Operational Research in Engineering Sciences: Theory and Applications
Vol. 3, Issue 2, 2020, pp. 39-53
ISSN: 2620-1607
eISSN: 2620-1747
DOI: https://doi.org/10.31181/oresta2003034z

MODELLING PROCEDURE FOR THE SELECTION OF STEEL PIPE SUPPLIER BY APPLYING THE FUZZY AHP METHOD

Edmundas Kazimieras Zavadskas [1], Zenonas Turskis [1], Željko Stević [2]*, Abbas Mardani [3,4]

[1] Vilnius Gediminas Technical University, Institute of Sustainable Construction, Faculty of Civil Engineering, Lithuania
[2] University of East Sarajevo, Faculty of Transport and Traffic Engineering Doboj, Bosnia and Herzegovina
[3] Informetrics Research Group, Ton Duc Thang University, Vietnam
[4] Faculty of Business Administration, Ton Duc Thang University, Vietnam

Received: 22 May 2020
Accepted: 03 July 2020
First online: 03 July 2020

Original scientific paper

Abstract: *The objective of this study is the supplier evaluation and selection by applying the fuzzy multi-criteria analysis. The study used the fuzzy Analytic Hierarchy Process (FAHP) to choose the most suitable supplier for the purchase of materials necessary for the production of pre-insulated pipes. Decision-makers selected among five suppliers based on nine criteria. Effective execution of procurement, in this case, the procurement of material needed for the production logistics subsystem, influences the overall efficiency of the business. Results show that it is very important to perform the right ranking in the process of supplier selection. Good decisions can ensure lower costs and higher quality of the production and therefore a better position in the market. Also, applied methodology and the rank show that supplier A is the most suitable solution.*

Keywords: *fuzzy AHP, optimization, supplier selection*

1. Introduction

Lately, the area of multi-criteria analysis is rapidly developing, thanks to the large number of publications dealing with the adoption of individual decisions based on the applied methods that belong to the specified field. For example, Fallahpour et al. (2020) introduced a new integrated MCDM approach under uncertainty by integrating Fuzzy Preference Programming as a modification of Fuzzy Analytic Hierarchy Process, with Fuzzy Inference System as a fuzzy rule-based expert system.

* Corresponding author.
edmundas.zavadskas@vgtu.lt (E. K. Zavadskas), zenonas.turskis@vgtu.lt (Z. Turskis), zeljkostevic88@yahoo.com and zeljko.stevic@sf.ues.rs (Ž. Stević), mabbas3@liveutm.onmicrosoft.com (A. Mardani)

The AHP method is one of the most common methods, among the dozens of approaches proposed, to solve complex multi-level decision-making problems. The importance of this method is the fact that there are conferences dedicated only to the method of the Analytic Hierarchy Process. However, despite this fact, there is a constant strive to create better opportunities and more accurate problem-solving. For this reason, there is an enlargement of the AHP method, and creation of a fuzzy approach that allows a more precise definition of the most favourable alternative, or decision. AHP is often used in integration with other approaches, as can be seen in the study (Stević et al., 2015) where this method is integrated with TOPSIS.

For this study, the extended fuzzy AHP method based on triangular fuzzy numbers (TFN) was used, where extended analysis of the target was performed for each object. In addition to this one, some other methods can be applied as well, such as Maxmax, Maxmin, SAW, ELECTRE, PROMETHEE, TOPSIS, but for the issues addressed in this paper, it is much better to apply the AHP method. Methods Minmax, Maxmin and SAW are straightforward methods of multi-criteria analysis, of which only the SAW method takes the importance of criteria into account, and as such are not applied frequently in solving complex problems. Methods ELECTRE and PROMETHEE have several versions and based on the authors' knowledge stemming from the extensive review of the literature, we cannot say that these methods are not applied, they are, but to a much lesser extent than the AHP method, especially when it comes to the field of choice of suppliers. Due to its simple concept, the TOPSIS method has become very popular and is applied in many areas of decision-making procedures (Zavadskas et al., 2016). However, despite that, this method is often criticized because there is no possibility for adequate handling of uncertainty and imprecision at the moment when the decision-maker wants accurate results. When compared to other methods, the AHP method has frequently shown features that are more practical, which is of great importance. Some of the advantages of this method are outstanding problem structuring from the highest to the lowest level, pointing to the subjectivity that exists with the decision-makers, less susceptibility to errors in assessing thanks to the redundancy of comparison in pairs, use for complex decision-making and the like. As the most common shortcomings of this method stand out that there are not enough measures in the Saaty scale to compare pairs of elements of specific decision-making problems with quite many criteria.

However, a combination with fuzzy logic can somehow eliminate or reduce the disadvantage. Chapter 3 presents it in detail. Applying the AHP method enables more accurate interpretation of results because all values are the sum of an alternative one as a contrast to other methods where it is not the case, and thus it is possible to see how exactly the optimum solution is better than other estimated solutions. The primary reason for the AHP method application would be its ability to handle quantitative and qualitative criteria equally.

In current business conditions, for one company to achieve the market position that makes it competitive, and to keep it, continuous measuring and monitoring of performance is necessary. If there is a deviation (which is often the case) from the planned values, it is necessary to undertake specific corrective measures to ensure the achievement of higher values. However, a better route by which it is possible to achieve efficient business management is a proactive way, where business results are not expected, but they are managed instead. Thanks to the constant changes to which the market is exposed and to increasingly stringent requirements placed on the market, it is undoubtedly a challenge to maintain a competitive position. It can be achieved if there is an adequate production, which means as low product cost as possible, as higher product quality as possible, high accuracy of delivery to final users, reliability, response to specific requirements set by users, i.e. flexibility and cooperation that can be accomplished with both – customers and suppliers. The research carried out in this paper connects the first two logistics stages: the procurement and production, which, with their consolidation, are making logistics of materials-effective execution of activities related to the system. The inclusion of the selection of the best suppliers significantly affects the price and quality of the final product. These are some of the most important factors determining success in the market. The correct choice of suppliers from the start provides the ability for timely, continuous and efficient production, which enables achieving the above-described benefits and makes that production competitive.

The researched company is engaged in the production of pre-insulated pipes for heating and their application and installation in all heating systems. To be able to carry out the production smoothly, one of the necessary materials that need to be procured is steel pipes. In the market, there are many potential suppliers of the material mentioned above, and it is necessary to set aside those who particularly stand out based on their characteristics and based on criteria of the company that is the subject of research. After a thorough market analysis carried out by experts from the commercial service, the choice was reduced to five suppliers representing variants of which three are located in the domestic and the other two on the international market, which includes the territory of neighbouring countries.

A similar issue is treated in (Bronja and Bronja, 2015; Chatterjee and Stević, 2019), where it can be seen the exact significance of the expert team, which, in addition to the selection of potential solutions, created a total of nine quantitative and qualitative criteria based on which it is necessary to evaluate potential suppliers. Based on the current market needs and demands, as well as on the knowledge, skills and abilities acquired over the years in the same business, an expert team has evaluated criteria, bringing out the different weight value. The most significant aim and the contribution of this study is performing the optimization of the purchasing process through the proposed model for the application of fuzzy AHP method to this problem, and the possibility of establishing a long-term collaboration with the chosen supplier, which would enable additional benefits for the company.

The paper is structured in several sections. In the introduction, aims and motivation for research are described. The second section shows a brief literature review with an emphasis on the fuzzy AHP method and the problem of supplier selection. The third section shows steps used in the fuzzy AHP method, while in the fourth section, an empirical study is shown. The paper ends with a conclusion and future tasks.

2. Brief literature review

There are many criteria to evaluate suppliers but the question is how to choose the right one from a given set, which will help to choose the best option. Some authors have tried to answer this question, so Webber (1991) investigated the criteria for the selection of suppliers in the manufacturing and retail environment in the 74 documents published from 1966 to 1991. He concluded that quality, delivery and price are prevailing as the dominant criteria. Besides, geographical location, financial position and production capacity fall to the second group of factors.

Verma and Pullman (1998) conducted a study among 139 managers whose aim was to examine how to make a compromise when selecting suppliers. Their work indicated that the managers are paying the greatest attention to quality as the most critical attribute of suppliers, followed by delivery and price. Karpak et al. (2001) took delivery reliability as a criterion for selection, while Bhutta and Huq (2002) used four criteria to evaluate suppliers: price, quality, technology and service.

Many researchers use Multi-Criteria Decision-Making (MCDM) methods and differently control target alternatives (Turskis et al., 2019). Different researchers developed different models to select the best supplier in a competitive market environment. Keshavarz Ghorabaee et al. (2016) extended the EDAS method for fuzzy multi-criteria decision-making. Later, Keshavarz Ghorabaee et al. (2017) presented a novel model based on interval type-2 fuzzy sets and EDAS method. Aouadni et al. (2017) presented a model based on the Meaningful Mixed Data TOPSIS (TOPSIS-MMD) method. Recently, Yazdani et al. (2019) developed a grey combined compromise solution (CoCoSo-G) method for supplier selection.

The criteria that are a base for the choice of suppliers were selected based on two factors: the most commonly used criteria in the same or similar research, and current needs of the company and demands that it might face in the market. As mentioned in the introduction, the company's expert team selected the criteria set.

The AHP method was addressed to the problem of supplier selection, in many types of research (Galankashi et al., 2016; Chen et al., 2006; Jain et al., 2018; Stević et al., 2016) the choice of supplier in the industry, where the general purpose of the model is applied to the leading electro motor manufacturer of Turkey (Barbarosoglu and Yazgac, 1997), the choice of supplier in textile company (Ertugrul and Karakasoglu, 2006), where the focus is on the identification and discussion of criteria which make up an essential part of the decision. It is the price, quality, service level and profile of suppliers (Chan and Kumar, 2007). Then, the choice of supplier among manufacturers of TFT-LCD, where the applied model can identify strengths, opportunities on the one, and the cost and risk on the other hand (Lee 2009).

The AHP method has a wide application in practical research in a wide range of areas, thus contributing to the improvement of the entire management system (Erdogan et al., 2017; Hashemkhani Zolfani et al., 2011). In the supply chain, decisions based on this method provide the proper choice of suppliers that affects the formation of a more efficient flow of further chain. Decision-makers used many methods, which do not belong to the field of multi-criteria analysis, to solve similar problems. However, they frequently combined them with the AHP method.

3. The fuzzy AHP

The creator of the AHP method is Thomas Saaty (1977; 1980). According to (Saaty, 1990), the AHP is a measurement theory, which is dealing with comparing pairs and which relies on expert opinion in order to perform the priority scale. Fuzzy ratings and scales provide decision-makers possibilities to express better the level of their knowledge accuracy (Zemlickienė & Turskis, 2020; Turskis et al., 2015). Various approaches of fuzzy AHP method were developed as an extended fuzzy AHP method based on triangular fuzzy numbers (Setyohadi & Suyoto, 1977; Saaty, 1978, 1982; Van Laarhoven & Pedrycz, 1983; Chang, 1996; Zhu et al., 1999). Zadeh (1965) introduced the theory of fuzzy sets. Its application enables DMs to deal with uncertainties effectively. Fuzzy sets used generally triangular, trapezoidal and Gaussian fuzzy numbers, which convert uncertain fuzzy numbers. More details can be found in (Xu and Liao, 2014). The authors use Chang's (1996) extent analysis method in this study. Steps of the approach application are relatively simple and easy, requiring less time than many other fuzzy extensions of the AHP method. At the same time, it can eliminate the shortcomings of the classical AHP method.

Assume that $X = \{x_1, x_2, ..., x_n\}$ is a number of objects, and $U = \{u_1, u_2,...,u_m\}$ is a number of aims.

For each object, an extended goal analysis is performed. Values of the extended analysis "m" for each object can be shown:

$$M_{gi}^1, M_{gi}^2, M_{gi}^m, i = 1,2, \dots n., \tag{1}$$

where $M_g^j, j = 1,2, \dots m.,$ are TFNs.

Steps of fuzzy AHP are:

Step 1: The value of fuzzy synthetic extent Si for the i-th criterion is as follows:

$$S_i = \sum_{j=1}^{n} M_{gi}^j \times \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j\right]^{-1} \tag{2}$$

To obtain equation (3),

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j\right]^{-1} \tag{3}$$

we need to perform additional fuzzy operations with "m" values:

$$\sum_{j=1}^{n} M_{gi}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{4}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{n} M_{gi}^j = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \tag{5}$$

Then it is necessary to calculate:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j\right]^{-1} \left[\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right] \tag{6}$$

Step 2: The sets of weight values for each criterion are calculated by decision-makers according to the principle of comparing fuzzy numbers. For example, for two fuzzy numbers S_b and S_a,, the decision-makers define the possibility degree of $S_b \geq S_a$ as follows:

$$V(Sb \geq Sa) = \sup \geq [\min \mu_{Sb}(x), \mu_{Sa}(y)] \tag{7}$$

where *sup* represents the supremum and when a pair (x, y) exists such that x ≥ y and $\mu_{Sb}(x) = \mu_{Sa}(y) = 1$, it follows that V(Sb ≥ Sa) =1 and V(Sa ≥ Sb) = 0. Since S_b and S_a are convex fuzzy numbers defined by the TFNs (l_1, m_1, u_1) and (l_2, m_2, u_2) respectively, it follows that:

$$V(Sb \geq Sa) = 1 \text{ iff } Sb \geq Sa; V(Sa \geq Sb) = hgt(Sb \cap Sa = \mu_{Sb}(x_d) \tag{8}$$

where *iff* represents “if and only if” and *d* is the ordinate of the highest intersection point between the μ_{Sb} and μ_{Sa} TFNs and x_d is the point on the domain of μ_{Sb} and μ_{Sa} where the ordinate *d* is found. The term *hgt* is the height of fuzzy numbers on the intersection of S_b and S_a.

$$V(S_b \geq S_a) = \begin{cases} 1, & if\ m_b \geq m_a \\ 0, & if\ l_a \geq u_b \\ \frac{l_a - u_b}{(m_b - u_b) - (m_a - l_a)}, & otherwise \end{cases} \tag{9}$$

where *"d"* is the ordinate of the largest cross-section in point *D* between μS_a and μS_b, as shown in Figure 1.

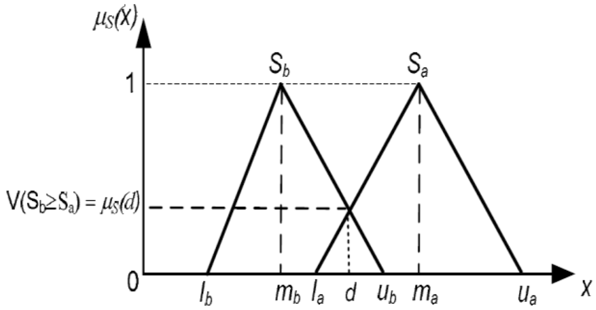

Figure 1. Intersection between S_b and S_a

The decision-makers need both values V($S_1 \geq S_2$) and V($S_2 \geq S_1$) to compare S_1 and S_2.

Step 3: The level of possibility for a convex fuzzy number to be greater than *"k"* convex number S_i (*i* =1, 2, ..., k) can be defined as follows:

$$V(S_i \geq S_1, S_2, \ldots, S_k) = \min V(S_i \geq S_k), = w'(S_i) \tag{10}$$

$$d'(A_i) = \min V(S_i \geq S_k), k \neq i, k = 1,2, \ldots, n \tag{11}$$

The following expression gives the weight vector:

$$W' = (d'(A_1), d'(A_2), \dots, d'(A_n))^T, \tag{12}$$

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

$$W = (d(A_1), d(A_2), \dots, d(A_n))^T, \tag{13}$$

where W represents a crisp number.

Through its application, the fuzzy AHP method alleviates the main disadvantage of the classical AHP method, and that is, as previously mentioned, an insufficiently big comparison scale. To this end, various scales have been developed based on comparing the fuzzy triangular numbers, where the decision-maker can evaluate the significance of criteria or alternatives much closer and easier, and thus reducing his/her subjectivity that is present in solving these problems to a minimum.

4. Numerical example

The following criteria are applied in this study: the price of materials, pipe length, delivery time, way of payment, transport distance, quality, reliability, flexibility and relationship with customers that are still in operation, which are marked with C_1-C_9 respectively. Therefore, there are four criteria, quantitatively expressed and five qualitative criteria, as shown in Figure 2. Detailed explanation of used criteria in this study can be found in (Stević et al. 2016).

As mentioned in the introduction, the panel selected a set of criteria for evaluating suppliers. These selected critical criteria are the same as those most widely used in practice. Consideration of them and their share in the selection of suppliers achieves a significant overall business performance. The level of meeting the needs of end-users and the requirements of strict standards and norms is well reflected in the company's profit.

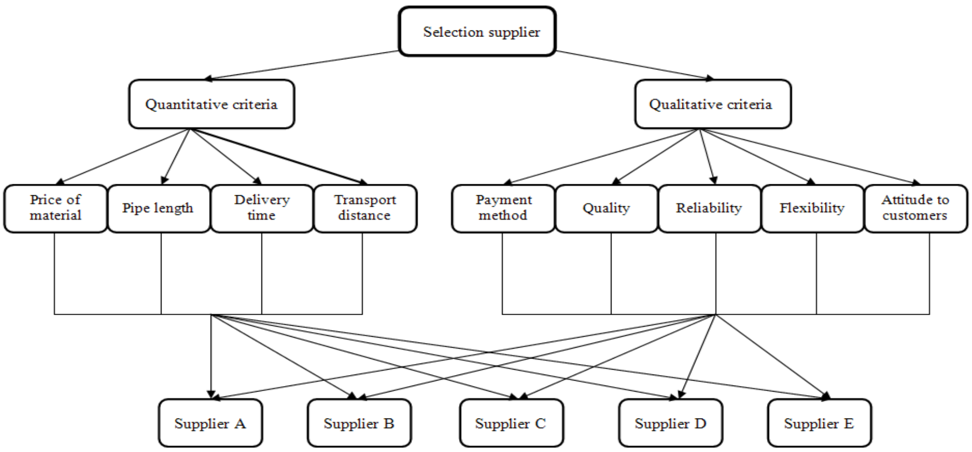

Figure 2. The hierarchical structure of the proposed model

Table 1. Values of triangular fuzzy scale

Linguistic Scale	Triangular Fuzzy	Triangular Fuzzy

	Scale	Reciprocal Scale
Just equal	(1, 1, 1)	(1, 1, 1)
Equally 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)

One of the main features of MCDM 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, i.e. fuzzy AHP to get the required results, it is necessary to perform criteria comparison based on TFNs, as shown in Table 2. The comparison was made based on the scale shown in Table 1 (Chang, 1996).

By comparing them, weight values of criteria are determined. The criteria weights have a large significance in the further application of methods because, on the base of these values, the best solution is determined. If a variant is better according to criteria that are very important when deciding, it increases the possibility to have exactly this variant as an optimum.

Table 2. Comparison of criteria on the base of triangular numbers

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

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

By applying the equation (4), (5) and (6), the following values are obtained:

S_1=(6.333;8.667;12.5)x(1/120;1/84.5;1/61.364)=(0.053; 0.103;0.204)

S_2=(6.667;10;14) x(1/120;1/84.5;1/61.364)=(0.056;0.118; 0.228)

S_3=(9.5;13.5;17.5)x(1/120;1/84.5;1/61.364)=(0.079;0.160;0.285)

S_4=(6.4;8.167;12.167) x(1/120;1/84.5;1/61.364)=(0.053;0.097; 0.198)

S_5=(5.9;7.833;12.167) x(1/120;1/84.5;1/61.364)=(0.049; 0.093; 0.198)

S_6=(6.667;10;14)x(1/120;1/84.5;1/61.364)=(0.056;0.118;0.228)

S_7=(6.833;8.667;12)x(1/120;1/84.5;1/61.364)=(0.057;0.103;0.196)

S_8=(6.667;9.5;13.5)x(1/120;1/84.5;1/61.364)=(0.056;0.112;0.220)

S_9=(6.4;8.167;12.167)x(1/120;1/84.5;1/61.364)=(0.053;0.097. 0.198)

After completion of the calculation using the equation (9), values are obtained as described in step three to the amounts:

$V(S_1 \geq S_2)=V(S_1 \geq S_6)=0.908; V(S_1 \geq S_3)=0.687; V(S_1 \geq S_4)=(S_1 \geq S_5)=V(S_1 \geq S_7)=V(S_1 \geq S_9)=1; V(S_1 \geq S_8)=0.943$

$V(S_2 \geq S_1)=V(S_2 \geq S_4)=V(S_2 \geq S_5)=V(S_2 \geq S_6)=V(S_2 \geq S_7)=V(S_2 \geq S_8)=V(S_2 \geq S_9)=1; V(S_2 \geq S_3)=0.78$

$V(S_3 \geq S_1)=V(S_3 \geq S_2)=V(S_3 \geq S_4)=V(S_3 \geq S_5)=V(S_3 \geq S_6)=V(S_3 \geq S_7)= V(S_3 \geq S_8)= V(S_3 \geq S_9)=1$

$V(S_4 \geq S_1)=0.960$; $V(S_4 \geq S_2)=V(S_4 \geq S_6)=0.871$; $V(S_4 \geq S_3)= 0.654$; $V(S_4 \geq S_5)=V(S_4 \geq S_9)=1$; $V(S_4 \geq S_7)=0.959$; $V(S_4 \geq S_8) =0.904$

$V(S_5 \geq S_1)=0.935$; $V(S_5 \geq S_2)= V(S_5 \geq S_6)=0.850$; $V(S_5 \geq S_3)= 0.640$; $V(S_5 \geq S_4)= V(S_5 \geq S_9)=0.973$; $V(S_5 \geq S_7)=0.934$; $V(S_5 \geq S_8)=0.882$

$V(S_6 \geq S_1)=V(S_6 \geq S_2)=V(S_6 \geq S_4)=V(S_6 \geq S_5)=V(S_6 \geq S_7)=V(S_6 \geq S_8)=V(S_6 \geq S_9)=1; V(S_6 \geq S_3)=0.78$

$V(S_7 \geq S_1)=V(S_7 \geq S_4)=V(S_7 \geq S_5)=V(S_7 \geq S_9)=1$; $V(S_7 \geq S_2)= V(S_7 \geq S_6)=0.903$; $V(S_7 \geq S_3)=0.672$; $V(S_7 \geq S_8)=0.934$

$V(S_8 \geq S_1)=V(S_8 \geq S_4)=V(S_8 \geq S_5)=V(S_8 \geq S_7)=V(S_8 \geq S_9)=1$; $V(S_8 \geq S_2)= V(S_8 \geq S_6)=0.965$; $V(S_8 \geq S_3)=0.746$

$V(S_9 \geq S_1)=0.960$; $V(S_9 \geq S_2)=0.871$; $V(S_9 \geq S_3)=0.654$; $V(S_9 \geq S_4)=V(S_9 \geq S_5)=1$; $V(S_9 \geq S_6)=0.871$; $V(S_9 \geq S_7)=0.959$; $V(S_9 \geq S_8)=0.904$.

Then, using the equation (10) and (11), the values shown below are obtained.

$d'(A_1)=\min V(S_1 \geq S_2,S_3,S_4,S_5,S_6,S_7,S_8,S_9)=0.687$

$d'(A_2)=\min V(S_2 \geq S_1,S_3,S_4,S_5,S_6,S_7,S_8,S_9)=0.780$

$d'(A_3)=\min V(S_3 \geq S_1,S_2,S_4,S_5,S_6,S_7,S_8,S_9)=1$

$d'(A_4)=\min V(S_4 \geq S_1,S_2,S_3,S_5,S_6,S_7,S_8,S_9)=0.654$

$d'(A_5)=\min V(S_5 \geq S_1,S_2,S_3,S_4,S_6,S_7,S_8,S_9)=0.640$

$d'(A_6)=\min V(S_6 \geq S_1,S_2,S_3,S_4,S_5,S_7,S_8,S_9)=0.780$

$d'(A_7)=\min V(S_7 \geq S_1,S_2,S_3,S_4,S_5,S_6,S_8,S_9)=0,672$

$d'(A_8)=\min V(S_8 \geq S_1,S_2,S_3,S_4,S_5,S_6,S_7,S_9)=0,746$

$d'(A_9)=\min V(S_9 \geq S_1,S_2,S_3,S_4,S_5,S_6,S_7,S_8)=0,654$

After the equation (12) is applied, criteria weights are obtained, and from the equation (13), normalized weights of criteria are determined:

W'=(0.687;0.780;1;0.654;0.640;0.780;0.672;0.746;0.654)

W=(0.104;0.118;0.151;0.099;0.097;0.118;0.102;0.113;0.099)

On the basis of the procedure and obtained results, the most significant criterion in this study is the third criterion, delivery time, which has importance of 15.1%, then the quality and pipe length have the same importance with a share of 11.8 %, while the other criteria have lower values. These three most significant criteria in a large number of practical examples dealing with similar tasks have large importance.

A crisp value from Table 2 is taken to calculate the level of consistency CR = 0.01.

After these values were obtained in order to reach a ranking, and then after making the choice of the suitable variant, it is necessary to compare suppliers in relation to each criterion individually as already described, depending on whether the criteria are quantitative or qualitative. Comparison of suppliers with respect to the first criterion, the cost of materials, is shown in Table 3.

Table 3. Comparison of suppliers with respect to the first criterion

C_1	S_A	S_B	S_C	S_D	S_E
S_A	(1,1,1)	(1,3/2,2)	(3/2,2,5/2)	(2,5/2,3)	(5/2,3,7/2)
S_B	(1/2,2/3,1)	(1,1,1)	(1/2,1,3/2)	(1,3/2,2)	(3/2,2,5/2)
S_C	(2/5,1/2,2/3)	(2/3,1,2)	(1,1,1)	(1/2,1,3/2)	(1,3/2,2)
S_D	(1/3,2/5,1/2)	(1/2,2/3,1)	(2/3,1,2)	(1,1,1)	(1/2,1,3/2)
S_E	(2/7,1/3,2/5)	(2/5,1/2,2/3)	(1/2,2/3,1)	(2/3,1,2)	(1,1,1)

By applying the equation (4), (5) and (6), the following values are obtained:

S_A=(8;10;12)x(1/38.234;1/28.734;1/21.919)=(0.209;0.348;0.547)

S_B=(4.5;6.617;8)x(1/38.234;1/28.734;1/21.919)=(0.118; 0.215; 0.365)

S_C=(3.567;5;7.167)x(1/38.234;1/28.734;1/21.919)=(0.093;0.174;0.327)

S_D=(3;4.067;6) x(1/38.234;1/28.734;1/21.919) =(0.078; 0.142; 0.274)

S_E=(2.852;3.5;5.067) x(1/38.234;1/28.734;1/21.919)=(0. 075;0.122;0.231)

After the application of Eq. (7), values are obtained as described in step three to the amounts:

$V(S_A \geq S_B)=V(S_A \geq S_C)=V(S_A \geq S_D)=V(S_A \geq S_E)=1$

$V(S_B \geq S_A)=0.540$; $V(S_B \geq S_C)=V(S_B \geq S_D)=V(S_B \geq S_E)=1$

$V(S_C \geq S_A)=0.404$;$V(S_C \geq S_B)=0.836$; $V(S_C \geq S_D)=V(S_C \geq S_E)=1$

$V(S_D \geq S_A)=0.240$;$V(S_D \geq S_B)=0.681$;$V(S_D \geq S_C)=0.850$;$V(S_D \geq S_E)=1$

$V(S_E \geq S_A)=0.089$;$V(S_E \geq S_B)=0.549$; $V(S_E \geq S_C)=0.726$;$V(S_E \geq S_D)=0.884$

Then, by applying the equation (8), the following values are obtained:

$d'(A_A)=\min V(S_A \geq S_B,S_C,S_D,S_E)=1$

$d'(A_B)=\min V(S_B \geq S_A,S_C,S_D,S_E,)=0.540$

$d'(A_C)=\min V(S_C \geq S_A,S_B,S_D,S_E)=0.404$

$d'(A_D)=\min V(S_D \geq S_A,S_B,S_C,S_E)=0.240$

$d'(A_E)=\min V(S_D \geq S_A, S_B, S_C, S_D,)=0.089$

By applying the equation (10), criteria weight values are computed, and applying equation (11), normalized weight values of criteria are as follow:

W'=(1; 0.540; 0.404; 0.240; 0.089)

W=(0.404; 0.237; 0.178; 0.106; 0.039)

It shows that, according to the first criterion, material prices, the best solution is supplier A. In the same way, values are obtained for suppliers for the remaining eight criteria, whose final values are shown in the table below.

Table 4. Final values for suppliers according to each criterion

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
	0.104	**0.118**	**0.151**	**0.099**	**0.097**	**0.118**	**0.102**	**0.113**	**0.099**
S_A	0.440	0.241	0.280	0.090	0.169	0.285	0.242	0.214	0.264
S_B	0.237	0.241	0.280	0.436	0.133	0.236	0.169	0.170	0.121
S_C	0.178	0.132	0.194	0.161	0.242	0.146	0.242	0.258	0.264
S_D	0.106	0.187	0.246	0.090	0.242	0.146	0.214	0.179	0.264
S_E	0.039	0.199	0	0.223	0.214	0.186	0.133	0.179	0.087

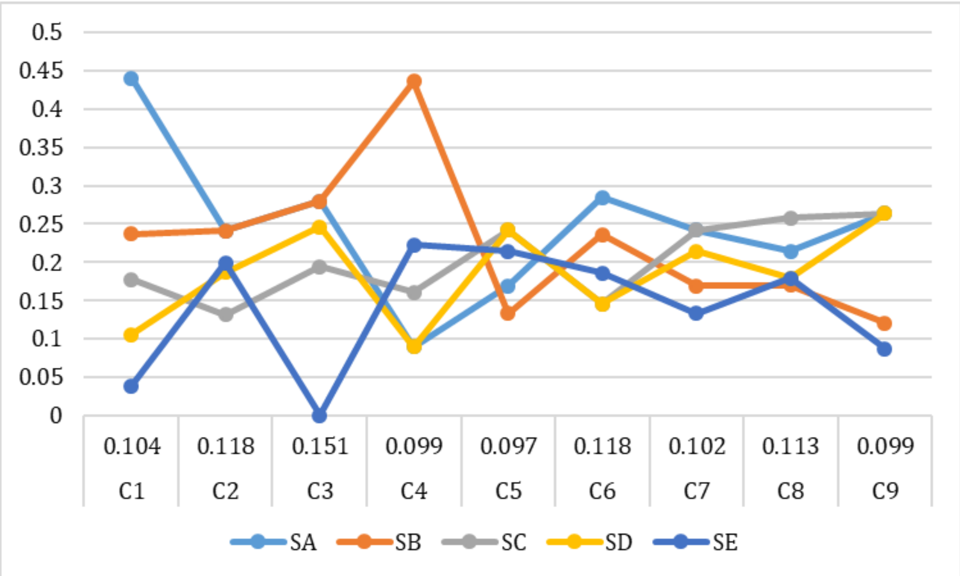

Figure 3. Values of suppliers in relation to criteria

Suppliers' values based on each criterion are shown in Fig. 3, where it is clearly visible which supplier is the best solution, and based on which criteria. Supplier A according to the first criterion and supplier B according to the fourth criterion reach the greatest values.

In order to choose the best solution and the best supplier, obtained values for suppliers from Table 4 should be multiplied by the values of the criteria in the following way:

$A_A=W_{K1}*WA_A+W_{K2}*WA_A+W_{K3}*WA_A+W_{K4}*WA_A+W_{K5}*WA_A+W_{K6}*WA_A+W_{K7}*WA_A+W_{K8}*WA_A+W_{K9}*WA_A$

$A_B=W_{K1}*WA_B+W_{K2}*WA_B+W_{K3}*WA_B+W_{K4}*WA_B+W_{K5}*WA_B+W_{K6}*WA_B+W_{K7}*WA_B+W_{K8}*WA_B+W_{K9}*WA_B$

$A_C=W_{K1}*WA_C+W_{K2}*WA_C+W_{K3}*WA_C+W_{K4}*WA_C+W_{K5}*WA_C+W_{K6}*WA_C+W_{K7}*WA_C+W_{K8}*WA_C+W_{K9}*WA_C$

$A_D=W_{K1}*WA_D+W_{K2}*WA_D+W_{K3}*WA_D+W_{K4}*WA_D+W_{K5}*WA_D+W_{K6}*WA_D+W_{K7}*WA_D+W_{K8}*WA_D+W_{K9}*WA_D$

$A_E=W_{K1}*WA_E+W_{K2}*WA_E+W_{K3}*WA_E+W_{K4}*WA_E+W_{K5}*WA_E+W_{K6}*WA_E+W_{K7}*WA_E+W_{K8}*WA_E+W_{K9}*WA_E$

Application of previously described methodology leads to results shown in Figure 4.

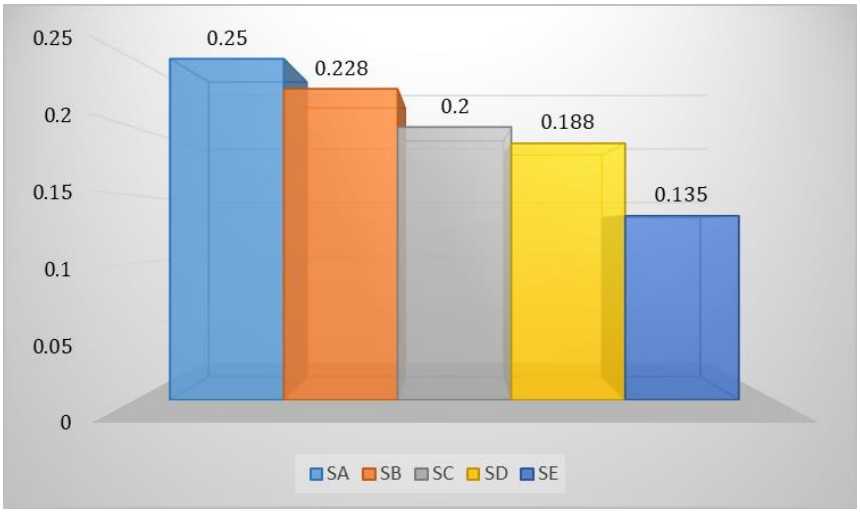

Figure 4. Ranking alternatives

Since suppliers A and B have the maximum values according to the first and fourth criterion, when it comes to comparison of alternatives against the criteria, modeling the results in the best way possible can be done by a change of their values. Obtained results in which supplier A is the most suitable solution are valid if the lower limit of the first criterion is 0.063 and the upper limit of the fourth criterion is 0.140. Given the fact that, based on the great number of criteria, the selected supplier stands out as the best or equally best solution, which can be seen in Table 4, to change the obtained results, except for the previous modeling, it is necessary to change the weight value largely.

5. Conclusion

Making decisions based on overview of great number of different criteria that largely are influencing efficiency of day–to–day business is certainly a challenge because multiple criteria are to be satisfied, which sometimes may be opposed. Procurement logistics in today's modern age is a very important factor in a complete supply chain, so its optimization can ascertain a certain effect on the entire logistics system. It is necessary to take into account a number of criteria that could affect the formation of the final price of the product, and therefore the position company achieves in the market. Application of fuzzy AHP Method makes decisions possible, by taking into account the importance of criteria and their relative priority that reflects market demands and needs. By using the fuzzy AHP Method in this study, it can be concluded that the purchase of steel pipes for the production of pre-insulted pipes should be done from supplier A.

After the sensitivity analysis, it can be concluded that the model is stable because, in the case of changing the importance of the criteria up to 30%, results remain the same and the chosen solution remains first ranked. This means that a change of results obtained requires large turbulences in the market, both in terms of suppliers and their characteristics, as well as from the aspect of user requirements.

Depending on market trends where demands and needs change frequently, it is necessary to apply the methods of multi-criteria analysis more often to adopt appropriate decisions that ensure efficient operations which can be one way of future research.

References

Aouadni, S., Rebai, A., & Turskis, Z. (2017). The Meaningful Mixed Data TOPSIS (TOPSIS-MMD) Method and its Application in Supplier Selection. *Studies in Informatics and Control, 26*(3), 353–363.

Barbarosoglu, G.; Yazgac, T. (1997). An application of the Analytic Hierarchy Process to the supplier selection problem. *Production and Inventory Management Journal, 38*(1), 14-21.

Bhutta, K. S.; Huq, F. (2002). Supplier selection problem: a comparison of the total cost of ownership and Analytic Hierarchy Process approaches. *Supply Chain Management: An International Journal, 7*(3), 126-135.

Bronja, H.; Bronja, H. (2015). Two-phase selection procedure of aluminized sheet supplier by applying fuzzy AHP and fuzzy TOPSIS methodology. *Tehnički vjesnik, 22*(4), 821-828.

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

Chang, D. Y. (1996) Applications of the extent analysis method on fuzzy AHP. *European Journal of Operational Research, 95*(3), 649-655.

Chatterjee, P., & Stević, Ž. (2019). A two-phase fuzzy AHP-fuzzy TOPSIS model for supplier evaluation in manufacturing environment. *Operational Research in Engineering Sciences: Theory and Applications, 2(*1*), 72-90.*

Chen, C. T.; Lin, C. T.; Huang, S. F. (2006). A fuzzy approach for supplier evaluation and selection in supply chain management. *International journal of production economics*, *102*(2), pp. 289-301.

Erdogan, S. A., Šaparauskas, J., & Turskis, Z. (2017). Decision making in construction management: AHP and expert choice approach. *Procedia Engineering, 172*, 270–276.

Ertugrul, I.; Karakasoglu, N. (2006). The fuzzy analytic hierarchy process for supplier selection and an application in a textile company. *Proceedings of 5th International Symposium on Intelligent Manufacturing Systems* pp. 195-207.

Fallahpour, A., Wong, K. Y., Rajoo, S., Olugu, E. U., Nilashi, M., & Turskis, Z. (2020). A fuzzy decision support system for sustainable construction project selection: an integrated FPP-FIS model. *Journal of Civil Engineering and Management, 26*(3), 247-258.

Galankashi, M. R., Helmi, S. A., & Hashemzahi, P. (2016). Supplier selection in automobile industry: A mixed balanced scorecard–fuzzy AHP approach*. Alexandria Engineering Journal, 55*(1), 93-100.

Hashemkhani Zolfani, S., Rezaeiniya, N., Kazimieras Zavadskas, E., & Turskis, Z. (2011). Forest roads locating based on AHP and COPRAS-G methods: an empirical study based on Iran. *E & M: Ekonomie a Management, 14*(4), 6–21.

Jain, V., Sangaiah, A. K., Sakhuja, S., Thoduka, N., & Aggarwal, R. (2018). Supplier selection using fuzzy AHP and TOPSIS: a case study in the Indian automotive industry. *Neural Computing and Applications*, *29*(7), 555-564.

Karpak, B.; Kumcu, E.; Kasuganti, R. R. (2001). Purchasing materials in the supply chain: managing a multi-objective task. *European Journal of Purchasing & Supply Management, 7*(3), 209-216.

Keshavarz Ghorabaee, M. K., Zavadskas, E. K., Amiri, M., & Turskis, Z. (2016). Extended EDAS method for fuzzy multi-criteria decision-making: an application to supplier selection. *International Journal of Computers Communications & Control, 11*(3), 358–371.

Keshavarz-Ghorabaee, M., Amiri, M., Zavadskas, E. K., Turskis, Z., & Antucheviciene, J. (2017). A new multi-criteria model based on interval type-2 fuzzy sets and EDAS method for supplier evaluation and order allocation with environmental considerations. *Computers & Industrial Engineering, 112*, 156–174.

Lee, A. H. (2009). A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks. *Expert Systems with Applications, 36*(2), 2879-2893.

Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology, 15*(3), 234-281.

Saaty, T. L. (1978). Exploring the interface between hierarchies, multiple objectives and fuzzy sets. *Fuzzv Sets and Sysfems, I*, 57-68.

Saaty, T. L. (1980). *The Analytic Hierarchy Process*, Mc Graw-Hill, NewYork,

Saaty, T. L. (1982). The Analytic Hierarchy Process: A new approach to deal with fuzziness in architecture. *Architectural Science Review, 25*(3), 64-69.

Saaty, T. L. (1990) How to make a decision: the analytic hierarchy process. *European Journal of Operational Research, 48*(1), 9-26.

Setyohadi, D. B., & Suyoto, S. (1977). Alternative selection scenarios of oil and gas using fuzzy analytical hierarchy process (FAHP). In *AIP Conference Proceedings* (Vol. 20021, No. 2018).

Stević Ž.; Alihodžić A.; Božičković Z.; Vasiljević M.; Vasiljević Đ. (2015) Application of combined AHP-TOPSIS model for decision making in management. / *5th International conference "Economics and Management – based On New Technologies" EMONT* (plenary session) / Vrnjačka Banja, Serbia, pp. 33-40

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.

Turskis, Z., Antuchevičienė, J., Keršulienė, V., Gaidukas, G. (2019). Hybrid group MCDM model to select the most effective alternative of the second runway of the airport. *Symmetry 2019, 11*(6), 792.

Turskis, Z., Zavadskas, E. K., Antucheviciene, J., & Kosareva, N. (2015). A hybrid model based on fuzzy AHP and fuzzy WASPAS for construction site selection. *International Journal of Computers Communications & Control, 10*(6), 113–128.

Van Laarhoven, P. J., & Pedrycz, W. (1983). A fuzzy extension of Saaty's priority theory. *Fuzzy sets and Systems, 11*(1-3), 229-241.

Verma, R.; Pullman, M. E. (1998). An analysis of the supplier selection process. *Omega, 26*(6), 739-750.

Weber, C. A.; Current, J. R.; Benton, W. C. (1991). Vendor selection criteria and methods. *European Journal of Operational Research, 50*(1), 2-18.

Xu, Z.; Liao, H. (2014). Intuitionistic fuzzy Analytic Hierarchy Process. *Fuzzy Systems, IEEE Transactions on, 22*(4), 749-761.

Yazdani, M., Wen, Z., Liao, H., Banaitis, A., & Turskis, Z. (2019). A grey combined compromise solution (CoCoSo-G) method for supplier selection in construction management. *Journal of Civil Engineering and Management, 25*(8), 858–874.

Zadeh, L.A. (1965). Fuzzy sets. *Information and Control, 8*(3), 338-353.

Zavadskas, E. K., Mardani, A., Turskis, Z., Jusoh, A., & Nor, K. M. (2016). Development of TOPSIS method to solve complicated decision-making problems—An overview on developments from 2000 to 2015. *International Journal of Information Technology & Decision Making, 15*(03), 645-682.

Zemlickienė, V., & Turskis, Z. (2020). Evaluation of the expediency of technology commercialization: a case of information technology and biotechnology. *Technological and Economic Development of Economy, 26*(1), 271-289.

Zhu, K. J.; Jing, Y.; Chang, D. Y. (1999). A discussion on extent analysis method and applications of fuzzy AHP. *European Journal of Operational Research, 116*(2), 450-456.

© 2020 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).