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Supplier Selection Among Different Scale Construction Companies Using Fuzzy AHP And Fuzzy TOPSIS

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Abstract: Supplier selection is an important strategic decision for construction companies due to long-term project durations and high costs. In the construction sector, supplier selection decisions should take several criteria and alternatives into account. Along with the high number of alternative suppliers, choosing the best method to evaluate the alternative suppliers is another critical step. In this study, we compare the effectiveness of different multi-criteria decision-making methods for selecting the most convenient supplier for construction companies. In this respect, we study the integration of powerful multi-criteria decision-making methods, Fuzzy Analytic Hierarchy Process (AHP) and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). We use Fuzzy AHP for the calculation of decision criteria weights, and then we apply Fuzzy TOPSIS for ranking the alternatives. Several interviews were made with the experts at construction companies and as a result of those interviews, 7 main criteria and 24 sub-criteria for comparing alternative suppliers of the companies were determined. We test our approach for two construction companies and use an integrated Fuzzy AHP and Fuzzy TOPSIS method to find the best supplier for the selected criteria. The contribution of this study is not limited to the multi-criteria decision-making methods for the supplier selection problem in the construction sector, but also we make a comparison of the supplier selection decisions of two different sized companies having the same supplier pool, and we show the effect of company based criteria weights in supplier selection.

Keywords: Fuzzy AHP; Fuzzy TOPSIS; Supplier selection.

Farklı Büyüklükteki İnşaat Firmaları için Bulanık AHP ve Bulanık TOPSIS Yöntemleriyle Tedarikçi Seçimi

Öz: İnşaat firmaları için tedarikçi seçimi, uzun dönemli proje süreleri ve yüksek maliyetler açısından stratejik bir karardır. İnşaat sektöründe tedarikçi seçimi yapılırken pek çok kriter ve alternatif dikkate alınmalıdır. Alternatif tedarikçilerin sayısının fazla olmasının yanı sıra alternatif tedarikçileri kıyaslamak için en iyi metodun seçimi de kritik bir karardır. Bu çalışmada, inşaat firmaları için en iyi tedarikçiyi seçme sürecinde farklı çok kriterli karar verme metotlarının etkinliğini kıyaslamaktayız. Bu nedenle, çok kriterli karar verme problemi çözümünde oldukça etkili olduğu bilinen bulanık AHP (Analitik Hiyerarşi Prosesi) ve bulanık TOPSIS (İdeal Çözüme Benzerlik Bakımından Sıralama Performansı Tekniği) metotlarının entegrasyonunu incelemekteyiz. Bulanık AHP metodu ile kriter ağırlıklarını hesaplayıp bulanık TOPSIS metodu ile alternatifleri sıralamaktayız. İnşaat sektöründeki çok sayıda uzman ile yaptığımız görüşmeler sonucunda inşaat firmalarının tedarikçilerinin seçimi için 7 ana ve 24 alt kriter belirlenmiştir. Yaklaşımımızı iki inşaat firması için belirlenen kriterlere göre en iyi tedarikçiyi seçmek için bulanık AHP ve bulanık TOPSIS metotlarını bütünleşik olarak kullanıp test etmekteyiz. Bu çalışmanın literatüre katkısı sadece çok kriterli karar verme metotlarının inşaat sektöründe uygulanmasıyla sınırlı olmayıp aynı zamanda aynı tedarikçi havuzunu kullanan farklı ölçekteki iki inşaat firmasının tedarikçi seçimleri kıyaslanmakta ve firmalara göre belirlenen kriter ağırlıklarının tedarikçi seçimine etkisi gösterilmektedir.
Anahtar Kelimeler: Bulanık AHP; Bulanık TOPSIS; Tedarikçi seçimi.

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1. Introduction

Supply is defined as providing the required product or service within the desired time at the right quantity and with the acceptable quality. Supply chain is a network of producers and distributors in which raw materials are procured, semi-finished and final goods are produced, and products are distributed to customers [1]. Until 1990, the main objective of manufacturers was minimizing the unit production costs. This was due to the popularity of mass production systems and economies of scale approach used for producing large quantities of standardized products. After 1990s, due to the increase in product variety and the competition between companies, customer focused production has emerged. Customer demand and needs became the most important factors affecting the business decisions. In order to ensure customer satisfaction, it is necessary for all members of the supply chain (suppliers, producers, retailers, etc.) to cooperate with each other considering the fact that a single supply chain member cannot control the intra-company activities alone without cooperation. Because of this necessity, the Supply Chain Management, which enables to manage all supply chain, has emerged [2, 3].

Today, companies focus on responding to their customers in shorter time and thus try to become superior to their competitors and gain more profit with an effective supply chain management. In order to achieve these, all members in the chain should be in coordination and act as one unit. Among the members of the supply chain (suppliers, manufacturers, retailers, etc.), maybe the most important actor in the supply chain is the supplier, because suppliers are critical sources that provide direct and indirect materials to manufacturers for the production [4]. Therefore, in order to meet the changing customer needs, companies prefer to work with the most suitable supplier or suppliers that meet their needs along with the quality and time tolerances that fit their own strategies. As a result of this, supplier selection problem is critical in today's competing market conditions.

The supplier selection is described as determining the best supplier from a set of alternatives within the acceptable cost range satisfying the company's requirements. The high number of different criteria and decision models, and also the difficulty of group decision making under uncertainty, make the selection process complicated [3].

Options for the supplier are either choosing from the current suppliers or finding a new one by conducting research in the market [5]. In both cases, supplier selection problem is a multi-criteria decision-making problem, because there are multiple criteria evaluation processes [6].

Another important issue in the supplier selection problem is determining the most appropriate method. There are various methods in the literature for the supplier selection problem and these methods embed a multi-criteria decision-making structure in general. Some of these methods include Analytic Hierarchy Process (AHP) [7, 8], game theory [9], Bayesian Network Model [10], Quality Function Deployment (QFD) [11], Multi-Criteria Optimization and Compromise Solution (VIKOR) [12], Best Worst Method [13], Fuzzy AHP and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [14], Data Envelopment Analysis [15], AHP - Fuzzy TOPSIS [16], Fuzzy AHP and Decision Making Trial and Evaluation Laboratory (DEMATEL) [17], Fuzzy TOPSIS, Fuzzy VIKOR, and Fuzzy Grey Relational Analysis (GRA) [18], Fuzzy AHP-VIKOR [19], Fuzzy AHP [20, 21], mixed-integer linear programming [22], mixed integer nonlinear programming based on a mathematical model [23], linear programming [24].

In this study, the most widely used methods, fuzzy AHP and fuzzy TOPSIS, are used in a sequentially integrated manner. Weights of evaluation criteria are found with fuzzy AHP since this method is most superior method for calculation of the weight due to the calculation approach. Then we use fuzzy TOPSIS, one of the most appropriate methods to define the differences of two alternatives according to their order preference concept, to select the right supplier among a set of alternative suppliers. This study is not limited to the multi-criteria decision-making methods for the supplier selection problem using the defined criteria from literature. Additionally, we make a comparison of the supplier selection decisions of two different sized companies having the same supplier pool using the sector related criteria defined by a survey among the experts in this field, and we show the effect of company based criteria weights in supplier selection.

2. Literature Review

Supplier selection is an important activity of procurement process which has a great impact on the quality of products and the success of enterprises, and consequently the whole supply chain [5]. The supplier selection can generally be defined as the determination of the best supplier among a set of alternative suppliers. There are many qualitative and quantitative criteria for the comparison of supplier alternatives. These criteria can change according to the sector and the company [20]. So an important sub-problem of supplier selection problem is defining the criteria for evaluating and selecting suppliers. Consequently, in this study the literature review can be divided in to two parts.

The first part of our literature review focuses on the definition of evaluation criteria. The precursor study on identifying the selection criteria was conducted by Dickson [25] in 1966. Dickson identified 23 supplier selection criteria since then which have been widely adopted and reviewed in several studies. He reported that the quality has extreme importance; the delivery, performance history, warranties & claims policy, production facilities and capacity, price, technical capability, and financial position have considerable importance according to mean rating. Weber and Current [26] also published a study which analyzed 74 papers on supplier selection criteria during a 25-year period, 1966-1990. They remarked that price is the most important criterion and then it is followed by other criteria namely, delivery, quality, production facilities, and capacity, respectively. Choi and Hartley [27] worked on selection criteria in auto industry companies that had different structures such as having direct and indirect auto assemblers. Gunasekaran and Patel [28] also developed a framework based on the literature review, for measuring strategical, tactical and operational level performance in a supply chain. Wu and Weng [29], studied eight key factors (capabilities for price response, quality management, technology, delivery, flexibility, management, commercial image, and finance) for supplier selection that are considered by manufacturers. Chang and Chang [30] used the DEMATEL method for evaluating the supplier performance and finding key factor criteria. When we look other studies on the determination of the supplier evaluation criteria, it seems that they mostly used evaluation criteria given in literature reviews [13, 31, 32]. Therefore, instead of using the evaluation criteria which are already defined in literature, defining the criteria with respect to the sector based variables becomes an outstanding topic as we did in this study.

Another important issue in supplier selection problems is the determination of the most appropriate method for the selection. There are many methods in the literature to solve this multi-criteria decision making problem. The critical step in deciding on a method is to determine the best method that fits to the structure of the problem, because the method used in supplier selection affects the result as much as the evaluation criteria used in this decision-making process. The literature includes both individual and integrated methods, and the individual approaches are generally more popular than integrated approaches. Although there are many integrated methods for supplier selection, AHP is the most common one due to its clarity, ease of handling, and adaptability [33]. The objective of AHP is doing calculations by taking the expert's experience into account, but it does not reflect the actual human thinking process. Therefore, fuzzy extension of AHP seems to be preferable over classical AHP [20]. TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), which is also one of the most used classical multi criteria decision making (MCDM) method, based on the idea that the most ideal alternative has the minimum distance from the Positive Ideal Solution (PIS) and the largest from the Negative Ideal Solution (NIS). But for real-life problems, exact data can be inadequate. For such situations, a classical AHP approach, using fuzzy form of TOPSIS could be better. So, the human judgement which has a vague structure could be integrated in decision making process [3].

In Chen [34]'s study, TOPSIS method was extended with fuzzy logic and he presented the applicability of this method in a multi-criteria decision-making problem as a new method. He defined linguistic expressions in terms of triangular fuzzy numbers to use in the evaluation of criteria and alternatives and to overcome the uncertainty. Chen, Lin [3] used fuzzy TOPSIS method for supplier selection problem and demonstrated the applicability of the method. Kannan, Jabbour [35] also used Fuzzy TOPSIS method for green supplier selection problem. They proposed a framework using Fuzzy TOPSIS to build the criteria of green supply chain management practices. Kahraman and Cebeci [20] defined the most appropriate supplier according to the determined criteria using fuzzy AHP method which used extend analysis method. Kilincci and Onal [36] used extent analysis method on Fuzzy AHP to determine the best supplier firm based on customer satisfaction criteria. Lima Junior, Osiro [5] compared the fuzzy AHP and fuzzy TOPSIS methods for supplier selection problem. The comparison was made according to the adequacy for changing of alternatives or criteria, speediness in the decision process, the computational complexity, the qualification to support group decision making, the number of alternative suppliers and criteria, and the performance against uncertainty. The results show that both methods are well suited to deal with the supplier selection problem. Stević, Božičković [37] used combined classical AHP and fuzzy AHP methods to rank and select the most suitable supplier among chipboard importers. Ak [46] finds decision criteria weights via AHP and uses VIKOR and TOPSIS to rank the suppliers. Chaising and Temdee [38], studied the problem of selecting the best raw material supplier in a SME (Small and Medium Enterprise) for a multi-period process. The Fuzzy AHP and TOPSIS methods were used in an integrated way to handle quantitative and qualitative criteria in the selection of the raw material supplier. Gupta and Barua [39] studied on supplier selection among SMEs in terms of their green innovation ability by using best worst method and Fuzzy TOPSIS. Ortiz-Barrios and Kucukaltan [17] used Fuzzy AHP, DEMATEL and TOPSIS methods to determine the most suitable polyethylene supplier. In the decision-making process, the Fuzzy AHP method was used to deal with the problem of uncertainty of the evaluations of individuals and the inability to make decisions with numerical values. This method was integrated with DEMATEL to evaluate the relationship between factors and sub-factors and to identify potential advanced strategies, and then TOPSIS method was used to rank the suppliers using the weights calculated with the Fuzzy AHP-DEMATEL method. Banaeian, Mobli [18], compared the results of Fuzzy TOPSIS, Fuzzy VIKOR, and Fuzzy GRA methods. The application of these 3 methods was made for the selection of green suppliers in an agricultural-food sector enterprise and the results showed GRA has better time performance while the suppliers ranking was similar. To the best of our knowledge, there is no study which use the fuzzy AHP and fuzzy TOPSIS sequentially to take the advantages of different perspective of these two methods for construction sector.

3. Methods

MCDM methods are suitable for supplier selections problems thanks to their nature. Although there are several MCDM method used in this field fuzzy AHP and fuzzy TOPSIS is preferred hieratically to make use of their differences. While fuzzy AHP is an outstanding method for calculation of weight, fuzzy TOPSIS is such a method better for ordering. It is also needs to be mentioned that in state of using the classical form of these methods, using the fuzzy methods give better solution. Due to all the given reasons, fuzzy AHP and fuzzy TOPSIS methods are used in this paper.

3.1. Fuzzy AHP

Fuzzy AHP extends AHP to imitate human thinking using the fuzzy logic and relies on pairwise comparison. In the literature, there exists a number of fuzzy AHP methods in the literature given by different studies. All these methods depend on fuzzy set theory and have a hierarchical alternative selection structure.[20].

The first method for fuzzy AHP is developed by van Laarhoven and Pedrycz in 1983 and then Buckley [41], Boender, de Graan [42], Chang [43], and Cheng [44] developed respectively different fuzzy AHP methods that had both some advantages and disadvantages [45]. Although all of these methods are used for solving multi-criteria decision making problems, the most popular one is Chang [43]'s extend analysis method due to its easy implementation, less time and calculation requirements [5, 37].

Extent analysis method of fuzzy AHP has 4 steps for application [43]. Let X={x_1,x_2,…,x_n } describe object set and G={g_1,g_2,…,g_n } a goal set. Chang [43] takes each object and extend analysis is performed for each goal. So, *m* extent analysis values for the objects can be obtained as shown below:

$$M_{g_i}^1, M_{g_i}^2, \dots, M_{g_i}^m \quad i = 1,2,\dots,n \tag{1}$$

All the above $M_{g_i}^j$ $(\mathrm{j} = 1,2,\dots,\mathrm{m})$ are triangular numbers.

Step 1: Calculate the fuzzy synthetic extent for the i^th object according to equation (2).

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

To obtain $\sum_{j=1}^{m} M_{g_i}^j$, perform the fuzzy addition operation of m extent analysis values for a particular matrix such that:

$$\sum_{j=1}^{m} M_{g_i}^j = \left(\sum_{j=1}^{m} l_j , \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{3}$$

where

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^j\right]^{-1} = \left(\frac{1}{\sum_{j=1}^{n} u_i}, \frac{1}{\sum_{j=1}^{n} m_i}, \frac{1}{\sum_{j=1}^{n} l_i}\right) \tag{4}$$

Step 2: As well as $\widetilde{M}_1=(l_1, m_1, u_1)$ and $\widetilde{M}_2=(l_2, m_2, u_2)$ are two fuzzy numbers, the degree of possibility of $\widetilde{M}_2 \geq \widetilde{M}_1$ is defined as:

$$V(\widetilde{M}_2 \geq \widetilde{M}_1) = \underset{y \geq x}{sub}\left[min\left(\mu_{M_1}(x), \mu_{M_2}(y)\right)\right] \tag{5}$$

Equation (5) is the expression of the $y \geq x$ according to the expansion principle. Therefore, the equation states that, the relationship of a pair (x, y) such as y ≥ x, in other words shows $V(\widetilde{M}_2 \geq$ $\widetilde{M}1$ that indicates the magnitude relationship between them, that is, M_2 may be greater than M_1.

$\widetilde{M}_1$ and $\widetilde{M}_2$ are convex fuzzy numbers so:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d)\begin{cases} 1, & if \quad m_2 \geq m_1 \\ 0, & if \quad l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \tag{6}$$

Where *d* is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2} (see Fig. 1).

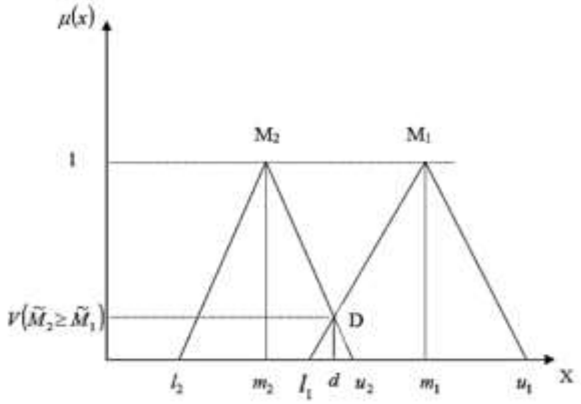

Figure 1. Intersection of M_1 *and* M_2

Step 3: The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers $M_i(i = 1,2, \dots, k)$ can be defined by:

$$V(M \geq M_1, M_2 \dots M_k) \quad (7)$$

which means

$$\min V(M \geq M_i),\ i = 1,2, \dots, k \quad (8)$$

Assume that:

$$d'(A_i) = \min V(S_i \geq S_k) \quad (9)$$

For $k = 1,2, \dots, n; k \neq i$. After that the weight vector is defined as:

$$W' = \left(d'(A_1), d'(A_2), \dots, d'(A_n)\right)^T \quad (10)$$

where A_i $(i = 1,2, \dots, n)$ are *n* elements.

Step 4: The normalized weight vector is pointed out by

$$W = \left(d(A_1), d(A_2), \dots, d(A_n)\right)^T \quad (11)$$

where *W* is a non-fuzzy number.

3.2. Fuzzy TOPSIS

Fuzzy TOPSIS, developed by [34], uses linguistic variables in ranking calculations. The fuzzy positive ideal solution (FPIS) and the fuzzy negative ideal solution (FNIS) are defined by considering classical TOPSIS [3].

In Fuzzy TOPSIS, $\tilde{a}$=(a_1, a_2, a_3) and $\tilde{b}$=(b_1, b_2, b_3) are both triangular fuzzy numbers. The distance between these numbers is calculated by using the vertex method as in equation (12).

$$d\left(\tilde{a}, \tilde{b}\right) = \sqrt{\frac{1}{3}\sum_{i=1}^{3}(a_i - b_i)^2} \quad (12)$$

In Fuzzy TOPSIS method, there are several linguistic variables used in raking process, as depicted in Table 1 and Table 2, respectively.

Assume that for a decision group having K persons, the importance of the criteria and the rating of alternatives calculated by using equation (13) and (14), respectively.

$$\widetilde{w}_j = \frac{1}{K}\left[\widetilde{w}_j^1(+)\widetilde{w}_j^2(+)\widetilde{w}_j^3(+)\ldots\widetilde{w}_j^K\right] \tag{13}$$

$$\tilde{x}\text{ij}=\frac{1}{K}\left[\tilde{x}_{ij}^1(+)\tilde{x}_{ij}^2(+)\tilde{x}_{ij}^3(+)\ldots\tilde{x}_{ij}^K\right] \tag{14}$$

Table 1. Linguistic variables for the importance weight of each criterion [34]

Very low (VL)	(0, 0, 0.1)
Low (L)	(0, 0.1, 0.3)
Medium low (ML)	(0.1, 0.3, 0.5)
Medium (M)	(0.3, 0.5, 0.7)
Medium high (MH)	(0.5, 0.7, 0.9)
High (H)	(0.7, 0.9, 1.0)
Very high (VH)	(0.9, 1.0, 1,0)

According to the responses from the decision makers, matrices are defined as follows:

$$\widetilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{21} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \ldots & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \tag{15}$$

$$\widetilde{W} = [\widetilde{w}_1 \quad \widetilde{w}_2 \quad \cdots \quad \cdots \quad \widetilde{w}_n] \tag{16}$$

Table 2. Linguistic variables for the ratings [34]

Very poor (VP)	(0, 0, 1)
Poor (P)	(0, 1, 3)
Medium poor (MP)	(1, 3, 5)
Fair (F)	(3, 5, 7)
Medium good (MG)	(5, 7, 9)
Good (G)	(7, 9, 10)
Very good (VG)	(9, 10, 10)

Where $\widetilde{D}$ is fuzzy decision matrix and $\widetilde{W}$ is fuzzy weight matrix. In matrices $\widetilde{D}$ and $\widetilde{W}$, $\tilde{x}_{ij}$ ($\forall_{ij}$) and $\widetilde{w}_j$ j=(1,2,…,n) are linguistic variables These linguistic variables are described as triangular fuzzy numbers, $\tilde{x}_{ij} = \left(a_{ij}, b_{ij}, c_{ij}\right)$ and $\widetilde{w}_j = \left(w_{j1}, w_{j2}, w_{j3}\right)$.

Chen [34] uses linear scaling to transform the various criterion scales to a comparable scale to avoid complex normalization formulas used in classical TOPSIS. The normalized fuzzy decision matrix, denoted by $\widetilde{R}$, is constructed as follows:

$$\widetilde{R} = \left[\widetilde{r}_{ij}\right]_{mxn} \tag{17}$$

The normalized fuzzy decision matrix B and C contain benefit and cost criteria, respectively and formed using equations (18) and (19).

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), \quad j \in B \tag{18}$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), \quad j \in C \tag{19}$$

where

$$c_j^* = \max c_{ij} \text{ if } j \in B \tag{20}$$

$$a_j^- = min\, a_{ij} \text{ if } j \in C \tag{21}$$

Then the weighted normalized fuzzy decision matrix is found as follows:

$$\tilde{V} = \left[\tilde{v}_{ij}\right]_{mxn} \quad i = 1,2,\dots,m\,; j = 1,2,\dots,n \tag{22}$$

In equation (22), $\tilde{v}_{ij}$ is calculated as shown by equation (23).

$$\tilde{v}_{ij} = \tilde{r}_{ij}(.)\tilde{w}_{ij} \tag{23}$$

The FPIS (A^*) and the FNIS (A^-) are defined according to equations (24) and (25), respectively.

$$A^* = \tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^* \tag{24}$$

$$A^- = \tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^- \tag{25}$$

where $\tilde{v}_j^* = (1,1,1)$ and $\tilde{v}_j^- = (0,0,0)$, j= (1,2,…, n).

The distance between the alternatives A^* and A^- is given by:

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*, i = 1,2,\dots,m \tag{26}$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-, \ i = 1,2,\dots,m \tag{27}$$

In order for the alternatives to be sorted, the closeness coefficients are calculated using equation (28).

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \ i = 1,2,\dots,m \tag{28}$$

4. Results of Supplier Selection Problem using Fuzzy AHP and Fuzzy TOPSIS

High project budgets and long project completion times are very common in the construction projects. Before the start of a project, the answers of the most questions are already known, such as “when the project will be completed”, “who will be involved in the project, “with which suppliers it is going to be worked with”, and “when the raw materials will be procured”. In this sector, the identification of suppliers for procurement has more importance than other sectors, because after the start of the project, change of suppliers or delays caused by the suppliers can lead to serious costs as well as delay of the project completion time.

Applying the steps given by equations (2-11), the results given in Table 4 is obtained.

Table 3. Pairwise Fuzzy Numbers of flexibility for Company A

	After-sales support	Warranty	Response to changes	Fulfilling the urgent
After-sales support	1, 1, 1	1.5, 2, 2.5	0.4, 0.5, 0.67	0.22, 0.25, 0.29
Warranty	0.4, 0.5, 0.67	1, 1, 1	0.29, 0.33, 0.4	0.29, 0.33, 0.4
Response to changes	1.5, 2, 2.5	2.5, 3, 3.5	1, 1, 1	0.22, 0.25, 0.29
Fulfilling the urgent	3.5, 4, 4.5	2.5, 3, 3.5	3.5, 4, 4.5	1, 1, 1

Table 4. Weights of criteria

Main Criteria	Weight A	Weight B	Sub-Criteria	Weight A	Weight B
Flexibility	0,0725	0,0176	After-sales support	-	-
			Warranty	-	-
			Response to changes	-	-
			Fulfilling the urgent requirements	0,1429	0,0955
Quality	0,0366	-	Finding solutions to quality problems	0,0081	-
			Technical competence	-	-
			Certificate of quality	-	0,0070
			Product quality	0,1429	0,0955
Price	0,2676	0,2642	Terms of payment	0,1429	0,0955
			Availability at the market price	0,0067	0,0339
			Transportation cost	-	-
			Discount commitment	-	0,0195
Relationship	0,0653	0,1585	Compliance with contract terms	0,0690	0,0891
			Ease of communication	-	0,0955
			Communication openness	0,1429	0,0097
			Potential for collaboration	0,0293	-
Profile	0,1014	0,2521	Performance history	-	-
			Sustainability performance	0,0293	0,0500
			Production facility and capacity	0,1429	0,0955
Delivery	0,2676	0,1292	The right product delivery	0,1429	0,0955
			Conformity of delivery quantity	-	0,0495
			On-time Delivery	-	0,0495
			Delivery time	-	0,0233
Vendor - supplier relationships	0,1890	0,1784	Financial stability	0,1429	0,0955

In this study we worked with two companies that are called as Company A and Company B, both of them from construction sector and located in mid-Anatolia, Turkey. Company A was founded in 1978 and it works on projects such as construction of industrial buildings, shopping centers, and living areas. The company has a large scale project in mid-Anatolia and nowadays they start a new project in Istanbul in partnership with a large scale company. Company B was founded in 2010 and started the service with a shopping center project. After this project, the company built some living areas but all project are in mid-Anatolia. So we can say the company B has a smaller business scope than Company A. Besides this, two company work with same suppliers. So in this part we identify the best supplier for different scale companies.

Firstly, we defined which supplier group we will evaluate. According the construction purchasing experts, the sector has 3 fundamental different purchasing area which are construction, mechanical, and electrical. In this study, we deal with only ready-mixed concrete suppliers which are in construction materials area. After this step, the evaluation criteria are determined from the literature along with expert opinions. 7 main criteria and 24 sub-criteria are determined for construction. The determined criteria's weights are calculated with extent analysis method on fuzzy AHP, systematically as shown below. Table 3 shows that the pairwise comparison of flexibility criteria for Company A and the reference calculation is made according to this pairwise comparison. All the calculations for Companies A and B are done according the fuzzy numbers that are achieved by pairwise comparison of experts' opinions.

Table 5. Weighted Normalized Decision Matrix for Company A

	S1			**S2**			**S3**		
Fulfilling the urgent requirements	0,7778	1,0000	0,5556	0,7778	1,0000	0,5556	0,7778	1,0000	0,7778
Finding solutions to quality problems	0,0441	0,0567	0,0315	0,0441	0,0567	0,0189	0,0315	0,0441	0,0441
Product quality	0,9000	1,0000	0,5000	0,7000	0,9000	0,3000	0,5000	0,7000	0,9000
Terms of payment	-	0,1000	0,7000	0,9000	1,0000	-	0,1000	0,3000	-
Availability at the market price	-	0,0052	0,0260	0,0364	0,0468	0,0260	0,0364	0,0468	-
Compliance with contract terms	0,4347	0,4830	0,2415	0,3381	0,4347	0,2415	0,3381	0,4347	0,4347
Financial stability	0,9000	1,0000	0,5000	0,7000	0,9000	0,3000	0,5000	0,7000	0,9000
Ease of communication	-	-	-	-	-	-	-	-	-
Communication openness	0,9000	1,0000	0,7000	0,9000	1,0000	0,5000	0,7000	0,9000	0,9000
Potential for collaboration	0,1594	0,2049	0,1138	0,1594	0,2049	0,1138	0,1594	0,2049	0,1594
Performance history	-	-	-	-	-	-	-	-	-
Sustainability performance	0,1594	0,2049	0,0683	0,1138	0,1594	0,1138	0,1594	0,2049	0,1594
Production facility and capacity	0,7000	0,9000	0,3000	0,5000	0,7000	0,7000	0,9000	1,0000	0,7000
The right product delivery	0,9000	1,0000	0,7000	0,9000	1,0000	0,7000	0,9000	1,0000	0,9000

After the calculation of criteria weights, alternatives are evaluated using with fuzzy TOPSIS method. The calculations are made using MS Excel according to the given equations related with Fuzzy TOPSIS. Since the weights are calculated using the Fuzzy AHP, weighted normalized fuzzy decision matrix is the first calculation step of fuzzy TOPSIS using the equations from 17 to 23. The weighted normalized fuzzy decision matrix results for each company is given in Table 5 and Table 6 separately using the evaluation values.

The FPIS (A^*) and the FNIS (A^-) are defined according to equations (24) and (25), respectively. Here for A^* and A^- are $\tilde{v}_j^*$=(1,1,1) and $\tilde{v}_j^-$=(0,0,0).

To find the best alternative the distance between the each alternatives from the positive and negative ideal solutions A^* and A^- is calculated by using equations (26) and (27) considering vertex distance respectively and results are given in the Tables 7 for both Company A and B.

Table 6. Weighted Normalized Decision Matrix for Company B

	S1			**S2**			**S3**		
Fulfilling the urgent requirements	0,5000	0,7000	0,9000	0,9000	1,0000	1,0000	0,7000	0,9000	1,0000
Certificate of quality	0,0512	0,0658	0,0731	0,0512	0,0658	0,0731	0,0512	0,0658	0,0731
Product quality	0,7000	0,9000	1,0000	0,7000	0,9000	1,0000	0,7000	0,9000	1,0000
Terms of payment	0,5000	0,7000	0,9000	0,7000	0,9000	1,0000	0,7000	0,9000	1,0000
Availability at the market price	0,2482	0,3191	0,3545	0,2482	0,3191	0,3545	0,2482	0,3191	0,3545
Transportation cost	-	-	-	-	-	-	-	-	-
Discount commitment	0,0877	0,1461	0,2046	0,0877	0,1461	0,2046	0,0877	0,1461	0,2046
Compliance with contract terms	0,6532	0,8398	0,9331	0,6532	0,8398	0,9331	0,6532	0,8398	0,9331
Financial stability	0,7000	0,9000	1,0000	0,7000	0,9000	1,0000	0,7000	0,9000	1,0000
Ease of communication	0,0714	0,0917	0,1019	0,0714	0,0917	0,1019	0,0714	0,0917	0,1019
Performance history	0,3664	0,4711	0,5234	0,3664	0,4711	0,5234	0,3664	0,4711	0,5234
Sustainability performance	0,7000	0,9000	1,0000	0,9000	1,0000	1,0000	0,7000	0,9000	1,0000
Production facility and capacity	0,7000	0,9000	1,0000	0,7000	0,9000	1,0000	0,7000	0,9000	1,0000
The right product delivery	0,3630	0,4668	0,5186	0,3630	0,4668	0,5186	0,3630	0,4668	0,5186
Conformity of delivery quantity	0,3630	0,4668	0,5186	0,3630	0,4668	0,5186	0,3630	0,4668	0,5186
On-time Delivery	0,1708	0,2195	0,2439	0,1708	0,2195	0,2439	0,1708	0,2195	0,2439
Delivery time	0,7000	0,9000	1,0000	0,7000	0,9000	1,0000	0,7000	0,9000	1,0000

Table 7. d^- and d^* Values

	d_i^-			d_i^*		
	S1	S2	S3	S1	S2	S3
Company A	5,8760	6,1022	5,2481	18,5482	18,3584	19,2029
Company B	8,8302	9,3282	9,1438	15,6657	15,0980	15,3477

Finally, using equation (28) with the information given Table 7, the ranking of Company A's suppliers are S2 (0.2495), S1 (0.2495) and S3 (0.2146), while supplier of Company B is sorted as S2 (0.3819), S3 (0.3733) and S1 (0.3605). These results imply that both companies have the same best supplier yet order of suppliers change for the second and third best suppliers depending on the company.

5. Discussion and Conclusions

Supplier selection is one of the important problems for the supply chain management in the construction sector. For construction companies, the studies directly concentrating on supplier selection with use of multi-criteria decision-making techniques are limited in number. In addition, because of the structure of sector, purchase of materials for construction, mechanical, and electrical areas can be different from each other. There are no specific study for the selection of construction materials providers. Therefore, by this study, an integrated multi-criteria decision-making method is applied to select the most appropriate supplier in the construction area based on Fuzzy AHP and Fuzzy TOPSIS methods. This integration is useful for evaluation and selection process, because AHP works based on weighted criteria and TOPSIS is better for ranking. Also for the expression of assessment difficulty in numerical terms due to human vagueness, fuzzy logic is involved in selection process.

According to our study, the results show that the most preferred supplier is same for both companies although the companies have different sizes. However, in this sector it is not possible to work only with one supplier so alternative suppliers should be considered, too. At this point, our results show that the second and the third preferred suppliers may differ depending to the size of companies. Another important outcome of the study is the differences in evaluation criteria weights. As the most important criterion, price, and vendor - supplier relationships have the same ranking, however the criteria for quality, profile, and delivery have different weights for companies A and B. After-sales support, warranty, response to changes, technical competence, and performance history criteria weights are zero for two companies because of the structure of construction purchasing. On the other hand, these criteria weights for mechanical and electrical area purchases could be different than zero. Therefore, we conclude that in construction sector, the criteria weights may be different according to purchase category. According to the results, the fulfillment of urgent requirements, the product quality, terms of payment, the production facility and the capacity, the right product delivery and the financial stability have different weight scores for both companies A and B but have the largest weights. In addition, some other criteria like ease of communication, on-time delivery have different scores and different ranks. Therefore, we conclude that although the most important criteria are same for different companies regardless of company size, the less important criteria may have different rankings for different companies.

Furthermore, future studies may focus on the other purchase categories (electrical and mechanical) of construction sector and show the difference. In addition, other multi-criteria decision-making methods can be performed on this problem and the results can be compared with our findings. Also, use of evaluation criteria related to environmental protection for green supply chain management can be considered for construction companies in supplier selection problem.

Yazarların Katkıları

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Çıkar Çatışması

Yazarlar, çıkar çatışması olmadığını beyan eder.

References

[1]. Lee, H.L. and C. Billington, Managing supply chain inventory: pitfalls and opportunities, Sloan Management Review, 1992, 33(3): 65.

[2]. Özdemir, A.İ., Tedarik zinciri yönetiminin gelişimi, süreçleri ve yararları. Erciyes Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi, 2004, 23.

[3]. Chen, C.-T., C.-T. Lin, and S.-F. Huang, A fuzzy approach for supplier evaluation and selection in supply chain management, International Journal of Production Economics, 2006, 102(2): 289-301.

[4]. Akman, G. and A. Alkan, Tedarik Zinciri Yönetiminde Bulanık AHP yöntemi kullanılarak tedarikçilerin performansının ölçülmesi: Otomotiv Yan Sanayiinde bir uygulama, İstanbul Ticaret Üniversitesi Fen Bilimleri Dergisi, 2006, 5(9): 23-46.

[5]. Lima Junior, F.R., L. Osiro, and L.C.R. Carpinetti, A comparison between Fuzzy AHP and Fuzzy TOPSIS methods to supplier selection, Applied Soft Computing, 2014, 21: 194-209.
[6]. Chai, J., J.N.K. Liu, and E.W.T. Ngai, Application of decision-making techniques in supplier selection: A systematic review of literature, Expert Systems with Applications, 2013, 40(10): 3872-3885.
[7]. Mani, V., R. Agrawal, and V. Sharma, Supplier selection using social sustainability: AHP based approach in India, International Strategic Management Review, 2014, 2(2): 98-112.
[8]. Deng, X., et al., Supplier selection using AHP methodology extended by D numbers, Expert Systems with Applications, 2014, 41(1): 156-167.
[9]. Mohammaditabar, D., S.H. Ghodsypour, and A. Hafezalkotob, A game theoretic analysis in capacity-constrained supplier-selection and cooperation by considering the total supply chain inventory costs, International Journal of Production Economics, 2016, 181: 87-97.
[10]. Hosseini, S. and K. Barker, A Bayesian network model for resilience-based supplier selection, International Journal of Production Economics, 2016, 180: 68-87.
[11]. Lima-Junior, F.R. and L.C.R. Carpinetti, A multicriteria approach based on fuzzy QFD for choosing criteria for supplier selection, Computers & Industrial Engineering, 2016, 101: 269-285.
[12]. Wu, Y., et al., Supplier selection in nuclear power industry with extended VIKOR method under linguistic information, Applied Soft Computing, 2016, 48: 444-457.
[13]. [13]. Rezaei, J., et al., A supplier selection life cycle approach integrating traditional and environmental criteria using the best worst method, Journal of Cleaner Production, 2016, 135: 577-588.
[14]. Jain, V., et al., Supplier selection using fuzzy AHP and TOPSIS: A case study in the Indian automotive industry, Neural Computing and Applications, 2016, 29(7): 555-564.
[15]. Dobos, I. and G. Vörösmarty, Inventory-related costs in green supplier selection problems with Data Envelopment Analysis (DEA), International Journal of Production Economics, 2018, 209: 374-380.
[16]. Hamdan, S. and A. Cheaitou, Supplier selection and order allocation with green criteria: An MCDM and multi-objective optimization approach, Computers & Operations Research, 2017, 81: 282-304.
[17]. Ortiz-Barrios, M.A., et al., Strategic hybrid approach for selecting suppliers of high-density polyethylene, Journal of Multi-Criteria Decision Analysis, 2017, 24(5-6): 296-316.
[18]. Banaeian, N., et al., Green supplier selection using fuzzy group decision making methods: A case study from the agri-food industry, Computers & Operations Research, 2018, 89: 337-347.
[19]. Awasthi, A., K. Govindan, and S. Gold, Multi-tier sustainable global supplier selection using a fuzzy AHP-VIKOR based approach, International Journal of Production Economics, 2018, 195: 106-117.
[20]. Kahraman, C., U. Cebeci, and Z. Ulukan, Multi-criteria supplier selection using fuzzy AHP, Logistics Information Management, 2003, 16(6): 382-394.
[21]. Gold, S. and A. Awasthi, Sustainable global supplier selection extended towards sustainability risks from (1+ n) th tier suppliers using fuzzy AHP based approach, IFAC-PapersOnLine, 2015, 48(3): 966-971.
[22]. Bohner, C. and S. Minner, Supplier selection under failure risk, quantity and business volume discounts, Computers & Industrial Engineering, 2017, 104: 145-155.
[23]. Ahmad, M.T. and S. Mondal, Dynamic supplier selection model under two-echelon supply network, Expert Systems with Applications, 2016, 65: 255-270.
[24]. Sodenkamp, M.A., M. Tavana, and D. Di Caprio, Modeling synergies in multi-criteria supplier selection and order allocation: An application to commodity trading, European Journal of Operational Research, 2016, 254(3): 859-874.
[25]. Dickson, G.W., An analysis of vendor selection systems and decisions, Journal of Purchasing, 1966, 2(1): 5-17.

[26]. Weber, C.A., J.R. Current, and W. Benton, Vendor selection criteria and methods, European journal of operational research, 1991, 50(1): 2-18.
[27]. Choi, T.Y. and J.L. Hartley, An exploration of supplier selection practices across the supply chain, Journal of operations management, 1996, 14(4): 333-343.
[28]. Gunasekaran, A., C. Patel, and E. Tirtiroglu, Performance measures and metrics in a supply chain environment, International Journal of Operations & Production Management, 2001, 21(1-2): 71-87.
[29]. Wu, M.-Y. and Y.-C. Weng, A study of supplier selection factors for high-tech industries in the supply chain, Total Quality Management, 2010, 21(4): 391-413.
[30]. [Chang, B., C.-W. Chang, and C.-H. Wu, Fuzzy DEMATEL method for developing supplier selection criteria, Expert Systems with Applications, 2011, 38(3): 1850-1858.
[31]. Dweiri, F., et al., Designing an integrated AHP based decision support system for supplier selection in automotive industry, Expert Systems with Applications, 2016, 62: 273-283.
[32]. [Büyüközkan, G. and F. Göçer, Application of a new combined intuitionistic fuzzy MCDM approach based on axiomatic design methodology for the supplier selection problem, Applied Soft Computing, 2017, 52: 1222-1238.
[33]. Ho, W., X. Xu, and P.K. Dey, Multi-criteria decision making approaches for supplier evaluation and selection: A literature review, European Journal of Operational Research, 2010, 202(1): 16-24.
[34]. Chen, C.-T., Extensions of the TOPSIS for group decision-making under fuzzy environment, Fuzzy Sets and Systems, 2000, 114(1): 1-9.
[35]. Kannan, D., A.B.L.d.S. Jabbour, and C.J.C. Jabbour, Selecting green suppliers based on GSCM practices: Using fuzzy TOPSIS applied to a Brazilian electronics company, European Journal of Operational Research, 2014, 233(2): 432-447.
[36]. Kilincci, O. and S.A. Onal, Fuzzy AHP approach for supplier selection in a washing machine company, Expert systems with Applications, 2011, 38(8): 9656-9664.
[37]. Stević, Ž., Z. Božičković, and B. Mićić, Optimization of the import of chipboard-A case study, International Journal of Engineering, Business and Enterprise Applications, 2015, 14(1): 19-23.
[38]. Chaising, S. and P. Temdee, Application of a hybrid multi-criteria decision making approach for selecting of raw material supplier for small and medium enterprises, in 2017 International Conference on Digital Arts, Media and Technology (ICDAMT), 2017.
[39]. Gupta, H. and M.K. Barua, Supplier selection among SMEs on the basis of their green innovation ability using BWM and fuzzy TOPSIS, Journal of Cleaner Production, 2017, 152: 242-258.
[40]. Van Laarhoven, P.J. and W. Pedrycz, A fuzzy extension of Saaty's priority theory, Fuzzy Sets and Systems, 1983, 11(1-3): 229-241.
[41]. Buckley, J.J., Fuzzy hierarchical analysis, Fuzzy Sets and Systems, 1985, 17(3): 233-247.
[42]. Boender, C.G.E., J.G. de Graan, and F.A. Lootsma, Multi-criteria decision analysis with fuzzy pairwise comparisons. Fuzzy Sets and Systems, 1989. 29(2): 133-143.
[43]. Chang, D.-Y., Applications of the extent analysis method on fuzzy AHP. European Journal of Operational Research, 1996, 95(3): 649-655.
[44]. Cheng, C.-H., Evaluating naval tactical missile systems by fuzzy AHP based on the grade value of membership function, European Journal of Operational Research, 1997, 96(2): 343-350.
[45]. Büyüközkan, G., C. Kahraman, and D. Ruan, A fuzzy multi-criteria decision approach for software development strategy selection, International Journal of General Systems, 2004, 33(2-3): 259-280.
[46]. Ak, M.F., A Multi criteria decision making methodology based novel model for supplier selection, El-Cezeri Journal of Science and Engineering, 2020, 7(2): 410-423. DOI: 10.31202/ecjse.648856.