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Intuitionistic fuzzy green supplier selection and an application in the machine manufacturing sector

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Abstract

Green supplier selection(GSS) is a mandatory function of green supply chain management and has an important role for enterprises to maintain their strategic competitiveness. GSS is an important milestone in the transition to sustainable supply chain design and management. Therefore, it is important to provide a well-functioning green supplier decision-making system to enterprises and it is a critical process for them. In this study, a selection model including green criteria was proposed for green supplier selection. In order to show the applicability and effectiveness of the proposed model, a real-world case study is presented. The results of this study proved that the proposed comprehensive model could solve the green supplier selection problem well by considering the uncertainties associated with the decisions of experts.

1. Introduction

Green supply chain has been formed to alleviate environmental problems and control air, waste pollution, water with the espousal of green applications in enterprises (Khan, 2018). Today, sustainable corporate governance promotes green supply chain applications. A green supply chain provides green production practices that support to reduce wastes and greenhouse emissions generating during the production process and have an environmentally friendly design. Many enterprises aiming to minimize environmental problems are trying to participate in green supply chains with economically, socially, and environmentally sustainable supply, material and production processes. Additionally, sustainable producers focus on GSS to reduce costs and save the environment, as well (Phochanikorn and Tan, 2019).

GSS is one of the decision making procedures of enterprises and directly affects the environmental performance of the enterprises. In addition, GSS provides economic benefits and competitive advantages to enterprises. GSS for this purpose is depend on a series of green criteria to appraise selected suppliers. (Gaoa et.al., 2020). When we look at the literature, the green criteria used for GSS are pollution control, pollution production, source consumption, green image, environmental management system, green product, green/eco design, green competencies, green innovation and management commitment (Amin et.al.,2019). In addition, GSS involves more than one decision makers (DM), which makes GSS a complex decision problem. DM generally have limited knowledge about GSS and they may not know the properties of all criteria. This situation causes uncertainty in decision-making (Gaoa et al., 2020). Intuitionistic fuzzy (IF) sets are one of the most effective methods in decision making in uncertain environments. For this purpose, IF-TOPSIS (Intuitionistic fuzzy-Technique for Order Preference by Similarity to Ideal Solution) method for GSS was recommended in this study.

In this study, the GSS problem of a machine manufacturing enterprise is evaluated. The company plans to improve its supply chain management and make it green. For this purpose, criteria that can be evaluated both economically and environmentally were determined and a selection was made for four alternatives. The result obtained from the study has been an alternative solution proposal for the company in choosing a green supplier.

The study consists of five parts. In the second part, a literature review on green supplier selection is presented. In the third part, basic information about the IF set and the IF-TOPSIS method is given. In the fourth part, GSS has been made by using the IF-TOPSIS method, taking into account the green criteria. In the last part, the results obtained from the study are given.

2. Literature Review

An enterprise needs a well-functioning GSS system to determine whether or not a supplier is a right partner in green supply chain management. In addition, selection of green suppliers is harder than choice of customary supplier for an enterprise. Since GSS requires considering both qualitative and conflicting environmental criteria, it is accepted as a multi-criteria decision making (MCDM) problems (Kannan et al., 2013; Ecer,2020). Recently, GSS has attracted great attention in business and academic environments with the increase of environmental planning and environmental awareness. When we examine the literature, we see that various MCDM problems are used for GSS. If we summarize these methods in general, Büyüközkan and Çiftçi (2012b) proposed a model that includes fuzzy DEMATEL- ANP- TOPSIS methods for GSS. Tseng and Chiu (2013) made a GSS for a company manufacturing electronics using fuzzy grey relational analysis (GRA) method. GSS was made with Fuzzy TOPSIS method by Shen et al., (2013) for a company producing automobiles for a Brazilian electronics company. Li and Wu (2015), Cao et al., (2015), Tian et al., (2015), Memari et al., (2019) and Rouyendegh et al., (2020) improved a GSS model with an IF-TOPSIS method. Kuo et al., (2015) improved a GSS model using VIKOR and ANP. Kannan et al., (2015) made the GSS for a company that manufactures plastic using fuzzy axiomatic design method. Freeman and Chen (2015) made a selection with a model based on AHP-Entropy-TOPSIS. Ghorabaee et al., (2016) presented a model based on WASPAS with range type-2 fuzzy sets for GSS. Yazdani et al., (2017) improved a method including SWARA- QFD - WASPAS for GSS. Qin et al., (2017) applied TODIM technique to the GSS problem using type-2 fuzzy sets. Sen et al., (2017) made a GSS in fuzzy environment with MULTIMOORA method. Daldır and Tosun (2018) made GSS with fuzzy WASPAS method. Banaeian et al., (2018) made GSS for agro-food industry using TOPSIS-VIKOR-GRA methods. Çalık (2018), Deshmukh and Sunnapwar (2019) made GSS using fuzzy AHP. Mishra et al., (2019) proposed a new model consisting of entropy and WASPAS methods in an unstable fuzzy medium for GSS. Madenoglu (2019) used Fuzzy TOPSIS-VIKOR-Grey Relational Analysis-Aras methods for GSS. Ecer (2020) made GSS with a model joining type-2 fuzzy set and AHP method. Xu et al.,(2020) made GSS with a single-valued complex neutrosophic EDAS method. Çalık (2021) made the selection of green supplier by integrating AHP and TOPSIS methods in Pythagoras fuzzy environment. Zhao et al.,(2021) made GSS with classical TODIM method based on cumulative prospect theory (CPT-TODIM) including interval-valued Pythagorean fuzzy set (IVPFSs). Zhang et al.(2021) made GSS with CODAS method, which includes Under Picture 2-Tuple Linguistic Environment. Erbıyık et al.(2021) made a GSS using the ELECTRE method.
GSS is accepted as a decision-making problem with multiple criteria. It is aimed that decision makers (DM) choose the most suitable green supplier depending on the decision-making situations from a decision set. However, in some cases, no alternative can meet all determined criteria at the best level (Gaoa et al., 2020). In this selection problem, it is necessary to produce the most appropriate and ideal solution that will meet the determined needs and criteria. TOPSIS method is one of the decision-making methods that consider both positive solution and negative solution to determine the most appropriate alternative meeting the criteria the best. TOPSIS method, developed by Hwang and Yoon, is a method that tries to select alternatives with the shortest distance to the positive ideal solution and the furthest distance to the negative ideal solution. (Pınar,2020). Selection and ranking problems, it is hard for the DMs to determine the importance of criteria, to evaluate alternatives according to the criteria, and to express exactly with clear data. The IF sets presented by Atanassov (1986) is an appropriate method to cope with these difficulties and have been applied to many decision-making problems in an uncertain environment. It has been shown that IF sets are quite suitable for uncertainty and dealing with uncertainty (Memari, 2019). TOPSIS method takes both positive-ideal and negative-ideal solution into account and TOPSIS method integrated with IF set has a great success chance for green supplier selection process. For this purpose, it was preferred in this study. In addition, with the method suggested, the aim of this study was to contribute to the GSS literature by developing effective and reliable criteria by addressing uncertainty more effectively, to help managers to make decisions and to support suppliers for improving their environmental performances.

3.Method

3.1. IF set Theory

The concept of Fuzzy Set (FS), an effective method to overcome uncertainty, was developed by Zadeh (1965) and has been successfully applied in many different fields such as economy, engineering and management. FS is expressed as a dual membership function in complex systems containing human judgments and thoughts in real world problems. This method has been developed based on the insufficiency of classical sets. The degree of membership, forming the basis of FSs, proposes to express the qualities with ordered membership functions and can get all values in the range of [0,1]. In classical sets, the degree of membership takes the value 0 or 1. The IF set theory was developed by Atanassov (1986) by making additions to the FS theory. While FS theory is modelled to show the degree of membership defined in the range of [0,1], the degree of non-membership is defined in addition to the degree of membership in IF set theory. The degrees of membership and non-membership are in the range of [0,1] in IF set theory. In general, FZ theory, the sum of the degrees of membership and non-membership is calculated as 1. In IF set theory, the sum of membership degree and non-membership degree does not have to be 1. In IF set theory, Attanassov defined a third parameter named hesitancy degree to make the sum equal to 1 (Yıldırım,2019).

3.2. IF-TOPSIS method

In this part, definitions for IF-TOPSIS method are given. Firstly, the set of alternatives $A = \{A_1, A_2, \dots \dots . A_m\}$ and set of criteria $C = \{C_1, C_2, \dots \dots . C_n\}$ were defined. The decision making group is not identical and include 1 different DM. Since DMs have different experience and knowledge, their significance levels are different from each other. $\lambda = \{\lambda_1, \lambda_2, \dots \dots . \lambda_l\}$ is the weight vector of DMs and $\lambda_k \geq 0, k = 1,2, \dots \dots l$ $\sum_{k=1}^{1} \lambda_k = 1$. $R^{(k)} = (r_{ij}^{(k)})_{m\times n}$ k. is the decision matrix (DMX) of the DM and $r_{ij}^{(k)} = (\mu_{ij}^{(k)}, \nu_{ij}^{(k)}, \pi_{ij}^{(k)})_{m\times n}$ is the IF value taken from the j. criteria of i. alternative given by the DMs. $\mu_{ij}^{(k)}$ degree of i. alternative to meet j. criteria according to the kth DM, $\nu_{ij}^{(k)}$ degree of i. alternative to meet j. criteria according to the kth DM and $\pi_{ij}^{(k)}$ refers to the uncertainty level according to kth DM. According to these definitions, the steps of IF-TOPSIS method are explained below (Boran et al., 2009).

Step 1. Detect the weights of DMs. Suppose that decision group includes l DM. The importance of the DM is accepted as linguistic terms stated within the scope of IF numbers.

Let $D_k = [\mu_k, \nu_k, \pi_k]$ be an IF number to rate kth DM. Then the weight of kth DM can be detected as following equation:

$$\lambda_k = \frac{\left(\mu_k + \pi_k \left(\frac{\mu_k}{\mu_k + \nu_k}\right)\right)}{\sum_{k=1}^{l}\left(\mu_k + \pi_k \left(\frac{\mu_k}{\mu_k + \nu_k}\right)\right)}$$

and $\sum_{k=1}^{l} \lambda_k = 1$ (1)

Step 2. Build the unified IF DMX based on the views of the DMs. In the group decision-making process, all individual decision views must be included in a group view to form a unified IF DMX. For this reason, IFWA (Intuitionistic Fuzzy Weighted Averaging) operator proposed by Xu (2007) is employed.

$$r_{ij} = IFWA_\lambda\left(r_{ij}^{(1)}, r_{ij}^{(2)}, \dots \dots . r_{ij}^{(l)}\right) = r_{ij}^{(1)}\lambda_1 \oplus r_{ij}^{(2)}\lambda_2 \oplus \dots \dots \oplus r_{ij}^{(l)}\lambda_l$$

$$= \left[1 - \prod_{k=1}^{l}\left(1 - \mu_{ij}^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{l}\left(\nu_{ij}^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{l}\left(1 - \mu_{ij}^{(k)}\right)^{\lambda_k} - \prod_{k=1}^{l}\left(\nu_{ij}^{(k)}\right)^{\lambda_k}\right] \quad (2)$$

Here $r_{ij} = \left(\mu_{Ai}(x_j), \nu_{Ai}(x_j), \pi_{Ai}(x_j)\right)$ $(i = 1,2 \dots . m; j = 1,2 \dots . n)$.

The combined IF DMX can be defined as follows:

$$R: \begin{bmatrix} (\mu_{A1}(x_1), \nu_{A1}(x_1), \pi_{A1}(x_1)) & (\mu_{A1}(x_2), \nu_{A1}(x_2), \pi_{A1}(x_2)) \dots . & (\mu_{A1}(x_n), \nu_{A1}(x_n), \pi_{A1}(x_n)) \\ (\mu_{A2}(x_1), \nu_{A2}(x_1), \pi_{A2}(x_1)) & (\mu_{A2}(x_2), \nu_{A2}(x_2), \pi_{A2}(x_2)) \dots . & (\mu_{A2}(x_n), \nu_{A2}(x_n), \pi_{A2}(x_n)) \\ \vdots & \vdots & \vdots \\ (\mu_{Am}(x_1), \nu_{Am}(x_1), \pi_{Am}(x_1)) & (\mu_{Am}(x_2), \nu_{Am}(x_2), \pi_{Am}(x_2)) \dots & (\mu_{Am}(x_n), \nu_{Am}(x_n), \pi_{Am}(x_n)) \end{bmatrix}$$

$$R = \begin{bmatrix} r_{11} & r_{12} \dots . & r_{1m} \\ r_{21} & r_{22 \dots \dots} & r_{2m} \\ r_{31} & r_{32 \dots \dots} & r_{3m} \\ \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots \\ r_{n1} & r_{n2 \dots \dots} & r_{nm} \end{bmatrix}$$

Step 3. Determine the weights of the criteria. It may not be recommended that all criteria are of equal importance. W offers a range of severity levels. For the importance of each criterion to obtain W, all individual DM views must be combined.

Let $W_j^{(k)} = \left[\mu_j^{(k)}, \nu_j^{(k)}, \pi_j^{(k)}\right]$ be an IF number assigned to criterion Xj by the kth DM. Then, IFWA operator is used to detect the weights of the criteria:

$$W_j = IFWA_\lambda\left(W_j^{(1)}, W_j^{(2)}, \dots \dots . W_j^{(l)}\right) = \lambda_1 W_j^{(1)} \oplus \lambda_2 W_j^{(2)} \oplus \dots \dots \oplus \lambda_l W_j^{(l)}$$

$$=\left[1-\prod_{k=1}^{l}\left(1-\mu_j^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{l}\left(\nu_j^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{l}\left(1-\mu_j^{(k)}\right)^{\lambda_k}-\prod_{k=1}^{l}\left(\nu_j^{(k)}\right)^{\lambda_k}\right] \quad (3)$$

$W=[W_1, W_2, W_3 \ldots\ldots W_j]$ here $W_j=(\mu_j, \nu_j, \pi_j)(j=1,2 \ldots . n)$

Step 4. Build a combined weighted IF DMX. After determining the criterion weights (W) and the combined IF DMX, the combined weighted IF DMX is formed based on the following equation:

$$R \oplus W=\left\{\left(x, \mu_{Ai}(x). \mu_w(x)+\nu_{Ai}(x). \nu_w(x)-\nu_{Ai}(x). \nu_w(x)\right) | x \in X\right\} \quad (4)$$

And

$$\pi_{A_i w}(x)=1-\nu_{Ai}(x)-\nu_w(x)-\mu_{Ai}(x). \mu_w(x)+\nu_{Ai}(x). \nu_w(x) \quad (5)$$

Then, the combined weighted IF DMX can be detected as follows:

$$R:\begin{bmatrix}\left(\mu_{A1W}(x_1), \nu_{A1W}(x_1), \pi_{A1W}(x_1)\right) & \left(\mu_{A1W}(x_2), \nu_{A1W}(x_2), \pi_{A1W}(x_2)\right) \ldots . & \left(\mu_{A1W}(x_n), \nu_{A1W}(x_n), \pi_{A1W}(x_n)\right) \\ \left(\mu_{A2W}(x_1), \nu_{A2W}(x_1), \pi_{A2}(x_1)\right) & \left(\mu_{A2W}(x_2), \nu_{A2W}(x_2), \pi_{A2W}(x_2)\right) \ldots . & \left(\mu_{A2W}(x_n), \nu_{A2W}(x_n), \pi_{A2W}(x_n)\right) \\ \vdots & \vdots & \vdots \\ \left(\mu_{AmW}(x_1), \nu_{AmW}(x_1), \pi_{AmW}(x_1)\right) & \left(\mu_{AmW}(x_2), \nu_{AmW}(x_2), \pi_{AmW}(x_2)\right) \ldots & \left(\mu_{AmW}(x_n), \nu_{AmW}(x_n), \pi_{AmW}(x_n)\right)\end{bmatrix}$$

$$R'=\begin{bmatrix} r'_{11} & r'_{12} \ldots . & r'_{1m} \\ r'_{21} & r'_{22 \ldots\ldots} & r'_{2m} \\ r'_{31} & r'_{32 \ldots\ldots} & r'_{3m} \\ \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots \\ r'_{n1} & r'_{n2 \ldots .} & r'_{nm}\end{bmatrix}$$

$r'_{ij}=\{\mu'_{ij}, \nu'_{ij}, \pi'_{ij}\}=\{\mu_{A_iW}(x_j), \nu_{A_iW}(x_j), \pi_{A_iW}(x_j)\}$ is an element of the combined weighted IF DMX.

Step 5. Detect IF positive ideal solution (PIS) and IF negative ideal solution (NIS). J_1 *and* J_2 be benefit criteria and cost criteria, respectively. A^* is an IF PIS and A^- is an IF NIS. Then, A^* and A^- are obtained as:

$$A^*=\{\mu_{A^*W}(x_j), \nu_{A^*W}(x_j)\} \text{ and } A^-=\{\mu_{A^-W}(x_j), \nu_{A^-W}(x_j)\} \quad (6)$$

Where

$$\mu_{A^*W}(x_j)=((max_i \mu_{A_iW}(x_j) | j \in J_1), (min_i \mu_{A_iW}(x_j) | j \in J_2)) \quad (7)$$

$$\nu_{A^*W}(x_j)=((min_i \nu_{A^*W}(x_j) | j \in J_1), (max_i \nu_{A^*W}(x_j) | j \in J_2)) \quad (8)$$

$$\mu_{A^-W}(x_j)=((min_i \mu_{A_iW}(x_j) | j \in J_1), (max_i \mu_{A_iW}(x_j) | j \in J_2)) \quad (9)$$

$$\nu_{A^-W}(x_j)=((max_i \nu_{A^*W}(x_j) | j \in J_1), (min_i \nu_{A^*W}(x_j) | j \in J_2)) \quad (10)$$

Step 6: Detect the separation measures. Hamming distance, Euclidean distance and their normalized distance measures can be used to determine the distinction between alternatives in the IF set. After selecting the distance measure, the separation measures S_{i^*} and S_{i^-} of each alternative from IF PIS and NIS are determined. Hamming distance was used in this study.

$$S_{i^*}=\frac{1}{2} \sum_{j=1}^{n}\left[\left|\mu'_{ij}-\mu_j'^*\right|+\left|\nu'_{ij}-\nu_j'^*\right|+\left|\pi'_{ij}-\pi_j'^*\right|\right] i=1,2 \ldots . m \quad (11)$$

$$S_{i^-}=\frac{1}{2} \sum_{j=1}^{n}\left[\left|\mu'_{ij}-\mu_j'^-\right|+\left|\nu'_{ij}-\nu_j'^-\right|+\left|\pi'_{ij}-\pi_j'^-\right|\right] i=1,2 \ldots . m \quad (12)$$

Step 7. Determine the relative affinity coefficient to the intuitionistic ideal solution. The relative affinity coefficient of an alternative A_i with respect to IF PIS is defined as follows:

$$C_i^*=\frac{S_i^-}{S_i^*+S_i^-}, 0 \leq C_i^* \leq 1, i=1,2, \ldots \ldots m \quad (13)$$

Step 8. Rank the alternatives.

After the relative proximity coefficient of each alternative is determined, the alternatives are ranked in descending order of C_i^* 's.

4. Application

In this study, GSS was made for a machine manufacturing company operating in Kayseri province in order to show the applicability and effectiveness of the proposed model. Within the company, an expert group consisting of General Manager, Purchasing Officer, Production Supervisor and Planning Supervisor was prepared. Each of the expert group was detected as the DM. The expert team wanted to determine sustainable and applicable criteria for GSS. Criteria that can be evaluated both economically and environmentally have been determined by considering the green criteria in the literature (Büyüközkan and Çiftçi, 2012a; Gao et al., 2020). Cost, performance, environmental protection capacity and product quality were determined as the main criteria and product price, transportation fee, return rate, delivery performance, control level, green product, environmental management certificate, pollutant emission, green competitiveness, rejection rate, and quality evaluation were determined as sub-criteria. Table 1 shows criteria and sub-criteria. For 4 alternative green suppliers detected by the company, the model of the decision problem was constructed. Figure 1 shows the model of the decision problem.

Table 1. Criteria

Criteria	
Cost	Product price (C1): The total price of the product.
	Transportation fee (C2): The price includes all costs related to transportation. (Such as shipping, handling, and packaging)
Performance	Delivery performance (C3): It is the capability of suppliers to comply with specified delivery schedules.
	Return rate (C4): It is the ability of the supplier company to respond to customer requests (such as price, order frequency, demand structure).
Environmental protection capacity	Pollutant emission control level (C5): The ability of suppliers to reduce or eliminate their pollutant emissions.
	Green product (C6): The degree of supplier company to meet environmental needs in the production and use of the product.
	Environmental management certificate (C7): The capability of supplier company to establish environmental management system and to implement its policies.
	Green competitiveness (C8): The capability of the supplier company to provide environmentally friendly solutions.
Product quality	Rejection Rate (C9): The number of products rejected by the customer due to quality issues.
	Quality assessment (C10): Quality assessments of supplier companies

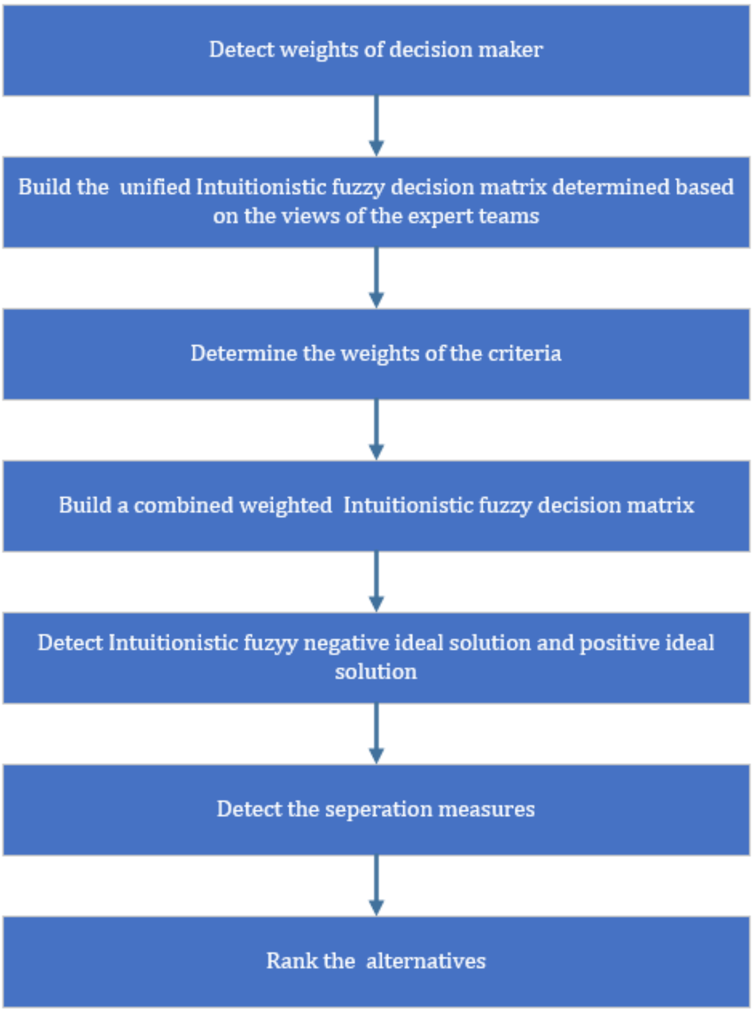

Figure 1. Models of the decision problem

The application steps of IF-TOPSIS model prepared for the selection of the best green supplier after the determination of criteria and alternatives together with the expert team (DM) are described below.
In the first step, the weights of each of the expert team were determined. The importance levels of the expert team were defined as linguistic variables. The general manager was determined as E1 with the importance level of "very important", Purchasing Officer as E2 with importance level of "important", production supervisor as E3 with importance level of "important", and Planning supervisor as E4 with importance level of "medium". The linguistic terms used to determine the weights of the expert team were converted into IF numbers. Table 2 shows linguistic terms and IF numbers.

Table 2. Linguistic terms used to determine the importance levels of the expert team

Linguistic terms	IF numbers
very important	0,80-0,10
important	0,50-0,30
medium	0,50-0,50
unimportant	0,30-0,50
very unimportant	0,20-0,70

Table 3 shows the importance levels and weight values of the expert team. The weight value of each expert was calculated using Equation 1.

Table 3. Weight values of the expert team

	E1	E2	E3	E4
Linguistic terms	very important	important	important	moderate
Weight value	0,322	0,249	0,249	0,180

In the second step, the evaluations of the expert team regarding the alternatives were combined and the combined DMX was obtained. In the evaluation of alternatives by the expert team, linguistic terms were used and the linguistic terms were converted into IF numbers. Table 4 shows the linguistic terms and IF numbers used.

Table 4. Linguistic terms and IF numbers

Linguistic terms	IF numbers
very good	0,70-0,10-0,15
good	0,60-0,25-0,15
medium	0,50-0,50-0,00
bad	0,25-0,60-0,15
very bad	0,10-0,75-0,15

Each expert evaluated alternatives according to the criteria. Table 5 shows evaluation results. In order not to lose information of the entire expert team, the views of the experts had to be combined as group thoughts. IFWA operator was used for this purpose. Table 6 shows the combined DMX obtained with the information of four experts.

Table 5. Evaluation results

		E1	E2	E3	E4			E1	E2	E3	E4
GS1	C1	vg	g	m	m	GS2	C1	g	g	vg	g
	C2	g	g	g	g		C2	g	vg	g	g
	C3	g	vg	g	g		C3	g	vg	g	b
	C4	b	m	b	b		C4	vg	g	m	m
	C5	b	m	b	vb		C5	b	b	m	b

	C6	vb	b	m	vb		C6	b	b	m	b
	C7	m	g	g	b		C7	vb	b	b	m
	C8	m	m	b	g		C8	m	vb	b	m
	C9	g	g	vg	g		C9	m	b	vb	b
	C10	g	vg	g	g		C10	g	m	g	m
		E1	E2	E3	E4			E1	E2	E3	E4
GS3	C1	g	g	g	g	GS4	C1	vg	g	g	g
	C2	g	g	g	g		C2	g	m	b	m
	C3	b	b	b	b		C3	g	m	b	m
	C4	b	b	b	b		C4	m	g	vg	g
	C5	b	m	b	b		C5	m	g	g	m
	C6	b	b	b	b		C6	g	g	g	m
	C7	g	m	m	g		C7	g	g	vg	g
	C8	m	g	m	g		C8	vg	g	g	g
	C9	g	m	g	m		C9	g	m	m	b
	C10	g	g	m	m		C10	g	m	m	b

Table 6. The combined DMX

	C1			C2		
GS1	(0,522	0,271	0,207)	(0,601	0,25	0,149)
GS2	(0,629	0,199	0,173)	(0,629	0,199	0,173)
GS3	(0,601	0,25	0,149)	(0,601	0,25	0,149)
GS4	(0,635	0,186	0,179)	(0,486	0,418	0,096)
	C3			C4		
GS1	(0,628	0,199	0,173)	(0,322	0,572	0,106)
GS2	(0,583	0,233	0,184)	(0,522	0,271	0,207)
GS3	(0,249	0,599	0,152)	(0,249	0,599	0,152)
GS4	(0,486	0,418	0,096)	(0,66	0,148	0,192)
	C5			C6		
GS1	(0,300	0,596	0,104)	(0,281	0,64	0,075)
GS2	(0,322	0,572	0,106)	(0,322	0,572	0,106)
GS3	(0,322	0,572	0,106)	(0,249	0,599	0,152)
GS4	(0,565	0,353	0,212)	(0,584	0,283	0,301)
	C7			C8		
GS1	(0,520	0,365	0,115)	(0,331	0,608	0,061)
GS2	(0,260	0,623	0,117)	(0,377	0,577	0,046)
GS3	(0,578	0,297	0,125)	(0,546	0,371	0,083)
GS4	(0,628	0,199	0,173)	(0,635	0,186	0,179)
	C9			C10		
GS1	(0,628	0,199	0,173)	(0,628	0,199	0,173)
GS2	(0,377	0,577	0,046)	(0,561	0,336	0,225)
GS3	(0,561	0,336	0,225)	(0,561	0,336	0,225)
GS4	(0,500	0,413	0,087)	(0,500	0,413	0,087)

In the third step, the weights of the criteria were determined. The weights of each criterion were not equal. The importance level of criteria is also different for each expert. For this purpose, IF values given to criteria by each expert are combined. Table 7 shows the linguistic terms and IF numbers used by the expert team to evaluate criteria.

Table 7. Linguistic terms and IF numbers

Linguistic terms	IF fuzzy numbers
very good	0,70-0,10-0,15
good	0,60-0,25-0,15
medium	0,50-0,50-0,00
bad	0,25-0,60-0,15
very bad	0,10-0,75-0,15

Each criterion was evaluated by the expert team using linguistic terms. Table 8 shows evaluation results. Linguistic terms were transformed into IF numbers in Table 7. The weight values of the criteria were obtained by using the IFWA operator and by making calculations in equation 3. Table 9 shows the obtained values.

Table 8. Evaluation results

	E1	E2	E3	E4
C1	g	g	vg	g
C2	vg	vg	g	g
C3	m	m	g	m
C4	g	g	g	g
C5	m	m	m	b
C6	b	b	m	b
C7	b	g	g	m
C8	m	m	m	m
C9	g	g	m	g
C10	g	g	g	g

Table 9. The obtained values.

W	Obtained values		
W1	(0,628	0,199	0,173)
W2	(0,660	0,148	0,192)
W3	(0,468	0,473	0,059)
W4	(0,601	0,250	0,149)
W5	(0,464	0,515	0,021)
W6	(0,322	0,572	0,106)
W7	(0,490	0,375	0,135)
W8	(0,502	0,498	0,000)
W9	(0,578	0,297	0,125)
W10	(0,601	0,250	0,149)

In the fourth step, a weighted combined DMX was constructed. After the weights of the criteria and the combined DMX were constructed, a weighted combined DMX was obtained using Equations 4 and 5. Table 10 shows the weighted combined DMX obtained.

Table 10. Weighted combined DMX

	C1			C2		
GS1	(0,328	0,416	0,256)	(0,397	0,361	0,242)
GS2	(0,395	0,358	0,247)	(0,415	0,318	0,267)
GS3	(0,377	0,399	0,223)	(0,397	0,361	0,242)
GS4	(0,399	0,348	0,253)	(0,321	0,504	0,175)
	C3			C4		
GS1	(0,294	0,578	0,128)	(0,194	0,679	0,127)
GS2	(0,273	0,596	0,131)	(0,314	0,453	0,233)
GS3	(0,117	0,789	0,095)	(0,150	0,699	0,151)
GS4	(0,227	0,693	0,079)	(0,397	0,361	0,242)
	C5			C6		
GS1	(0,139	0,804	0,057)	(0,090	0,846	0,064)
GS2	(0,149	0,792	0,058)	(0,104	0,817	0,080)
GS3	(0,149	0,792	0,058)	(0,080	0,828	0,091)
GS4	(0,262	0,686	0,052)	(0,188	0,693	0,119)
	C7			C8		
GS1	(0,255	0,603	0,142)	(0,166	0,803	0,031)
GS2	(0,127	0,764	0,108)	(0,189	0,788	0,023)
GS3	(0,283	0,561	0,156)	(0,274	0,684	0,042)
GS4	(0,308	0,499	0,193)	(0,319	0,591	0,090)
	C9			C10		
GS1	(0,363	0,437	0,200)	(0,377	0,399	0,223)
GS2	(0,218	0,703	0,079)	(0,337	0,502	0,161)
GS3	(0,324	0,533	0,143)	(0,337	0,502	0,161)
GS4	(0,289	0,587	0,124)	(0,301	0,560	0,140)

In the fifth step, IF PIS A* and IF NIS A− for each alternative were calculated using Equation 6. Table 11 shows the calculation results.

Table 11. The calculation results.

A*			A-		
(0,399	0,348	0,253)	(0,328	0,416	0,256)
(0,415	0,318	0,267)	(0,321	0,504	0,175)
(0,294	0,578	0,128)	(0,117	0,789	0,095)
(0,397	0,361	0,242)	(0,150	0,699	0,151)
(0,262	0,686	0,052)	(0,139	0,804	0,057)
(0,188	0,693	0,119)	(0,080	0,828	0,091)
(0,308	0,499	0,193)	(0,127	0,764	0,108)
(0,319	0,591	0,090)	(0,166	0,803	0,031)
(0,363	0,437	0,200)	(0,218	0,703	0,079)
(0,377	0,399	0,223)	(0,301	0,560	0,140)

In the sixth step, positive and negative separation measures were calculated. The separation measures between IF PIS and IF NIS were calculated for each alternative using Equations 11 and 12. Table 12 shows the calculation results. In the seventh step, the closeness coefficient for each alternative was calculated. Using Equation 13, the closeness coefficients of the alternatives were calculated according to IF PIS and IF NIS and given in Table 12.

Table 12. IF PIS and IF NIS

	S*	S-	C
GS1	1,024	0,013	0,013
GS2	1,190	0,809	0,405
GS3	1,245	0,754	0,377
GS4	0,613	1,370	0,691

In the final step, the alternatives were ranked according to their closeness coefficient values. The alternatives were ranked as GS4-GS2-GS3-GS1. GS4 having the highest coefficient was determined as the best alternative company among the green supplier company alternatives and GS1 having the lowest closeness coefficient was determined to be the worst alternative among the green supplier company alternatives. The alternative green supplier company meeting the determined criteria the best was found to be GS4. The obtained result was accepted as appropriate by the expert team and it was predicted that the recommended model for the selection of green supplier would give good results in similar problems.

5. Conclusion

GSS of for sustainable green supplier chain is one of the important decision-making problems. It is essential to determine the criteria suitable for an effective GSS and to choose the best supplier according to the determined criteria. IF-TOPSIS method is a decision making method according to both the positive solution and negative solution to determine the most suitable alternative considering the determined criteria in selection and ranking problems. IF-TOPSIS method not only allows to select both best and most suitable alternative from the determined alternatives but also the most appropriate alternative and it was preferred in this study due to these advantages.

In this study, a systematic approach was presented for supply chain managers who can make economic and environmental evaluations. For a GSS, an applicable model with sustainability was proposed. With the recommended model, selection was made from four alternative green suppliers with 4 main criteria and 10 sub-criteria. In the assessment process, each alternative, criteria, and the weights of the criteria were given in linguistic terms expressed in IF numbers. In addition, IFWA operator was used to collect the experts' opinions. After the IF PIS and IF NIS were calculated according to the hamming distance, the related closeness coefficients of the alternatives were obtained and the alternatives were sorted.

TOPSIS method combined with IF set was preferred in this study , it was aimed to contribute to the GSS literature by developing effective and reliable criteria by addressing uncertainty more effectively, to help managers to make decisions and to support suppliers to improve their environmental performance. This method is anticipated to be used in the supply selection and evaluation of other enterprises in the machine manufacturing sector in the future.

Çıkar Çatışması

Yazar tarafından herhangi bir çıkar çatışması beyan edilmemiştir.

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