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A TWO-PHASE FUZZY AHP – FUZZY TOPSIS MODEL FOR SUPPLIER EVALUATION IN MANUFACTURING ENVIRONMENT

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Abstract: *Supplier selection is one of the most important issues in supply chain management (SCM) which greatly affects its performance and market competitiveness. In the recent years, supplier selection in SCM has become imperative to balance between the ordinal and cardinal criteria. This paper proposes a two-phase model which aims to evaluate and select suppliers using an integrated Fuzzy Analytical Hierarchy Process (FAHP) and Fuzzy Technique for Ordering Preference by Similarity to Ideal Solution (FTOPSIS) methods. A fully developed model consisting of several evaluation criteria, both quantitative and qualitative in nature, as assessed by FAHP method to estimate the criteria weights, while FTOPSIS method is used to rank the potential suppliers that have been singled out through expert assessment. The proposed model is a support tool in the optimization of the purchasing process, and it provides the possibility of realizing additional savings by developing stronger cooperation with the optimal supplier.*

Key words: *Supply chain management, Supplier selection, FAHP, FTOPSIS*

1. Introduction

According to Gunasekaran and Ngai, (2004), supply chain management (SCM) is one of the vital strategies in the 21st century to achieve global competitive advantage. Supply logistics plays a crucial role in today's SCM. In the last few decades, and especially in recent years; there is an evidential change in the role of SCM in business policies. According to Knežević et. al. (2012), acquisition is treated as an integrated strategic business function that aims to connect all other functions, enable smooth execution of all processes and activities in the company, and create a high added value based on the relationship with suppliers. From all the above, it is well understood that importance of SCM will continue to grow over time.

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Appropriate choice of suppliers is an issue of strategic importance and key activity for industries in modern SCs due of its central role in deciding price, quality, delivery and service to achieve organizational objectives (Kagnicioglu, 2006).

According to Lasch and Janker, (2005) effective supplier management that begins with the identification of potential suppliers is vital for a successful SCM. Ghodsypour and O'Brien, (2001) believed that satisfactory choice of suppliers significantly reduces costs which, according to Ghodsypour and O'Brien, (1998) represented up to 70% of the product price and increase competitiveness, while Önüt et. al. (2009) focused on end-user satisfaction associated with it.

The policy of relations and evaluation of sources of supply has a strategic importance for the whole procurement subsystem. This subsystem can effectively perform the tasks relating to the supply of the company, if it selects supplier or suppliers (not too many of them) that can meet the requirements of the procurement subsystem, and which are related to the quality, quantity, price, terms of delivery and other terms, reliability, flexibility, as well as other objectives that are to be met, satisfying other criteria too.

Search for suppliers that meets the above criteria is a permanent and primary task. To that end, it is necessary to continuously collect and process information about suppliers and establish and maintain adequate relations with them; further, it is necessary to develop and apply methods for the evaluation and ranking of potential suppliers. De Boer et. al. (2001), have identified four stages of the selection of suppliers, as follows: problem definition, formulation of criteria, qualification and, selection. The correct choice of suppliers from the start provides opportunity for a timely, continuous and quality production which brings above mentioned benefits making the production competitive.

The main activity of the company where the research was carried out is the production of pre-insulated pipes for heating; in order for the company to organize this production it is necessary to procure steel pipes. Out of a large number of companies which could be potential suppliers of steel pipes it is necessary to select those whose characteristics, according to the criteria of the procurement subsystem of the company, are the most adequate. After a complete and long-term market analysis performed by the company's expert team, they selected five suppliers that represent potential solutions. In addition, the expert team had set a total of nine criteria on the basis of which it is necessary to make the evaluation of suppliers. Considering the current market needs and requirements, and at the same time taking into account the knowledge and skills obtained through the years of work, the team of experts has evaluated the criteria as well in order to provide different weight value, which greatly affects the ranking of alternatives.

The primary objective and the contribution of this paper is to propose a two-phase model integrating Fuzzy Analytical Hierarchy Process (FAHP) and Fuzzy Technique for Ordering Preference by Similarity to Ideal Solution (FTOPSIS) methods for supplier selection through establishing long-term cooperation with the selected supplier to gain additional market advantage.

This paper is structured as follows. Section 2 presents the literature review on supplier selection. Section 3 presents fundamentals of fuzzy sets, FAHP and FTOPSIS methods. Section 4 demonstrates the considered real time example and explains the results of the integrated multi-criteria model. Section 5 presents a sensitivity analysis which includes the experiment of 24 sets where the values of criteria are changed. This section also discuss about the stability of the model. Section 6 sets out the conclusions.

2. Literature review

There are numerous criteria for evaluating suppliers, but the question is how to choose the right ones from a given set, which will be used to choose the best solution. Dickson, (1966) is considered to be a pioneer in this field because he was the first to create a study on the evaluation of suppliers in which he defined a set of 23 criteria by which the evaluation and selection of the best suppliers could be carried out.

In his paper Ellram, (1990), he tried to increase the importance of qualitative criteria that should enable long-term cooperation between the company and suppliers. He divided criteria into four groups: financial aspects, organizational culture and strategic issues, technology issues, and other. Further, the authors from the end of the last century attempted to answer this question, and Webber et. al. (1991) investigated the criteria for the selection of suppliers in manufacturing and retail environment. A group of authors concluded that quality, delivery and price prevail as dominant criteria, while geographical location, financial position and production capacity are secondary factors. After this, Verma and Pullman, (1998) conducted a survey among a large number of managers in order to examine how they reach compromise when selecting suppliers. Their research indicated that managers place highest priority to quality as the most important attribute of suppliers, followed by delivery and price. Research on the impact of the criteria in the SC continues at the beginning of this century, and Karpak et. al. (2001) recognized reliability of delivery as a criterion for selection, whereas Bhutta and Huq, (2002) used four criteria for evaluating suppliers: price, quality, technology and service. Research conducted in (Çebi and Bayraktar, 2003) singled out the following group of criteria: logistics, technology, commerce and business cooperation that contain both quantitative and qualitative criteria.

Combination FAHP and FTOPSIS methods are often used for evaluation performance in SC and selection supplier, for example evaluating performance for selection of suppliers in car manufacturing factory in Turkey (Zeydan et. al. 2011), for evaluation of the performance of suppliers in company which produced several types of electronic cards (Eraslan and Atalay, 2014). Shukla et. al. (2014) illustrates how FAHP and FTOPSIS can be integrated to allow for a more consistent evaluation and prioritization of SC partner. Chen and Yang, (2011) are used constrained FAHP and FTOPSIS for supplier selection. These integrated methods are also used for solving next problems: for the selection and development of reverse logistics partner in India (Prakash and Barua 2016), ranking of the industry alternatives for portfolio investments (Dincer et. al. 2016), for handling equipment selection (Yazdani, 2014), for mining method selection in zinc producer in Iran (Yazdani et. al. 2012) or combination more methods of MCDM with QFD for selection green supplier (Yazdani et. al. 2016), combination AHP, GIS and integer programming for evaluation in reverse logistics (Acar et. al. 2015), combination fuzzy VIKOR and AR-DEA method for supplier selection (Mohaghar et. al. 2013)

By using FAHP and FTOPSIS, uncertainty and vagueness from subjective perception and the experiences of decision maker can be effectively represented and reached to a more effective decision (Ertugrul and Karakasoglu, 2008).

3. Material and methods

3.1. Fuzzy Sets

Fuzzy sets are sets whose elements have degrees of membership. The theory of fuzzy sets was first introduced by Zadeh, (1965), whose application enables decision makers to effectively deal with the uncertainties. In classical set theory, the membership of elements in a set is assessed in binary terms according to a bivalent condition - an element either belongs or does not belong to the set. Fuzzy sets used generally triangular (TFN), trapezoidal and Gaussian fuzzy numbers.

A fuzzy number A˜ on R to be a TFN if its membership function leA μ_A~(x): R→[0,1] is equal to following Equation (1):

$$M_A{\sim}(x) = \begin{cases} \frac{x-l}{m-l}, & l \le x \le m \\ \frac{u-x}{u-m}, & m \le x \le u \\ 0, & otherwise \end{cases} \tag{1}$$

From equation (1), *l* and *u* mean the lower and upper bounds of the fuzzy number $\tilde{A}$, and *m* is the modal value for $\tilde{A}$ (Figure 1). The TFN can be denoted by $\tilde{A} = (l, m, u)$.

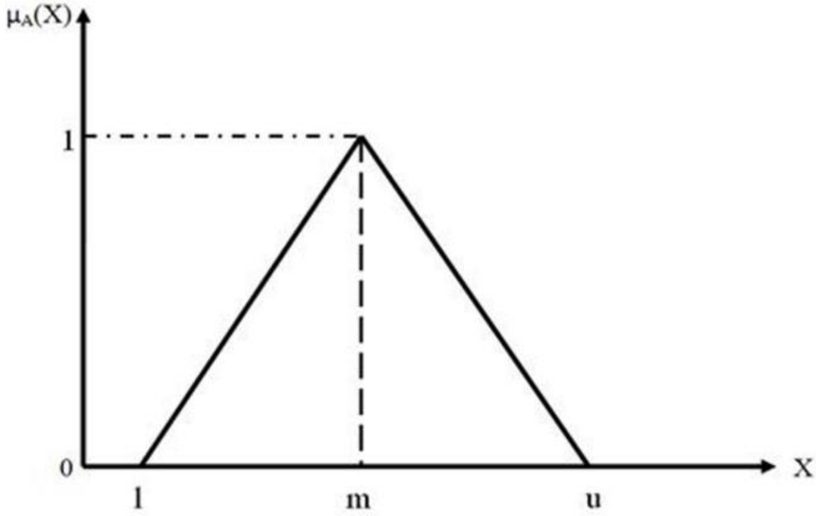

Figure 1. The membership functions of the TFN

The operational laws of TFN $\check{A}_1 = (l_1, m_1, u_1)$ and $\check{A}_2 = (l_2, m_2, u_2)$ are displayed as following equations.

Addition:

$$\check{A}_1 + \check{A}_2 = (l_1, m_1, u_1) + (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{2}$$

Multiplication:

$$\check{A}_1 x \check{A}_2 = (l_1, m_1, u_1) x (l_2, m_2, u_2) = (l_1 l_2, m_1 m_2, u_1 u_2) \text{ for } l_1 l_2 > 0;\ m_1 m_2 > 0;\ u_1 u_2 > 0 \tag{3}$$

Subtraction:

$$\breve{A}_1 - \breve{A}_2 = (l_1, m_1, u_1) - (l_2, m_2, u_2) = (l_1 - u_2, m_1 - m_2, u_{1-}l_2) \quad (4)$$

Division:

$$\frac{\breve{A}_1}{\breve{A}_2} = \frac{(l_1,m_1,u_1)}{(l_2,m_2,u_2)} = \left(\frac{l_1}{u_2}, \frac{m_1}{m_2}, \frac{u_1}{l_2}\right) \text{ for } l_1 l_2 > 0;\ m_1 m_2 > 0;\ u_1 u_2 > 0 \quad (5)$$

Reciprocal:

$$\breve{A}^{-1} = (l_1, m_1, u_1)^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \text{ for } l_1 l_2 > 0;\ m_1 m_2 > 0;\ u_1 u_2 > 0 \quad (6)$$

3.2. Fuzzy AHP method

Analytic hierarchy process is created by Thomas Saaty (Saaty, 1980) and according to him, AHP is a measurement theory which deals with pairwise criteria comparisons and which relies on expert opinion in order to perform the priority scale.

AHP in a certain ways resolves the problem of subjective influence of the decision-maker because it measures the degree of consistency (CR), and informs the decision makers of the result. Depending on the size of the matrix the value of this ratio is recommended, so in (Lee et. al. 2008) we find that the maximum permissible level of consistency for the 3x3 matrix is 0.05, for the 4x4 matrix it is 0.08, and for larger matrices it is 0.1.

Kwong's method (Kwong and Bai, 2003) has been used to check the consistency of pairwise judgement of comparison matrix. A TFN, denoted as M=(l,m,u), can be defuzzified to a crisp number as follows:

$$M_{-crisp} = \frac{(4m + l + u)}{6} \quad (7)$$

TFN, which were used in this work are marked as (lij,mij,uij). The parameters (l_{ij},m_{ij},u_{ij}) are the smallest possible value, the most promising value and highest possible value that describes a fuzzy event, respectively.

In this study, the extent analysis method by Chang, (1996) is adopted. Some advantages of this method are: Effectively handle both qualitative and quantitative data and easy to implement and understand (Tuysuz and Kahraman 2006), fuzzy AHP is preferable for widely spread hierarchies, where few importance/rating pairwise comparisons are required at lower level trees, can adopt linguistic variables (Ertugrul and Karakasoglu, 2008).

Let assume that X={x_1,x_2,...,xn} is number of objects, and U={u_1,u_2,...,um} is number of aims. According to the methodology of extended analysis set up by Chang, for each object an extended goal analysis is made. Values of the extended analysis "m" for each object can be represented as follows:

$$M_{gi,}^1 M_{gi,}^2 M_{gi,}^m i = 1,2, \dots n., \quad (8)$$

where $M_{g,}^j\ j = 1,2, \dots m.,$ are fuzzy triangular numbers.

Chang's expanded analysis includes following steps:

Step 1: the value of fuzzy synthetic extent S_i with respect to the i[th] criteria is defined as:

$$S_i = \sum_{j=1}^{n} M_{gi}^{j} \times \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \tag{9}$$

In order to obtain expression

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \tag{10}$$

it is necessary to perform additional fuzzy operations with "m" values of the extended analysis, which is represented by the following expressions:

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{11}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{n} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \tag{12}$$

Then it is necessary to calculate the inverse vector:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left[\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right] \tag{13}$$

Step 2: The degree of possibility of Sb ≥ Sa is defined as:

$$V(S_b \geq S_a) = \begin{cases} 1, & if\ m_b \geq m_a \\ 0, & if\ l_a \geq u_b \\ \frac{l_a - u_b}{(m_b - u_b) - (m_a - l_a)}, & otherwise \end{cases} \tag{14}$$

where „d" ordinate of a largest cross-section in point D between μSa andi μSb as shown in figure 2.

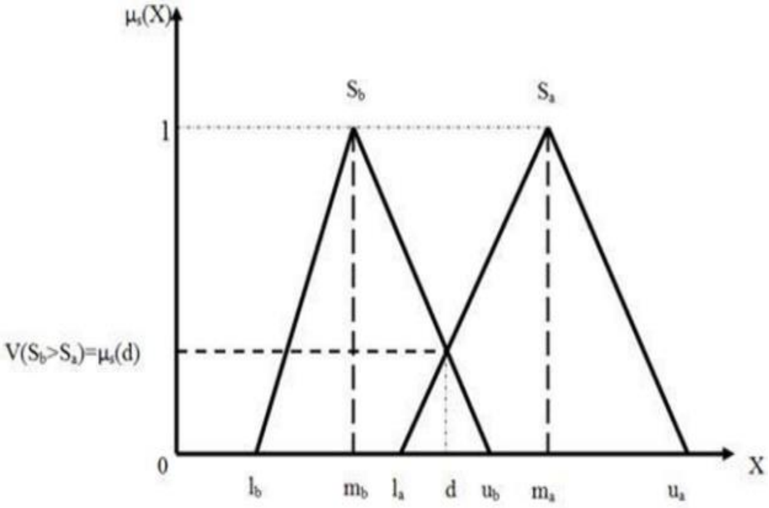

Figure 2. Intersection between Sa and Sb

To compare S_1 and S_2, both values $V(S_1 \geq S_2)$ and $V(S_2 \geq S_1)$ are needed.

Step 3: Level of possibility for convex fuzzy number to be greater than „k" convex number Si (i =1,2,...,k) can be defined as follows:

$$V(S_i \geq S_1,\ S_2, \ldots, S_k) = \min V(S_i \geq S_k), = w'\ (S_i) \tag{15}$$

$$d'(A_i) = \min V(S_i \geq S_k), k \neq i, k = 1,2, \ldots, n \tag{16}$$

The weight vector is given by the following expression:

$$W' = (\mathrm{d}'(A_1),\ \ \mathrm{d}'(A_2), \ldots, \mathrm{d}'(A_n))^T, \tag{17}$$

Step 4: Through normalization, the weight vector is reduced to the phrase:

$$W = (\mathrm{d}(A_1),\ \ \mathrm{d}(A_2), \ldots, \mathrm{d}(A_n))^T, \tag{18}$$

3.3. Fuzzy TOPSIS method

Due to its simple concept, TOPSIS method has become very popular and it is applied in many areas of decision-making. However, despite that, this method is often criticized because it lacks the ability to adequately handle uncertainty and imprecision in the moment when the decision maker needs accurate results. For this reason, in this paper we use the extended FTOPSIS method which allows proper handling of uncertainty and imprecision, and it is completely appropriate for the ranking of alternatives.

TOPSIS was first proposed by (Hwang and Yoon, 1981) and a Fuzzy TOPSIS method was later introduced by (Chen and Hwang, 1992).

The algorithm of the FTOPSIS method can be described as follows: (Chen, 2000)

Step 1: Form a committee of decision-makers, then identify the evaluation criteria.

Step 2: Choose the appropriate linguistic variables for the importance weight of the criteria and the linguistic ratings for alternatives with respect to criteria.

Step 3: Aggregate the weight of criteria to get the aggregated fuzzy weight $\widetilde{w}_j$ of criterion C_j, and pool the decision maker's opinions to get the aggregated fuzzy rating $\tilde{x}_{ij}$ of alternative A_i under criterion C_j

$$\tilde{R}_k = (a_k, b_k, c_k), k = 1,2,3, \ldots K, \tag{19}$$

then the aggregated Fuzzy rating can be determined as

$$R = (a, b, c), k = 1,2,3, \ldots K \tag{20}$$

$$a = min_k(a_k), b = \frac{1}{K}\sum_{k=1}^{K} b_k\ ,\ c = max_k(c_k) \tag{21}$$

Step 4: Construct the fuzzy decision matrix and the normalized fuzzy decision matrix.

$$\tilde{R}_k = [r_{ij}]_{mxn}\ i = 1,2,3, \ldots, m;\ \ j = 1,2,3, \ldots, n \tag{22}$$

where B and C are the set of benefit criteria and cost criteria, respectively, and

$$r_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right),\ j \in B \tag{23}$$

$$r_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{c_{ij}}{a_{ij}}\right),\ j \in C \tag{24}$$

$c_j^* = \max_i c_{ij}$ if $j \in B$

$a_j^- = \min_i a_{ij}$ if $j \in C$

Step 5: Considering the different importance of each criterion, we can construct the weighted normalized fuzzy decision matrix as:

$$\tilde{V} = [\tilde{v}_{ij}]_{mxn}\ i = 1,2,,\dots,m;\ \ j = 1,2,,\dots,n \tag{25}$$

$$\tilde{v}_{ij} = r_{ij}W \tag{26}$$

where W is the weighted vector of evaluating criteria.

Step 6: Determine the Fuzzy positive ideal solution (FPIS) and Fuzzy negative ideal solution (FNIS) where according (Yu et. al. 2011):

$$A^* = (\tilde{v}_1^*,\tilde{v}_2^*,\dots,\tilde{v}_n^*) = (max_j v_{ij}\big|i \in B),\ (min_j v_{ij}\big|i \in C), i = 1,2 \dots m;\ j = 1,2 \dots n, \tag{27}$$

$$A^- = (\tilde{v}_1^-,\tilde{v}_2^-,\dots,\tilde{v}_n^-) = (min_j v_{ij}\big|i \in B), (max_j v_{ij}\big|i \in C), i = 1,2 \dots m;\ j = 1,2 \dots n, \tag{28}$$

where B and C are the set of benefit criteria and cost criteria, respectively.

Step 7: Calculate the distance of each alternative from FPIS and FNIS, respectively. The distance of each alternative from A* and A⁻ can be currently calculated as:

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij},\tilde{v}_j^*), i = 1,2,\dots m, \tag{29}$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij},\tilde{v}_j^-), i = 1,2,\dots m, \tag{30}$$

where d(.;.) is the distance measurement between two fuzzy numbers.

Step 8: Calculate the closeness coefficient of each alternative.

A closeness coefficient is defined to determine the ranking order of all alternatives once the d_i^* and d_i^- of each alternative A_i(i=1;2;m) has been calculated. The closeness coefficient of each alternative is calculated as:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-},\ i = 1,2,\dots,m \tag{31}$$

Step 9: According to the closeness coefficient, the ranking order of all alternatives can be determined.

4. Numerical example

The criteria used in this study were selected based on two important factors: criteria which are commonly used in the same or similar research and based on the current needs of the company and the requirements that the company faces on the market. The criteria (Puška et al. 2018) applied in this study are: the price of material, pipe length, delivery time, payment method, geographical location, quality, financial stability, flexibility and communication system, and in this paper they are marked C_1-C_9 respectively. Therefore, there are four quantitative criteria and five criteria that are qualitative, as shown in Figure 3. Steps of the proposed model for supplier evaluation are shown in Figure 4. One of two components of multicriteria evaluation methods is represented by the values of the criteria weights (Ginevičius and Podvezko, 2008) and one of the main features of multi-criteria decision-making process is that the different criteria cannot have the same significance, so following the methodology described for decision making which applies the extended AHP method ie. FAHP to get the required results is necessary to perform criteria comparison on the basis of TFN, as shown in Table 2. The comparison was made based on the scale shown in Table 1.

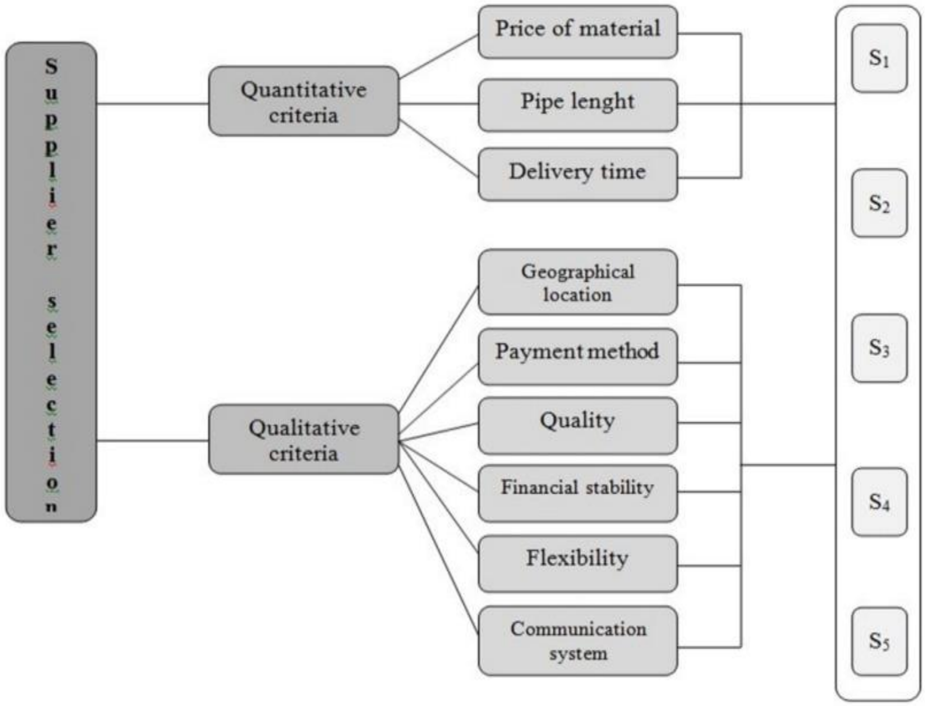

Figure 3. Hierarchical structure of the proposed model

Table 1. Triangular fuzzy scale

Linguistic Scale	TF Scale	TF Reciprocal Scale
Just equal	(1,1,1)	(1,1,1)
Equal important	(1/2,1,3/2)	(2/3,1,2)
Weakly more important	(1,3/2,2)	(1/2,2/3,1)
Strongly more important	(3/2,2,5/2)	(2/5,1/2,2/3)
Very strongly more important	(2,5/2,3)	(1/3,2/5,1/2)
Absolutely more important	(5/2,3,7/2)	(2/7,1/3,2/5)

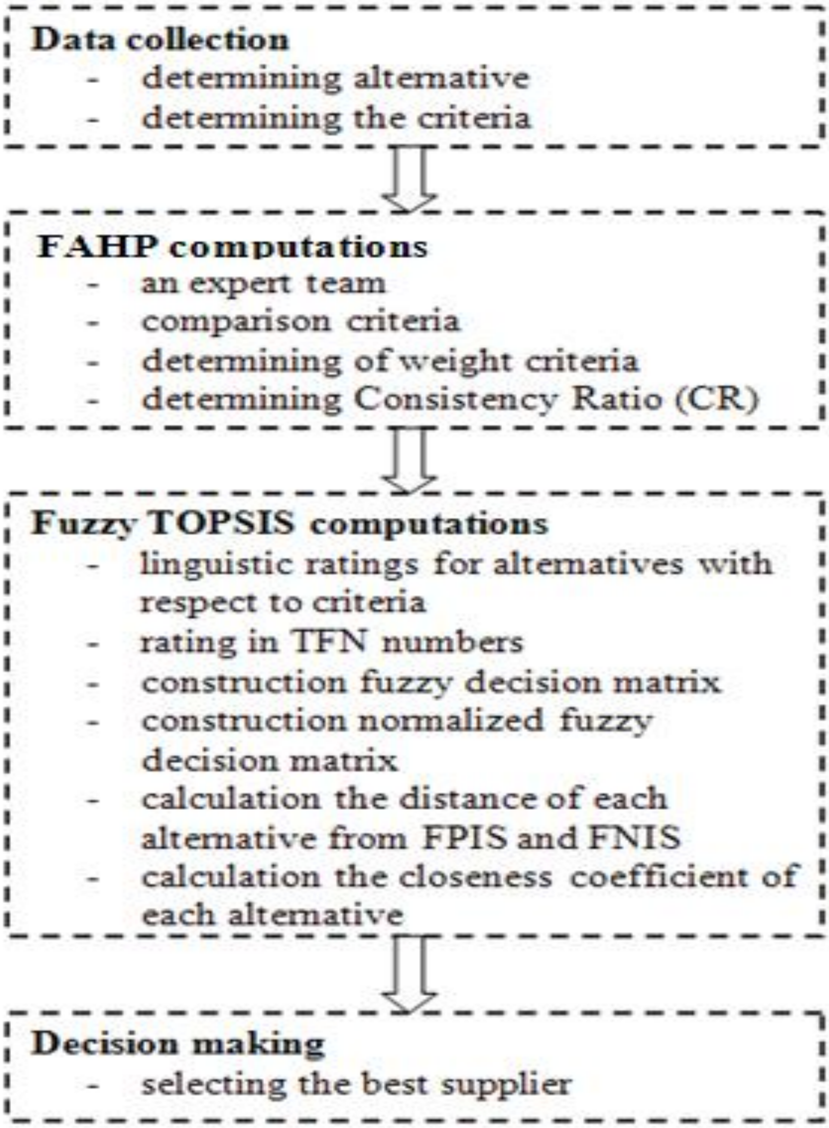

Figure 4. Steps of the proposed model

By comparing them, weight value criteria is determined, and that criteria plays very important role in the further implementation of methods, because on the base of these values the optimal solution is determined. If some variant is better according to criteria that are very important when deciding, it increases the possibility to have excatly this variant as an optimum.

Fuzzy important weight of the criteria is calculated by taking geometric mean of the responses of the experts (Lee, 2009), this is shown in Table 3. Example calculation of geometric mean for C_{42} is: $n^{-}= (1/2x2/5x2/5)^{1/3}=0,431$; $n=(2/3x1/2x1/2)^{1/3}=0,550$; $n^{+}=(1x2/3x2/3)^{1/3}=0,763$

Table 2. Comparison criteria by 3 experts

		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
	E_1	(1,1,1)	(2/3,1,2)	(1/2,2/3,1)	(1/2,1,3/2)	(1/2,1,3/2)	(2/3,1,2)	(1,1,1)	(1,1,1)	(1/2,1,3/2)
C_1	E_2	(1,1,1)	(2/3,1,2)	(2/3,1,2)	(1,3/2,2)	(1/2,1,3/2)	(2/3,1,2)	(1/2,1,3/2)	(1/2,1,3/2)	(1,3/2,2)
	E_3	(1,1,1)	(1/2,2/3,1)	(2/5,1/2,2/3)	(1/2,1,3/2)	(1/2,1,3/2)	(2/7,1/3,2/5)	(1/2,1,3/2)	(1,3/2,2)	(1,3/2,2)
	E_1	(1/2,1,3/2)	(1,1,1)	(2/3,1,2)	(1,3/2,2)	(1,3/2,2)	(1,1,1)	(1/2,1,3/2)	(1/2,1,3/2)	(1/2,1,3/2)
C_2	E_2	(1/2,1,3/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(1,3/2,2)	(1,1,1)	(1,3/2,2)	(1,3/2,2)	(3/2,2,5/2)
	E_3	(1,3/2,2)	(1,1,1)	(2/3,1,2)	(3/2,2,5/2)	(3/2,2,5/2)	(2/5,1/2,2/3)	(3/2,2,5/2)	(2,5/2,3)	(2,5/2,3)
	E_1	(1,3/2,2)	(1/2,1,3/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(1/2,1,3/2)	(1,3/2,2)	(1,3/2,2)	(3/2,2,5/2)
C_3	E_2	(1/2,1,3/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(1,3/2,2)	(1,1,1)	(1,3/2,2)	(1,3/2,2)	(3/2,2,5/2)
	E_3	(3/2,2,5/2)	(1/2,1,3/2)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(1/2,2/3,1)	(2,5/2,3)	(5/2,3,7/2)	(5/2,3,7/2)
	E_1	(2/3,1,2)	(1/2,2/3,1)	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(2/3,1,2)	(2/3,1,2)	(1/2,1,3/2)	(1,1,1)
C_4	E_2	(1/2,2/3,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(1/2,1,3/2)	(2/5,1/2,2/3)	(1/2,1,3/2)	(1/2,1,3/2)	(1,1,1)
	E_3	(2/3,1,2)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1,1,1)	(1,1,1)	(2/7,1/3,2/5)	(1,1,1)	(1/2,1,3/2)	(1/2,1,3/2)
	E_1	(2/3,1,2)	(1/2,2/3,1)	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(1/2,2/3,1)	(2/3,1,2)	(2/3,1,2)	(1/2,1,3/2)
C_5	E_2	(2/3,1,2)	(1/2,2/3,1)	(1/2,2/3,1)	(2/3,1,2)	(1,1,1)	(1/2,2/3,1)	(1,1,1)	(1,1,1)	(2/3,1,2)
	E_3	(2/3,1,2)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1,1,1)	(1,1,1)	(2/7,1/3,2/5)	(1,1,1)	(1/2,1,3/2)	(1/2,1,3/2)
	E_1	(1/2,1,3/2)	(1,1,1)	(2/3,1,2)	(1/2,1,3/2)	(1,3/2,2)	(1,1,1)	(1/2,1,3/2)	(1/2,1,3/2)	(1,3/2,2)
C_6	E_2	(1/2,1,3/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(1,3/2,2)	(1,1,1)	(1,3/2,2)	(1,3/2,2)	(3/2,2,5/2)
	E_3	(5/2,3,7/2)	(3/2,2,5/2)	(1,3/2,2)	(5/2,3,7/2)	(5/2,3,7/2)	(1,1,1)	(5/2,3,7/2)	(5/2,3,7/2)	(5/2,3,7/2)
	E_1	(1,1,1)	(2/3,1,2)	(1/2,2/3,1)	(1/2,1,3/2)	(1/2,1,3/2)	(2/3,1,2)	(1,1,1)	(1,1,1)	(1,1,1)
C_7	E_2	(2/3,1,2)	(1/2,2/3,1)	(1/2,2/3,1)	(2/3,1,2)	(1,1,1)	(1/2,2/3,1)	(1,1,1)	(1,1,1)	(2/3,1,2)
	E_3	(2/3,1,2)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1,1,1)	(1,1,1)	(2/7,1/3,2/5)	(1,1,1)	(1/2,1,3/2)	(1/2,1,3/2)
	E_1	(1,1,1)	(2/3,1,2)	(1/2,3/2,1)	(2/3,1,2)	(1/2,1,3/2)	(2/3,1,2)	(1,1,1)	(1,1,1)	(2/3,1,2)
C_8	E_2	(2/3,1,2)	(1/2,2/3,1)	(1/2,2/3,1)	(2/3,1,2)	(1,1,1)	(1/2,2/3,1)	(1,1,1)	(1,1,1)	(2/3,1,2)
	E_3	(1/2,2/3,1)	(1/3,2/5,1/2)	(2/7,1/3,2/5)	(2/3,1,2)	(2/3,1,2)	(2/7,1/3,2/5)	(2/3,1,2)	(1,1,1)	(1,1,1)
	E_1	(2/3,1,2)	(2/3,1,2)	(2/5,1/2,2/3)	(1,1,1)	(2/3,1,2)	(1/2,2/3,1)	(1,1,1)	(1/2,1,3/2)	(1,1,1)
C_9	E_2	(1/2,2/3,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(1/2,1,3/2)	(2/5,1/2,2/3)	(1/2,1,3/2)	(1/2,1,3/2)	(1,1,1)
	E_3	(1/2,2/3,1)	(1/3,2/5,1/2)	(2/7,1/3,2/5)	(2/3,1,2)	(2/3,1,2)	(2/7,1/3,2/5)	(2/3,1,2)	(1,1,1)	(1,1,1)

Table 3. Fuzzy important weight of the criteria calculated by taking geometric mean

	C_1	C_2	C_3	C_4	C_5
C_1	(1,1,1)	(0.606,0.874,1.587)	(0.511,0.693,1.817)	(0.63,1.145,1.651)	(0.5,1,1.5)
C_2	(0.63,1.145,1.651)	(1,1,1)	(0.763,1,1.587)	(1.31,1.817,2.31)	(1.145,1.651,2.154)
C_3	(0.909,1.442,1.957)	(0.63,1,1.31)	(1,1,1)	(1.651,2.154,2.657)	(1.442,1.957,2.466)
C_4	(0.606,0.784,1.587)	(0.431,0.55,0.763)	(0.376,0.464,0.606)	(1,1,1)	(0.794,1,1.145)
C_5	(0.667,1,2)	(0.464,0.606,0.874)	(0.405,0.511,0.693)	(0.874,1,1.26)	(1,1,1)
C_6	(0.855,1.442,1.99)	(1.145,1.26,1.357)	(0.874,1.145,1.587)	(1.233,1.817,2.359)	(1.357,1.89,2.41)
C_7	(0.763,1,1.587)	(0.511,0.693,1.101)	(0.083,0.562,0.794)	(0.693,1,1.442)	(0.794,1,1.145)
C_8	(0.693,0.874,1.26)	(0.481,0.644,1)	(0.415,0.693,0.737)	(0.667,1,2)	(0.693,1,1.442)
C_9	(0.55,0.763,1.26)	(0.446,0.585,0.874)	(0.358,0.585,0.562)	(0.874,1,1.26)	(0.606,1,1.817)

	C_6	C_7	C_8	C_9
C_1	(0.503,0.694,1.17)	(0.63,1,1.31)	(0.794,1.145,1.442)	(0.794,1.31,1.817)
C_2	(0.737,0.794,0.874)	(0.909,1.442,1.957)	(1,1.554,2.08)	(1.145,1.71,2.241)
C_3	(0.63,0.874,1.145)	(1.26,1.778,2.289)	(1.357,1.89,2.41)	(1.778,2.289,2.797)
C_4	(0.424,0.55,0.811)	(0.693,1,1.442)	(0.5,1,1.5)	(0.794,1,1.142)
C_5	(0.415,0.529,0.737)	(0.874,1,1.26)	(0.874,1,1.442)	(0.55,1,1.651)
C_6	(1,1,1)	(1.077,1.651,2.19)	(1.077,1.651,2.19)	(1.554,2.08,2.596)
C_7	(0.457,0.606,0.928)	(1,1,1)	(0.794,1,1.145)	(0.693,1,1.442)
C_8	(0.457,0.606,0.928)	(0.874,1,1.26)	(1,1,1)	(0.763,1,1.587)
C_9	(0.385,0.481,0.644)	(0.693,1,1.442)	(0.63,1,1.442)	(1,1,1)

To determine Fuzzy combination expansion for each one of the criteria, first we calculate $\sum_{j=1}^{n} M_{gi}^{j}$ value for each row of the matrix.

C1=(1+0.606+0.511+0.630+...;1+0.874+0.693+1.145...;1+1.587+1.817+1.651+...)=(5.968; 8.861; 13.294) etc.

The $\sum_{i=1}^{n}\sum_{j=1}^{n} M_{gi}^{j}$ value is calculated as:

(5.968;8.861;13.294)+(8.639;12.113;15.854)+(10.657;14.384;18.031)+(5.618;7.348;10.296)+(6.123;7.646;10.917)+(10.172;13.936; 17.679)+...=(64.55;87.38;118.17)

Then, $S_i = \sum_{j=1}^{n} M_{gi}^{j} \times \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$:

S1=(5.968;8.861;13.294)x(1/118.17;1/87.38;1/64.55)=(0.050;0.101;0.206)

Now, the V values are calculated using these vectors.

$V(S_1 \geq S_2) = \frac{0.073-0.206}{(0.101-0.206)-(0.139-0.073)} = 0.778$

V(S1≥S3)=0.644; V(S1≥S4,S5)=1; V(S1≥S6)=0.670; V(S1≥S7,S8,S9)=1

The priorities of weights are calculated using:

d'=(C1)=0.644, d'=(C2)=0.857, d'=(C3)=1, d'=(C4)=0.464, d'=(C5)= 0.503, d'=(C6)=0.974, d'=(C7)= 0.497, d'=(C8)= 0.525, d'=(C9)= 0.467

After the equation is applied (17), weight values are obtained, and from the equation (18) normalized weights of criteria are received:

W'=(0.644;0.857;1;0.464;0.503;0.974;0.497;0.525;0.467)

W=(0.109;0.144;0.169;0.078;0.085;0.164;0.084;0.088;0.079)

Table 4. Defuzzification using Kwong's method

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1	0.948	0.85	1.144	1	0.742	0.99	1.136	1.309
C_2	1.144	1	1.058	1.815	1.651	0.798	1.439	1.549	1.704
C_3	1.439	0.99	1	2.154	1.956	0.879	1.777	1.888	2.289
C_4	0.888	0.566	0.473	1	0.99	0.573	1.023	1	0.989
C_5	1.111	0.627	0.524	1.022	1	0.545	1.022	1.053	1.034
C_6	1.436	1.257	1.174	1.81	1.888	1	1.645	1.645	2.078
C_7	1.058	0.731	0.521	1.023	0.99	0.655	1	0.99	1.023
C_8	0.908	0.676	0.654	1.111	1.023	0.635	1.023	1	1.058
C_9	0.81	0.61	0.543	1.023	1.071	0.492	1.023	1.012	1

After defuzzification shown in the previous table, by applying the AHP method steps, we obtain the following values: λ_{max} = 9.262; CI = 0.033; CR = 0.023, which means that the degree of consistency is 0.023, which is much less than the maximum permitted limit of 0.1 according to the size of the matrix used in the paper.

On the basis of the procedure and obtained results the most important criterion for the decision on the selection of suppliers is the third criterion: the time of delivery, which has a relative importance of 16.9%, while the quality and length of pipes follow immediately after the time of delivery with a share of 16.4%, and 14.4%, respectively. The first criterion, the price of material, has the importance of 10.9%, while other criteria are somewhat lower in value. Delivery time, quality and price are the criteria that a large number of practical researches dealing with similar issues are of great importance. However, the length of the pipes as a criterion is rarely used, and even more rarely is of great importance as is the case in this study. The reason for such importance of this criteria is the activity in which the company is engaged, so this criterion can greatly contribute to an easier implementation of the finished product to the heating system, which is one of the current demands of end users in the market.

Table 5 shows the evaluation of suppliers by three experts using the linguistic variables. Based on the characteristics of the suppliers and the expert opinion Table 5 was formed.

Table 5. Rating of the suppliers in linguistic terms

Expert	Supp.	Criterion								
		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
E_1	S_1	VG	VG	VG	F	MG	VG	VG	VG	G
	S_2	G	VG	VG	VG	MG	VG	G	G	MG
	S_3	G	G	G	G	VG	MG	VG	G	G
	S_4	MG	G	G	F	VG	MG	VG	VG	G
	S_5	MG	MG	MP	VG	G	G	G	G	MG
E_2	S_1	VG	G	VG	MG	F	VG	G	G	VG
	S_2	G	G	VG	VG	F	VG	MG	MG	G
	S_3	G	MG	MG	G	VG	G	G	MG	VG
	S_4	MG	F	G	MG	VG	G	G	VG	VG
	S_5	F	MG	MP	VG	MG	G	MG	MG	G
E_3	S_1	G	VG	VG	F	MG	VG	VG	VG	VG
	S_2	G	VG	VG	VG	MG	G	MG	MG	G
	S_3	G	F	G	G	VG	MG	VG	G	VG
	S_4	MG	G	G	F	VG	MG	G	VG	VG
	S_5	MG	VG	MP	G	MG	G	MG	G	MG

By applying the 3rd and 4th step of the FTOPSIS method we get the values that are presented in tables 6 and 7, which represent a fuzzy decision matrix and normalized fuzzy decision matrix.

Table 6. Fuzzy decision matrix

Supp.	Criterion				
	C_1	C_2	C_3	C_4	C_5
S_1	(7,9.667,10)	(7,9.667,10)	(7,9.667,10)	(3,5.667,9)	(3,6.333,9)
S_2	(7,9.333,10)	(7,9.667,10)	(9,10,10)	(9,10,10)	(3,6.333,9)
S_3	(7,9,10)	(3,7,10)	(5,8.333,10)	(7,9,10)	(9,10,10)
S_4	(5,7,9)	(3,7.667,10)	(7,9,10)	(3,5.667,9)	(9,10,10)
S_5	(3,6.333,9)	(5,8,10)	(1,3,5)	(7,9.667,10)	(5,7.667,10)

Supp.	C_6	C_7	C_8	C_9
S_1	(9,10,10)	(7,9.667,10)	(7,9.667,10)	(7,9.667,10)
S_2	(7,9.667,10)	(5,7.667,10)	(5,7.667,10)	(5,8.333,10)
S_3	(5,7.667,10)	(7,9.667,10)	(5,8.333,10)	(7,9.667,10)
S_4	(5,7.667,10)	(7,9.333,10)	(9,10,10)	(7,9.667,10)
S_5	(7,9,10)	(5,7.667,10)	(5,8.33,10)	(5,7.667,10)

Table 7. Normalized Fuzzy decision matrix

	Criterion				
	C_1	C_2	C_3	C_4	C_5
S_1	(0.3,0.31,0.429)	(0.7,0.967,1)	(0.1,0.103,0.143)	(0.3,0.567,0.9)	(0.3,0.633,0.9)
S_2	(0.3,0.321,0.429)	(0.7,0.967,1)	(0.1,0.1,0.111)	(0.9,1.0,1)	(0.3,0.633,0.9)
S_3	(0.3,0.333,0.429)	(0.3,0.7,1)	(0.1,0.12,0.2)	(0.7,0.9,1)	(0.9,1,1)
S_4	(0.333,0.429,0.6)	(0.3,0.767,1)	(0.1,0.111,0.143)	(0.3,0.567,0.9)	(0.9,1,1)
S_5	(0.333,0.474,1)	(0.5,0.8,1)	(0.2,0.333,1)	(0.7,0.967,1)	(0.5,0.767,1)

	C_6	C_7	C_8	C_9
S_1	(0.9,1,1)	(0.7,0.967,1)	(0.7,0.967,1)	(0.7,0.967,1)
S_2	(0.7,0.967,1)	(0.5,0.767,1)	(0.5,0.767,1)	(0.5,0.833,1)
S_3	(0.5,0.767,1)	(0.7,0.967,1)	(0.5,0.833,1)	(0.5,0.833,1)
S_4	(0.5,0.767,1)	(0.7,0.933,1)	(0.9,1,1)	(0.7,0.967,1)
S_5	(0.7,0.9,1)	(0.5,0.767,1)	(0.5,0.833,1)	(0.5,0.767,1)

By multiplying the values shown in Table 8 with the values of criteria which obtained by FAHP method we get weighted normalized fuzzy decision matrix shown in Table 8, while Table 9 shows the final results and ranking of alternatives.

Table 8. Weighted normalized Fuzzy decision matrix

	Criterion		
	C_1	C_2	C_3
S_1	(0.033,0.034,0.047)	(0.101,0.139,0.144)	(0.017,0.017,0.024)
S_2	(0.033,0.035,0.047)	(0.101,0.139,0.144)	(0.017,0.017,0.019)
S_3	(0.033,0.036,0.047)	(0.043,0.101,0.144)	(0.017,0.02,0.034)
S_4	(0.036,0.047,0.065)	(0.043,0.11,0.144)	(0.017,0.019,0.024)
S_5	(0.036,0.052,0.109)	(0.072,0.115,0.144)	(0.034,0.056,0.169)
	C_4	C_5	C_6
S_1	(0.023,0.044,0.07)	(0.026,0.054,0.077)	(0.148,0.164,0.164)
S_2	(0.07,0.078,0.078)	(0.026,0.054,0.077)	(0.115,0.159,0.164)
S_3	(0.055,0.07,0.078)	(0.077,0.085,0.085)	(0.082,0.126,0.164)
S_4	(0.023,0.044,0.07)	(0.077,0.085,0.085)	(0.082,0.126,0.164)
S_5	(0.055,0.075,0.078)	(0.043,0.065,0.085)	(0.115,0.148,0.164)
	C_7	C_8	C_9
S_1	(0.059,0.081,0.084)	(0.062,0.085,0.088)	(0.055,0.076,0.079)
S_2	(0.042,0.064,0.084)	(0.044,0.067,0.088)	(0.04,0.066,0.079)
S_3	(0.059,0.081,0.084)	(0.044,0.073,0.088)	(0.04,0.066,0.079)
S_4	(0.059,0.078,0.084)	(0.079,0.088,0.088)	(0.055,0.076,0.079)
S_5	(0.042,0.064,0.084)	(0.044,0.073,0.088)	(0.04,0.061,0.079)

Table 9 contains the final results and ranking of alternatives.

Table 9. Closeness coefficient of alternatives and their ranking

	d_i^*	d_i^-	$d_i^*+d_i^-$	CC_i	Rank
S_1	0.166	0.551	0.717	0.768	1
S_2	0.185	0.546	0.731	0.747	2
S_3	0.218	0.531	0.749	0.709	4
S_4	0.214	0.526	0.741	0.711	3
S_5	0.33	0.465	0.795	0.585	5

5. Sensitivity analysis

The sensitivity analysis includes the experiment of 24 sets where the values of criteria are changed. The first nine sets mean increasing each criterion separately by 8% starting from the first one to the last. Since there is no significant change in the ranking of suppliers the following nine sets are formed which include increasing the value of each criterion individually by 16%. The set number 19 includes reducing the three most relevant criteria (C_2, C_3 and C6) by 8%, while the other six criteria increase by 4%. The set number 20 represents an increase in the three most important criteria (C_2, C_3 and C_6) by 8%, while the remaining criteria are reduced by 4%. Next set number 21 analyses the increase of the three weakest criteria (C_4, C_7 and C_9) by 8%, while the rest are reduced by 4%. The set number 22 means equal weighting of all the criteria, while in the set number 23 the four most important criteria (C_1, C_2, C_3 and C_6) have equal values of 0.25, and the rest of the criteria are equal to zero or not taken into account. The last set number 24 analyses the change of the criteria in the following way: the first five criteria are equal to the value of 0.12, and the other four criteria are also identical in value of 0.1.

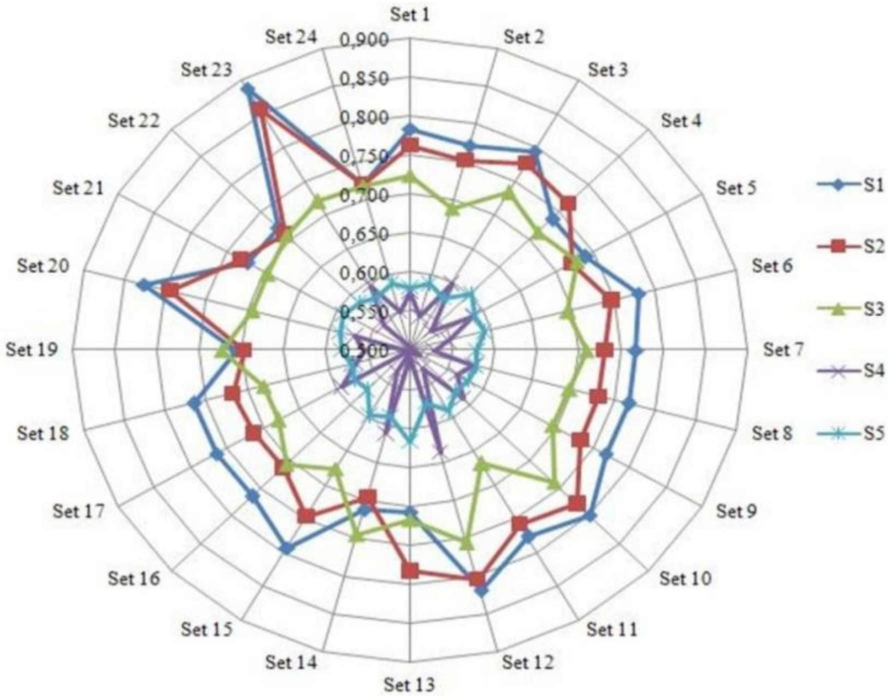

Figure 5. Results of sensitivity analysis

After the formation of sets and the analysis shown in Figure 5, it is evident that the first supplier is ranked as the most acceptable solution in 18 out of a total of 24 cases, therefore, he holds the first position. In the first nine sets only the change of the fourth criterion affect the change of preferred supplier, and then the second supplier becomes number one. In the nine sets that follow the number one supplier is ranked first in seven cases. The change occurs with the increase in the fourth criterion when the second supplier takes one the first place, i.e. with the change of the fifth criterion when supplier number three is ranked first. Set 19 also places third supplier as the first, because the values of the three most important criteria are reduced. Supplier number one is the most appropriate solution also in the sets number 20, 22 and 23, while in set 21 the second supplier has the rank one with a slight difference in comparison to the first supplier, while in the final set number 24 the first and the second supplier are almost identical. It is important to note that the first supplier in those six cases where he is not the most appropriate solution still holds second position, which speaks volumes about the qualities of the same. Even in the situation when all criteria are equally important with the same values, this supplier is the best solution.

6. Conclusion

This paper presents a two-phase model for evaluating suppliers in the manufacturing sector. Since today production is highly dependent on our own capacities but also on the capacity of suppliers, the importance of resolving this problem is evident. When it comes to a concrete example entertained in this paper, it is necessary to take into account a large number of criteria that can influence the formation of the final price of the product, and consequently the position that the company holds in the market. It is necessary to make decisions taking into account the importance of the criteria, i.e. the priorities that reflect market demands and needs, which was achieved in this paper through the creation of an expert team.

After the sensitivity analysis, it can be concluded that the model is well stable because supplier one emerged out as the best solution in a number of situations where the weight values of certain criteria were changed. This means that change of the obtained results would require significant turbulence in the market, both in terms of suppliers and their characteristics and end user perspectives.

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