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Fuzzy TOPSIS Method in Supplier Selection and Application in the Garment Industry

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Abstract
In today's world where intensive competition exists between enterprises, it is of great importance to work in cooperation with the right suppliers. Selection of the right suppliers is a significant factor in the success of enterprises. In the selection of the best supplier (s), the strengths and weaknesses of potential suppliers should be taken into consideration. Many qualitative and quantitative criteria are included in this selection process as well as the decision-maker. One of the issues that leaves the decision maker in a difficult position is selecting the most appropriate one from the alternatives available, as traditional methods may not produce a realistic solution in this process. However, multicriteria decision making methods facilitate the process of finding a solution and enable decision makers to reach the right decisions. In this study, the fuzzy TOPSIS method, which is one of the multi-criteria decision making methods, is used in this problem area to select the most appropriate supplier of garment 'X' operating in Turkey. It is detected through analyses conducted in line with the results obtained. The ranking of the three supplier firms determined by firm X are as follows in terms of closeness index values: supplier 1, supplier 3 and supplier 2.

Key words: *supplier selection, multicriteria decision making, fuzzy TOPSIS, textil industry.*

Introduction

In today's competitive corporate environment, all dimensions of product delivery, quality, flexibility and the response time need to be incorporated through the effective design and operation of the supply chain. Supplier evaluation and selection is one of the most important components of the supply chain, which influences the long term commitments and performance of the company. Suppliers have variable strengths and weaknesses which require careful assessment of the purchasers before they are ranked based on some criteria. Therefore, every decision needs to be integrated by trading off the performances of different suppliers at each stage of the supply chain [1 - 3].

In the supply chain management process, the firm selects the best supplier, who takes the competitive advantage to other companies. Thus supplier selection is an important issue. The supplier selection problem includes both tangible and intangible factors due to the multi-criteria decision making approach. Building long term and close relationships between the purchaser and supplier is a critical objective and factor in the success of supply chain management. To achieve this objective, decision-makers should apply the best method and determine the proper criteria for the supplier selection problem [4].

The supplier selection problem requires the consideration of multiple factors and hence can be viewed as a multi-criteria decision-making problem [5]. It is affected by several conflicting factors such as price, quality and delivery. As a pioneer in the supplier selection problem, Dickson identified 23 different criteria for this problem including quality, delivery, performance history, warranties, price, technical capability and financial position [6]. As multi-criteria decision making approaches are mostly based on qualitative data and personal opinions, the fuzzy logic method is frequently used in the analysis of such data [7]. In this regard, the Fuzzy TOPSIS method [8], which is one of the fuzzy multi-criteria decision making methods, was used in the solution of the supplier selection problem of the firm where the practice took place.

The Fuzzy TOPSIS method

The Fuzzy TOPSIS method displays relatively successful practice samples, especially in realistic problems where personal opinions and convictions are expressed by linguistic data. The application of the Fuzzy TOPSIS method for traditional supplier selection has recently been investigated in the studies of Boran et al. [9], Wang et al. [10], Onut et al. [11]. While this method is a mathematical model processing the convictions of experts as quantitative data, it is acknowledged to be superior to the classical TOPSIS method as it provides an opportunity for experts to express their opinions in specific intervals, where they can analyse them without converting them into quantitative data.

In the fuzzy TOPSIS method, linguistic scores that each alternative receives from all the criteria are used in the formation of a fuzzy decision matrix and normalised fuzzy decision matrix. Fuzzy positive and fuzzy negative ideal solutions are obtained by taking into consideration the rates of all criteria. At this point, the distance coefficient of each alternative is calculated, and in this way the preference order of the alternatives is determined in line with the criteria specified [9].

TOPSIS was extended by Chen (2000) to fuzzy environments, which used a fuzzy linguistic value as a substitute for the directly given crisp value in the grade assessment. This modified version of the TOPSIS method is a practical method that matches human thinking in an actual environment. The linguistic expressions of fuzzy theory are considered as natural representations of preferences/judgments [10]. In the fuzzy TOPSIS procedure, the fuzzy importance weights of the criteria ($\tilde{w}_j$; j = 1, 2, ..., number of criteria (n))

and the fuzzy rating of alternatives at criteria (x_{ij}, i = 1, 2, ..., number of alternative (m), j = 1, 2, ..., number of criteria (n)) are inputs that are placed in a matrix form. The TOPSIS procedure consists of the following steps [9]:

Step 1: Inputs are expressed in the decision matrix format as:

$$\widetilde{D} = \begin{bmatrix} \widetilde{x}_{11} & \widetilde{x}_{12} & \cdots & \widetilde{x}_{1n} \\ \widetilde{x}_{21} & \widetilde{x}_{22} & \cdots & \widetilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{x}_{m1} & \widetilde{x}_{m2} & \cdots & \widetilde{x}_{mn} \end{bmatrix} \quad (1)$$

$$\widetilde{W} = [\widetilde{w}_1, \widetilde{w}_2, \cdots, \widetilde{w}_n] \quad (2)$$

Step 2: Calculate the normalised fuzzy decision matrix, $\widetilde{R}$:

$$\widetilde{R} = [\widetilde{r}_{ij}]_{mxn}$$
$$i = 1, 2, ..., m, \quad j = 1, 2, ... n \quad (3)$$

For the benefit criteria, the normalized value $\widetilde{r}_{ij}$ is calculated as:

$$\widetilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+} \right) \quad (4)$$

where; $u_j^+ = \max_i u_{ij}$ (5)

Similarly, the normalised value $\widetilde{r}_{ij}$ for the cost criteria is calculated as:

$$\widetilde{r}_{ij} = \left(\frac{l_j^-}{u_{ij}}, \frac{l_j^-}{m_{ij}}, \frac{l_j^-}{l_{ij}} \right) \quad (6)$$

where; $l_j^- = \min_i l_{ij}$ (7)

Step 3: Calculate the weighted normalised fuzzy decision matrix, $\widetilde{V}$:

$$\widetilde{V} = [\widetilde{v}_{ij}]_{m \times n},$$
$$i = 1, 2, ..., m, j = 1, 2, ..., n \quad (8)$$

Considering the different weight of each criterion, the weighted normalised decision matrix can be computed by multiplying the importance weights of the evaluation criteria and the values in the normalized fuzzy decision matrix. The weighted normalized fuzzy value $\widetilde{v}_{ij}$ is calculated as:

$$\widetilde{v}_{ij} = \widetilde{r}_{ij} \otimes \widetilde{w}_j \ ,$$
$$i = 1, 2, ..., m, j = 1, 2, ..., n \quad (9)$$

Where $\widetilde{v}_{ij}$ is the fuzzy weight of j^{th} criterion.

Step 4: Identify the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS):

$$A^+ = \{\widetilde{v}_1^+, \widetilde{v}_2^+, ..., \widetilde{v}_n^+\} \quad (10)$$

$$A^- = \{\widetilde{v}_1^-, \widetilde{v}_2^-, ..., \widetilde{v}_n^-\} \quad (11)$$

Where $\widetilde{v}_j^+ = (1,1,1)$ and $\widetilde{v}_j^- = (0,0,0)$, $j = 1, 2, \ldots, n$

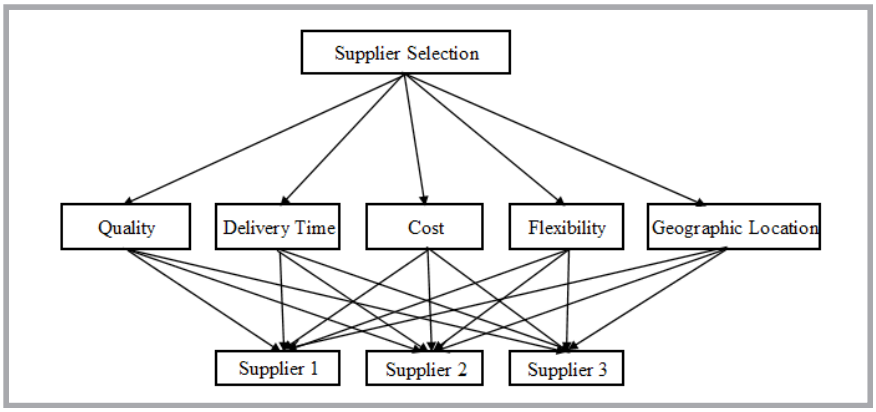

Figure 1. *Hierarchy of the supplier selection problem.*

Step 5: Calculate the distances of each alternative to the fuzzy positive ideal solution and fuzzy negative ideal solution using:

$$d_i^+ = \sum_{j=1}^{n} d\left(\widetilde{v}_{ij} - \widetilde{v}_j^+\right),$$
$$i = 1, 2, ..., m, j = 1, 2, ..., n \quad (12)$$

$$d_i^- = \sum_{j=1}^{n} d\left(\widetilde{v}_{ij} - \widetilde{v}_j^-\right),$$
$$i = 1, 2, ..., m, j = 1, 2, ..., n \quad (13)$$

Where $d(\widetilde{v}_a, \widetilde{v}_b)$ denotes the distance measurement between two fuzzy numbers.

Step 6: Calculate the relative closeness to the ideal solution. The relative closeness of alternative A_i is calculated as:

$$C_i = d_i^- / (d_i^- + d_i^+), i = 1, 2, ..., m \quad (14)$$

where $0 \le C_i \le 1$, that is, alternative i is closer to the fuzzy positive ideal reference point and far from the fuzzy negative ideal reference point as C_i approaches 1.

Step 7: Rank the preference order. Choose an alternative with maximum C_i or rank alternatives according to C_i in descending order.

The case study

In this study, the selected supplier of garment 'X' operating in Turkey in the garment industry as a women's upper wears manufacturer has 600 employees and a monthly production capacity of 300,000 items. The firm exports all of its production out of three alternative fabric suppliers, which was examined using the Fuzzy TOPSIS method. In the solution of the problem, the selection criteria determined: quality, delivery time, cost, flexibility, and geographical location were specified in line with a literature review and the opinions of the firm's decision makers. The decision making group was composed of three experts working at the administrative level in the firm. The hierarchy of the supplier selection problem put forward by these experts is indicated in ***Figure 1***.

After the criteria and hierarchy of selection were determined, the decision makers used the linguistic variables in ***Table 1*** in order to determine the importance weights of the supplier selection criteria (***Table 2***).

In the next step, the decision makers performed an assessment of the alternative suppliers with the help of linguistic vari-

Table 1. *Linguistic variables for the importance weight of each criterion.*

Linguistic variable	Triangular fuzzy numbers (TFNs)
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)
Very high (VH)	(0.9, 1, 1)

Table 2. *Assessment results of the decision makers regarding the decision criteria; DM1 - Decision Maker 1, DM2 - Decision Maker 2, DM3 - Decision Maker 3.*

Criteria	Decision Makers		
	DM1	DM2	DM3
Quality	H	H	MH
Delivery time	H	H	H
Cost	VH	H	MH
Flexibility	ML	M	M
Geographic location	M	ML	M

Table 3. Linguistic variables used in the assessment of alternatives.

Linguistic variable	Triangular fuzzy numbers (TFNs)
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)

Table 4. Assessment results of alternatives in line with the criteria.

Criteria	Alternatives	Decision makers		
		DM1	DM2	DM3
Quality	A1	G	VG	G
	A2	MG	MG	MP
	A3	G	G	G
Delivery time	A1	MG	G	G
	A2	MG	MP	MG
	A3	G	VG	MG
Cost	A1	G	P	F
	A2	G	F	VG
	A3	MG	MG	MP
Flexibility	A1	G	VG	MP
	A2	MG	F	P
	A3	VG	MG	P
Geographic location	A1	P	MP	P
	A2	P	MP	P
	A3	P	P	MP

ables in ***Table 3*** according to the decision criteria in the manner specified in the ***Table 4***.

Tables 5 and ***6*** were formed through the conversion of the linguistic assessments belonging to the three decision makers in ***Tables 2*** and ***4*** into triangle fuzzy numbers.

The importance weights specified in ***Table 7*** were obtained by reducing the criteria assessment results of the decision makers to a single value.

The fuzzy decision matrix shown in ***Table 8*** was normalised with the help of ***Equation 4***, and a normalised fuzzy decision matrix was obtained, shown in ***Table 9***. Each of the values included in this matrix was multiplied with the relevant criterion weight, and in this way a weighted normalized fuzzy decision matrix, indicated in ***Table 10***, was formed.

The distance from the fuzzy positive ideal solution (d_i^+) values of each of the alternative supplier firms was calculated with ***Equation 10***, and their distance from the fuzzy negative ideal solution (d_i^-) values was calculated with ***Equation 11***. Afterwards the closeness index was calculated for each alternative with ***Equation 14*** by using the d_i^+ and d_i^- values. These calculations are presented in ***Table 11***.

Taking the alternatives' closeness index values into consideration, the alternative supplier firms were enumerated as A1> A3 > A2 from the most appropriate to the least appropriate. According to this result, it will be appropriate for the garment 'X' firm to select supplier A1 from among the three alternative suppliers as it has the highest closeness index value.

Table 5. Expression of criteria assessment results as fuzzy numbers.

Criteria	Decision makers		
	DM1	DM2	DM3
Quality	(0.7, 0.9, 1)	(0.7, 0.9, 1)	(0.5, 0.7, 0.9)
Delivery time	(0.7, 0.9, 1)	(0.7, 0.9, 1)	(0.7, 0.9, 1)
Cost	(0.9, 1, 1)	(0.7, 0.9, 1)	(0.5, 0.7, 0.9)
Flexibility	(0.1, 0.3, 0.5)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)
Geographic location	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.3, 0.5, 0.7)

Table 6. Expression of alternative assessment results as fuzzy numbers.

Criteria	Alternatives	Decision makers		
		DM1	DM2	DM3
Quality	A1	(7, 9, 10)	(9, 10, 10)	(7, 9, 10)
	A2	(5, 7, 9)	(5, 7, 9)	(1, 3, 5)
	A3	(7, 9, 10)	(7, 9, 10)	(7, 9, 10)
Delivery time	A1	(5, 7, 9)	(7, 9, 10)	(7, 9, 10)
	A2	(5, 7, 9)	(1, 3, 5)	(5, 7, 9)
	A3	(7, 9, 10)	(9, 10, 10)	(5, 7, 9)
Cost	A1	(7, 9, 10)	(0, 1, 3)	(3, 5, 7)
	A2	(7, 9, 10)	(3, 5, 7)	(9, 10, 10)
	A3	(5, 7, 9)	(5, 7, 9)	(1, 3, 5)
Flexibility	A1	(7, 9, 10)	(9, 10, 10)	(1, 3, 5)
	A2	(5, 7, 9)	(3, 5, 7)	(0, 1, 3)
	A3	(9, 10, 10)	(5, 7, 9)	(0, 1, 3)
Geographic location	A1	(0, 1, 3)	(1, 3, 5)	(0, 1, 3)
	A2	(0, 1, 3)	(1, 3, 5)	(0, 1, 3)
	A3	(0, 1, 3)	(0, 1, 3)	(1, 3, 5)

Conclusion

Firms want to work with suppliers that can provide a service of a desired quality level, are appropriate in terms of cost and can be flexible in the event of demand changes. The consideration of several criteria and sub-criteria thereof makes the process of supplier selection even more difficult. The Fuzzy TOPSIS method is one of the multi-criteria decision making methods that enable decision makers to reach the right decision regarding supplier selection by allowing several decision makers to enumerate the alternatives by assessing them in uncertainty according to multiple criteria. In this regard, the fuzzy TOPSIS method was used in a study of the selection of the suppliers of garment 'X'. The criteria used in the supplier selection were determined at the end of a literature review and interviews conducted with the decision makers of the firm. The decision makers used the triangular fuzzy numbers in the assessment process. When the application steps of the method were completed, the selection of supplier A1 was deemed appropriate as its closeness index value was found to be the highest according to the criteria specified, and, in turn, this selection was thought to provide both a competition advantage and effective supply chain management to the garment 'X' firm. With this study it is shown that the fuzzy TOPSIS method can be effectively utilised in the supplier selection process in a real industrial case, enabling decision makers to rank their alternative suppliers.

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***Table 7.** Importance weights of the criteria.*

Criteria	Weights
Quality	(0.633, 0.833, 0.967)
Delivery time	(0.700, 0.900, 1.000)
Cost	(0.700, 0.867, 0.967)
Flexibility	(0.233, 0.433, 0.633)
Geographic location	(0.233, 0.433, 0.633)

***Table 8.** Fuzzy decision matrix.*

Criteria	A1	A2	A3
Quality	(7.7, 9.3, 10)	(3.7, 5.7, 7.7)	(7, 9, 10)
Delivery time	(6.3, 8.3, 9.7)	(3.7, 5.7, 7.7)	(7, 8.7, 9.7)
Cost	(3.3, 5, 6.7)	(6.3, 8, 9)	(3.7, 5.7, 6.3)
Flexibility	(5.7, 7.3, 8.3)	2.7, 4.3, 6.3)	(4.7, 6, 7.3)
Geographic location	(0.3, 1.7, 3.7)	(0.3, 1.7, 3.7)	(0.3, 1.7, 3.7)

***Table 9.** Normalized fuzzy decision matrix.*

Criteria	A1	A2	A3
Quality	(0.77, 0.93, 1)	(0.37, 0.57, 0.77)	(0.7, 0.9, 1)
Delivery time	(0.65, 0.85, 1)	(0.38, 0.58, 0.79)	(0.72, 0.90, 1)
Cost	(0.37, 0.55, 0.74)	(0.70, 0.89, 1)	(0.41, 0.63, 0.70)
Flexibility	(0.69, 0.88, 1)	(0.33, 0.52, 0.76)	(0.57, 0.72, 0.88)
Geographic location	(0.08, 0.46, 1)	(0.08, 0.46, 1)	(0.08, 0.46, 1)

***Table 10.** Weighted normalized fuzzy decision matrix.*

Criteria	A1	A2	A3
Quality	(0.49, 0.77, 0.97)	(0.23, 0.47, 0.74)	(0.44, 0.75, 0.967)
Delivery time	(0.46, 0.77, 1)	(0.27, 0.41, 0.79)	(0.50, 0.81, 1)
Cost	(0.26, 0.48, 0.72)	(0.49, 0.77, 0.67)	(0.29, 0.55, 0.68)
Flexibility	(0.16, 0.38, 0.63)	(0.08, 0.23, 0.48)	(0.13, 0.31, 0.56)
Geographic location	(0.02, 0.20, 0.63)	(0.02, 0.20, 0.63)	(0.02, 0.20, 0.633)

***Table 11.** d_i^+, d_i^- and C_i values.*

Criteria	A1	A2	A3
d_i^+	2.60	2.96	2.77
d_i^-	2.92	2.58	2.89
C_i	0.53	0.47	0.51

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