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Green Supplier selection for plastic industry using integrated model based on Pythagorean fuzzy AHP and fuzzy TOPSIS

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ABSTRACT

Purpose –Supply Chain Management (SCM) has emerged in recent years and is now increasing in popularity. It aims to reduce production costs, maximize earnings, improve customer relations, improve inventory management and increase customer satisfaction. Reducing total cost of procurement is one of the most important parameters in aligning the objectives of partners in a supply network.

Design/methodology/approach – This paper proposed Pythagorean Fuzzy Analytic Hierarchy Process (PFAHP) and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) integrated model for green supplier selection for plastic industry. In the first phase of the study, the parameters to be used in selecting suppliers are determined. Then, by making pairwise comparisons, the weights of these parameters are determined with PFAHP method. Finally, the supplier that is most suitable for 3 suppliers is determined using the FTOPSIS method.

Findings – Among the criteria evaluated by 5 experts, the most important criteria, the parameters of the Inspection methods and management and organizations are determined as the most important parameters respectively. The supplier no. 3 has been identified as the most suitable supplier.

Discussion –The case study is performed under a fuzzy environment to reduce uncertainty and vagueness, and linguistic variables parameterized by interval-valued Pythagorean and triangular fuzzy numbers are used. Through the case study, 8 main and 45 sub-criteria supplier selection evaluation criteria used to assess 3 suppliers by FTOPSIS. However, our study has some disadvantages and possible further work is recommended. Other possible different fuzzy sets can be used in the projected method.

1. Introduction

Supply Chain Management (SCM) has emerged in recent years and is now increasing in popularity. Academic and industrial fields are interested in SCM. SCM's primary goal is to reduce supply chain (SC) risk. It is also a goal of the SCM to reduce production costs, maximize earnings, improve customer relations, improve inventory management and increase customer satisfaction (Chou and Chang, 2008; Ha and Krishnan, 2008). Supplier selection decisions can be made at different phases of the life sequence of a product, in the case of multiple suppliers. (Bai and Sarkis, 2010). Effective supplier selection plays a vital role in the success of businesses, especially in today's competitive environment. Careful consideration of suppliers by decision makers is one of the most challenging stages of the decision-making process, as there are a number of conflicting goals to consider (Liu and Hai, 2005). Manufacturing industries should work with different suppliers to ensure that their activities continue in a healthy manner (Ghodsypour and O'Brien, 1998).

Reducing total cost of procurement is one of the most important parameters in aligning the objectives of partners in a supply network. Nowadays the social and environmental effects of business activities and employees' health have become as important as the profits of business owners. The environmental and social

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impacts of commercial activities have become publicly monitored. The integration of ecological, economic and social concerns into business decisions that promote sustainable development has become a major strategic activity for many global industries (Moheb-Alizadeh and Handfield, 2017; Lee, 2009). Sustainable SCM deals with the coordination of companies throughout the supplier chain, as well as the management of materials, meeting the needs of customers and stakeholders (Seuring, and Müller 2008).

Many supplier selection approach in the literature are concerned with the benefits that can be gained from the selection of supplier (Lee, 2009). In fact, the cost and risks involved in choosing suppliers should be addressed more extensively. There are many studies that include conventional criteria, but green suppliers and environmental criteria are very limited in the literature. For this reason, the primary objective of this approach is to offer a green supplier model selection including environmental and economic criteria.

Many of the problems based on human evaluation are uncertain and it is hard to decide to determine exact numerical values. For this reason, evaluations of the suppliers based on the determined criteria are usually expressed linguistically by the decision-makers. Furthermore, it is also recognized that human judgment is always subjective and thus imprecise. The use of fuzzy logic is thought to give more favorable results in solving problems where decision makers have uncertain linguistic expressions.

This study aims to determine the most suitable supplier for plastic injection production in case there are conflicting objectives. Environmental criteria for materials in plastics production should be evaluated together with other criteria such as quality and cost. In addition, environmental criteria such as employee rights and work safety must be included in the decision-making model. The selection process should be adopted as a multi-criteria approach since some criteria in the supplier selection conflict with each other. In this study, 8 main and 45 sub-criteria were identified which play an important role in supplier selection. Experts in the field were compared these criteria using linguistic expressions. PFAHP was used to determine the criterion weights. Pythagorean fuzzy sets are an expansion of intuitionistic fuzzy sets. Pythagoras fuzzy sets are allowed the decision makers to express opinion about uncertainty and ideas about real-world problems more freely in MCDM problems. Potential 3 suppliers were rated linguistically by the FTOPSIS method. In the FTOPSIS method, the weights obtained by the PFAHP method were used.

2. Literature Review

2.1. Supplier selection

There are many studies in the literature related to supplier selection and evaluation. This current literature shows how the firm selection process affects firm operations. Some studies that do not include the Green and Environmental assessment parameters can be listed as follows.

Akarte et al. (2001) developed a web AHP origin decision making model for the supplier selection of casting enterprises. In this model, 18 criteria were determined. Suppliers were required to record and enter the raw specifications. To evaluate the suppliers, decision makers had to determine the relative importance weights Muralidharan et al. (2002) have identified 9 evaluation criteria. Using these criteria, they proposed a 5-step AHP-based model. During the linguistic evaluation of the criteria, the purchasing, warehouse and quality control experts of the business were assigned. Chan (2003) proposed the AHP model to help decision makers in supplier selection. The AHP method was used using 6 main criteria and 20 sub-criteria criteria. These evaluations were based on customer requirements. A different supplier choosing system for selecting suppliers which has its roots on AHP is proposed by Hou and Su (2007). Internal and external influences are considered when criteria are set. It was targeted to meet the needs of the market. Kahraman et al. (2003) and Chan and Kumar (2007) have proposed fuzzy AHP (FAHP) model for supplier selection for white goods manufacturers. The decision makers evaluated the criteria using linguistic expressions. Jain et al. (2018) proposed a decision support system using a combination of FAHP and TOPSIS methods for use in the Indian automotive industry. The weights of the parameters were computed by the FAHP method. Suppliers were rated by the TOPSIS method. Then the consistency of the results was tested. Awasthi et. get. (2018) proposed a sustainable supplier system using a combination of FAHP and Viekriterijumsko kompromisno rangiranje (VIKOR) methods. The study was designed as two parts. In the first part, FAHP was used to determine the weights. In the second part, the best suppliers are determined by the weights obtained and

VIKOR method. Kumar and Dash (2018) uses fuzzy Delphi and AHP-DEMATEL methods to optimize the decision support systems of automobile manufacturing factories.

Supply chain management, which takes environmental and green criteria into consideration, has become important in recent years. Some work has been listed in this area. Recently, many methods for green supplier selection have been developed.

2.2. Green supplier selection

Noci (1997) designed green supplier evaluation system with using 4 green and environmental criteria using AHP. Enarsson (1998) proposed a quality improvement approach that takes environmental criteria into consideration using the Ishikawa fishbone diagram Walton, et al. (1998) suggested using a flow chart to determine proper methods and criteria for green supplier evaluation and selection. Handfield et.al. (2002) proposed a supplier assessment system using the AHP method, considering the green and environmental criteria. Lee et al. (2009) proposed a decision support system using the AHP method which considers the environmental problem and green supplier criteria in order to be used in the high-tech sector. Tsai and Huang (2009) used goal programming to optimize costs and value chain structure and proposed a procurement management model with green criteria. Zhu et al. (2010) has proposed a portfolio-based analytical method to improve the performance of green supplier management. Bai and Sarkis (2010) proposed a green supplier selection model using a rough set. Kuo et. al. (2010) proposed a model of green supplier selection using artificial neural networks and MADA methods. Zhu and Geng (2001) examined supply selection models using green and environmental criteria in large and medium-sized public enterprises in China. Handfield et al. (2002) used the AHP method to assess the relative importance of various environmental criteria. Hsu and Hu (2009) used the Analytic Network Process (ANP) method to select green suppliers. Suggesting that ANP could give more realistic results when choosing suppliers. Zouggari and Benyoucef (2012) offer a new model for group multi-criteria supplier selection problems using FAHP and FTOPSIS methods together. The proposed model can be easily modified by decision makers when needed. Kannan et al. (2013) used the integrated approach of FAHP, FTOPSIS and fuzzy linear programming in green supplier selection problems. They suggested that the proposed model evaluates suppliers according to qualitative and quantitative criteria. Denizhan et. al. (2017) compared green supplier selection and classic supplier selection methodologies. Supplier selection activities of the companies in eastern Turkey are evaluated. Green supplier selection criteria are determined using Fuzzy AHP method. It has been suggested that the results obtained with the green criterion and the choice of classic supplier are different. Çalık (2018) proposed type-2 FAHP and fuzzy linear programming combined model for asses to appropriate green supplier. Tayali (2017) aims to determine green supplier by weighted aggregated sum product Assessment method (WASPAS) to support the decision-making process of the enterprises by considering the interaction between supplier alternatives and the criteria affecting supplier selection.

The green supply chain did not provide consensus on all researchers (Ahi and Searcy, 2013). However, many researchers agree that businesses should be greener (Marcus and Fremeth, 2009). The green supply chain can be specify as the coordination of activities such as material management, information sharing, capital flow and cooperation, with the aim of minimizing the environmental impact of its operations by considering the financial interests of the company (Seuring and Müller, 2008).

Supplier selection is one of the most impactful elements that ensures that supply chain is sustainable and that the other operations of the enterprise are maintained (Kumar et al., 2014). A sustainable supply chain should include green and environmental criteria as well as economic targets (Ageron et al., 2012). In addition, the success of the sustainability-focused supply chain depends directly on the selection and selection of appropriate suppliers (Hsu et al., 2013). In general, decision makers take into consideration criteria such as quality, flexibility and price. But, when included in the green and environmental criteria, the supplier determination process becomes more complex. However, these criteria must be taken into consideration in recent years (Brandenburg et al., 2014, Azadi et al. 2015) The primary objective of the green supplier selection is to minimize pollution and other environmental effect and to recognize suppliers' environmental concerns and to help suppliers to resolve these problems to encourage improvements (Tseng, 2011; Lu et al., 2007).

3. Methodology

3.1. Pythagorean fuzzy sets

Intuitionistic fuzzy sets are developed by Atanasov (1986). It has been used to express ambiguity in many real applications. These sets can be expressed in terms of membership functions, non-membership function and hesitancy degree. However, if the degree of membership and non-membership is greater than 1, Intuitionistic fuzzy set fails to express uncertainty. To overcome this weakness Yager (2014) proposed Pythagorean fuzzy sets. This set is an improved version of the intuitionistic fuzzy set. In many cases it expresses the uncertainty of real world problems more clearly (Oz et. al., 2018; Ilbahar et al., 2018; Gul, 2018; Ak and Gul, 2018; Yucesan and Kahraman, 2019).

Differently from the intuitionistic fuzzy sets, the entirety of membership and non-membership degrees may exceed 1 but the totality of squares cannot in Pythagorean fuzzy sets, (Ilbahar et al. 2018; Zeng et al. 2015; Zhang and Xu, 2014; Mete, 2018). This event is shown below in Definition (1).

Definition 1:. A Pythagorean fuzzy set P is an object having the procedure (Zhang and Xu, 2014):

$$P = \{< x,\ P(\mu_P(x), v_P(x)) > \mid x \in X\} \tag{1}$$

where $\mu_P(x): X \mapsto [0,1]$ shows the degree of membership and $v_P(x): X \mapsto [0,1]$ shows the degree of non-membership of the element $x \in X$ to P, respectively, and, for every $x \in X$, it holds:

$$0 \le \mu_P(x)^2 + v_P(x)^2 \le 1 \tag{2}$$

Definition 2: Let $\beta_1 = P(\mu_{\beta_1}, v_{\beta_1})$ and $\beta_2 = P(\mu_{\beta_2}, v_{\beta_2})$ be two Pythagorean fuzzy numbers, and $\lambda > 0$, then the operations on these two Pythagorean fuzzy numbers are defined as follows (Zeng et al. 2015; Zhang and Xu, 2014):

$$\beta_1 \oplus \beta_2 = P(\sqrt{\mu_{\beta_1}{}^2 + \mu_{\beta_2}{}^2 - \mu_{\beta_1}{}^2 \mu_{\beta_2}{}^2},\ v_{\beta_1} v_{\beta_2}) \tag{3}$$

$$\beta_1 \otimes \beta_2 = P(\mu_{\beta_1} \mu_{\beta_2},\ \sqrt{v_{\beta_1}{}^2 + v_{\beta_2}{}^2 - v_{\beta_1}{}^2 v_{\beta_2}{}^2}) \tag{4}$$

$$\lambda \beta_1 = P(\sqrt{1-(1-\mu_{\beta_1}{}^2)^{\lambda}}, (v_{\beta_1})^{\lambda}),\ \lambda > 0 \tag{5}$$

$$\beta_1^{\lambda} = P((\mu_{\beta_1})^{\lambda}, \sqrt{1-(1-v_{\beta_1}{}^2)^{\lambda}}),\ \lambda > 0 \tag{6}$$

3.2. PFAHP and related linguistic terms

AHP method is extensively used multi-criteria decision-making problems (Perçin and Ayan, 2015). PFAHP is extension of AHP designed to express the real case issues more properly. This method is explained in following stages.

Step 1: The formula of compromised pairwise comparison matrix $A = (a_{ik})_{mxm}$ depends on linguistic assessment of experts using a ruler projected by (Ilbahar et al. 2018) in Table 1.

Table 1 Weighting scale for PAHP (Ilbahar et al. 2018)

Linguistic term	Pythagorean fuzzy numbers			
	μ_L	μ_U	v_L	v_U
Certainly low important (CLI)	0.00	0.00	0.90	1.00
Very low important (VLI)	0.10	0.20	0.80	0.90
Low important (LI)	0.20	0.35	0.65	0.80
Below average important (BAI)	0.35	0.45	0.55	0.65
Average important (AI)	0.45	0.55	0.45	0.55
Above average important (AAI)	0.55	0.65	0.35	0.45
High important (HI)	0.65	0.80	0.20	0.35
Very high important (VHI)	0.80	0.90	0.10	0.20
Certainly high important (CHI)	0.90	1.00	0.00	0.00
Exactly equal (EE)	0.1965	0.1965	0.1965	0.1965

Step 2: The difference matrices $D=(d_{ik})_{mxm}$ are calculated using Eqs. (7) and (8):

$$d_{ik_L} = \mu_{ik_L}^2 - v_{ik_U}^2 \tag{7}$$

$$d_{ik_U} = \mu_{ik_U}^2 - v_{ik_L}^2 \tag{8}$$

Step 3: Interval multiplicative matrix $S=(s_{ik})_{mxm}$ is computed using Eqs. (9) and (10):

$$s_{ik_L} = \sqrt{1000^{d_L}} \tag{9}$$

$$s_{ik_U} = \sqrt{1000^{d_U}} \tag{10}$$

Step 4: The determinacy value $\tau=(\tau_{ik})_{mxm}$ is calculated using Eq. (11):

$$\tau_{ik} = 1-(\mu_{ik_U}^2 - \mu_{ik_L}^2)-(v_{ik_U}^2 - v_{ik_L}^2) \tag{11}$$

Step 5: The determinacy degrees are multiplied with $S=(s_{ik})_{mxm}$ matrix for obtaining the matrix of weights, $T=(t_{ik})_{mxm}$ before normalization using Eq. (12).

$$t_{ik} = (\frac{s_{ik_L}+s_{ik_U}}{2})\tau_{ik} \tag{12}$$

Step 6: The normalized priority weights w_i is computed via using Eq. (13).

$$w_i = \frac{\sum_{k=1}^{m} t_{ik}}{\sum_{i=1}^{m}\sum_{k=1}^{m} t_{ik}} \tag{13}$$

3.3. Fuzzy TOPSIS

Hwang and Yoon (1981) offers TOPSIS in order to find out the best alternative respect to the compromise solution concept. The compromise solution concept is way to select the smallest and the farthest distance from a negative ideal solution. Since the ratings while evaluating alternatives against criteria usually refer to the subjective uncertainty, TOPSIS is extended to consider the situation of fuzzy numbers (Tzeng and Huang, 2011; Celik et al. 2012). It was followed by the procedure of the Chen's (2000) FTOPSIS method in the case study of this work for the hazard prioritization aim. The steps are as in the following (Tzeng and Huang, 2011; Gul and Guneri, 2018; Carpitella et al. 2018):

Step 1: Alternative scores according to each parameter. The evaluation by the K number of experts and the following formula is calculated: $\tilde{x}_{ij} = \frac{1}{K}[\tilde{x}_{ij}^1(+)\tilde{x}_{ij}^2(+)....(+)\tilde{x}_{ij}^K]$ While $A=\{A_i \mid i=1,....,m\}$ demonstrations the set of alternatives, $C=\{C_j \mid j=1,....,n\}$ represent the criteria set. Where $X=\{X_{ij} \mid i=1,....,m; j=1,....,n\}$ denotes the set of fuzzy ratings and $\tilde{W}=\{\tilde{w}_j \mid j=1,....,n\}$ is the set of fuzzy weights. The linguistic variables are described by trapezoidal fuzzy number as follows: $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}, d_{ij})$. Tables 2 shows the linguistic terms (Samantra et al. 2017).

Table 2 Five-point fuzzy linguistic scale

Linguistic term	Corresponding fuzzy number
Very high (VH)	(0.7,0.8,0.9,1)
High (H)	(0.5,0.6,0.7,0.8)
Moderate (M)	(0.3,0.4,0.5,0.6)
Low (L)	(0.1,0.2,0.3,0.4)
Very low (VL)	(0,0.1,0.2,0.3)

Step 2: Normalized ratings are computed by Eq. (6).

$$\tilde{r}_{ij} = \begin{cases} \left(\dfrac{a_{ij}}{d_j^*}, \dfrac{b_{ij}}{d_j^*}, \dfrac{c_{ij}}{d_j^*}, \dfrac{d_{ij}}{d_j^*}\right), \text{ where } d_j^* = \max_i d_{ij} \text{ if } j \in \text{benefit criteria} \\ \left(\dfrac{a_j^-}{d_{ij}}, \dfrac{a_j^-}{c_{ij}}, \dfrac{a_j^-}{b_{ij}}, \dfrac{a_j^-}{a_{ij}}\right), \text{ where } a_j^- = \min_i a_{ij} \text{ if } j \in \text{cost criteria} \end{cases} \tag{14}$$

Step 3: Weighted normalized ratings are obtained by Eq. (7).

$$\tilde{v}_{ij} = w_j(x)\tilde{r}_{ij}, \quad i = 1, \ldots., m; \; j = 1, \ldots., n \tag{15}$$

Step 4: The fuzzy positive ideal point (FPIS, A*) and the negative ideal point (FNIS, A$^-$) are calculated with Eqs. (8-9). J$_1$ and J$_2$ are represent the benefit and the cost attributes, respectively.

$$\text{FPIS=A}^* = \{\tilde{v}_1^*, \tilde{v}_2^*, \ldots., \tilde{v}_n^*\} \text{ where } \tilde{v}_j^* = (1,1,1,1) \tag{16}$$

$$\text{FNIS=A}^- = \{\tilde{v}_1^-, \tilde{v}_2^-, \ldots., \tilde{v}_n^-\} \text{ where } \tilde{v}_j^- = (0,0,0,0) \tag{17}$$

Step 5: In this stage it involves finding the difference between FPIS and FNIS. Eqs (10-11) is used for this calculation.

$$\tilde{d}_i^* = \sqrt{\frac{1}{4}\sum_{j=1}^{n}[\tilde{v}_{ij} - \tilde{v}_j^*]^2}, \quad i = 1, \ldots., m \tag{18}$$

$$\tilde{d}_i^- = \sqrt{\frac{1}{4}\sum_{j=1}^{n}[\tilde{v}_{ij} - \tilde{v}_j^-]^2}, \quad i = 1, \ldots., m \tag{19}$$

Step 6: Then, the similarities to the ideal solution are calculated with Eq.(12).

$$C_i^* = \tilde{d}_j^- / (\tilde{d}_j^* + \tilde{d}_j^-), \quad i = 1, \ldots., m \tag{20}$$

4. Case study

Injection molding is one of the most common methods used in the production of plastic parts. Thanks to this method; complex, non-symmetric products can be produced. The injection method consists of 4 main stages. The production steps with plastic injection are shown in Figure 2. These stages are drying, blending and dosing, injection molding and regrinding, respectively (Madan et al.,2015; Yucesan et al., 2018).

In this respect, the quality of plastic injection production is directly related to the raw material selected. Therefore, to be successful in this sector, a good and sustainable supplier selection system is needed.

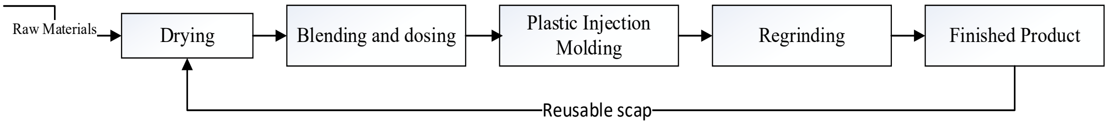

Figure 2. Stages of an injection molding facility

4.1. Steps of the proposed approach

The proposed model consists of 6 steps as shown in Figure 3. In the first phase of the study, the parameters to be used in selecting suppliers are determined. Then, by making pairwise comparisons, the weights of these parameters are determined with PFAHP method. After obtaining weights of the criteria, decision matrix will be completed. Finally, suppliers are evaluated by using FTOPSIS method.

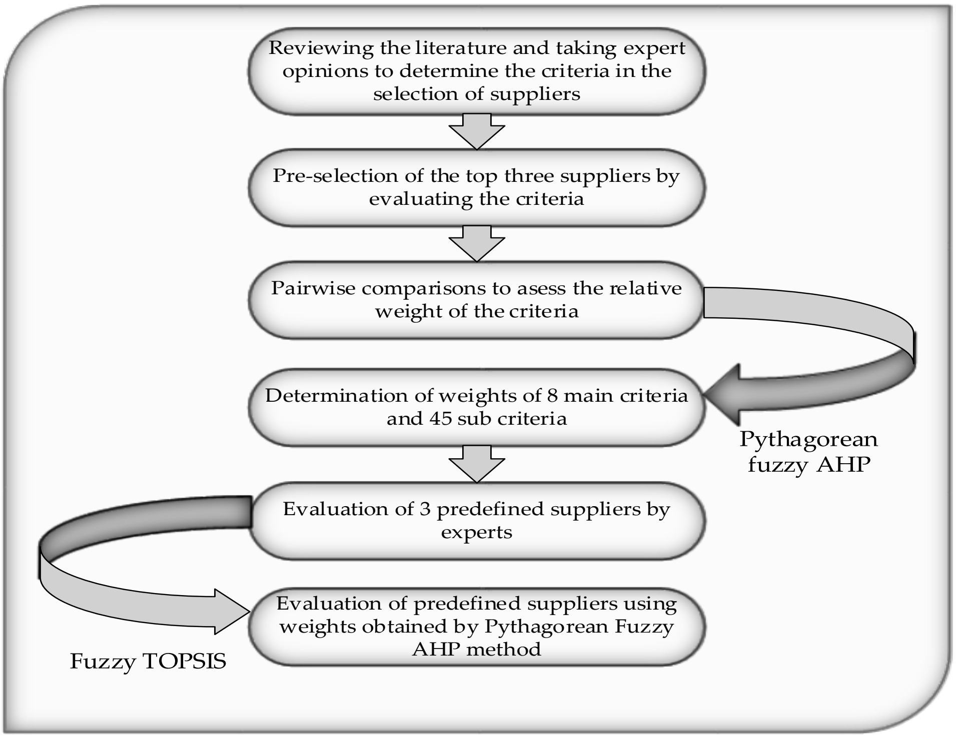

Figure 3. Green supplier selection stages

4.2. Linguistic scales and their corresponding fuzzy numbers

In this study, we benefited from two linguistic scales. First, we use the scale proposed by Ilbahar et al. (2018) in evaluating suppliers according to the main and the sub-criteria using pairwise comparison of PFAHP. That scale is based on Pythagorean fuzzy numbers (Table 1). Second, in evaluating suppliers with respect to the criteria using FTOPSIS, we apply the scale of Samantra et al. (2017). The prioritization of suppliers is performed by using five members' trapezoidal fuzzy linguistic scale (Table 2).

4.3. Weighting calculation using PFAHP

Eight main evaluation criteria including 45 sub-criteria are considered in this study to evaluate suppliers (Yucesan et al.,2018). Weighs for these 45 sub-criteria are obtained via FPAHP computations of 5 evaluators. 5 evaluators realized pairwise comparisons about the importance of weights of each evaluation criterion by using the linguistic expression defined in Table 1. At this stage, the linguistic expressions of the experts are transformed into fuzzy numbers. Since the evaluations of each expert were different, the averages of these evaluations are used. The aggregated compromised pairwise comparison matrix for the main criteria is presented in Table 4. The difference matrix D and interval multiplicative matrix S are also shown in Tables 5-6, respectively.

Table 4 Aggregated compromised pairwise comparison evaluation of experts in matrix form

C8	C7	C6	C5	C4	C3	C2	C1	
<0.33,0.42,0.56,0.67>	<0.29,0.36,0.6,0.71>	<0.13,0.2,0.76,0.87>	<0.19,0.29,0.69,0.81>	<0.65,0.76,0.24,0.33>	<0.25,0.33,0.65,0.75>	<0.08,0.14,0.8,0.92>	<0.1965,0.1965,0.1965,0.1965>	C1
<0.54,0.64,0.36,0.46>	<0.48,0.58,0.4,0.52>	<0.4,0.48,0.5,0.6>	<0.37,0.49,0.51,0.63>	<0.56,0.66,0.34,0.4>	<0.42,0.52,0.46,0.56>	<0.1965,0.1965,0.1965,0.1965>	<0.8,0.92,0.08,0.14>	C2
<0.74,0.84,0.16,0.2>	<0.67,0.78,0.22,0.29>	<0.54,0.65,0.35,0.44>	<0.64,0.76,0.24,0.32>	<0.72,0.83,0.17,0.24>	<0.1965,0.1965,0.1965,0.1965>	<0.46,0.56,0.42,0.52>	<0.65,0.75,0.25,0.33>	C3
<0.56,0.68,0.32,0.44>	<0.28,0.4,0.6,0.72>	<0.42,0.52,0.46,0.58>	<0.45,0.55,0.45,0.55>	<0.1965,0.1965,0.1965,0.1965>	<0.17,0.24,0.72,0.83>	<0.34,0.4,0.56,0.66>	<0.24,0.33,0.65,0.76>	C4
<0.64,0.77,0.23,0.34>	<0.79,0.9,0.1,0.19>	<0.46,0.59,0.41,0.54>	<0.1965,0.1965,0.1965,0.1965>	<0.45,0.55,0.45,0.55>	<0.24,0.32,0.64,0.76>	<0.51,0.63,0.37,0.49>	<0.69,0.81,0.19,0.29>	C5
<0.6,0.72,0.28,0.36>	<0.62,0.74,0.26,0.36>	<0.1965,0.1965,0.1965,0.1965>	<0.41,0.54,0.46,0.59>	<0.46,0.58,0.42,0.52>	<0.35,0.44,0.54,0.65>	<0.5,0.6,0.4,0.48>	<0.76,0.87,0.13,0.2>	C6
<0.43,0.51,0.47,0.55>	<0.1965,0.1965,0.1965,0.1965>	<0.26,0.36,0.62,0.74>	<0.1,0.19,0.79,0.9>	<0.6,0.72,0.28,0.4>	<0.22,0.29,0.67,0.78>	<0.4,0.52,0.48,0.58>	<0.6,0.71,0.29,0.36>	C7
<0.1965,0.1965,0.1965,0.1965>	<0.47,0.55,0.43,0.51>	<0.28,0.36,0.6,0.72>	<0.23,0.34,0.64,0.77>	<0.32,0.44,0.56,0.68>	<0.16,0.2,0.74,0.84>	<0.36,0.46,0.54,0.64>	<0.56,0.67,0.33,0.42>	C8

Table 5 The difference matrix

C8	C7	C6	C5	C4	C3	C2	C1	Main criteria
<-0.34,-0.1372>	<-0.42,-0.2304>	<-0.74,-0.5376>	<-0.62,-0.392>	<0.3136,0.52>	<-0.5,-0.3136>	<-0.840,-0.6204>	<0.000,0>	C1
<0.08,0.28>	<-0.04,0.1764>	<-0.2,-0.0196>	<-0.26,-0.02>	<0.1536,0.32>	<-0.1372,0.0588>	<0.000,0>	<0.634,0.84>	C2
<0.5076,0.68>	<0.3648,0.56>	<0.098,0.3>	<0.3072,0.52>	<0.4608,0.66>	<0,0>	<-0.059,0.1372>	<0.360,0.5>	C3
<0.12,0.36>	<-0.44,-0.2>	<-0.16,0.0588>	<-0.1,0.1>	<0,0>	<-0.66,-0.4608>	<-0.320,-0.1536>	<-0.365,-0.0.3136>	C4
<0.294,0.54>	<0.588,0.8>	<-0.08,0.18>	<0,0>	<-0.1,0.1>	<-0.52,-0.3072>	<0.020,0.26>	<0.440,0.62>	C5
<0.2304,0.44>	<0.2548,0.48>	<0,0>	<-0.18,0.08>	<-0.0588,0.16>	<-0.3,-0.098>	<0.020,0.2>	<0.561,0.74>	C6
<-0.1176,0.0392>	<0,0>	<-0.48,-0.2548>	<-0.8,-0.588>	<0.2,0.44>	<-0.56,-0.3648>	<-0.176,0.04>	<0.276,0.42>	C7
<0,0>	<-0.0392,0.1176>	<-0.44,-0.2304>	<-0.54,-0.294>	<-0.36,-0.12>	<-0.68,-0.5076>	<-0.280,-0.08>	<0.205,0.34>	C8

Table 6 The interval multiplicative matrix

C8	C7	C6	C5	C4	C3	C2	C1	Main criteria
<0.309,0.623>	<0.234,0.451>	<0.078,0.156>	<0.117,0.258>	<2.954,6.026>	<0.178,0.339>	<0.055,0.117>	<1.000,1.000>	C1
<1.318,2.630>	<0.871,1.839>	<0.501,0.935>	<0.407,0.933>	<1.700,3.020>	<0.623,1.225>	<1.000,1.000>	<8.921,18.197>	C2
<5.773,10.471>	<3.525,6.918>	<1.403,2.818>	<2.889,6.026>	<4.911,9.772>	<1.000,1.000>	<0.816,1.606>	<3.467,5.623>	C3
<1.514,3.467>	<0.219,0.501>	<0.575,1.225>	<0.708,1.413>	<1.000,1.000>	<0.102,0.204>	<0.331,0.588>	<0.284,0.339>	C4
<2.761,6.457>	<7.621,15.849>	<0.759,1.862>	<1.000,1.000>	<0.708,1.413>	<0.166,0.346>	<1.072,2.455>	<4.571,8.511>	C5
<2.216,4.571>	<2.411,5.248>	<1.000,1.000>	<0.537,1.318>	<0.816,1.738>	<0.355,0.713>	<1.070,1.995>	<6.935,12.882>	C6
<0.666,1.145>	<1.000,1.000>	<0.191,0.415>	<0.063,0.131>	<1.995,4.571>	<0.145,0.284>	<0.544,1.148>	<2.593,4.266>	C7
<1.000,1.000>	<0.873,1.501>	<0.219,0.451>	<0.155,0.362>	<0.288,0.661>	<0.095,0.173>	<0.380,0.759>	<2.028,3.236>	C8

The determinacy value matrix is computed with Eq.(11) and matrix of weights before normalization as in Eq. (12) are represented in Tables 7-8, respectively.

Table 7 The determinacy value matrix (T)

T	C1	C2	C3	C4	C5	C6	C7	C8
C1	1	0.7804	0.8136	0.7936	0.772	0.7976	0.8104	0.7972
C2	0.7804	1	0.8040	0.8336	0.76	0.8196	0.7836	0.8
C3	0.8136	0.804	1	0.8008	0.7872	0.798	0.8048	0.8276
C4	0.7936	0.8336	0.8008	1	0.8	0.7812	0.76	0.76
C5	0.772	0.76	0.7872	0.8	1	0.74	0.788	0.754
C6	0.7976	0.8196	0.798	0.7812	0.74	1	0.7748	0.7904
C7	0.8104	0.7836	0.8048	0.76	0.788	0.7748	1	0.8432
C8	0.7972	0.8	0.8276	0.76	0.754	0.7904	0.8432	1

Table 8 Matrix of weights before normalization (t)

T	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
C1	1	0.0672	0.2100	3.5630	0.1450	0.0932	0.2778	0.3713
C2	10.5813	1	0.7428	1.9671	0.5094	0.5883	1.0617	1.5794
C3	3.6981	0.9738	1	5.8793	3.5089	1.6842	4.2025	6.7218
C4	0.2468	0.3832	0.1224	1	0.8481	0.7033	0.2735	1.8927
C5	5.0497	1.3399	0.2015	0.8481	1	0.9696	9.2470	3.4748
C6	7.9032	1.2561	0.4259	0.9975	0.6864	1	2.9671	2.6822
C7	2.7792	0.6628	0.1723	2.4951	0.0765	0.2344	1	0.7635
C8	2.0981	0.4555	0.1111	0.3606	0.1949	0.2647	1.0010	1

Weights of main criteria are computed using Eq, (13). Due to field constraints, not all the calculations related to the sub-criteria could be shown using PFAHP.

Similarly, in Table 9 weights of sub evaluation criteria are shown following the PFAHP procedure for weighting eight main criteria.

Table 9 Importance weights supplier evaluation criteria

Criteria	Local weights	Ranking Order	Global Weight	Ranking Order
C1-Environmental	0.0518			
C11: Environment management systems	0.1124	5	0.0058	35
C12: Green design and purchasing	0.2247	2	0.0116	28
C13: Green manufacturing	0.0677	6	0.0035	39
C14: Green management	0.1499	3	0.0078	32
C15: Green packing and labeling	0.1428	4	0.0074	33
C16: Waste management and pollution prevention	0.2576	1	0.0133	24
C17: Environmental competencies	0.0447	7	0.0023	42
C2-Social	0.1630			
C21: Occupational Health and Safety Systems	0.0086	6	0.0014	44
C22: The interests and rights of employees	0.0785	5	0.0128	26
C23: The rights of stakeholders	0.1471	3	0.0240	18
C24: Information Disclosure	0.3286	2	0.0536	7
C25: Labor relation records	0.3562	1	0.0581	6
C26: training aids	0.0810	4	0.0132	25
C3-Quality	0.2501			
C31: Low defect rate	0.0470	4	0.0118	27
C32: Inspections methods and plans	0.4620	1	0.1156	1

C33: Adherence to quality tools	0.3749	2	0.0938	2
C34: Quality systems	0.1161	3	0.0290	13
C4-Service	0.0495			
C41: Quick Responsiveness	0.5005	1	0.0247	16
C42: Flexibility and Agility	0.4515	2	0.0223	20
C43: After sales service	0.0480	3	0.0024	41
C5-Risk	0.2001			
C51: Supply Constraint	0.0546	7	0.0109	29
C52: Buyer Supplier Constraint	0.1313	4	0.0263	14
C53: Supplier's past performance and reputation	0.1275	5	0.0255	15
C54: Variation in price	0.1455	3	0.0291	12
C55: Supplier's production limitations	0.1210	6	0.0242	17
C56: amount of past business	0.1575	2	0.0315	10
C57: Uncompleted orders	0.2627	1	0.0526	9
C6-Cost/Price	0.1620			
C61: Transportation Cost	0.1881	3	0.0305	11
C62: Purchase cost	0.3612	2	0.0585	5
C63: Quantity discount	0.0408	4	0.0066	34
C64: Payment terms	0.0217	5	0.0035	38
C65: Profit on Product	0.3882	1	0.0629	4
C7-Capability	0.0740			
C71: Financial capability	0.0259	7	0.0019	43
C72: Change order capability	0.3126	1	0.0231	19
C73: Technical capability	0.2684	2	0.0199	21
C74: Understanding of technology	0.0491	5	0.0036	37
C75: Engineering/technical support resources	0.1184	4	0.0088	30
C76: Technical know how	0.0446	6	0.0033	40
C77: Distribution capability	0.1809	3	0.0134	23
C8-Business structure	0.0496			
C81: Knowledge of market	0.1729	4	0.0086	31
C82: Information systems	0.0219	6	0.0038	36
C83: Communication system	0.0569	5	0.0012	45
C84: Desire for business	0.2839	1	0.0162	22
C85: Management and organizations	0.2537	2	0.0720	3
C86: Market share	0.2106	3	0.0534	8

Table 9 provides the importance weight and rank of each evaluation criterion determinate by 5 experts. The results show that the five most important criteria for supplier selection are: (C32) Inspections methods, (C33) adherence to quality tools, (C85), management and organizations, (C65), profit on product, (C62) purchase cost.

4.4. Prioritization of Suppliers using FTOPSIS

The purchasing expert in the enterprise determined their evaluations according to the existing criteria by using Table 2. The evaluation is presented in Table 10.

Table 10. Evaluation of experts

Criteria	Supplier 1	Supplier 2	Supplier 3
C11	(0.2,0.3,0.4,0.5)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.9,1)
C12	(0.1,0.2,0.3,0.4)	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)
C13	(0.2,0.3,0.4,0.5)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.9,1)
C14	(0.1,0.2,0.3,0.4)	(0.2,0.3,0.4,0.5)	(0.2,0.3,0.4,0.5)
C15	(0.2,0.3,0.4,0.5)	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)
C16	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.9,1)
C17	(0.2,0.3,0.4,0.5)	(0.2,0.3,0.4,0.5)	(0.2,0.3,0.4,0.5)
C21	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1,1)
C22	(0.1,0.2,0.3,0.4)	(0.2,0.3,0.4,0.5)	(0.4,0.5,0.5,0.6)
C23	(0.8,0.9,1,1)	(0.7,0.8,0.9,1)	(0.5,0.6,0.7,0.8)
C24	(0.2,0.3,0.4,0.5)	(0.1,0.2,0.3,0.4)	(0.1,0.2,0.3,0.4)
C25	(0.4,0.5,0.5,0.6)	(0.2,0.3,0.4,0.5)	(0.2,0.3,0.4,0.5)
C26	(0.4,0.5,0.5,0.6)	(0.8,0.9,1,1)	(0.8,0.9,1,1)
C31	(0.2,0.3,0.4,0.5)	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)
C32	(0.2,0.3,0.4,0.5)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1,1)
C33	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
C34	(0.4,0.5,0.5,0.6)	(0.8,0.9,1,1)	(0.8,0.9,1,1)
C41	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.9,1)	(0.7,0.8,0.9,1)
C42	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
C43	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)
C51	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
C52	(0.2,0.3,0.4,0.5)	(0.1,0.2,0.3,0.4)	(0.4,0.5,0.5,0.6)
C53	(0.4,0.5,0.5,0.6)	(0.1,0.2,0.3,0.4)	(0,0,0.1,0.2)
C54	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.2,0.3,0.4,0.5)
C55	(0.4,0.5,0.5,0.6)	(0.2,0.3,0.4,0.5)	(0.4,0.5,0.5,0.6)
C56	(0.5,0.6,0.7,0.8)	(0.8,0.9,1,1)	(0.8,0.9,1,1)
C57	(0.4,0.5,0.5,0.6)	(0,0,0.1,0.2)	(0,0,0.1,0.2)
C61	(0.2,0.3,0.4,0.5)	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)
C62	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.9,1)	(0.7,0.8,0.9,1)
C63	(0.4,0.5,0.5,0.6)	(0.1,0.2,0.3,0.4)	(0.5,0.6,0.7,0.8)
C64	(0.7,0.8,0.9,1)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)
C65	(0.4,0.5,0.5,0.6)	(0.2,0.3,0.4,0.5)	(0.4,0.5,0.5,0.6)
C71	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
C72	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
C73	(0.2,0.3,0.4,0.5)	(0.8,0.9,1,1)	(0.7,0.8,0.9,1)
C74	(0.2,0.3,0.4,0.5)	(0.8,0.9,1,1)	(0.7,0.8,0.9,1)
C75	(0.2,0.3,0.4,0.5)	(0.8,0.9,1,1)	(0.7,0.8,0.9,1)
C76	(0.4,0.5,0.5,0.6)	(0.8,0.9,1,1)	(0.8,0.9,1,1)
C77	(0.2,0.3,0.4,0.5)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
C81	(0.8,0.9,1,1)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.9,1)
C82	(0,0,0.1,0.2)	(0.1,0.2,0.3,0.4)	(0.2,0.3,0.4,0.5)
C83	(0.4,0.5,0.5,0.6)	(0.2,0.3,0.4,0.5)	(0.4,0.5,0.5,0.6)
C84	(0.8,0.9,1,1)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)
C85	(0.1,0.2,0.3,0.4)	(0.2,0.3,0.4,0.5)	(0.2,0.3,0.4,0.5)
C86	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.2,0.3,0.4,0.5)

The fuzzy linguistic expressions are changed into fuzzy trapezoidal numbers. This is the first phase of the FTOPSIS method. The weights of criteria which are computed in PFAHP stage are then added into the calculation in FTOPSIS analysis. In this stage fuzzy decision matrix computed using Eq. (15). The FPIS and the FNIS values are considered as: (1, 1, 1, 1) and (0, 0, 0, 0), For the next stage, S_k^+ and S_k^- are computed using Eqs, (18) and (19). The next stage is about the similarities to an ideal solution and computed with Eq, (20). The resulting closeness coefficients values of suppliers are reported in Table 11. The supplier which has the biggest C_i* value has performed best in terms of supplier criteria. According to Table 11, Supplier 3 has shown the best performance.

Table 11 FTOPSIS C_i^*

Suppliers	S_i^+	S_i^-	C_i^*	*Order*
Supplier 1	76.184	1.357	0.0175	3
Supplier 2	76.128	1.419	0.0183	2
Supplier 3	76.042	1.503	0.0194	1

5. Conclusion

Effective supplier selection plays a vital role in the success of businesses, especially in today's competitive environment. Careful consideration of suppliers by decision makers is one of the most challenging stages of the decision-making process, as there are several conflicting goals to consider. The green supply chain can be defined as the coordination of activities such as material management, information sharing, capital flow and cooperation, with the aim of minimizing the environmental impact of its operations by considering the financial interests of the company.

In this study, an application of a supplier evaluation approach including an integration of PFAHP and FTOPSIS is presented. The case study is performed under a fuzzy environment to reduce uncertainty and vagueness, and linguistic variables parameterized by interval-valued Pythagorean and triangular fuzzy numbers are used. Through the case study, 8 main and 45 sub-criteria supplier selection evaluation criteria used to assess 3 suppliers by FTOPSIS.

Although the proposed model can be developed more, it will bring several contributions to green supplier evaluation and selection literature. To our knowledge, no previous work investigated this green supplier selection problem by integrating PFAHP and FTOPSIS. As the proposed approach is novel, it might be applied to other MCDM problems. However, our study has some disadvantages and possible further work is recommended. Other possible techniques for future studies include VIKOR and Preference Ranking Organizational Method for Enrichment Evaluation (PROMETHEE). In addition, different fuzzy sets can be used in the proposed approach.

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