value of
the C1 criterion was changed in "absolutely strong", while the value of the other
criteria remained unchanged. This procedure was applied to all criteria.

Table 12. Criterion weights in sensitivity analysis

	1	2	3	4	5	6	7	8	9
C_1	0.42	0.10	0.12	0.12	0.09	0.09	0.09	0.10	0.10
C_2	0.07	0.43	0.07	0.07	0.05	0.05	0.05	0.06	0.05
C_3	0.14	0.13	0.43	0.17	0.13	0.13	0.13	0.14	0.15
C_4	0.17	0.16	0.19	0.44	0.16	0.16	0.16	0.16	0.15
C_5	0.04	0.04	0.04	0.04	0.43	0.03	0.03	0.04	0.03
C_6	0.02	0.02	0.02	0.02	0.02	0.44	0.02	0.02	0.02
C_7	0.05	0.04	0.05	0.05	0.04	0.03	0.42	0.04	0.03
C_8	0.06	0.06	0.07	0.07	0.05	0.05	0.06	0.43	0.05
C_9	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.43

By applying these methods of conducting the sensitivity analysis, results have been
obtained that the values of the criteria for which the strength "absolutely strong"
were assigned were between 0.42 and 0.44. In this way, the value of this criterion
is absolutely higher than other criteria. By using the weights presented in Table 14,
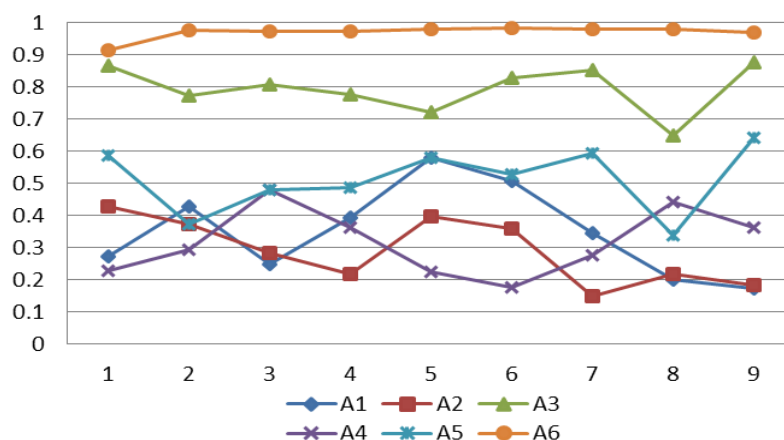the results of the sensitivity analysis presented in Figure 2 are obtained.

Figure 2. New CC* values of the alternatives

The obtained results of the sensitivity analysis show that supplier A_6 is completely insensitive to the change in the weights of certain criteria and has shown the best results in all 9 calculations. Similar results are shown by the supplier A_3, who was in second place in all the changes in the criteria. The biggest change in the results of this supplier was when C_8 criterion were changed - delivery time. Supplier A_5 showed sensitivity to C_2 - product certification changes, when it split 4th place with A_2 supplier and when C_8 criterion was changed, when A_4 supplier was better than him. In changing C_9 criterion this supplier has achieved the best results. Supplier A_1 showed the highest sensitivity when changing the criteria C_3, C_8 and C_9 when it showed the worst results compared to other suppliers. The best result he was achieved when changing the C_5 criterion. A_4 supplier showed the highest sensitivity to changes in the C_1, C_5 and C_6 criteria, where he scored the worst result compared to other suppliers. The best results were achieved by this supplier when changing the criterion C_3. Supplier A_2 achieved the worst results in changing the C_7 criterion and the best results for C_1 criterion when this supplier got fourth place in ranking.

7. Conclusion

A supplier's selection is a technique for estimating a limited number of suppliers and a selection of suppliers that best meets the decision-making goals. On this basis, the aim of this work is analyzing the potential suppliers and selects the best supplier by using interval fuzzy logic. Many criteria influence this selection which makes the decision making process more difficult. Due to the existence of different types of criteria fuzzy approach simplifies the process of evaluating suppliers using linguistic values. In the paper the IVFS AHP is used to assess the weights of criteria and IVFS TOPSIS method is used to select suppliers. The results showed that supplier A_6 showed the best results and the smallest sensitivity to the change in the weights of the criteria. This evaluation of suppliers has proven to be very useful when applying different criteria. In future studies, the above procedure should be

applied to other MCDM methods and different ways of determining the weights of
the criteria as well as using other criteria.

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