Journal of Economics and Sustainable Development www.iiste.org
ISSN 2222-1700 (Paper) ISSN 2222-2855 (Online)
Vol.6, No.18, 2015

Supplier Selection with Fuzzy TOPSIS

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Abstract
For businesses, carrying out their activities successfully is directly related to the suppliers' efficiency as well as their own performances. Properly selected suppliers make a significant contribution to the competition capacity of enterprises. Therefore, selecting proper suppliers is regarded as a multiple criteria decision making (MCDM) problem, which includes many qualitative and quantitative factors in the process.In this study, a supplier selection model has been developed in order to help executives with proper supplier selection. In this model, Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) method, which is an MCDM method, was used with positive trapezoidal fuzzy numbers. The decision structure and the criteria used in decision support model have been determined based on the literature review. The result of the model demonstrated that all the suppliers evaluated in the study are suitable enough to work with, but the supplier B deserves the first place.
Keywords: Fuzzy TOPSIS, Multiple-Criteria Decision Making, Supplier Selection.

1. Introduction

With technological advances, customer needs have changed, for demand for lower prices and higher quality at the same time is now on the increase. New developments have led to a fierce market competition in many countries, so organizations have had to meet customer needs with new products and services. Therefore, they have had to cooperate with new suppliers. For businesses, carrying out their activities successfully is directly related to the suppliers' efficiency as well as their own performances. Supplier selection process is one of the most important issues for organizations. The role of the procurement function is often described as supplying raw material and equipment as well as other materials in sufficient quantity and quality, at an affordable price with appropriate delivery (Tam & Tummal, 2001).

Businesses need to find the right suppliers to work with to get ahead of their competitors. They have to meet the demands from their customers in time, and adapt to rapid changes in this increasingly globalized world. It is also important to keep inventory levels at the appropriate point. They need to reduce production costs and manage business processes well. Working with the right suppliers will reduce purchase costs, increase customer satisfaction, and improve competition capacity in a business. In many businesses, the purchase costs, supplying of the raw materials and the cost of semi-finished goods come up to 70% of the total cost (Ghodsypour & O'Brien, 1998: 199). Therefore, in today's highly competitive environment, an efficient supplier selection decision is crucial for the success of an organization (Liu & Hai, 2005: 308).

Therefore, businesses should be very careful in signing long-termed contracts with suppliers, since a contract with the wrong supplier could lead to loss of performance and an increase in the costs. In other words, it is of vital importance for businesses to select the right suppliers. Rightly selected suppliers make great contributions to the competition capacity of businesses.

There are many supplier selection and evaluation methods in the literature, from simple analytical techniques to multi-criteria methods, however this study could still be a contribution to the literature as it is based on Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) method and takes price, quality, delivery performance, service and past performance into account by using positive trapezoidal fuzzy numbers.

The purpose of this study is to develop a decision support model, which is easy to use without special software, to be used in the selection of the most suitable supplier by business managers. This decision support model, based on FTOPSIS, is supposed to serve an international business in particular. The business is based in Kayseri, Turkey and deals with aluminum profile production. It is a quality-oriented company that sells its products in every corner of Turkey as well as in Central and Western European countries. It gives importance to performance improvement and customer satisfaction.

The rest of this paper will include section 2, which shows the literature review, section 3, which presents the fuzzy sets, section 4, which introduces FTOPSIS theoretically, section 5, which describes the supplier selection model, and section 6, which discusses the results and gives recommendations for the future studies.

2. Literature Review

A number of Multi-Criteria Decision Making (MCDM) methods used for the solution of supplier selection problems can be found in the literature. Table 1 shows some of the studies found in the literature.

Table 1. Literature Review

Method	Author
AHP	Yahya & Kingsman (1999); Deng et al. (2014)
AHP & GP	Wang et al. (2004)
AHP & LP	Ghodsypour & O'Brien (1998)
AHP & Quality Function Deployment	Rajesh & Malliga (2013)
AHP, DEA & Artificial Neural Network	Ha & Krishnan (2008)
AHP, TOPSIS & Multi-Purpose LP	Kannan et al. (2013)
AHP, TOPSIS & Multi-Purpose Non-LP	Fazlollahtabar et al.(2011)
ANP	Sarkis &Talluri (2002); Gencer & Gürpınar (2007); Lang et al (2009); Lin et al. (2011)
DEA	Saen (2010); Toloo & Nalchigar (2011); Azizi (2013); Kumar (2014)
DEMATEL & Quality Function Deployment	Dey et al. (2012)
FAHP & FTOPSIS	Chan & Kumar (2007)
FAHP & Multi-Purpose LP	Shaw et al. (2012); Ayhan & Kilic (2015),
FAHP, FTOPSIS, DEA	Zeydan et al. (2011)
FSMART	Chou, S.Y., & Chang, Y.-H.(2008)
FTOPSIS	Chen et al. (2006); Wang et al. (2009); Zouggari & Benyoucef (2012); Roshandel et al. (2013); Kannan et al. (2014a)
Fuzzy Axiomatic Design	Kannan et al. (2014b); Kannan et al. (2015)
Fuzzy DEMATEL & FTOPSIS	Dalalah et al. (2011)
Fuzzy DEMATEL, FANP & FTOPSIS	Büyüközkan & Çiftçi (2012)
Fuzzy Quality Function Deployment	Bevilacqua et al. (2006); Karsak & Dursun (2015)
FVIKOR	Shemshadi et al. (2011)
FVIKOR & Environmental Impact Analysis Method	Girubha & Vinodh (2012); Sanayei et al. (2010)
GP	Karimi & Rezaeinia (2014); a et al. (2014); Jadidi et al. (2014b)
Grey system theory	Memon et al. (2015)
LP & FTOPSIS	Kılıç (2013)
Mixed Integer Non-LP	Ware et al. (2014)
Multidimensional analysis of preference (LINMAP)	Chen (2015)
Multi-objective model and Fuzzy GP	Moghaddam (2015)
Taguchi, TOPSIS & Multi-Criteria GP	Sharma & Balan (2012)
TOPSIS	Zhao & Ren (2013)
TOPSIS & GP	Liao & Kao (2011)

The following are some of these methods, used in the selection and evaluation of suppliers integrated or separately: Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), TOPSIS, Data Envelopment Analysis (DEA), VIKOR (Serbian: Vise Kriterijumsk to Optimizacij I Kompromisno Resenj), Linear Programming (LP), Goal Programming (GP), Fuzzy AHP (FAHP), Fuzzy ANP (FANP), Fuzzy VIKOR (FVIKOR), and FTOPSIS. By examining 126 studies, Chai et al. (2013: 3877) found out that there were 26 different methods used in the selection of suppliers. The following is the details of these 126 studies examined: AHP: 24.8% (n = 30), LP: 15.08% (n = 19), TOPSIS: 14.28% (n = 18), ANP: 11.90% (n = 15), DEA: 10.32% (n = 13), Multi-Purpose Programming Method: 10.32% (n = 13), and other methods: 14.28% (n=18).

The literature review revealed that there were quite a lot of studies dealing with the selection or evaluation of suppliers. This paper especially mentions the most recent ones of these studies which employed different methods.

3. Fuzzy Sets

Fuzzy sets were first used by Zadeh (1965) to overcome the uncertainty stemming from inconsistencies and ambiguities. The most important advantage of the fuzzy set theory is its capacity to represent uncertain data. Fuzzy logic is a method commonly used in the solution of ambiguous and uncertain problems (Chen & Chen, 2008: 85). The theory is quite suitable for mathematical operations and programming in the fuzzy area. The Fuzzy Set Theory is used to remove the uncertainty and subjectivity in the decision-making process by means of linguistic variables. Fuzzy numbers are used in the evaluations where linguistic variables are employed. The Absolute Set Theory may be inadequate in the presence of linguistic variables in solving a decision problem. Many decision problems include unclear and imprecise data. Solution methods developed without taking into account the uncertainty and ambiguity do not always lead to accurate results.

The members of a fuzzy set μA(x) can take values between 0 and 1, which is called membership degree. If x is definitely an element of set A, then it is defined as μA(x) =1. If not, then it is defined as μA(x) =0. The higher the value of the membership degree is, the higher the degree of x as a member of set A. (Dağdeviren, 2007:793).

Triangular or trapezoidal fuzzy numbers (TFN) are commonly used in most studies. This study also utilized TFNs. A TFN is defined as $\tilde{n} = (n_1, n_2, n_3, n_4)$, and shown as in Figure 1 (Chen et al, 2006:292).

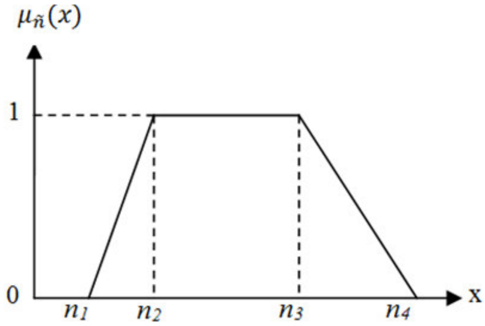

Figure 1. Trapezoidal Fuzzy Number (Chen et al., 2006: 292)

A Positive TFN membership function is defined in Equation (1) (Chen et al., 2006: 292).

$$\mu_{\tilde{n}}(x) = \begin{cases} 0, & x < n_1, \\ \dfrac{x - n_1}{n_2 - n_1}, & n_1 \leq x \leq n_2, \\ 1, & n_2 \leq x \leq n_3, \\ \dfrac{x - n_4}{n_3 - n_4}, & n_3 \leq x \leq n_4, \\ 0, & x > n_4. \end{cases} \quad (1)$$

If $n_2 = n_3$ in $\tilde{n} = (n_1, n_2, n_3, n_4)$, then $\tilde{n}$ is a triangular fuzzy number.

The following are the basic arithmetical operations between two positive TFNs $\tilde{n} = (n_1, n_2, n_3, n_4)$ and $\tilde{m} = (m_1, m_2, m_3, m_4)$ ***r***, (real number):

$$\tilde{m}(+)\tilde{n} = [m_1 + n_1, m_2 + n_2, m_3 + n_3, m_4 + n_4] \quad (2)$$

$$\tilde{m}(-)\tilde{n} = [m_1 - n_4, m_2 - n_3, m_3 - n_2, m_4 - n_1] \quad (3)$$

$$\tilde{m}(x)\tilde{n} \cong [m_1 n_1, m_2 n_2, m_3 n_3, m_4 n_4] \quad (4)$$

$$\tilde{m}(x)\, r = [m_1 r, m_2 r, m_3 r, m_4 r] \quad (5)$$

4. Fuzzy TOPSIS

TOPSIS, developed by Hwang and Yoon in 1980 in order to solve the problems of MCDM, has successfully been applied in the industrial and other areas (Hwang & Yoon, 1981: 128). TOPSIS aims to determine the alternative in the shortest distance to the positive-ideal solution (PIS) and in the longest distance to the negative-ideal solution (NIS). The alternative closest to the PIS and farthest to the NIS is considered to be the best one (Cheng et al. 2002: 983).

There have to be minimum two alternatives in order to apply TOPSIS method, which requires determining the criteria first. Generally there are two types of criteria in TOPSIS: “benefit criteria” and “cost criteria” (Janic, 2003: 491-512). The best value in the cost criteria is the smallest one (the lowest cost), while in the benefit criteria, it is the biggest value (the most beneficial). In other words, the worst value in the cost criteria is the highest one (the highest cost), and in the benefit criteria, it is the smallest value (the least beneficial) (Cheng & Wang, 2001: 449-467).

FTOPSIS uses fuzzy numbers rather than absolute numbers in the evaluation of alternatives and criteria. This study, in which TFNs have been used, is based on FTOPSIS algorithm, implemented by Chen et al. (2006: 289-301). TFNs have been defined by linguistic variables as shown in Figure 2 and Figure 3. The Decision Makers (DM) determine the importance weights by using the linguistic variables shown in Figure 2 and the performance values of the alternatives by using the linguistic variables in Figure 3.

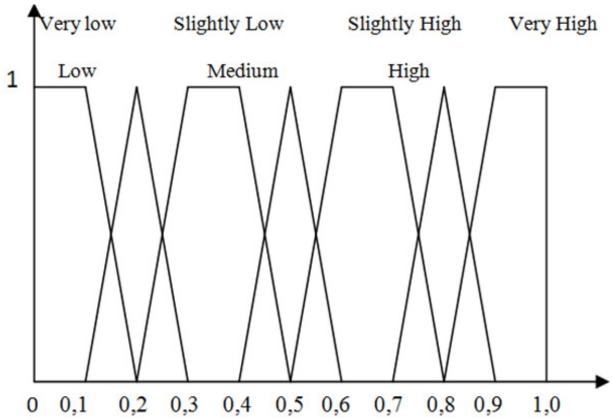

Figure 2. Linguistic Variables for the Importance Weights of the Criteria

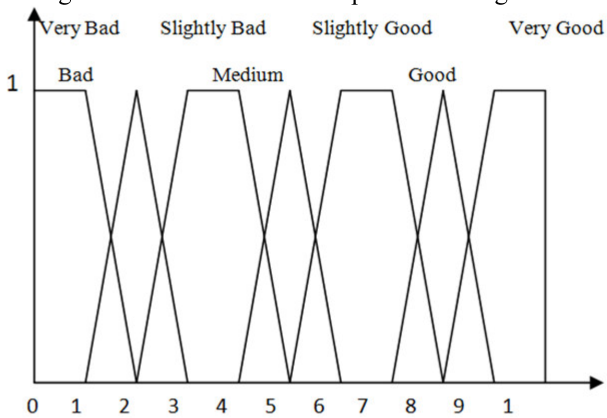

Figure 3. Linguistic Variables for the Performance Values of the Alternatives

For instance, the equivalent of the linguistic variable 'Slightly Low' (SL) as a TFN is (0.2,0.3,0.4,0.5). The membership function of this number is as follows:

$$\mu_{\tilde{n}}(x) = \begin{cases} 0, & x < 0.2, \\ \dfrac{x-0.2}{0.3-0.2}, & 0.2 \le x \le 0.3, \\ 1, & 0.3 \le x \le 0.4, \\ \dfrac{x-0.5}{0.4-0.5}, & 0.4 \le x \le 0.5, \\ 0, & x > 0.5 \end{cases}$$

FTOPSIS Algorithm consists of the steps below:

A. Formation of the Hierarchical Structure the Problem

The hierarchical structure is formed by determining the main criteria and the sub-criteria, if there are any, as well as the potential suppliers. If the list of suppliers is too long, the number of suppliers can be reduced by pre-selection.

B. Creating the Initial Matrix by evaluating the Criteria Weights and Suppliers

The weights of the criteria are evaluated by the DMs through the linguistic variables shown in Table 2, and then integrated. Similarly, the suppliers are evaluated by the DMs using the linguistic variables listed in Table 3, and then integrated.

A_i: Alternatives

C_j: Criteria

K: the number of DMs

$\tilde{x}_{ij}$: the performance value of A_i based on C_j

$\tilde{w}_j, (i = 1,2,\dots,m; j = 1,2,\dots,n)$: Criteria weights

The problem is defined as in Equation (6) with the initial fuzzy matrix ($\tilde{D}$), and the criteria weights are shown in Equation (7) as ($\tilde{W}$).

$$\widetilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1j} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2j} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{i1} & \tilde{x}_{i2} & \dots & \tilde{x}_{ij} & \dots & \tilde{x}_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mj} & \dots & \tilde{x}_{mn} \end{bmatrix} \quad (6)$$

$$\widetilde{W} = [\widetilde{w}_{1,} \widetilde{w}_{2,} \dots, \widetilde{w}_n] \quad (7)$$

$\tilde{x}_{ijk} = (a_{ijk}, b_{ijk}, c_{ijk}, d_{ijk})$, *i=1,2,..,m*; *j=1,2,..,n* defines the fuzzy values of the alternatives determined by the DMs by taking into account the criteria determined for the alternatives. All fuzzy values determined by the DMs are integrated by using Equation (8).

Here;

$$\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}, d_{ij}) \quad (8)$$

$$a_{ij} = \min_k\{a_{ijk}\}, \quad b_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ijk}, \quad c_{ij} = \frac{1}{K}\sum_{k=1}^{K} c_{ijk}, \quad d_{ij} = \max_k\{d_{ijk}\}$$

$\widetilde{w}_{jk} = (w_{jk1}, w_{jk2}, w_{jk3}, w_{jk4})$, *i=1,2,..,m*; *j=1,2,..,n* defines the fuzzy importance weight determined by kth DM. All fuzzy importance weights determined by the DMs are integrated by using Equation (9*)*

$$\widetilde{w}_j = (w_{j1}, w_{j2}, w_{k3}, w_{j4}) \quad (9)$$

Here;

$$w_{j1} = \min_k\{w_{jk1}\}, \quad w_{j2} = \frac{1}{K}\sum_{k=1}^{K} w_{jk2}, \quad w_{j3} = \frac{1}{K}\sum_{k=1}^{K} w_{jk3}, \quad w_{j4} = \max_k\{w_{jk4}\}$$

C. Normalization of the Initial Matrix

Having created $\widetilde{D}$, the normalized decision matrix($\tilde{R}$), as in Equation (11), is obtained by using Equation (10) through the members of $\widetilde{D}$. If the evaluation criterion is benefit type, then the highest performance value and the best preference is used. If it is cost type, then the lowest performance and the worst preference is used.

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{d_j^*}, \frac{b_{ij}}{d_j^*}, \frac{c_{ij}}{d_j^*}, \frac{d_{ij}}{d_j^*}\right), \quad j \in B, \tilde{r}_{ij} = \left(\frac{a_j^-}{d_{ij}}, \frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), \qquad j \in C \quad (10)$$

$$d_j^* = \max_i d_{ij}, \quad j \in B, \quad a_j^- = \min_i a_{ij}, j \in C$$

$$\tilde{R} = \begin{bmatrix} \tilde{r}_{11} & \tilde{r}_{12} & \dots & \tilde{r}_{1j} & \dots & \tilde{r}_{1n} \\ \tilde{r}_{21} & \tilde{r}_{22} & \dots & \tilde{r}_{2j} & \dots & \tilde{r}_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \tilde{r}_{i1} & \tilde{r}_{i2} & \dots & \tilde{r}_{ij} & \dots & \tilde{r}_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \tilde{r}_{m1} & \tilde{r}_{m2} & \dots & \tilde{r}_{mj} & \dots & \tilde{r}_{mn} \end{bmatrix} \quad (11)$$

D. Creating Weighted Fuzzy Decision Matrix

Weighted fuzzy decision matrix ($\tilde{V}$)is formed by Equation (12) considering the fuzzy weight of each criterion ($\widetilde{w}_j$).

$$\tilde{V} = \begin{bmatrix} \widetilde{w}_1\tilde{r}_{11} & \widetilde{w}_2\tilde{r}_{12} & \dots & \widetilde{w}_j\tilde{r}_{1j} & \dots & \widetilde{w}_n\tilde{r}_{1n} \\ \widetilde{w}_1\tilde{r}_{21} & \widetilde{w}_2\tilde{r}_{22} & \dots & \widetilde{w}_j\tilde{r}_{2j} & \dots & \widetilde{w}_n\tilde{r}_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \widetilde{w}_1\tilde{r}_{i1} & \widetilde{w}_2\tilde{r}_{i2} & \dots & \widetilde{w_j\tilde{r}_{ij}} & \dots & \widetilde{w}_n\tilde{r}_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \widetilde{w}_1\tilde{r}_{m1} & \widetilde{w}_2\tilde{r}_{m2} & \dots & \widetilde{w}_j\tilde{r}_{mj} & \dots & \widetilde{w}_n\tilde{r}_{mn} \end{bmatrix} \quad (12)$$

$$i = 1,2, \dots, m, \qquad j = 1,2, \dots, n$$

E. Creating the Fuzzy Positive Ideal Solutions and the Fuzzy Negative Ideal solutions

Two different solution sets as fuzzy PIS (A^*) and fuzzy NIS (A^-) are obtained from $\tilde{V}$ by using Equation (13) and Equation (14) for A^* and A^-respectively.

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*) \quad (13)$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-) \quad (14)$$

$$\tilde{v}_j^* = \max_i\{v_{ij4}\} \ \ and \ \ \tilde{v}_j^- = \min_i\{v_{ij1}\}, \ \ i = 1,2, \dots, m, \ \ j = 1,2, \dots, n$$

F. Calculation of the Distances of the Alternatives to the fuzzy PIS and NIS

Equations (15) and (16) are used respectively for the calculation of distance of each alternative to A^* and $A^{-'}$

$$d_i^* = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_j^*), \quad i = 1,2, \dots, m \quad (15)$$

$$d_i^- = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_j^-), \quad i = 1,2, \dots, m \quad (16)$$

$d_v(\tilde{m}, \tilde{n})$ defines the distance between two fuzzy numbers. This distance has been calculated by vertex method, shown in Equation (17), as recommended by Chen (2000:3).

$$d_v(\tilde{m}, \tilde{n}) = \sqrt{\frac{1}{4}[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2 + (m_4 - n_4)^2]} \quad (17)$$

G. Calculation of the Proximity Coefficient and Ranking of the alternatives

The proximity coefficient must be calculated to rank the alternatives. The proximity coefficient defines the distance to the A^* and A^- considering the relative closeness to the fuzzy PIS simultaneously. Equation (18) is used to calculate the proximity coefficient of each alternative.

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, \quad i = 1,2, \dots, m \quad (18)$$

The closer the coefficient CC_i is to 1, the closer *ith* alternative to A^* is, and the more distant it is to A^-. The alternatives are ranked from the highest to the lowest according to coefficient CC_i.

5. Application

The aim of this study is to develop a supplier selection model for a medium scaled company producing aluminum profiles. The process involved the evaluation of 3 suppliers by 3 DMs according to the following criteria: Quality (Q), Price (P), Delivery Performance (DP), Service (S), and Past Performance (PP). P is cost type criteria while Q, DP, S, PP are benefit type.

A. Creating the Hierarchical Structure of the Problem

The hierarchical structure of the decision problem shown in Figure 4 has been formed by considering the criteria determined by means of the results obtained from the literature review and considering the potential suppliers.

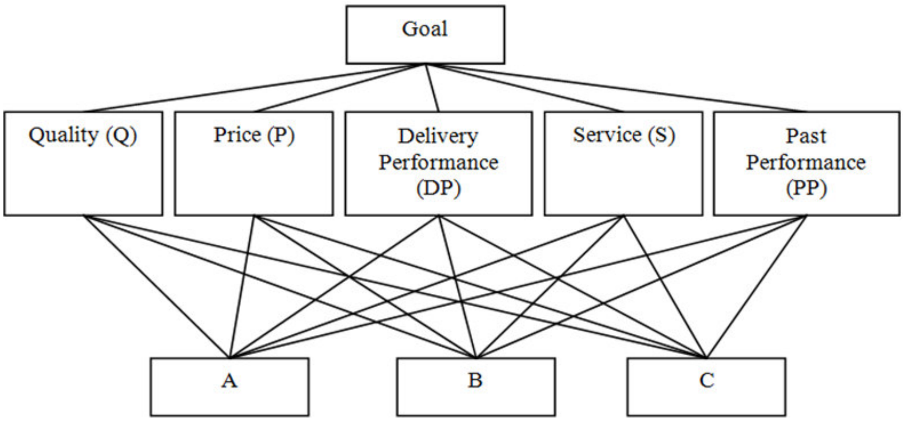

Figure 4. Hierarchical Structure of the Decision Problem

B. Creating the Initial Matrix by Evaluating Criteria Weights and Suppliers

The 3 DMs evaluated the importance of the criteria using the linguistic variables shown in Table 2. Table 3 shows the importance weights in TFNs.

Table 2. The Importance Weight of the Criteria

Criteria	Decision Makers		
	DM1	DM2	DM3
Quality	H	H	H
Price	VH	VH	VH
Delivery Performance	H	H	H
Service	H	VH	H
Past Performance	H	H	SH

Table 3. The Importance Weights of the Criteria in TFNs

Criteria	DM1	DM2	DM3
Q	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
P	(0.8,0.9,1,1)	(0.8,0.9,1,1)	(0.8,0.9,1,1)
DP	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
S	(0.7,0.8,0.8,0.9)	(0.8,0.9,1,1)	(0.7,0.8,0.8,0.9)
PP	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)

Table 4 gives the integrated importance weights of the criteria calculated by Equation (9)

Table 4. Integrated Importance Weights of the Criteria

Criteria	Importance Weights
Q	(0.7,0.8,0.8,0.9)
P	(0.8,0.9,1,1)
DP	(0.7,0.8,0.8,0.9)
S	(0.7,0.83,0.87,1)
PP	(0.5,0.73,0.77,0.9)

The suppliers were evaluated by the three DMs separately according to each criterion. The linguistic variables shown in Figure 3 were used for the evaluation. Table 5 gives the results of the supplier selection in linguistic variables. Table 6 shows the fuzzy weights of the suppliers and the fuzzy decision matrix.

Table 5. Evaluation of the Suppliers by DMs according to the Criteria

Criterion	Supplier	Decision Makers		
		DM1	DM2	DM3
Quality	A	M	G	G
	B	G	G	VG
	C	G	G	M
Price	A	VG	M	G
	B	SG	G	G
	C	SG	VG	SG
Delivery Performance	A	G	G	G
	B	VG	VG	VG
	C	G	SG	SB
Service	A	SB	G	G
	B	M	G	G
	C	G	G	G
Past Performance	A	G	SG	VG
	B	G	G	VG
	C	G	VG	SG

Table 6. Fuzzy Decision Matrix and Fuzzy Weights of the Suppliers

	Q	P	DP	S	PP
A	(4.7.7.9)	(4,7.3,7.7,10)	(7,8,8,9)	(2,6.3,6.7,9)	(5,7.7,8.3,10)
B	(7,8.3,8.7,10)	(5,7.3,7.7,9)	(8,9,10,10)	(4,7,7,9)	(7,8.3,8.7,10)
C	(4,7,7,9)	(5,7,8,10)	(2,5.7,6.3,9)	(7,8,8,9)	(5,7.7,8.3,10)

C. Normalization of the Initial Fuzzy Decision Matrix

Normalization of the elements of the Initial Matrix was realized by Equation (10). What is important here is to determine the type of the criteria: cost or benefit? The criteria here are all benefit type except F. Table 7 shows the normalized fuzzy decision matrix.

Table 7. Normalized Fuzzy Decision Matrix

	Q	P	DP	S	PP
A	(0.4,0.7,0.7,0.9)	(0.4,0.52,0.55,1)	(0.7,0.8,0.8,0.9)	(0.2,0.7,0.74,1)	(0.5,0.77,0.83,1)
B	(0.7,0.8.3,0.8.7,1)	(0.44,0.52,0.55,0.8)	(0.8,0.9,1,1)	(0.44,0.78,0.78,1)	(0.7,0.83,0.87,1)
C	(0.4,0.7,0.7,0.9)	(0.4,0.5,0.57,0.8)	(0.2,0.57,0.63,0.9)	(0.78,0.89,0.89,1)	(0.5,0.77,0.83,1)

D. Creating the Weighted Fuzzy Decision Matrix

Weighted Fuzzy Decision Matrix $(\tilde{V})$ shown in Table 8 is formed by Equation (12) considering the fuzzy weight of each criterion ($\tilde{w}_i$).

Table 8. Weighted Fuzzy Decision Matrix

	Q	P	DP	S	PP
A	(0.28,0.56,0.56,0.81)	(0.32,0.47,0.55,1)	(0.49,0.64,0.64,0.81)	(0.16,0.59,0.64,1)	(0.25,0.56,0.64,0,9)
B	(0.49,0.67,0.69,0,9)	(0.36,0.47,0.55,0.8)	(0.56,0.72,0.8,0,9)	(0.31,0.65,0.67,1)	(0.35,0.61,0.66,0,9)
C	(0.28,0.56,0.56,0.81)	(0.32,0.45,0.57,0.8)	(0.14,0.45,0.51,0.81)	(0.54,0.74,0,77,1)	(0.25,0.56,0.64,0,9)

E. Creating the Fuzzy Positive Ideal Solutions and the Fuzzy Negative Ideal solutions
Two different solution sets as (A^*) and (A^-) are obtained from $\tilde{V}$ by using Equation (13) and Equation (14) for A^* and A^-respectively.
A^*=[(0.9,0.9,0.9,0.9),(1,1,1,1),(0.9,0.9,0.9,0.9),(1,1,1,1),(0.9,0.9,0.9,0.9)]
A^-=[(0.28,0.28,0.28,0.28),(0.32,0.32,0.32,0.32),(0.14,0.14,0.14,0.14)]
F. Calculation of the Distances of the Suppliers to A^* and A^-
Equations (15) and (16), (17) are used for the calculation of distance of each supplier to A^* and A^- considering each criterion, and these distances are shown in Table 9 and 10.
Table 9. Distances of the Suppliers to A^*

	Q	P	DP	S	PP
$d(A,A^*)$	0,39	0,49	0,28	0,50	0,39
$d(B,A^*)$	0,26	0,49	0,20	0,42	0,33
$d(C,A^*)$	0,39	0,50	0,48	0,29	0,39

Table10. Distances of the Suppliers to A^-

	Q	P	DP	S	PP
$d(A,A^*)$	0,39	0,49	0,28	0,50	0,39
$d(B,A^*)$	0,26	0,49	0,20	0,42	0,33
$d(C,A^*)$	0,39	0,50	0,48	0,29	0,39

G. Calculation of the Proximity Coefficient and Ranking of the Suppliers
Equation (18) is used to calculate the proximity coefficient showing the distance of the suppliers to A* and A−. The results are shown in Table 11.

Table11. Proximity Coefficients and Ranking

	d_i^*	d_i^-	$d_i^* + d_i^-$	CC_i
A	2,05	2,16	4,21	0,51
B	1,69	2,31	4,01	0,58
C	2,05	2,06	4,11	0,50

The ranking of the suppliers is very close: B>A>C. The supplier B can be thought to be the most convenient supplier. There is no significant difference between A and C. In fact, it is possible to say all these three suppliers are suitable enough to work.

6. Conclusion and Discussion

Working with the right suppliers is very important for businesses for such reasons as having competitive advantage, adapting to rapid changes, reducing production costs, gaining a flexible structure and limiting risks. Therefore, many businesses are willing to establish strategic cooperation with the right suppliers in medium and long term.

In this study, a supplier selection model was developed to help the managers of a company make their decisions with the supplier selection. The model employs FTOPSIS, which is an MCDM method, with positive TFNs in linguistic variables.

Evaluating the results obtained from the literature review, the following 5 criteria were determined: Q, P, DP, S, PP. These criteria were evaluated and integrated by 3 DMs using linguistic variables. Then the DMs evaluated the suppliers according to the criteria through linguistic variables. The results revealed that the most suitable supplier was B though there were no significant differences among the suppliers, especially between A and C. The company can choose to work with all these three suppliers, but B has the priority.

Though the model developed in this study requires more procedures than calculations made by non-fuzzy methods, it can be applied using spreadsheet programs such as Excel, without any special software. The model can be used effectively as a decision-making tool in different areas by changing the criteria. It can also be used as an integrated model with such methods as FAHP or FAAP. In addition, such methods as VIKOR, PROMETHEE, MOORA, and ARAS can be used to develop new supplier selection models and the results can be compared.

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