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Fuzzy TOPSIS and Fuzzy ELECTRE-I Approach for Selecting the Best Suppliers by Multiple Criteria

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Abstract

Supplier selection is a multi-criteria decision making problem of supply chain management which includes evaluation of the strengths and weaknesses of potential suppliers. Multi-criteria decision making methods facilitate the process of finding a solution and enable decision makers to reach the right decisions. Thus, the integration of all the multi-criteria analysis and of the results of multi-analysis teams has an important meaning in supply chain design. In this work the authors propose a supplier selection analysis model using the Fuzzy TOPSIS and the Fuzzy ELECTRE-I methods. For numerical analysis data were derived from a shoes industry of Bangladesh, where five suppliers and three experts are available. The experts considered transportation cost, lead time, quality, flexibility, reliability and adaptation of new technology as the selection criteria.

Keywords: *Fuzzy TOPSIS, Fuzzy ELECTRE-I, Multi-criteria Decision Making, Suppliers Selection.*

1. Introduction

Supplier selection process is one of the most important components for all the companies. Selection of a wrong supplier could be enough to destroy the company's financial and operational position. Selecting the right supplier reduces the overall cost, improves competitiveness in the market and enhances customer's satisfaction. The selecting process mainly involves evaluation of different alternative criteria. This process is essentially considered as a *Multiple Criteria Decision Making* (MCDM) problem which is affected by different tangible and intangible criteria including price, quality, flexibility, reliability etc. A number of alternative approaches have been proposed to consider different criteria into account in the form of mathematical programming models, multiple attribute decision aid methods, cost-based methods, statistical and probabilistic methods, TOPSIS method etc. As the selection of the right supplier has a great impact on the quality of the goods, so everyone should consider all the possible criteria to choose the best supplier. Decision makers agree that supplier selection is one of the most important functions of a purchasing department, helping businesses save material cost and increase competitive advantage **[1]**. Supply chain includes all the participants and processes: from a raw materials producer to the customer, but from the point of view of operative management, the three basic components are elaborated: supply, storage and distribution **[2]**.

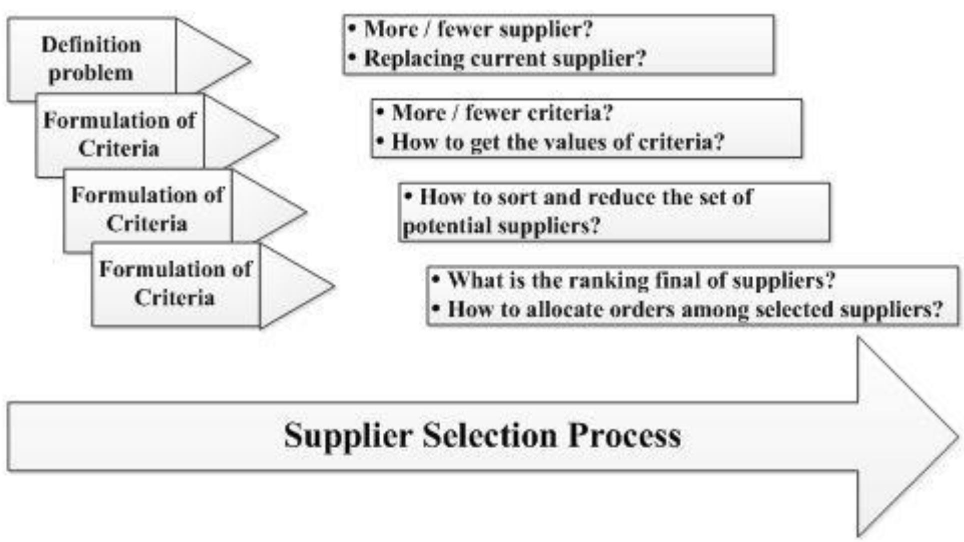

Figure 1: *The Supplier Selection Framework*

By applying coordinated management and control the total costs can be significantly decreased **[3]**. According to **[4]** the supplier selection process follows the steps shown in Figure 1. Different MCDM methods used mostly for outranking, suppliers ranking **[5].** That is where TOPSIS (***T****echnique for* ***O****rder*

***P**erformance by **S**imilarity to **I**deal **S**olution*) supports the experts to find the decision that best suits their needs and their understanding of the problem. TOPSIS, one of the known classical MCDM methods, was first developed in **[6]** to solve a MCDM problem**.** TOPSIS, one of the classical MCDM methods, was first developed in **[6]**. MCDM approaches are mostly based on qualitative data and personal opinions & the fuzzy logic method is frequently used in the analysis of such data. In this paper, the Fuzzy TOPSIS method **[7]** was used to select the best supplier., ELECTRE-I **[8]** is based on the study of outranking relations and it uses concordance and discordance indexes to analyze the outranking relations among the alternatives. Concordance and discordance indexes can be viewed as measurements of satisfaction and dissatisfaction that a decision maker chooses one alternative over the other. In this paper, ELECTRE-I has been combined with fuzzy set theory.

2. Literature Review

TOPSIS, one of the known MCDM methods was first developed by Hwang **[9]**. Multiple attribute decision making methods were proposed in **[10]**. Ching-Lai Hwang Kwangsun Yoon **[6]** proposed the methods for multiple attribute decision making process. Bronja **[5]** ranked suppliers in the supply chains concept. McIvor **[3]** developed a hybrid knowledge-based system for strategic purchasing. Sarker **[2]** reviewed the “Supply Chain Management: Strategy, Planning and Operation”. Farzipoor Saen, Reza **[1]** proposed a new mathematical approach for suppliers selection where Non-Homogeneity is important. Zadeh **[11,12]** developed information and control system using fuzzy sets. Safari **[13]** proposed fuzzy TOPSIS approach for ranking of supplier of a company. Mikhailov **[14]** evaluated services using a fuzzy analytic hierarchy process. Yeşim Yayla **[7]** implemented Fuzzy TOPSIS method in supplier selection and application in the garment industry. Patil **[15]** developed a hybrid approach based on fuzzy DEMATEL and FMCDM to predict success of knowledge management adoption in supply chain. Decision makers are ‘‘off line’’ from the optimization procedure done at the engineering level **[16]**. The engineering level of the MCDM performs the multi-criteria ranking of alternatives **[17]**. A more realistic approach may be to use linguistic assessments that is, to suppose the ratings and weights of the criteria in the problem are assessed by means of linguistic variables **[18-20]**. The application of fuzzy set theory to multi-criteria analysis models under the framework of utility theory has been proven to be an effective approach **[21-24]**. In fuzzy TOPSIS, attribute values are represented by fuzzy numbers. The weights of the criteria and the ratings of alternatives on each criterion are known precisely and crisp values are used in the evaluation process in traditional ELECTRE methods **[25]**. Exact data are inadequate to model real-life situations. Therefore, these data may have some structures such as fuzzy data, bounded data, ordinal data and interval data **[26]**. In fuzzy ELECTRE, linguistic preferences can easily be converted to fuzzy numbers **[27]**. There are many studies in the literature that combine all types of ELECTRE methods with fuzzy sets. Aytac & .Tus **[8]** used fuzzy ELECTRE-I method for evaluating catering firm alternatives. Rouyendegh **[25]** selected the best project using the fuzzy ELECTRE method. Sevkli **[28]** used fuzzy ELECTRE to select the supplier. Wu & Chen **[29]** developed the ELECTRE multi-criteria analysis approach based on Atanassov's intuitionistic fuzzy sets for solving multi-criteria decision making problems. Kaya & Kahraman **[27]** used fuzzy ELECTRE with AHP. In this paper, fuzzy ELECTRE-I method is considered which was proposed by Aytac, Tus, & Kundakc **[8]**.

3. Research Methodology

3.1 The Concept of Fuzzy Set

A fuzzy set $\tilde{F}$ in the set of discourse X is defined by: $\tilde{F} = \{x, \mu_{\tilde{F}}(x)\}, x \in X$ (1), where $\mu_{\tilde{F}}(x): X \rightarrow [0, 1]$ is the membership function of $\tilde{F}$ and $\mu_{\tilde{F}}(x)$ is the membership degree of x in $\tilde{F}$. The closer $\mu_{\tilde{F}}(x)$ to 1, the better x satisfies the characteristic property of $\tilde{F}$.

The notion of a triangular fuzzy number (l, m u) is commonly used in the decision making process due to its intuitive membership function given by

$$\mu(x) = \begin{cases} 0 & \text{if } x<1 \\ (x-l)/(m-l) & \text{if } l \le x \le m \\ (u-x)/(u-m) & \text{if } m \le x \le u \\ 0 & \text{if } x>u \end{cases}$$

with l, m and u real numbers such that $l < m < u$ (Figure **2**)

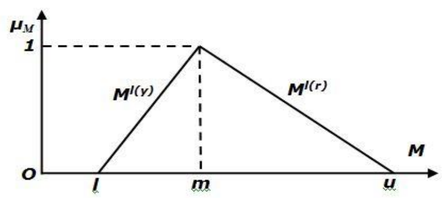

Figure 2: A Triangular Fuzzy Number

Given two fuzzy triangular numbers $\tilde{A}(l_{1,}m_{1,}u_1)$ and $\tilde{B}(l_{2,}m_{2,}u_2)$, addition an subtraction are performed as follows **[4]:**

$$\tilde{A} + \tilde{B} = l_1 + l_2, m_1 + m_2, u_1 + u_2)$$

$$\tilde{A} - \tilde{B} = l_1 - l_2, m_1 - m_2, u_1 - u_2)$$

3.2 Fuzzy TOPSIS

TOPSIS was extended to fuzzy environments by Chen **[18]**, who used a fuzzy linguistic value as a substitute for the directly given crisp value in the grade assessment. This modified version is a practical method that matches human thinking in an actual environment **[7]**. The linguistic expressions of fuzzy theory are considered as preferences/judgments of an individual. 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 $(\tilde{X}_{Ij}; i = 1,2,.....,$number of alternative (m) $j = 1,2,.....,$ number of criteria (n)) are inputs that are placed in a matrix. The fuzzy TOPSIS procedure consists of the following steps **[7]**:

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

$$\tilde{D} = \begin{matrix} \tilde{x}_{1l} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ & & \ddots & \\ \tilde{x}_{2l} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{ml} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{matrix} \tag{1}$$

$$\tilde{W} = [\tilde{w}_1 + \tilde{w}_2 + \tilde{w}_3 ..... + \tilde{w}_n] \tag{2}$$

Step 2: Calculate the normalized fuzzy decision matrix:

$\tilde{R} = [\tilde{r}_{ij}]_{max}$; $i = 1,2,.....,$number of alternative (m) $j = 1,2,.....,$ number of criteria (n)). Where for benefit criteria, $\tilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+} \right)$ (3)

Where, $u_j^+ = \max\ u_{ij}$ (4)

For cost criteria**,** $\tilde{r}_{ij} = \left(\frac{l_j^-}{u_{ij}}, \frac{l_j^-}{u_{ij}}, \frac{l_j^-}{u_{ij}} \right)$ (5)

Where, $i_j^- = \min\ i_{ij}$ (6)

Step 3: Calculate the weighted normalized fuzzy decision matrix, $\tilde{V}$:

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n} \tag{7}$$

$$\tilde{v}_{ij} = \tilde{r}_{ij} \otimes \tilde{w}_j \tag{8}$$

Where $\tilde{v}_{ij}$ is the fuzzy weight of jth criterion

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

$$S^+ = \{\tilde{v}_1^+, \tilde{v}_2^+, ..., \tilde{v}_n^+\} \tag{9}$$

$$S^- = \{\tilde{v}_1^-, \tilde{v}_2^-, ..., \tilde{v}_n^-\} \tag{10}$$

Where $\tilde{v}_j^+ = (0,0,0)$ & $\tilde{v}_j^- = (0,0,0)$

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

$$d_i^+ = \sum_{j=1}^{n} d(\tilde{v}_{ij} - \tilde{v}_j^+) \tag{11}$$

$$d_i^+ = \sum_{j=1}^{n} d\left(\tilde{v}_{ij} - \tilde{v}_j^-\right) \quad (12)$$

For triangular fuzzy numbers the equation is expressed as:

$$d\left(\tilde{A}, \tilde{B}\right) = \sqrt{\frac{1}{3}(l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2} \quad (13)$$

Step 6: Compute the relative closeness of alternative $C_i = \dfrac{d_i^-}{d_i^+ + d_i^-}$ (14)

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

Step 7: Rank the preference order. Choose the alternative with maximum C_i value.

3.3 Fuzzy ELECTRE

The algorithm of this method can be described as follows:

Step 1: The normalized weighted fuzzy decision matrix is constructed same as the fuzzy TOPSIS method.

Step 2: Concordance and discordance matrices are calculated using the weighted normalized fuzzy decision matrix ($\check{V}$) and the pair wise comparison among the alternatives. Considering two alternatives and the concordance set can be defined as $J_c = \{j | \check{v}_{gj} \geq \check{v}_{fj}$ (15)

Here J_c is the index of all criteria belonging to the concordance coalition with the outranking relation $A_g\ S\ A_f$ [30]. In this paper Hamming distance is calculated from **[30]**. Firstly, their least upper bound, max ($\check{v}_{gj}, \check{v}_{fj}$) is determined.

Then Hamming distances d (max ($\check{v}_{gj}, \check{v}_{fj}$), $\check{v}_{gj}$) and d (max ($\check{v}_{gj}, \check{v}_{fj}$), $\check{v}_{fj}$) are calculated. $|\check{v}_{gj} \geq \check{v}_{fj}$, when d (max ($\check{v}_{gj}, \check{v}_{fj}$), $\check{v}_{fj}$) is greater than D (max ($\check{v}_{gj}, \check{v}_{fj}$), $\check{v}_{gj}$).

The discordance set can be defined as;

$$J_D = \{j | \check{v}_{gj} \leq \check{v}_{fj}. \quad (16)$$

Here J_D is the index of all criteria belonging to the discordance coalition and it is against the assertion "A_g is at least as good as A_f." Similarly, for comparing each criterion of alternatives g and f

Step 3: The concordance matrix for each pair wise comparison of the alternatives can be defined as

$$\tilde{c} = \begin{matrix} - & \cdots & \tilde{c}_{lf} & \cdots & \tilde{c}_{1m} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{c}_{gl} & \cdots & \tilde{c}_{gf} & \cdots & \tilde{c}_{gm} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{c}_{ml} & \cdots & \tilde{c}_{mf} & \cdots & - \end{matrix} \tag{17}$$

The elements of the concordance matrix are determined as fuzzy summation of the fuzzy weights of all criteria in the concordance set

$$\tilde{C}_{gf} = \left(C_{gf}^{l}, C_{gf}^{m}, C_{gf}^{u}\right) = \sum_{j \in j_C} \tilde{W}_j = \left(\sum_{j \in J} \tilde{W}_j^{l}, \sum_{j \in J} \tilde{W}_j^{m}, \sum_{j \in J} \tilde{W}_j^{u} \right) \tag{18}$$

Step 4: The discordance matrix can be defined as:

$$\tilde{D} = \begin{matrix} - & \cdots & \tilde{d}_{lf} & \cdots & \tilde{d}_{1m} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{d}_{gl} & \cdots & \tilde{d}_{gf} & \cdots & \tilde{d}_{gm} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{d}_{ml} & \cdots & \tilde{d}_{mf} & \cdots & - \end{matrix} \tag{19}$$

$$d_{gf} = \frac{\max\limits_{j \in j_D} \left|\tilde{v}_{gj} - \tilde{v}_{fj}\right|}{\max\limits_{j} \left|\tilde{v}_{gj} - \tilde{v}_{fj}\right|} = \frac{\max\limits_{j \in j_D} \left|\max\left(\tilde{v}_{gj}, \tilde{v}_{fj}\right), \tilde{v}_{fj}\right|}{\max\limits_{j} \left|\max\left(\tilde{v}_{gj}, \tilde{v}_{fj}\right), \tilde{v}_{fj}\right|} \tag{20}$$

Step 5: According to the concordance level, the value of the concordance matrix elements are evaluated. The concordance level $\overline{C} = \left(c^{l}, c^{m}, c^{u}\right)$ can be defined as the average of the elements in the concordance matrix represented by[8]:

$$c^{l} = \frac{\sum_{f=1}^{m}\sum_{g=1}^{m} C_{gf}^{l}}{m(m-1)}, c^{M} = \frac{\sum_{f=1}^{m}\sum_{g=1}^{m} C_{gf}^{M}}{m(m-1)}, c^{u} = \frac{\sum_{f=1}^{m}\sum_{g=1}^{m} C_{gf}^{u}}{m(m-1)} \tag{21}$$

Step 6: Boolean matrix B is formed according to the minimum concordance level $\tilde{\tilde{C}}$ as:

$$B = \begin{matrix} - & \cdots & b_{lf} & \cdots & b_{1m} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ b_{g1} & \cdots & b_{gf} & \cdots & b_{gm} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ b_{m1} & \cdots & b_{mf} & \cdots & - \end{matrix} \quad (22)$$

$$\begin{cases} \tilde{c}_{gf} \geq \tilde{\tilde{c}} \Leftrightarrow b_{gf} = 1 \\ \tilde{c}_{gf} \leq \tilde{\tilde{c}} \Leftrightarrow b_{gf} = 0 \end{cases} \quad (23)$$

Step 7: The elements of the discordance matrix are measured by a discordance level. The discordance level $\bar{d} = \left(d^l, d^m, d^u\right)$ can be defined as the average of the elements in the discordance matrix represented by:

$$d^l = \frac{\sum_{f=1}^{m}\sum_{g=1}^{m} d_{gf}^l}{m(m-1)}, d^M = \frac{\sum_{f=1}^{m}\sum_{g=1}^{m} d_{gf}^M}{m(m-1)}, d^u = \frac{\sum_{f=1}^{m}\sum_{g=1}^{m} d_{gf}^u}{m(m-1)} \quad (24)$$

Step 8: Boolean matrix H is measured by a minimum discordance level

$$H = \begin{matrix} - & \cdots & h_{lf} & \cdots & h_{1m} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ h_{g1} & \cdots & h_{gf} & \cdots & h_{gm} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ h_{m1} & \cdots & h_{mf} & \cdots & - \end{matrix} \quad (26)$$

$$\begin{cases} d_{gf} \leq \bar{d} \Leftrightarrow d_{gf} = 1 \\ d_{gf} \geq \bar{d} \Leftrightarrow b_{gf} = 0 \end{cases} \quad (27)$$

Step 9: The global matrix G is calculated by peer to peer multiplication of the elements of the matrices B and H by $G = B \oplus H$

Step 10: Choosing the best alternative. For that, at first the elements of the global matrix G which contains 1, is selected. Then the location of that element is found. "The row dominates the column" this method is used to select, which supplier dominates. By this finally the best supplier is selected.

4. Problem Formulation

In this study, the selection of the best supplier is done for a shoe industry in Bangladesh. There are 5 suppliers, three experts are available. The experts considered transportation cost, lead time, quality, flexibility, reliability and adaptation of new technology as the selection criteria shown in Figure 3.

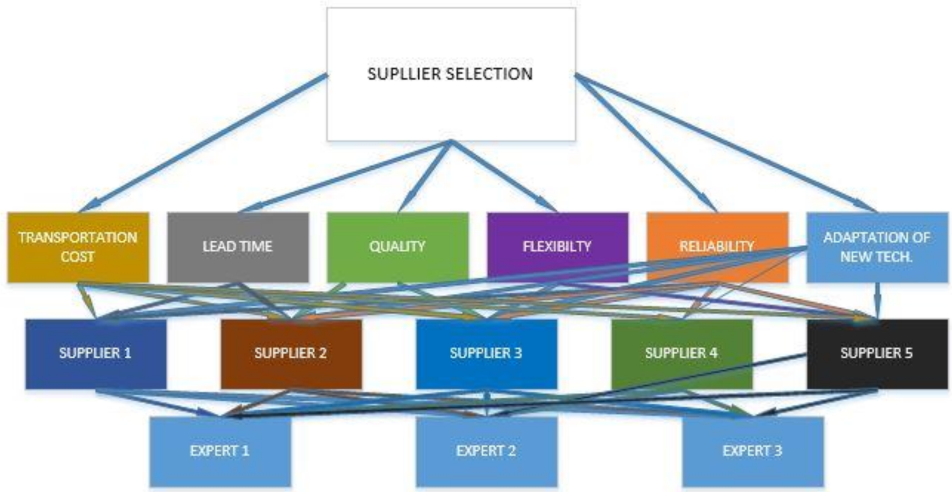

Figure 3: Hierarchy of the Supplier Selection Problem

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 in **Table 2**. In the next step, the decision makers performed an assessment of the alternative suppliers with the help of linguistic variables in **Table 3** according to the decision criteria in the manner specified in **Table 4**, **5** and **6** were formed through the conversion of the linguistic assessments belonging to the three decision makers in **Table 2** and in **Table 5** into triangular fuzzy numbers. The weights of the criterion are given in **Table 7**. The fuzzy decision matrix shown in **Table 8** was normalized with the help of equation (4) and a normalized 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 (di+) values of each of the alternative supplier firms was calculated using equation (10) and the values of their distance from the fuzzy negative ideal solution (di–) were calculated with equation (11). Afterwards the closeness index was calculated for each alternative with equation (15) by using the values of di+ and di–. These calculations are presented in **Table 11**, **12** and **13.** Taking the alternatives' closeness index values into consideration, the alternative supplier firms were enumerated as S4>S1>S5>S3>S2 from the most appropriate to the least appropriate.

Table 1: Linguistic variables for the importance weight of each criterion

Linguistic variables	Triangular fuzzy 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)	(0.7,0.9,1)
Very High (VH)	(0.9,1,1)

Table 2: Assesment results of the decision makers regarding the decision criteria

Criteria	Experts		
	E1	E2	E3
Quality	H	H	MH
Lead time	H	H	H
Transportation Cost	VH	H	MH
Flexibility	ML	M	M
Reliability	M	ML	M
Adaptation of New Technology	ML	ML	L

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	Suppliers	Experts		
		E1	E1	E1
Quality	S1	G	VG	G
	S2	MG	MG	MP
	S3	G	G	G
	S4	G	MP	G
	S5	VG	G	MG
Lead time	S1	MG	G	G
	S2	MG	MP	MG
	S3	G	VG	MG
	S4	VG	G	G
	S5	MP	G	MG
Transportation Cost	S1	G	P	F
	S2	G	F	VG
	S3	MG	MG	MP
	S4	G	VG	F
	S5	G	MG	MG
Flexibility	S1	G	VG	MP
	S2	MG	F	P
	S3	VG	MG	P
	S4	G	G	MG
	S5	MG	G	F
Reliability	S1	G	G	G
	S2	MG	MG	MP
	S3	G	VG	G
	S4	MG	G	F
	S5	F	G	G
Adaptation of New Technology	S1	P	MP	P
	S2	P	MP	P
	S3	P	P	MP
	S4	F	MP	P
	S5	F	F	MG

Table 5: Expression of criteria assessment results as fuzzy number

Criteria	Experts		
	E1	E2	E3
Quality	(0.7,0.9,1)	(0.7,0.9,1)	(0.5,0.7,0.9)
Lead time	(0.7,0.9,1)	(0.7,0.9,1)	(0.7,0.9,1)
Transportation 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)
Reliability	(0.3,0.5,0.7)	(0.1,0.3,0.5)	(0.3,0.5,0.7)
Adaptation of New Technology	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(0,0.1,0.3)

Table 6: Expression of alternative assessment results as fuzzy numbers

Criteria	Suppliers	Experts		
		E1	E1	E1
Quality	S1	(7,9,10)	(9,10,10)	(7,9,10)
	S2	(5,7,9)	(5,7,9)	(1,3,5)
	S3	(7,9,10)	(7,9,10)	(7,9,10)
	S4	(7,9,10)	(1,3,5)	(7,9,10)
	S5	(9,10,10)	(7,9,10)	(5,7,9)
Lead time	S1	(5,7,9)	(7,9,10)	(7,9,10)
	S2	(5,7,9)	(1,3,5)	(5,7,9)
	S3	(7,9,10)	(9,10,10)	(5,7,9)
	S4	(9,10,10)	(7,9,10)	(7,9,10)
	S5	(1,3,5)	(7,9,10)	(5,7,9)
Transportation Cost	S1	(7,9,10)	(0,1,3)	(3,5,7)
	S2	(7,9,10)	(3,5,7)	(9,10,10)
	S3	(5,7,9)	(5,7,9)	(1,3,5)
	S4	(7,9,10)	(9,10,10)	(3,5,7)
	S5	(7,9,10)	(5,7,9)	(5,7,9)
Flexibility	S1	(7,9,10)	(9,10,10)	(1,3,5)
	S2	(5,7,9)	(3,5,7)	(0,1,3)
	S3	(9,10,10)	(5,7,9)	(0,1,3)
	S4	(7,9,10)	(7,9,10)	(5,7,9)
	S5	(5,7,9)	(7,9,10)	(3,5,7)
Reliability	S1	(7,9,10)	(7,9,10)	(7,9,10)
	S2	(5,7,9)	(5,7,9)	(1,3,5)
	S3	(7,9,10)	(9,10,10)	(7,9,10)
	S4	(5,7,9)	(7,9,10)	(3,5,7)
	S5	(3,5,7)	(7,9,10)	(7,9,10)
Adaptation of New Technology	S1	(0,1,3)	(1,3,5)	(0,1,3)
	S2	(0,1,3)	(1,3,5)	(0,1,3)
	S3	(0,1,3)	(0,1,3)	(1,3,5)
	S4	(3,5,7)	(1,3,5)	(0,1,3)
	S5	(3,5,7)	(3,5,7)	(5,7,9)

Table 7: Weights of the criteria

Criteria	Weights
Quality	(0.633, 0.833, 0.967)
Lead time	(0.700, 0.900, 1.000)
Transportation cost	(0.700, 0.867, 0.967)
Flexibility	(0.233, 0.433, 0.633)
Reliability	(0.233, 0.433, 0.633)
Adaptation of New Technology	(.0667,0.233,0.433)

Table 8: Fuzzy numbers of the aggregated ratings of the alternative suppliers

Suppliers	Quality	Lead time	Transportation Cost	Flexibility	Reliability	Adaptation of New Technology
S1	(7.7,9.3,10)	(6.3,8.3,9.7)	(3.3, 5, 6.7)	(5.7,7.3,8.3)	(7,9,10)	(0.3,1.7,3.7)
S2	(3.7,5.7,7.7)	(3.7,5.7,7.7)	(6.3, 8, 9)	(2.7,4.3,6.3)	(4.7,5.7,7.7)	(0.3,1.7,3.7)
S3	(7,9,10)	(7, 8.7, 9.7)	(3.7, 5.7, 6.3)	(4.7, 6, 7.3)	(7.7,9.3,10)	(0.3,1.7,3.7)
S4	(5,7,8.3)	(7.7,9.4,10)	(6.3,8,9)	(6.3,7.7,9.7)	(5,7,8.7)	(1.3,3,5)
S5	(7,8.7,9.7)	(4.3,6.3,8)	(5.7,7.7,9.3)	(5,7,8.7)	(5.7,7.7,9)	(3.7,5.7,7.7)

Table 9: Normalized fuzzy decision matrix

Suppliers	Quality	Lead time	Transportation Cost	Flexibility	Reliability	Adaptation of New Technology
S1	(0.77,0.93,1)	(0.63, 0.83,0.97)	(0.35,0.54, 0.72)	(0.59,0.75,0.86)	(0.7,0.9,1)	(0.04,0.22,0.48)
S2	(0.37,0.57,0.77)	(0.37,0.57,0.77)	(0.67,0.86,0.97)	(0.28,0.44,0.65)	(0.47,0.57,0.77)	(0.04,0.22,0.48)
S3	(0.7,0.9, 1)	(0.7,0.87, 0.97)	(0.4, 0.61,0.68)	(0.49,0.62,0.76)	(0.77,0.93,1)	(0.04,0.22,0.48)
S4	(0.5,0.7, 0.83)	(0.77,0.94,1)	(0.68,0.87,0.97)	(0.65,0.8,1)	(0.5,0.7,0.87)	(0.17,0.39,0.65)
S5	(0.7,0.87,0.97)	(0.43,0.63,0.8)	(0.61,0.83,1)	(0.52,0.72,0.9)	(0.57,0.77,0.9)	(0.48,0.74,1)

Table 10: Weighted normalized fuzzy decision matrix

Suppliers	Quality	Lead time	Transportation Cost	Flexibility	Reliability	Adaptation of New Technology
S1	(0.49,0.78,0.97)	(0.44,0.75,0.97)	(0.25,0.47,0.7)	(0.14,0.32, 0.54)	(0.16,0.39,0.63)	(0.002,0.05,0.2)
S2	(0.23,0.48,0.75)	(0.26, 0.51,0.77)	(0.45,0.75,0.94)	(0.06,0.19, 0.41)	(0.11,0.25,0.49)	(0.002,0.05,0.2)
S3	(0.44,0.75,0.97)	(0.49,0.78, 0.97)	(0.28,0.53,0.66)	(0.11,0.27, 0.48)	(0.18,0.4,0.63)	(0.002,0.05,0.2)
S4	(0.32,0.59,0.8)	(0.54,0.85,1)	(0.48,0.75,0.94)	(0.15,0.35, 0.63)	(0.12,0.3,0.55)	(0.01,0.09,0.28)
S5	(0.44,0.72,0.93)	(0.3,0.57, 0.8)	(0.43,0.72,.97)	(0.12,0.31, 0.57)	(0.13,0.33,0.57)	(0.03,0.17,0.43)

Table 11: Distances of the ratings of each alternative from $\tilde{S}^+$ with respect to each criterion

	Quality	Lead time	Transportation Cost	Flexibility	Reliability	Adaptation of New Technology	d_i^+
D(S1,$\tilde{S}^+$)	0.32	0.35	0.56	0.69	0.64	0.92	3.476
D(S2,$\tilde{S}^+$)	0.56	0.53	0.35	0.79	0.73	0.98	3.945
D(S3,$\tilde{S}^+$)	0.35	0.32	0.53	0.73	0.62	0.92	3.483
D(S4,$\tilde{S}^+$)	0.47	0.28	0.33	0.65	0.70	0.88	3.321
D(S5,$\tilde{S}^+$)	0.36	0.49	0.37	0.69	0.68	0.81	3.399

Table 12: Distances of the ratings of each alternative from $\tilde{S}^-$ with respect to each criterion

	Quality	Lead time	Transportation Cost	Flexibility	Reliability	Adaptation of New Technology	d_i^-
D(S1,$\tilde{S}^-$)	0.77	0.75	0.51	0.37	0.44	0.12	2.452
D(S2,$\tilde{S}^-$)	0.53	0.55	0.74	0.26	0.32	0.03	1.701
D(S3,$\tilde{S}^-$)	0.75	0.77	0.51	0.32	0.44	0.12	2.411
D(S4,$\tilde{S}^-$)	0.60	0.82	0.75	0.43	0.37	0.17	2.385
D(S5,$\tilde{S}^-$)	0.73	0.59	0.74	0.38	0.39	0.27	2.354

Table 13: Ranking of alternative suppliers according to Fuzzy TOPSIS

Suppliers	c_i	Rank
S1	0.4137	2nd
S2	0.3012	5th
S3	0.4091	4th
S4	**0.4181**	**1st**
S5	0.4092	3rd

So, S4 is the best suppliers according to the FUZZY TOPSIS method.

Table 14: The concordance matrix

	S1	S2	S3	S4	S5
S1	(0,0,0)	(1.87,2.83,3.67)	(0.93,1.5,4.63)	(0.7,1.27,0.63)	(1.6,2.6,2.6)
S2	(0.77,1.1,1.4)	(0,0,0)	(0.77,1.1,1.4)	(0,0.87,0.97)	(0.7,0.87,0)
S3	(1.70,2.43,3.03)	(1.87,3.03,3.67)	(0,0,0)	(0.87,1.27,1.6)	(1.57,2.17,2.6)
S4	(1.69,2.53,3.03)	(2.57,3.7,4.63)	(1.7,3.26,3.03)	(0,0,0)	(1.63,2.2,1.64)
S5	(0.77,1.1,2.03)	(1.87,2.83,4.63)	(1.63,1.1,2.03)	(0.93,1.5,3)	(0,0,0)
Sum	(4.93,7.17,9.5)	(8.16,12.39,16.6)	(5.03,6.9,11.1)	(2.5,4.9,6.2)	(5.5,7.83,6.83)

From **Table 14**, we find the value of $\bar{c}$ = (1.30624, 1.9628, 2.51145)

Table 15: The discordance matrix

	S1	S2	S3	S4	S5
S1	(0,0,0)	(0.77,0.933,1)	(1,1,1)	(1,1,1)	(1,1,1)
S2	(1,0.86,0.92)	(0,0,0)	(1,1,0.79)	(1,1,1)	(1,1,1)
S3	(1,0.83,1)	(0.74,0.81,1)	(0,0,0)	(0.41,1,1)	(0.79,0.91,1)
S4	(0.74,0.68,0.71)	(1,1,1)	(1,0.72,0.61)	(0,0,0)	(0.5,0.46,0.75)
S5	(0.78,0.72,0.63)	(0.096,0.13,1)	(1,1,0.55)	(1,1,1.53)	(0,0,0)
Sum	(3.52,3.09,3.25)	(2.61,2.87,3)	(4,3.72,2.94)	(3.42,4,4.54)	(3.29,3.37,3.75)

From **Table 15** we find the value of $\bar{d}$ = (0.841332393, 0.852925806, 0.92421677)

Table 16: Boolean matrix based on the Minimum concordance level

	S1	S2	S3	S4	S5
S1	0	1	0	0	1
S2	0	0	0	0	0
S3	1	1	0	0	1
S4	1	1	1	0	0
S5	0	1	0	0	0

Table 17: Boolean matrix based on the Minimum discordance level

	S1	S2	S3	S4	S5
S1	0	0	1	1	1
S2	1	0	1	1	1
S3	1	1	0	0	1
S4	0	1	0	0	0
S5	0	0	0	1	0

Table 18: The global matrix

	S1	S2	S3	S4	S5
S1	0	0	0	0	1
S2	0	0	0	0	0
S3	1	1	0	0	1
S4	0	1	0	0	0
S5	0	0	0	0	0

In case of the ELECTRE method the concordance matrix is found by equations (16), (18) and (19) and it is shown in **Table 14.** Then the discordance matrix is found by equation (16), (18) and (19) and it is shown in **Table 15.** After finding the minimum discordance & concordance level from equations (22) and (25), the Boolean matrix is formed in **Tables 16** and **Table 17** with the help of equations

(23), (24), (26) and (27). So, from **Table 18** it is seen that S1>S5, S3>S1, S3>S2, S3>S5, S4>S2. Therefore, the rank will be like S3>S1>S5>S4>S2 or S3>S4>S2>S1>S5.

5. Conclusion

Every company wants to deal with suppliers that are flexible in the event of demand changes and appropriate in cost terms. In this paper, fuzzy TOPSIS and fuzzy ELECTRE method was used in a study of selection of the suppliers of a shoe industry. It is shown that this method can be effectively utilized in the supplier selection process in a real industrial case that enables decision makers to rank their alternative suppliers. On the other hand the real world decision making problems are taking place in a complex environment, where uncertain and imprecise knowledge has to be considered. Therefore, in future studies other multi decision criteria and other kinds of fuzzy numbers could be used for other selection problems.

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