SUPPLIER SELECTION BY USING FUZZY LOGIC: THE CASE OF GAZIANTEP

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BULANIK MANTIK YARDIMIYLA TEDARİKÇİ SEÇİMİ: GAZİANTEP ÖRNEĞİ

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Abstract

Supplier selection, which forms an important ring of supply chain management, is one of the strategic decisions taken by businesses and plays an important role in achieving the objectives of the business. Supplier choice is a multi-stage and difficult decision problem that needs to take into account many factors. Therefore; there are many criterion-based decision-making problems that require a large number of evaluation criteria and qualitative criteria as well as quantitative criteria have now become a necessity. Fuzzy logic based techniques come to the fore in the evaluation of qualitative criteria in this sense. In this study, the problem of supplier selection of a company operating in the textile sector was analyzed according to Quality, Delivery, Procedural Compliance, Performance History, Technical Capability criterions via Fuzzy Topsis method. At the end of the study, A3 company ranks first in supplier order based on fuzzy Topsis method.

***Keywords**: Supplier Selection, Fuzzy Topsis, Multi Criteria Decision Making (MCDM).*

***Jel Codes**: C10, C19, M10.*

Öz

Tedarik zinciri yönetiminin önemli bir halkasını oluşturan tedarikçi seçimi, işletmelerin aldığı stratejik kararlardan biridir ve işletmenin amaç ve hedeflerine ulaşmasında önemli rol oynamaktadır. Tedarikçi seçimi birçok faktörü göz önüne almayı gerektiren çok aşamalı ve zor bir karar problemidir. Bundan dolayı çok sayıda değerlendirme kriteri gerektiren birçok kriterli karar verme problemidir ve nicel kriterlerin yanında nitel kriterlerin de yer alması artık bir zorunluluk hâlini almıştır. Bulanık mantık temelli teknikler bu anlamda nitel kriterlerin değerlendirilmesinde öne çıkmaktadır. Bu çalışmada, Bulanık Topsis yöntemi kullanılarak tekstil sektöründe faaliyet gösteren bir firmanın tedarikçi seçim problemi; Kalite, Teslimat, Süreçsel Uygunluk, Performans Geçmişi, Teknik Yeterlilik kıstaslarına göre incelenmiştir. Çalışma sonunda, bulanık Topsis yöntemine dayalı tedarikçi sıralamasında A3 firması ilk sırada yer almıştır.

***Anahtar Kelimeler:** Tedarikçi Seçimi, Bulanık Topsis, Çok Kriterli Karar Verme (ÇKKV).*

***Jel Kodları**: C10, C19, M10.*

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1. INTRODUCTION

Business enterprises have to focus on supply chains which include activities from raw materials for products and services to final consumers to gain competitive advantage in business. Supplier selection, the first link in the chain, and the most important activity in procurement, must be made in accordance with the enterprise's purpose and objectives is one of the major steps taken towards the action. Selecting the right supplier will lower procurement costs, increase customer satisfaction, and improve competitiveness. The share of procurement costs in total costs is around 70% (Ghobadian et al., 2016:103), and this can clearly define the impact of supplier selection upon the success of a business enterprise.

Furthermore, supplier selection is a difficult multi-criteria decision making problem that requires focusing on a number of factors (Tsai et al., 2010:8313). Hence, selecting the right supplier and doing performance analyses correctly are strategically important for companies (Dagdeviren and Eraslan, 2008:69). A problem of this kind can be solved correctly by using scientific methods in decision making process. Among those methods, MCDM methods are analytical techniques that enable the analysis of a number of measurable and non-measurable strategic and operational factors at once, and that involve many individuals to decision making process. In decision making processes, these methods can help managers to analyze alternatives, and enable the efficient use of business enterprises' resources (Dagdeviren et al., 2005:116).

MCDM methods can enable many quantitative and qualitative criteria to involve in decision making process but the analysis of quantitative or qualitative criteria in decision making processes can be ambiguous depending on the subjective analyses carried out by different decision makers. The classical MCDM methods fail to involve such uncertainties and fuzziness in solution processes (Vahdani et all., 2010: 1231). In the modelling of uncertainties in decision making processes, the fuzzy sets introduced by Lotfi Zadeh (1965) identify hard-to-define and hard-to-understand concepts by assigning linguistic variables and a grade of membership to each of them (Karadogan et all., 2001:96).

In this study, the supplier selection problem of a textile company in Gaziantep was analysed. Firstly, the appropriate supplier selection criteria were identified, and then four suppliers of terry yarns were evaluated by using a fuzzy TOPSIS technique more appropriate to use in modelling the real life, and to evaluate decision making criteria and alternatives on the basis of linguistic variables. In order to identify the right supplier, linguistic expressions within the technique were used to identify weights, and to evaluate suppliers' performances.

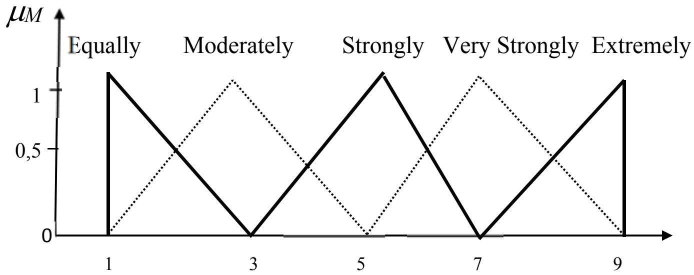
2. FUZZY SET THEORY AND TRIANGULAR FUZZY NUMBERS

In the real life, many decision problems have unclear and indefinite data; thus, models based on such information fail short to represent problems exactly and accurately. Therefore, a decision process must enable building models on unclear and indefinite information (Saremi et al., 2009:2744). Zadeh formalized fuzzy sets theory based on the idea that the key elements of human thinking were not numerical but linguistic variables to handle problems with imprecise and incomplete data (Mao, 1999:7). Fuzzy sets theory builds a model of uncertainty in natural language related to human perceptions and subjective judgments, helps to interpret qualitative parameters, and expresses the uncertainty of language with appropriate mathematical tools (Knight, 2001:17; Cheng et al., 2002:981). Fuzzy sets are the sets whose elements have degrees of membership (Zadeh, 1965).

A Fuzzy set is specified by a membership function, which assigns to each of its elements a value within the unit interval 0 – 1. If the assigned value is 0, then the given element does not belong to the set. If the assigned value is 1, then the element totally belongs to the set. If the value lies within the interval of 0 and 1, then the element only partially belongs to the set (Altas, 1999:80-85).

A linguistic variable is defined as a variable whose values are sentences in a natural or artificial language (Zadeh, 1973:28). It is used in qualitatively expressing very complicated or not well defined situations rather than expressing linguistic variables (Zimmermann, 1991:129). For example, ‘‘weight’’ is a linguistic variable whose values are very low, low, medium, high, very high, etc. Fuzzy numbers can also represent these linguistic values (Chen et al., 2006:293). As seen in Figure 1, triangular fuzzy numbers are used to express linguistic variables (Chen and Chen, 2010:2110).

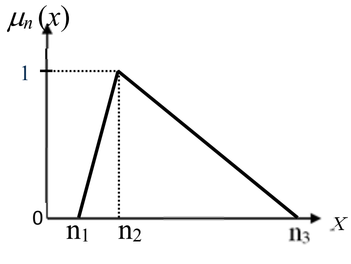
Figure 1: Linguistic Variables for the İmportance Weight of each Criterion.



In fuzzy MCDM problems, performance rating values and relative weights are usually characterized by fuzzy numbers. A fuzzy number is a convex fuzzy set, defined by a given interval of real numbers, each with a membership value between 0 and 1 (Ashtiani, 2009:458). There are various types of fuzzy numbers including triangular, bell-shaped, and trapezoidal. In terms of operational simplicity and heuristic possibilities, the most common type of fuzzy numbers is triangular fuzzy numbers (Sanchez and Gomez, 2003:667). In this paper, using triangular fuzzy numbers is preferred.

When $n_2 = n_3$ in a trapezoidal fuzzy number $\tilde{n} = (n_1, n_2, n_3, n_4)$, the new number formed is called a triangular fuzzy number and represented by $\tilde{n} = (n_1, n_2, n_3)$ (Chen et al., 2006:292). The triangular fuzzy number is as given in Figure 2.

Figure 2: A Triangular Fuzzy Number n.



Source: (Chen, 2000:3).

Assume that m and n are positive numbers, r is a positive real number, m_1^a and n_1^a represent the lower limit of the closed interval, and m_u^a and n_u^a represent the upper limit of the closed interval, and that α-cut of the two fuzzy numbers are $m^\alpha = \left[m_1^\alpha, m_u^\alpha\right]$ $n^\alpha = \left[n_1^\alpha, n_u^\alpha\right]$ Basic mathematical operations with triangular fuzzy numbers can be summarized as follows (Chen, 2000:3):

$$(m(+)n)^{\alpha} = \left[m_{\ell}^{\alpha} + n_{\ell}^{\alpha}, m_{u}^{\alpha} + n_{u}^{\alpha} \right] \quad \textbf{(1)}$$

$$(m(-)n)^{\alpha} = \left[m_{\ell}^{\alpha} - n_{\ell}^{\alpha}, m_{u}^{\alpha} - n_{u}^{\alpha} \right] \quad \textbf{(2)}$$

$$(m(.)n)^{\alpha} = \left[m_{\ell}^{\alpha}.n_{\ell}^{\alpha}, m_{u}^{\alpha}.n_{u}^{\alpha} \right] \quad \textbf{(3)}$$

$$\left(m(:)n\right)^{\alpha} = \left[\frac{m_{\ell}^{\alpha}}{n_{u}^{\alpha}}, \frac{m_{u}^{\alpha}}{n_{\ell}^{\alpha}} \right] \quad \textbf{(4)}$$

The distance between two fuzzy numbers is calculated with Vertex method (Chen, 2000:3). The distance between two triangular fuzzy numbers such as $m = (m_1, m_2, m_3)$ and $n = (\mathrm{n}_1, \mathrm{n}_2, \mathrm{n}_3)$ is calculated by using Vertex method like this (Chen, 2000:3):

$$d(m,n) = \sqrt{\frac{1}{3}\left[\left(m_1 - n_1\right)^2 + \left(m_2 - n_2\right)^2 + \left(m_3 - n_3\right)^2 \right]} \quad \textbf{(5)}$$

3. FUZZY TOPSIS METHOD

The Fuzzy TOPSIS Algorithm was first developed by Chen (2000) who used triangular fuzzy numbers to express linguistic variables used in the evaluation of alternatives. In his evaluations, Chen, Lin and Huang (2006) demonstrated that the technique could be applied from a different perspective by using trapezoidal fuzzy numbers. This study is based on the fuzzy TOPSIS algorithm model introduced by Chen (2000). Mathematical expression of the technique is given below (Chen, 2000:5-6):

The appropriate linguistic variables used by decision makers to evaluate importance weight of criteria and alternatives according to these criteria are given in Table 1 and Table 2 (Chen, 2000:5):

Table 1: Linguistic Variables for the Importance Weight of each Criterion

Linguistic Terms	Fuzzy Triangular Numbers
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)	(0.7,0.9,0.10)
Very high (VH)	(0.9,1.0,1.0)

Table 2: Linguistic variables for the ratings

Linguistic Terms	Fuzzy Triangular Numbers
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)

1) After generating feasible alternatives (m), determining the evaluation criteria (n), and setting a group of decision makers (K), choose the appropriate linguistic variables for the importance weight of the criteria and the linguistic ratings for alternatives with respect to criteria as triangular fuzzy number.

2) The importance of the criteria and the rating of alternatives with respect to each criterion can be calculated as,

$$x_{ij} = \frac{1}{K}\left[x_{ij}^{1}(+)\,\mathrm{x}_{ij}^{2}(+)...(+)\,\mathrm{x}_{ij}^{K} \right] \quad \textbf{(6)}$$

$$w_j = \frac{1}{K}\left[w_j^{1}(+)w_j^{2}(+)...(+)w_j^{K} \right] \quad \textbf{(7)}$$

K represents the number of decision makers, w_j^K the importance weight of criteria evaluated by the decision maker K, and Criterion value of the alternative is represented by x_{ij}^K i.

3) A fuzzy multi criteria group decision-making problem which can be concisely expressed in matrix format as

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix},\ W = \begin{bmatrix} w_1 & w_2 & \cdots & w_n \end{bmatrix} \quad \textbf{(8)}$$

where x_{ij}, $\forall i, j$ and w_j, $j = 1, 2, ..., n$ are linguistic variables. These linguistic variables can be described by triangular fuzzy numbers, $x_{ij} = (\mathrm{a}_{ij}, \mathrm{b}_{ij}, \mathrm{c}_{ij})$ and $w_j = (\mathrm{w}_{j1}, \mathrm{w}_{j2}, \mathrm{w}_{j3})$

4) Normalizing the decision matrix is the next step, after the fuzzy decision matrix is created. A normalized decision matrix is represented by R where $R = \left[r_{ij} \right]_{mxn}$ **(9)**

Decision criteria can be separated in two groups: benefit and cost criteria. Here, B represents the benefit criterion, and C represents the cost criterion;

$$r_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \right), j \in B; \quad c_j^* = \max_i c_{ij} \text{ if } j \in B; \tag{10}$$

$$r_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}} \right), j \in C; \quad c_j^- = \min_i a_{ij} \text{ if } j \in C; \tag{11}$$

5) The weighted normalized fuzzy decision matrix that considers different weights of each criteria is expressed as $V = \left[v_{ij} \right]_{mxn}$. **(12)**

$i = 1,2,...,m \quad j = 1,2,...,\mathrm{n}$. The elements of this matrix are calculated with the formula number 13.

$$v_{ij} = r_{ij}(.)\,\mathrm{w}_j \tag{13}$$

6) Fuzzy positive ideal solution (FPIS, A^*) and fuzzy negative ideal solution (FNIS, A^-) represents n, the number of criteria, and A^* and A^- are numbers equal to the number of criteria.

$$A^- = \left(v_1^-, v_2^-, ..., v_n^- \right) \tag{14}$$

$$A^* = \left(v_1^*, v_2^*, ..., v_n^* \right) \tag{15}$$

where $v_j^* = (1,1,1)$ and $v_j^- = (0,0,0) \quad j = 1,2,...,n$

The distance of each alternative from A^* and A^- can be currently calculated as

$$d_i^* = \sum_{j=1}^{n} d(\mathrm{v}_{ij}, \mathrm{v}_j^*) \; i = 1,2,...,m \tag{16}$$

$$d_i^- = \sum_{j=1}^{n} d(\mathrm{v}_{ij}, \mathrm{v}_j^-) \; i = 1,2,...,m \tag{17}$$

where $d(.,.)$ is the distance measurement between two fuzzy numbers. The distances are calculated by using Vertex method given in the equation number 5.

7) Proximity coefficients (CC_i) for each alternative are calculated with the formula number **18** to rank the alternatives, once the distances are found.

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \quad i = 1,2,...,m \tag{18}$$

Obviously, an alternative A_i is closer to the FPIS(A^*) and farther from FNIS (A^-) as CC_i approaches to 1. Therefore, according to the closeness coefficient, we can determine the ranking order of all alternatives and select the best one from among a set of feasible alternatives.

4. SUPPLIER SELECTION

Considering the fact that the competition between companies is the competition between suppliers, it is apparent that a company's success does not solely depend on its own performance, and the performance of each unit within a company's supply chain is effective on its success. Therefore, this is one of the major issues encountered in selecting and evaluating suppliers, the key elements in a supply chain (Gorener, 2009:100). Specification of methods to be used in decision making processes, and evaluation criteria are very important in selecting the right supplier.

4.1. Various Criteria for Supplier Selection

The identification and analysis of criteria for the selection and evaluation of suppliers has been the central focus of many academics and practitioners (Thiruchelvam and Tookey, 2011:441). According to the literature various criteria and techniques have been used in research studies on supplier selection. Literature reviews show that various types of criteria have been used to solve the supplier selection problem. One of the important studies on supplier evaluation criteria was done by Dickson. Dickson's study guided many other studies. In his study, Dickson (1966) listed 23 criteria for supplier evaluation and selection, based on a survey of 273 purchasing agents and managers selected from the membership list of the National Association of Purchasing Managers of the U.S. and Canada. (Table 3):

Table 3: Dickson's Supplier Selection Criterions

Rank	Criteria	Average Score	Assessment
1	Quality	3.508	Extreme Importance
2	Delivery	3.417	Considerable Importance
3	Performance History	2.998	
4	Warranties and Claim Policies	2.849	
5	Production Facilities and Capacity	2.775	
6	Price	2.758	
7	Technical Capability	2.545	
8	Financial Position	2.514	
9	Procedural Compliance	2.488	Average Importance
10	Communication System	2.426	
11	Reputation and Positioning Industry	2.412	
12	Desire for Business	2.256	
13	Management and Organization	2.216	
14	Operating Controls	2.211	
15	Repair Service	2.187	
16	Attitude	2.120	
17	Impression	2.054	
18	Packaging Ability	2.009	
19	Labour Relations Record	2.003	
20	Geographical Location	1.872	
21	Amount of Past Business	1.597	
22	Training Aids	1.537	
23	Reciprocal Arrangements	0.610	Slight Importance

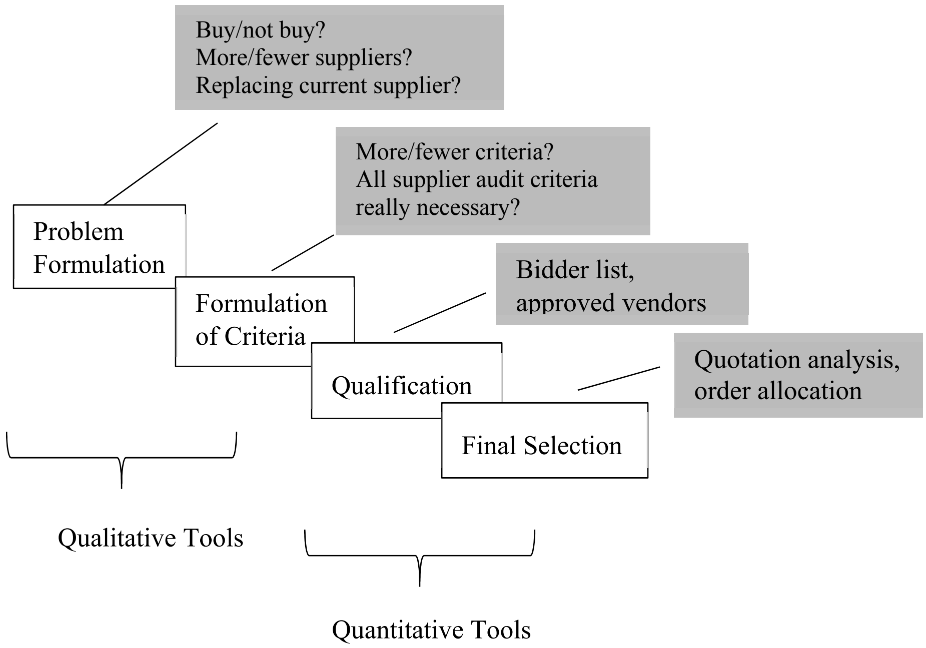
Source: Dickson (1966).

As it is seen in Table 3, "quality" from the 23 criteria listed by Dickson was considered the most important criterion of supplier evaluation processes. Some criteria such as "technical capability" and "price" were considered highly important, and "reciprocal arrangements" was considered the least important criterion. Many researchers still use these criteria. It is seen that in addition to these, there are also many other criteria used effectively in supplier selection processes. The criteria used in research studies on supplier selection and evaluation processes are listed in Annex 1.

4.2. Various Supplier Selection Methods

There are many different methods and criteria used in supplier selection process. Supplier selection process presents four stages including identification of the purpose of supplier selection, identification of decision making criteria, preselection and final selection of prospective suppliers, and the different positions in the framework have different characteristics that are determinative for the suitability of the various methods (Boer et al., 2001:79). Methods used in supplier selection problems are categorized in Figure 3.

Figure 3: Positioning of Decision Methods in Supplier Selection.



Source: (Boer et al., 2001:79).

Problem identification includes identifying the greatest problem in supplier selection, and why selecting one or more number of suppliers can be the best way of handling a problem (Boer et al., 2001:80). Appropriate criteria to solve the problem are specified in identification of decision making criteria. Qualitative techniques are used in the first two stages of supplier selection processes. No publications about problem identification were found in literature review. Brainstorming (Hwang et al., 2003; Kassaee et al., 2013; Shahroudi and Rouydel, 2012); Delphi Techique (Liao, 2010) and Fuzzy Delphi Method (Mokhtari et al., 2013; Cheng et al., 2009) and Structural Modelling (Mandal and Deshmukh, 1994) from the literature can be a good example of the qualitative techniques which have been frequently used in the stage of identification of decision criteria in supplier selection.

The suppliers' degree of meeting the criteria mentioned in the criteria formulation stage are identified in the qualifications stage. The final selection stage includes the activities such as identifying suppliers, and distributing orders among these suppliers, considering all qualitative and quantitative criteria, and system handicaps. Quantitative techniques are used in these stages. According to the literature, Data Envelope Analyze (DEA) (Shai et al., 2014; Forker and Mendez, 2001), Linear Weighting Methods (Ng, 2008; Talluri and Narasimhan, 2003); Neural Networks (Golmohammadi et al., 2009; Kumar and Roy, 2010); Artificial Neural Networks (Albino and Garavelli, 1998); Quality Function Deployment (QFD) and Data-Mining (DM) techniques (Ni et al., 2007); Case Based Reasoning (CBR) (Zhao and Yu, 2011; Choy et. al., 2003); Cluster Analysis (Hinkle et al., 1969); Multi-Objective Programming (Weber and Ellram, 1993) is the prefix attached to the quantitative techniques used in supplier selection.

MCDM methods are the other frequently used methods in supplier selection. Single and hybrid models of these methods are used in solving supplier selection problems. Tam and Tummala (2001), used AHP method in system supplier selection for Telecommunications Company. Min, (1994), used Multi-Attribute Utility (MAUT) approach for international supplier selection. Rajesh and Ravi (2015), used a Grey Relational Analysis (GRA) and DETAMEL method in supplier selection for electronic supply chain. Safari et al. (2012) presented PROMETHEE Method Based on Entropy Weight for Supplier Selection. A part of the supplier selection literature includes studies which integrated fuzzy logic into various methods. Lee (2009), used Fuzzy AHP method in color filter supplier selection for a manufacturing firm. Lin (2012), integrated Fuzzy Analytical Network Process method into fuzzy multi-objective linear programming method to select the best supplier. In their study, Chaghooshi et al., (2014) assigned weights to criteria with Fuzzy AHP, and then selected the best supplier by using Fuzzy Vikor.

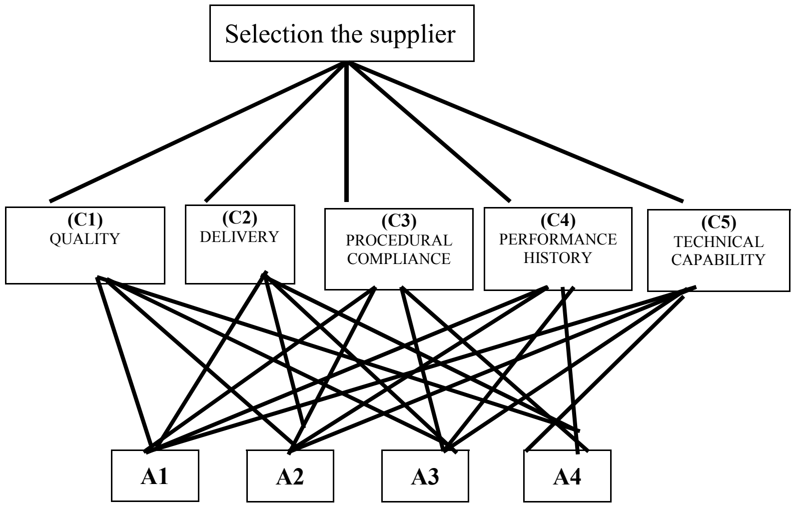
In this study, Fuzzy Topsis approach, one of the methods used in multi criteria decision making, and developed to eliminate uncertainties arising from human judgment during decision making process in solving problems that require group decision making, was applied (Chen, 2000: 4). This approach was implemented in various areas, such as for evaluating the competitive advantages of shopping websites (Sun and Lin, 2009), evaluating sustainable transportation systems (Awasthi et al., 2011), evaluation of the bank's performance (Ozcalici et al., 2016), Robot Selection (Chu and Lin, 2003), Clean Agent Selection of shopping websites (Aiello et al., 2009), evaluation of financial performance (Wang, 2014), group decision making (Krohling and Campanharo, 2011). According to the literature about supplier selection, the examples of researchers who applied Fuzzy Topsis approach to solve supplier selection problems include Shahanaghi and Yazdian (2009), spare parts supplier selection for an automotive industry; Sydani et al. (2011), cotton supplier selection for a textile industry; Kannan et al. (2014), greens supplier selection for sustainable environment, and Pourkiani and Hamzei (2015), technology supplier selection. As we have seen above, although there many studies applied with Fuzzy Topsis method, it is thought that this study will contribute literature in order to take the problem of supplier selection in a different sector.

5. APPLICATION OF FUZZY TOPSIS METHOD FOR SUPPLIER SELECTION

The aim of this study is to find a solution for the supplier selection problem of a textile company in Gaziantep. The company has been in the business since 1998, exports its products to almost all countries in the world, and has weaving, dyeing, and ready-made clothing departments to perform activities including towel weaving, fabric dyeing, and yarn dyeing. The company's main line of business is towel manufacturing, and in this study, we handled the problem of decision making to select the most appropriate yarn supplier.

In order to specify supplier selection criteria, a team composed of decision makers within the company was built. Supplier selection criteria were specified through interviews in participation of a team of four purchasing executives of the company. The team was provided with Dickson's (1966) 23 criteria given in Table 1 to examine to design criteria. The team selected four suppliers (A1,…,A4), and decided to evaluate the suppliers for five criteria such as "Quality, (C1)", "Delivery, (C2)", "Procedural Compliance, (C3)","Performance History, (C4)" and "Technical Capability, (C5)". The hierarchical database model set up for this study is given in Figure 4.

Figure 4: Hierarchy Structure of Decision Problem.



In this study, Chen's (2000) fuzzy TOPSIS model was used to make a decision on supplier selection, and the stages of implementation are given step wisely:

Step 1: The decision makers used the linguistic variables given in Table 2 to evaluate the decision criteria they had specified, and used the linguistic variables given in Table 3 to evaluate the alternatives (suppliers). The decision makers' evaluation of the criteria on the basis of linguistic expressions, and the triangular fuzzy numbers corresponded to the evaluation are given in Table 4, and evaluation of the alternatives on the basis of linguistic expressions, and the triangular fuzzy numbers corresponded to the evaluation are given in Annex 1.

Table 4: Importance Weight of Criteria from Four Decision-Makers

Linguistic terms					Fuzzy triangular numbers				
	DM1	DM2	DM3	DM4		DM1	DM2	DM3	DM4
C1	VH	H	H	VH	C1	(0.9,1.0,1.0)	(0.7,0.9,1.0)	(0.7,0.9,1.0)	(0.9,1.0,1.0)
C2	H	VH	MH	M	C2	(0.7,0.9,1.0)	(0.9,1.0,1.0)	(0.5,0.7,0.9)	(0.3,0.5,0.7)
C3	VH	M	H	H	C3	(0.9,1.0,1.0)	(0.3,0.5,0.7)	(0.7,0.9,1.0)	(0.7,0.9,1.0)
C4	VH	H	VH	H	C4	(0.9,1.0,1.0)	(0.7,0.9,1.0)	(0.9,1.0,1.0)	(0.7,0.9,1.0)
C5	VH	H	H	H	C5	(0.9,1.0,1.0)	(0.7,0.9,1.0)	(0.7,0.9,1.0)	(0.7,0.9,1.0)

DM: Decision Maker, C: Criterion, VH: Very High, H: High, M: Medium, MH: Medium High

Step 2: Values of the criteria evaluated by the decision makers using linguistic expressions, and converted to triangular fuzzy numbers were reduced to a single value by using the equation (6); the new values obtained are given in Table 5.

Table 5: Displaying the Fuzzy Number of Criteria Weights

Criteria	Weights
C1	(0.8,0.95,1)
C2	(0.6,0.78,0.9)
C3	(0.65,0.83,0.93)
C4	(0.8,0.95,1)
C5	(0.75,0.93,1)

Step 3: The triangular fuzzy numbers related to the evaluation of suppliers (Annex 1), were reduced to a single value by using the equation number (7). The fuzzy decision matrix obtained is given in Table 6.

Table 6: Fuzzy decision matrix

	C1	C2	C3	C4	C5
A1	(4.5,6.5,8)	(3.5,5.5,7.25)	(3.75,5.25,6.5)	(3.25,5,6.75)	(7,8.75,9.75)
A2	(4,6,7.75)	(6,8,9.5)	(8.5,9.75,10)	(6,8,9.5)	(4.5,6.5,8.25)
A3	(8,9.5,10)	(8,9.25,9.75)	(4.75,6.25,7.75)	(8,9.5,10)	(8,9.5,10)
A4	(7,8.75,9.75)	(6,8,9.5)	(5.75,7,8)	(8.5,9.75,10)	(6,8,9.5)

Step 4: The fuzzy decision matrix was normalized by using the equation (10); the normalized decision matrix is given in Table 7.

Table 7: Normalized Fuzzy Decision Matrix

	C1	C2	C3	C4	C5
A1	(0.45,0.65,0.8)	(0.36,0.56,0.74)	(0.38,0.53,0.65)	(0.33,0.5,0.68)	(0.7,0.88,0.98)
A2	(0.4,0.6,0.78)	(0.62,0.82,0.97)	(0.85,0.98,1)	(0.6,0.8,0.95)	(0.45,0.65,0.83)
A3	(0.8,0.95,1)	(0.82,0.95,1)	(0.48,0.63,0.78)	(0.8,0.95,1)	(0.8,0.95,1)
A4	(0.7,0.88,0.98)	(0.62,0.82,0.97)	(0.58,0.7,0.8)	(0.85,0.98,1)	(0.6,0.8,0.95)

Step 5: Each value in the normalized decision matrix was multiplied by the criteria weights given in Table 5 to obtain the weighted normalized decision matrix. These figures are given in Table 8.

Table 8: Weighted Normalized Fuzzy Decision Matrix

	C1	C2	C3	C4	C5
A1	(0.36,0.62,0.8)	(0.22,0.44,0.67)	(0.25,0.44,0.60)	(0.26,0.48,0.68)	(0.53,0.82,0.98)
A2	(0.32,0.57,0.78)	(0.37,0.64,0.87)	(0.55,0.81,0.93)	(0.48,0.76,0.95)	(0.34,0.60,0.83)
A3	(0.64,0.90,1)	(0.49,0.74,0.9)	(0.31,0.52,0.73)	(0.64,0.90,1)	(0.60,0.88,1)
A4	(0.56,0.84,0.98)	(0.37,0.64,0.87)	(0.38,0.58,0.74)	(0.68,0.93,1)	(0.45,0.74,0.95)

Step 6: The fuzzy positive ideal solution (FPIS, A*), and the fuzzy positive negative solution (FNIS, A-) were calculated by using the equations number (14) and (15), after the weighted normalized fuzzy decision matrix was formed.

$A^* = [(1,1,1),(1,1,1),(1,1,1),(1,1,1),(1,1,1)]$

$A^- = [(0,0,0), (0,0,0), (0,0,0), (0,0,0), (0,0,0)]$

Step 7: The equations number (16) and (17) were used to calculate the distance of each alternative to the FPIS and FNIS. The proximity coefficient of each alternative was calculated by using the equation number (18), after the distances were calculated. The calculation results are given in Table 9.

Table 9: Distances, Proximity Coefficients, and Alternate Ranking

Suppliers	d^*	d^-	CC_i	Ranking
A1	2,4636	2,8554	0,5368	**4**
A2	1,9802	3,4045	0,6323	**3**
A3	1,5178	3,8411	0,7168	**1**
A4	1,6954	3,6799	0,6846	**2**

According to the results given in Table 9, it was concluded that the company, participated in this study on supplier selection ought to prefer the supplier “A3”. The ranking of other suppliers was “A4” > “A2” > “A1”.

6. CONCLUSIONS

In this study, the performances of terry yarn suppliers of a textile company, which primarily manufactures towel in Gaziantep, were evaluated, and the company's decision on specifying and selecting the appropriate supplier was analysed. Hence, four suppliers and five supplier selection criteria namely "Quality", "Delivery", "Procedural Compliance", "Performance History" and "Technical Capability were specified through interviews in participation of a team four purchasing executives of the company. The level of significance of the criteria, and the relative priorities given to the suppliers according to these criteria were found by using a fuzzy TOPSIS technique.

Why Fuzzy TOPSIS was used in this study: (i) it makes it possible to evaluate each criterion or alternative independently of each other, and without making comparisons between them, (ii) it supports group decision making very effectively, (iii) it enables qualitative and quantitative evaluations to involve in decision making process synchronously, and (iv) calculations can be completed in a very short time, due to simplicity of formulations. At the end of the evaluation performed in accordance with the decision making criteria by the decision makers, the suppliers were given points. At the end of the problem solving process by using the recommended model, Supplier-A3 was ranked first with (0,7168) points. It was followed by Supplier-A4 (0,6846), Supplier-A2 (0,6323), and Supplier- A1 (0,5368) respectively as the best suppliers.

In this study, Fuzzy TOPSIS was tested once again, and it was demonstrated that it could be used as a decision making tool to be used in group decision making process to evaluate alternatives in a supplier selection process successfully. This study was conducted at a textile manufacturer. Other companies in the same sector or in different sectors may have different decision criteria for supplier selection. Therefore, the results provided herein are only specific to the company participated in this study. The application may be performed on the same sector or on different sectors, and different fuzzy multi-criteria decision making algorithms may be used to generalize the findings of future research studies.

REFERENCES

Abratt, R. (1986). Industrial buying in high-tech markets. Industrial Marketing Management, 15(4), 293-298.

Aiello, G., Enea, M., Galante, G., & Scalia, G. (2009). Clean agent selection approached by fuzzy TOPSIS decision-making method. *Fire Technology*, *45*(4), 405-418.

Altas, İ.H. (1999). Bulanık Mantık:Bulanıklılık Kavramı. *Enerji Elektrik Elektromekanik-3e,* 80-85.

Ashtiani, B., Haghighirad, F., Makui, A., & Ali M. G. (2009). Extension of fuzzy TOPSIS method based on interval-valued fuzzy sets. *Applied Soft Computing*, *9*(2), 457-461.

Awasthi, A., Chauhan, S. S., & Omrani, H. (2011). Application of fuzzy TOPSIS in evaluating sustainable transportation systems. *Expert Systems with Applications*, *38*(10), 12270-12280.

Behzadian, M., Otaghsara, S. K., Yazdani, M., & Ignatius, J. (2012). A state-of the-art survey of TOPSIS applications. *Expert Systems with Applications*, *39*(17), 13051-13069.

Boer, D. L., Labro, E., & Morlacchi, P. (2001). A review of methods supporting supplier selection. *European journal of purchasing & supply management*, *7*(2), 75-89.

Boer, D. Luitzen, E. L., and Pierangela M. (2001). "A review of methods supporting supplier selection." *European journal of purchasing & supply management* 7 (2), 75-89.

Chaghooshi, A., Fathi, M. R., Avazpour, R., & Ebrahimi, E. (2014). A Combined Approach for Supplier Selection: Fuzzy AHP and Fuzzy VIKOR. *International Journal of Engineering Sciences*, *3*(8), 67-74.

Chen, C.T. (2000). Extensions of the TOPSIS for Group Decision Making under Fuzzy Environment, Fuzzy Sets and Systems, 114, 1-9.

Chen, J. K., & Chen, I. S. (2010). A pro-performance appraisal system for the university. *Expert Systems with Applications*, *37*(3), 2108-2116.

Cheng, J. H., Lee, C. M., & Tang, C. H. (2009). An application of fuzzy Delphi and fuzzy AHP on evaluating wafer supplier in semiconductor industry. *WSEAS Transactions on Information Science and Applications*, *6*(5), 756-767.

Cheng, S., Chan, C. W., and Huang, G. H. (2002), Using Multiple Criteria Decision Analysis for Supporting Decisions of Solid Waste Management, Journal of Environment Science Health, 37(6), 975- 990.

Chin-N. L., (2010). Supplier selection project using an integrated Delphi, AHP and Taguchi loss function, Prob Stat Forum (03), 118-134.

Choy, K. L., Lee, W., & LO, V. (2003). Design of a case based intelligent supplier relationship management system—the integration of supplier rating system and product coding system. *Expert Systems with Applications*, *25*(1), 87-100.

Chu, T. C., & Lin, Y. C. (2003). A fuzzy TOPSIS method for robot selection.*The International Journal of Advanced Manufacturing Technology*, *21*(4), 284-290.

Dagdeviren M., Eraslan E., Kurt M. ve Dizdar, E.N. (2005), "Tedarikçi Seçimi Problemine Analitik Ağ Süreci İle Alternatif Bir Yaklaşım", Teknoloji Dergisi, 8(2): 115-122.

Dagdeviren, M. and Eraslan, E. (2008), Promethee Sıralama Yöntemiyle Tedarikçi Seçimi, Gazi Üniversitesi Mühendislik ve Mimarlık Fakültesi Dergisi, 23(1), 69-75.

Dickson, G., (1966), An Analysis of Vendor Selection Systems and Decisions., Journal of Purchasing, (2), 28-41.

Dweiri, F., Kumar, S., Khan, S. A., & Jain, V. (2016). Designing an integrated AHP based decision support system for supplier selection in automotive industry. *Expert Systems with Applications*, *62*, 273-283.

Forker, L. B., and Mendez, D. An analytical method for benchmarking best peer suppliers. International Journal of Operations and Production Management, 2001, 21(1/2), 195-209.

Ghobadian, A., Stainer, A., LIU, J. and KISS, T. (2016). A computerised vendor rating system. Developments in Logistics and Supply Chain Management. Palgrave Macmillan UK, 2016. 103-112.

Ghodsypour, S.H. and O'brien, C. (1996). A Decision Support System for Supplier Selection Using an Integrated Analytic Hierarchy Process and Linear Programming, International Journal of Production Economics, Vol. 56- 57, 199-212.

Golmohammadi, D., Robert C. C. and Haleh V. (2009). Neural network application for supplier selection. *International Journal of Product Development,* 8(3), 252-275.

Görener, A. (2009). Kesici Takım Tedarikçisi Seçiminde Analitik Ağ Sürecinin Kullanımı. *Journal of Aeronautics & Space Technologies/Havacılık ve Uzay Teknolojileri Dergisi* 4(1), 99-110.

HINKLE, C.L., ROBINSON, P. J., and GREEN, P. E. (1969). Vendor Evaluation Using Cluster Analysis, Journal of Purchasing, 5(3), 49-58.

Hwang, H. S., Moon, C., Chuang, C. L., & Goan, M. J. (2005). Supplier selection and planning model using AHP. *international Journal of the Information Systems for Logistics and Management (IJISLM)*, 1(1), 47-53.

Je, T. (2011). Evolving trends of supplier selection criteria and methods. *International Journal of Automotive and Mechanical Engineering (IJAME)* 4, 437-454.

Kannan, D., Sousa J., A. B. L., & Jabbour, C. J. C. (2014). Selecting green suppliers based on GSCM practices: Using fuzzy TOPSIS applied to a Brazilian electronics company. *European Journal of Operational Research*,*233*(2), 432-447.

Karadoğan, A., Başçetın, A., Kahrıman, A. and GÖRGÜN, S. (2001). Bulanık Küme Teorisinin Yeraltı Üretim Yöntemi Seçiminde Kullanılabilirliği. Türkiye 17. Uluslararası Madencilik Kongresi ve Sergisi-TUMAKS

Kassaee, M., Farrokh, M., & Nıa, H. H. (2013). An Integrated Hybrid MCDM Approach for Vendor Selection Problem (Case Study: Iran Khodro). *Business and Management Horizons*, *1*(1), 153.

Knight, K. G. (2001). A Fuzzy Logic Model for Predicting Commercial Building Design Cost Overruns, Master of Science Thesis, University of Alberta.

Kumar, J., and Roy, N. (2010). A hybrid method for vendor selection using neural network. *International Journal of Computer Applications*, 11(12), 35-40.

Lee, A. H. (2009). A fuzzy AHP evaluation model for buyer–supplier relationships with the consideration of benefits, opportunities, costs and risks. *International Journal of Production Research*, *47*(15), 4255-4280.

Lehmann, D.R. and O'shaughnessy, J. (1974). Difference in Attribute Importance for Different Industrial Products, Journal of Marketing, (38), 36-42.

Lin, H. T., & Chang, W. L. (2008). Order selection and pricing methods using flexible quantity and fuzzy approach for buyer evaluation. European Journal of Operational Research, 187(2), 415–428.

Lin, R. H. (2012). An integrated model for supplier selection under a fuzzy situation. *International Journal of Production Economics*, *138*(1), 55-61.

Mandal, A., & Deshmukh, S. G. (1994). Vendor selection using interpretive structural modelling (ISM). *International Journal of Operations & Production Management*, *14*(6), 52-59.

Mao, H. (1999), Estimating Labour Productivity Using Fuzzy Set Theory, Master of Science Thesis, University of Alberta.

Min, H. (1994). International supplier selection: a multi-attribute utility approach. *International Journal of Physical Distribution & Logistics Management*, *24*(5), 24-33.

Min, H., & Galle, W. P. (1999). Electronic commerce usage in business to business purchasing. International Journal of Operations and Production Management, 19(9), 909–921.

Ng, W. L. (2008). An efficient and simple model for multiple criteria supplier selection problem. *European Journal of Operational Research*, *186*(3), 1059-1067.

Ni, M., Xu, X., & Deng, S. (2007). Extended QFD and data-mining-based methods for supplier selection in mass customization. *International Journal of Computer Integrated Manufacturing*, *20*(2-3), 280-291.

Ozcalici, M., Bumin, M. and Ayricay, Y. (2016). "Forecasting the Rankings of Banks by Return on Assets in Turkish Banking Sector with Topsis, Fuzzy Topsis and Grey Relational Analysis Techniques." *Global Journal for Research Analysis*.

Parthiban, P.; Zubar, H.A.; Garge, C.P. (2012). A Multi Criteria Decision Making Approach for Suppliers Selection Procedia Engineering, Volume 38, 2312-2328.

Peng J., (2012). Selection of Logistics Outsourcing Service Suppliers Based on AHP, 2012 International Conference on Future Electrical Power and Energy Systems, Energy Procedia, 17, 595 – 601.

Phelps, L. (1996). Discriminative validity of the WRAML with ADHD and LD children. Psychology in the Schools, 33, 5-12

Rajesh, R. and, Ravi, V. (2015). Supplier selection in resilient supply chains: A Grey Relational Analysis Approach. Journal of Cleaner Production 86: 343-359.

Rajesh, R., & Ravi, V. (2015). Modeling enablers of supply chain risk mitigation in electronic supply chains: A Grey–Detamel approach. *Computers & Industrial Engineering*, *87*, 126-139.

Safari, H., Fagheyi, M., Ahangari, S., Fathi, M.R. (2012). Applying Promethee Method Based on Entropy Weight for Supplier Selection. Business management and strategy, Vol. 3, No. 1, 97-106.

Sahai, M., Agarwal, P., Mishra, V., Bag, M., & Singh, V. (2014). Supplier Selection through Application of DEA. *IJEM-International Journal of Engineering and Manufacturing (IJEM)*, *4*(1), 1.

Sanchez, J. A. and Gomez, A. T. (2003), Applications of Fuzzy Regression in Actuarial Analysis, The Journal of Risk and Insurance, 70(4), 665-699.

Saremi, M. S., Mousavi, F. and Sanayei, A. (2009). TQM consultant selection in SMEs with TOPSIS under fuzzy environment. *Expert Systems with Applications* 36.2, 2742-2749.

Shahroudi, K., & Rouydel, H. (2012). Using a multi-criteria decision making approach (ANP-TOPSIS) to evaluate suppliers in Iran's auto industry. *International Journal of Applied Operational Research-An Open Access Journal*, *2*(2).

Stavropolous, N. (2000). Suppliers in the new economy. Telecommunications Journal of Australia, 50(4), 27–29.

Sun, C. C., & Lin, G. T. (2009). Using Fuzzy TOPSIS method for evaluating the competitive advantages of shopping websites. *Expert Systems with Applications*, *36*(9), 11764-11771.

Talluri, S., & Narasimhan, R. (2003). Vendor evaluation with performance variability: A max–min approach. *European Journal of Operational Research*,*146*(3), 543-552.

Tam, M. C., & Tummala, V. R. (2001). An application of the AHP in vendor selection of a telecommunications system. *Omega*, *29*(2), 171-182.

Tsai, Y. L., Yao J. Y., and Lin, C. H. (2010). A Dynamic Decision Approach For Supplier Selection Using Ant Colony System. *Expert systems with applications* 37(12) , 8313-8321.

Vahdani, B., Hadipour, H., Sadaghiani, J.S. and Amiri, M. (2010). Extension of VIKOR method based on interval-valued fuzzy sets, International Journal of Advanced Manufacturing Technology, 47(9-12), 1231- 1239.

Wang, J.-W., Cheng, C.-H. and Cheng, H. K. (2008). Fuzzy hierarchical TOPSIS for supplier selection, Applied Soft Computing, doi:10.1016/j.asoc.

Wang, Y. J. (2014). The evaluation of financial performance for Taiwan container shipping companies by fuzzy TOPSIS. *Applied Soft Computing*, *22*, 8-35.

Weber, C. A., & Ellram, L. M. (1993). Supplier selection using multi-objective programming: a decision support system approach. *International Journal of Physical Distribution & Logistics Management*, *23*(2), 3-14.

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

Wind, Y., Green, P., ROBINSON, P. (1968). The Determinants of Vendor Selection: The evaluation Function Approach. Journal of Purchasing, 4(3), 29-41.

Zadeh, L. A. (1973). Outline of a new approach to the analysis of complex systems and decision processes. *IEEE Transactions on systems, Man, and Cybernetics* 1, 28-44.

Zadeh, L.A. (1965). Fuzzy Sets, Information and Control, Sayı: 8, 338-353.

Zarbini, S. A., Karbasi, A., & Atef-Y. E. (2011). Evaluating and selecting supplier in textile industry using hierarchical fuzzy TOPSIS. *Indian Journal of Science and Technology*, *4*(10), 1322-1334.

Zhao, K., & Yu, X. (2011). A case based reasoning approach on supplier selection in petroleum enterprises. *Expert Systems with Applications*, *38*(6), 6839-6847.

Zimmermann, H. J. (1991). Fuzzy Set Theory and its Applications, third ed. Kluwer Academic Publishers, Boston, Dordrecht, London.

Appendix 1: Ratings of the Five Candidates by Decision-Makers Under Various Criteria

Linguistic terms						Fuzzy triangular numbers					
C	**S**	Decision Makers				**C**	**S**	Decision Makers			
		D1	**D2**	**D3**	**D4**			**D1**	**D2**	**D3**	**D4**
C1	A1	G	F	G	MP	**C1**	A1	(7,9,10)	(3,5,7)	(7,9,10)	(1,3,5)
	A2	MG	F	G	MP		A2	(5,7,9)	(3,5,7)	(7,9,10)	(1,3,5)
	A3	VG	G	VG	G		A3	(9,10,10)	(7,9,10)	(9,10,10)	(7,9,10)
	A4	G	MG	G	VG		A4	(7,9,10)	(5,7,9)	(7,9,10)	(9,10,10)
C2	A1	F	MP	G	F	**C2**	A1	(3,5,7)	(1,3,5)	(7,9,10)	(3,5,7)
	A2	G	MG	G	MG		A2	(7,9,10)	(5,7,9)	(7,9,10)	(5,7,9)
	A3	VG	MG	VG	VG		A3	(9,10,10)	(5,7,9)	(9,10,10)	(9,10,10)
	A4	MG	G	G	MG		A4	(5,7,9)	(7,9,10)	(7,9,10)	(5,7,9)
C3	A1	G	G	MP	VP	**C3**	A1	(7,9,10)	(7,9,10)	(1,3,5)	(0,0,1)
	A2	VG	VG	VG	G		A2	(9,10,10)	(9,10,10)	(9,10,10)	(7,9,10)
	A3	MG	VG	P	MG		A3	(5,7,9)	(9,10,10)	(0,1,3)	(5,7,9)
	A4	VG	MG	P	VG		A4	(9,10,10)	(5,7,9)	(0,1,3)	(9,10,10)
C4	A1	P	G	MP	MG	**C4**	A1	(0,1,3)	(7,9,10)	(1,3,5)	(5,7,9)
	A2	G	G	MG	MG		A2	(7,9,10)	(7,9,10)	(5,7,9)	(5,7,9)
	A3	VG	G	VG	G		A3	(9,10,10)	(7,9,10)	(9,10,10)	(7,9,10)
	A4	VG	VG	VG	G		A4	(9,10,10)	(9,10,10)	(9,10,10)	(7,9,10)
C5	A1	MG	VG	G	G	**C5**	A1	(5,7,9)	(9,10,10)	(7,9,10)	(7,9,10)
	A2	G	MG	MP	MG		A2	(7,9,10)	(5,7,9)	(1,3,5)	(5,7,9)
	A3	VG	G	VG	G		A3	(9,10,10)	(7,9,10)	(9,10,10)	(7,9,10)
	A4	G	G	MG	MG		A4	(7,9,10)	(7,9,10)	(5,7,9)	(5,7,9)

C: Criterion, S: Suppliers, VG: Very Good, G: Good, MG: Medium Good, MP: Medium Poor, VP: Very Poor, P: Poor, F: Fair.

Appendix 2: List of Criteria Used in Supplier Selection Problem

Criteria	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Quality	✓			✓	✓			✓	✓	✓	✓	✓
Price	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
Delivery	✓	✓		✓	✓					✓		✓
Performance History				✓								
Technical Capability	✓			✓					✓			
Geographical Location	✓			✓								
Conflict/Problem Solving Capability							✓					
Safety											✓	
Environmentally Friendly Products					✓						✓	
İmpression		✓	✓	✓								
Relationship Closeness							✓					
Product Appearance						✓						
E-Commerce Capability					✓	✓						
Reputation and Position in Industry	✓	✓	✓	✓			✓					
Service										✓		✓
Packaging Ability				✓								
Ease of Use		✓	✓									
Collabration											✓	
Attitude			✓	✓								
Risk Awareness											✓	
Flexibility											✓	
Management and Organization				✓								
Financial Position		✓		✓								
Productivity									✓	✓		

1, Wind et al. (1968); 2, Lehmann and O'Shaughnessy (1974); 3, Abratt (1986); 4, Weber et al. (1991); 5, Min and Galle (1999); 6, Stavropolous (2000); 7, Lin and Chang (2008); 8,Wang et al. (2008); 9, Peng (2012); 10, Parthiban (2012); 11, Rajesh and Ravi (2015); 12, Dweiri etal. (2016).