Chapter 7

An Intuitionistic Fuzzy Group Decision-Making to Measure the Performance of Green Supply Chain Management with TOPSIS Method

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Additional information is available at the end of the chapter

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Abstract

Green supply chain management (GSCM) integrates environmental regulations into supply chain management to diminish the negative effects of supply chain processes on the environment. The environmental problems appeared by an enterprise arise from designing the product and last until the recycling process. GSCM activities include five drivers such as green design, green purchasing, green transformation, green logistics and reverse logistics. In this chapter, the main aim is to explain these drivers and to show how to measure the GSCM success of companies, which operate as tire manufacturers by using an evaluation of a group of experts in their field. The proposed method, intuitionistic fuzzy technique for order preference by similarity to an ideal solution as an effective group decision-making method, helped to identify the alternative company 1 with the best GSCM performance among six different alternative tire companies under the consideration of five important GSCM drivers. The ranking result was as follows: A1 > A3 > A4 > A2 > A6 > A5.

Keywords: intuitionistic fuzzy TOPSIS, group decision-making, green supply chain management

1. Introduction

After the Industrial Revolution, rapid developments in technology and industrialization cause environmental problems to meet the increasing needs. At this point, many countries have begun to implement environment protection rules, which are part of environmental management systems (EMS). Managing and improving environmental performances, increasing resource efficiency, complying with environmental laws and regulations and adapting to changing requirements are part of EMS and helped organizations for maintaining environmental policy. Environmental regulations can differ from country to country. So, these differences create barriers to trade. Firms have initiated various ventures in order to remove trading barriers and be able to make cleaner production and to use natural resources most efficiently as a result of compulsory pressures created by regulatory regimes. One of these powerful ventures is building an integration environmental thinking into supply chain management, which is called green supply chain management (GSCM). Jolley's research [1] supports that EMS and green supply chain practices are complementary to each other. Over the last years, GSCM has an important role to build powerful economic environmental performances at different levels in organizations [2]. To improve green skills, all firms need successful implementation of GSCM within the organization.

In the literature, there are many different definitions for GSCM. However, in general, GSCM means the explicit consideration of ecological dimensions in the planning, operations and management of supply chains [3]. Minimizing or eradicating wastes including hazardous chemical, emissions, energy and solid waste along supply chain process such as product design, material sourcing and selection, manufacturing process, delivery of final product to the consumers and end-of-life management of the product are the main aims of GSCM [4, 5]. In order to reach these main aims and increase the efficiency of green supply chain management, firms apply multi-criteria decision-making techniques. In a highly competitive fuzzy environment, using fuzzy group decision-making methods is more effective to find the optimal solutions.

Therefore, in this chapter, an extended technique for order preference by similarity to an ideal solution (TOPSIS) for group decision-making with intuitionistic fuzzy numbers is proposed to assess GSCM performance of tire manufacturing companies. First of all, performance drivers of GSCM performance are determined with the help of literature review and opinions of academic and industrial experts. After deciding the main drivers of GSCM performances, three decision-makers who have certain experience and expertise give individual opinions about drivers and alternatives. In other studies in this area, the weights of each decision-maker in a specific group are generally ignored; however, in this study, relative importance of each decision-maker's opinions is determined by using intuitionistic fuzzy numbers. Intuitionistic fuzzy weighted averaging (IFWA) operator, developed by Xu in 2007 [6], is utilized to aggregate individual opinions of decision-makers for rating the importance of criteria and alternatives.

This chapter proposes an intuitionistic fuzzy multi-criteria group decision-making with the TOPSIS method for GSCM performance evaluation. In Section 2, many definitions of GSCM are given and researches about GSCM have been explained. The rest of this chapter is organized as follows. In Section 3, the proposed methodology in this chapter is explained. A brief description of intuitionistic fuzzy sets is also given in subSection 1 of Section 3. SubSection 2 of Section 3 presents a detailed description of intuitionistic fuzzy TOPSIS method. In Section 4, a numerical example, which is about GSCM performances of tire manufacturing companies, is demonstrated. Finally, the conclusion of this chapter and obtained results are presented in Section 5.

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2. Green supply chain management

Environmentally responsible manufacturing created a relation between environmental researches in logistics and the reverse logistics. Therefore, the idea of GSCM emerged in this way, and it is said that its history was based on the researches on reverse logistics in 1990s [7]. According to [8], if a definition is to be made about supply chain and green supply chain, this definition depends on the economic, social, environmental, coordination, relationship, efficiency and performance criteria, which belong to business sustainability and supply chain management characteristics.

The GSCM notion in the literature has been defined in many researches and studies in recent years. Some of these definitions have been general and comprehensively covered the whole area, while others have focused on specific aspects [9]. Gilbert [10] explains that GSCM is an integration of traditional supply chain management facilities and environmental criteria. Hervani et al. [11] defined that GSCM is the collection of green purchasing, green manufacturing management, green distribution and reverse logistics. GSCM begins at the point of product design and continues until the end of the product's lifecycle in every step of the supply chain process, including recycling or environmentally friendly eradication of the product [12].

A number of researchers have focused on supply chain management and also GSCM as the potential multi-criteria decision-making problem in recent years. For example, Muduli and Barve [13] have made an attempt to identify main success criteria such as top management commitment, gap analysis, implementation and continual improvement for GSCM implementation in Indian mining industries and used the Analytic Hierarchy Process (AHP) to represent the existing interrelationship between factors in a structured way. Kamolkittiwong and Phruksaphanrat [14] also have tried to implement GSCM strategy of the electronic industry in Thailand to help the new companies that want to enter the market in their study. It aimed to determine the importance level of external and internal critical factors of GSCM strategy implementation. In another research, Toke et al. [15] have found the weights of critical success factors of GSCM in Indian manufacturing industry with the help of AHP steps. Mathiyazhagan et al. [16] examined the pressures for GSCM adoption via AHP. References [17–26] have built AHP and fuzzy AHP models for the evaluation of different GSCM practices. As seen, despite the fact that studies which applied on AHP models are mostly in the majority, in the green supply chain literature, GSCM practices can be often investigated differently by many different multi-criteria decision-making techniques such as TOPSIS, VIKOR, DEMATEL among researchers. For instance, Muralidhar et al. [27] have applied TOPSIS and fuzzy AHP together to evaluate various green supply chain management strategies, which are composed of green procurement, manufacturing, green service to customers and environmental management process. Akman and Piskin [28] have integrated Analytical Network Process (ANP) and TOPSIS to assess GSCM practices performance of 18 green suppliers by utilizing main criteria such as pollution control, environment management system, green products, environmental collaboration and environmental competency. The models [29–33] used in their articles are given as some examples of TOPSIS and fuzzy TOPSIS.

Rostamzadeh et al. [34] concentrated on fuzzy VIKOR to maintain GSCM activities in four laptop manufacturing companies. Main criteria such as green design, green purchasing, green production, green warehousing, green transportation and green recycling were evaluated to rank these companies in this research. According to Malviya and Kant [35], measuring the success of GSCM implementation via a hybrid model which constructed DEMATEL and fuzzy sets was contributed to green supply chain literature. Strategic, organizational, social-cultural, buyer and supplier activity, legislation and technical GSCM practices were the evaluated main factors to compare success and failure assessments in this research. Comparing to other multi-criteria decision-making techniques, in the literature, there are a few studies about GSCM performances under intuitionistic fuzzy environment. However, there is a growing interest about this specific subject. Govindan et al. [36] proposed an intuitionistic fuzzy DEMATEL method to obtain green practices in an efficient manner for the automotive sector. GSCM performances criteria such as reverse logistics, green design, green purchasing, carbon management, supplier environmental collaboration, customer environmental collaboration, ISO 14001 certification, internal management support, environmental performance and economic performance and their interdependencies were improved by applying the DEMATEL technique. It has been determined that automotive firms need to properly implement GSCM in order to avoid the adverse effects of strict regulations and increasing community concerns.

Wan and Li [37] developed a new fuzzy mathematical programming method for solving complex multi-attribute decision-making problems with interval-valued intuitionistic fuzzy sets to determine the weights and make green supplier selection. Green supplier selection is the one of the critical problems of GSCM. According to this research, the focuses of green supplier selection are different from the traditional supplier selections. Li and Wu [38] have improved intuitionistic fuzzy TOPSIS model for green supplier selection, and their findings show that the model can solve this selection problem under uncertain environment effectively.

The performance measurement perspective of GSCM has been supported by various authors. Hervani et al. [39] firstly aimed at determining the GSCM performance tools. After that, with an integrated study, green purchasing, green manufacturing, green marketing and reverse logistics were used in the main definition of GSCM performance. To provide long-term business life in green-based organizations, firms have to focus on all important criteria of GSCM performance. The purposes of this focus on GSCM performance have been identified as making robust external reporting, managing firms in the best way and also making an internal analysis about business and environment. Rao and Holt [2] analyzed supply chain management from the greening perspective and found a link between GSCM practices and necessity of competitive activities. According to them, if GSCM was applied by all organizations, economic performances and competitiveness could be obtainable. Zhu et al. [40] studied on GSCM practices of four different Chinese industries, and they reached the conclusion that the industrial differences affected the adoption of GSCM. Jakhar [41] determined main criteria and subcriteria of GSCM performances. Green supplier partnership performance, green production performance, green delivery and logistics performance are used as main criteria, while cost of raw material, carbon footprint, defect rate, flexibility rate, recycling rate, ordering cost, unit manufacturing cost, capacity utilization level, usage of energy, product quality, production flexibility, transportation cost, greenhouse gas emission, delivery time and delivery reliability

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are subcriteria. Uygun and Dede [26] applied DEMATEL, ANP and TOPSIS methods under fuzzy environment to make a general evaluation about GSCM main criteria and subcriteria. Green design, green purchasing, green transformation, green logistics and reverse logistics are defined as main criteria, along with product features, material selection, energy usage, life-cycle design, eco-design, design for environment, reusable materials, green manufacturing, green packaging, green stock politics, quality of service, quality of technology, quality regulations, and so on. The main aim of this research is to show the effectiveness of green activities of firms. Surmacz [42] explained why the firms need GSCM performance measurement systems. Recognition of green goals of firms and early warning for failures must be included while considering effective factors of GSCM performance measurement.

As seen, GSCM performance measurement is a very difficult problem for companies. This is mainly the case because measuring environmental performances is indeed a difficult task due to the reasons such as the lack of data, weak technology, cultural and organizational conflicts in an uncertain future. However, in a general view, in this chapter, the components of GSCM performance measurement are determined and used for GSCM evaluation in tire manufacturing companies. These components, which are called Green Design, Green Purchasing, Green Transformation, Green Logistics and Reverse Logistics, are used as criteria of GSCM performance. Green design is an environmental matter that both manufacturers and producers focus on. From the perspective of GSCM, green design proves helpful during the design phase particularly in terms of identifying product features, material selection, energy usage, and so on. Green purchasing is defined as an environmentally sensitive purchasing practice. According to Min and Galle [43], it is an ongoing procedure of recycling reusable or recyclable materials. It helps to satisfy customers and to ensure the brand image of the companies. Green transformation comprises all transformation activities such as green manufacturing, green packaging and green stock policies for production process of a product [44]. Green logistics uses an environmental way to deliver products and services. It aims to preserve resources to satisfy requirements about ecological balance [45]. Reducing idle use will help improve work efficiency. Reverse logistics is briefly about reusing the product materials. It manages networks which help product returns, remanufacturing, recovery, reuse and redistribution [46].

3. Methodology

A number of researchers have focused on supply chain management and also on green supply chain management as the potential multi-criteria decision-making problems in recent years. The evidence from the literature, therefore, is that there is a lack of consensus on the impact of GSCM on performance outcomes. This conflict was recognized and discussed in different studies including those by Eltayeb et al. and Zhu et al. [47, 48]. Zhu et al. [48] argued that the conflicting findings have the potential to become a barrier for organizations that intend to implement GSCM. In this chapter, the proposed performance evaluation model for GSCM is a hybrid model which combines TOPSIS and intuitionistic fuzzy set.

3.1. Intuitionistic fuzzy set

The first appearance of the concept of fuzzy logic came in 1965 when Zadeh published a paper entitled "Fuzzy Sets" in a journal named Information and Control [49]. Fuzzy logic, also expressed as the adaptation of mathematics to the real world, is based on uncertainties.

The fuzzy set theory, unlike the classical known set theory, operates according to the Aristo logic and allows the partial membership of an element to a set. For example, this suggests adding less sharp values into the cluster such as very long-long-medium-short-very short, hot-warm-less cold-cold-very cold values instead of using sharp values such as long-short, hot-cold, fast-slow, black and white. These intermediate values are in the form of verbal expressions and are called fuzzy variables. The intuitive fuzzy set was developed for the first time by Atanassov [50] and has appeared in the literature as a generalized version of the fuzzy set. According to Atanassov's definition [50], intuitionistic fuzzy set A in a nonempty set X can be shown as:

$A = \{\langle x, \mu_A(x), v_A(x)\rangle | x \in X\}$ where $\mu_A(x) :\rightarrow [0, 1]$, $v_A(x) : X \rightarrow [0, 1]$ are membership functions and nonmembership functions separately.

$$0 \le \mu_A(x) + v_A(x) \le 1 \tag{1}$$

$\pi_A(x)$ is a third parameter of intuitionistic fuzzy set. $\pi_A = 1 - \mu_A(x) - v_A(x)$ is known as the degree of indeterminacy of x which belongs to A or not. So, it is clear that $0 \le \pi_A(x) \le 1, \forall x \in X$. On the other hand, if the $\pi_A(x)$ is small, an understanding about x is more certain. If the $\pi_A(x)$ is big, an understanding about x is more uncertain. Apparently, when $\mu_A(x) = 1 - v_A(x)$ for all elements of the universe, the ordinary fuzzy set construction is retrieved [51]. A and B are intuitionistic fuzzy sets of the set X, and multiplication operator is exhibited as in Atanassov's research [50].

$$A \otimes B = \{\mu_A(x).\mu_B(x), v_A(x) + v_B(x) - v_A(x).v_B(x) x \in X|\} \tag{2}$$

3.2. Intuitionistic fuzzy TOPSIS

Technique for order preference by similarity to ideal solution methods (TOPSIS), one of the multi-criteria decision-making techniques, was developed by Hwang and Yoon in 1981 [52]; it is based on the shortest distance to positive ideal solution and the farthest distance to negative ideal solution and aims to rank alternatives according to distance measurement. TOPSIS also differs from other multi-criteria decision-making techniques in terms of being a technique that solves all the evaluation criteria at the same time and presents a single distribution to the decision-makers. Furthermore, its literature history is really powerful. In this chapter, the TOPSIS method intends to achieve the ultimate decision by expanding intuitively fuzzy environment.

Let $A = \{A_1, A_2, \ldots, A_m\}$ be a set of alternatives, while $C = \{C_1, C_2, \ldots, C_n\}$ be a set of criteria. The relative importance of decision-makers in group of l decision-makers is also a part of the account. The fact that some of decision-makers have different knowledge, experiences and education level differentiates the importance levels of their opinions.

$\lambda = \{\lambda_1, \lambda_2, ... \lambda_l\}$ is the weighted vector of decision-makers $\lambda_k \geq 0 \;\; k = 1,2,....l$ and $\sum_{k=1}^{l} \lambda_k = 1$.

$R^{(k)} = (r_{ij}^{(k)})_{mxn}$: kth decision-maker's intuitionistic fuzzy decision matrix.

$r_{ij}^{(k)} = (\mu_{ij}^{(k)}, v_{ij}^{(k)}, \pi_{ij}^{(k)})$: ith alternatives of an intuitive value from jth criterion given by kth decision-maker.

$\mu_{ij}^{(k)}$: jth criterion membership degree of ith alternatives to kth decision-maker.

$v_{ij}^{(k)}$: jth criterion nonmembership degree of ith alternatives to kth decision-maker.

$\pi_{ij}^{(k)}$: the uncertainty degree to kth decision-maker.

According to all given definitions, the hybrid use of the intuitive fuzzy set theory with TOPSIS is proposed by Boran et al. [53], and the steps of the Intuitionistic Fuzzy TOPSIS method are as follows:

Step 1: Determination of the weights of decision-makers.

Since group decision-making is a matter of concern, the significance ratings within the group of expert decision-makers are expressed in linguistic terms based on the fuzzy set theory, and at later stages, these terms are transformed into intuitive fuzzy numbers.

$D_k = (\mu_k, v_k, \pi_k)$ is an intuitionistic fuzzy number for rating kth decision-maker.

The weight of kth decision maker can be calculated, as shown in Eq. 3:

$$\lambda_k = \frac{(\mu_k + \pi_k(\frac{\mu_k}{\mu_k + v_k}))}{\sum_{k=1}^{l}(\mu_k + \pi_k(\frac{\mu_k}{\mu_k + \upsilon_k}))} \tag{3}$$

and also $\lambda_k \geq 0 \; k = 1,2,....l$ ve $\sum_{k=1}^{l} \lambda_k = 1$.

Step 2: Conversion of decision-makers' evaluation about alternatives into aggregated intuitionistic fuzzy decision matrix.

The intuitive fuzzy weighted averaging (IFWA) operator proposed by Xu [6] is used because all the decision-makers' evaluations on the subject can be presented as a group decision and no loss of thought by any party in the group occurs.

According to this operator, different evaluations can be presented as a single evaluation.

$$\begin{aligned} r_{ij} &= IFWA_\lambda(r_{ij}^{(1)}, r_{ij}^{(2)}, ..., r_{ij}^{(l)}) = r_{ij}^{(1)}\lambda_1 \oplus r_{ij}^{(2)}\lambda_2 \oplus ... \oplus r_{ij}^{(l)}\lambda_l \\ &= \left[1 - \prod_{k=1}^{l}(1-\mu_{ij}^{(k)})^{\lambda_k}, \prod_{k=1}^{l}(\upsilon_{ij}^{(k)})^{\lambda_k}, \prod_{k=1}^{l}(1-\mu_{ij}^{(k)})^{\lambda_k} - \prod_{k=1}^{l}(\upsilon_j^{(k)})^{\lambda_k}\right] \end{aligned} \tag{4}$$

In Eq. 4, the given $r_{ij} = (\mu_{ij}, v_{ij}, \pi_{ij})$ $(i = 1,2...,m;\ \mathrm{j} = 1,2,...\mathrm{n})$ is an element of R aggregated intuitionistic fuzzy decision matrix. R matrix can be shown as follows:

$$R=\begin{bmatrix}(\mu_{11},v_{11},\pi_{11}) & (\mu_{12},v_{12},\pi_{12}) & \cdots & (\mu_{1n},v_{1n},\pi_{1n})\\(\mu_{21},v_{21},\pi_{21}) & (\mu_{22},v_{22},\pi_{22}) & \cdots & (\mu_{2n},v_{2n},\pi_{2n})\\ \vdots & \vdots & \ddots & \vdots\\(\mu_{m1},v_{m1},\pi_{m1}) & (\mu_{m2},v_{m2},\pi_{m2}) & \cdots & (\mu_{mn},v_{mn},\pi_{mn})\end{bmatrix}=\begin{bmatrix}r_{11} & r_{12} & \cdots & r_{1n}\\r_{21} & r_{22} & \cdots & r_{2n}\\ \vdots & \vdots & \ddots & \vdots\\r_{m1} & r_{m2} & \cdots & r_{mn}\end{bmatrix}$$

Step 3: Calculation of the weights of criteria.

As each decision-maker may hold a different opinion on the criterion, the criterion taken for the evaluation in different topics may also be different from each other. In order to reflect this situation to the calculations, each decision-maker's thoughts about the criteria must be expressed in intuitive fuzzy values and combined with the idea of group decision without loss of thought. For this reason, a different IFWA operator, proposed by Xu [6] for the weights of the following criteria, is used as follows:

$$w_{ij}=IFWA_{\lambda}(w_j^{(1)},w_j^{(2)},\ldots,w_j^{(l)})=\lambda_1 w_j^{(1)}\oplus\lambda_2 w_j^{(2)}\oplus\ldots\oplus\lambda_l w_j^{(l)}$$
$$=\left[1-\prod_{k=1}^{l}(1-\mu_j^{(k)})^{\lambda_k},\prod_{k=1}^{l}(\upsilon_j^{(k)})^{\lambda_k},\prod_{k=1}^{l}(1-\mu_{ij}^{(k)})^{\lambda_k}-\prod_{k=1}^{l}(\upsilon_j^{(k)})^{\lambda_k}\right] \quad (5)$$

$W=\{w_1,w_2,w_3,\ldots.\mathrm{w}_j\}$ are the weights calculated for criteria. Each weight is expressed like that: $W_j=(\mu_j,v_j,\pi_j)$ $(j=1,2,\ldots,\mathrm{n})$.

Step 4: Construction of aggregated weighted intuitionistic fuzzy decision matrix.

The aggregated weighted intuitionistic fuzzy decision matrix is constructed by combining with criteria weights and the aggregated intuitionistic fuzzy decision matrix, which is determined in second step. The following definition is [50]:

$$R'=R\otimes W=(\mu_{ij}',v_{ij}')=\left\{\left\langle x,\mu_{ij}.\mu_j,v_{ij}+v_j-v_{ij}.v_j\right\rangle|x\in X\right\} \quad (6)$$

and

$$\pi'_{ij}=1-v_{ij}-v_j-\mu_{ij}.\mu_j+v_{ij}.v_j \quad (7)$$

$r'_{ij}=(\mu'_{ij},v'_{ij},\pi'_{ij})$ $(i=1,2,\ldots,m;j=1,2,\ldots,n)$ are the elements of matrix.

The aggregated weighted intuitionistic fuzzy decision matrix (R') can be shown as follows:

$$R'=\begin{bmatrix}(\mu'_{11},v'_{11},\pi'_{11}) & (\mu'_{12},v'_{12},\pi'_{12}) & \cdots & (\mu'_{1n},v'_{1n},\pi'_{1n})\\(\mu'_{21},v'_{21},\pi'_{21}) & (\mu'_{22},v'_{22},\pi'_{22}) & \cdots & (\mu'_{2n},v'_{2n},\pi'_{2n})\\ \vdots & \vdots & \ddots & \vdots\\(\mu'_{m1},v'_{m1},\pi'_{m1}) & (\mu'_{m2},v'_{m2},\pi'_{m2}) & \cdots & (\mu'_{mn},v'_{mn},\pi'_{mn})\end{bmatrix}=\begin{bmatrix}r'_{11} & r'_{12} & \cdots & r'_{1n}\\r'_{21} & r'_{22} & \cdots & r'_{2n}\\ \vdots & \vdots & \ddots & \vdots\\r'_{m1} & r'_{m2} & \cdots & r'_{mn}\end{bmatrix}$$

Step 5: Calculation of intuitionistic fuzzy positive-ideal solution and intuitionistic fuzzy negative-ideal solution.

J_1 is defined as the set of benefit criteria, and J_2 is also defined as the set of cost criteria. At this point, A^* is intuitionistic fuzzy positive-ideal solution and A^- is intuitionistic fuzzy negative-ideal solution. Respectively, solutions are formulated as:

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$$A^{*} = (r_1^{'*}, r_2^{'*}, \ldots, r_n^{'*}),\ r_j^{'*} = (\mu_j^{'*}, v_j^{'*}, \pi_j^{'*})\ \ j = 1, 2, \ldots, n$$
$$A^{-} = (r_1^{'-}, r_2^{'-}, \ldots, r_n^{'-}),\ r_j^{'-} = (\mu_j^{'-}, v_j^{'-}, \pi_j^{'-})\ \ j = 1, 2, \ldots, n \quad (8)$$

$$\mu_j^{'*} = \left\{ \left(\max_i \{\mu_{ij}^{'}\} \mid j \in J_1 \right), \left(\min_i \{\mu_{ij}^{'}\} \mid j \in J_2 \right) \right\} \quad (9)$$

$$v_j^{'*} = \left\{ \left(\min_i \{v_{ij}^{'}\} \mid j \in J_1 \right), \left(\max_i \{v_{ij}^{'}\} \mid j \in J_2 \right) \right\} \quad (10)$$

$$\pi_j^{'*} = \left\{ \left(1 - \max_i \{\mu_{ij}^{'}\} - \min_i \{v_{ij}^{'}\} \mid j \in J_1 \right), \left(1 - \min_i \{\mu_{ij}^{'}\} - \max_i \{v_{ij}^{'}\} \mid j \in J_2 \right) \right\} \quad (11)$$

$$\mu_j^{'-} = \left\{ \left(\min_i \{\mu_{ij}^{'}\} \mid j \in J_1 \right), \left(\max_i \{\mu_{ij}^{'}\} \mid j \in J_2 \right) \right\} \quad (12)$$

$$v_j^{'-} = \left\{ \left(\max_i \{v_{ij}^{'}\} \mid j \in J_1 \right), \left(\min_i \{v_{ij}^{'}\} \mid j \in J_2 \right) \right\} \quad (13)$$

$$\pi_j^{'-} = \left\{ \left(1 - \min_i \{\mu_{ij}^{'}\} - \max_i \{v_{ij}^{'}\} \mid j \in J_1 \right), \left(1 - \max_i \{\mu_{ij}^{'}\} - \min_i \{v_{ij}^{'}\} \mid j \in J_2 \right) \right\} \quad (14)$$

Step 6: Calculation of positive and negative separation measures.

To measure the separation between alternatives on the positive intuitive fuzzy ideal solution and the negative intuitive fuzzy ideal solution, calculation of distance measurement can vary. For instance, the TOPSIS method generally applies to Euclidean distance measurement; however, in the literature, to remove some mathematical set obstacles, Hamming distance measurement and normalized distance measurement are proposed by Szmidt ve Kacprzyk in 2000 [54]. In this chapter, Hamming distance measurement is used to measure the separation between the positive and the negative measurement of intuitive fuzzy ideal solution.

According to this, the following formulas are used to calculate for S_i^* and S_i^-:

$$S_i^{*} = \frac{1}{2} \sum_{j=1}^{n} \left[|\mu_{ij}^{'} - \mu_j^{'*}| + |v_{ij} - v_j^{'*}| + |\pi_{ij}^{'} - \pi_{ij}^{'*}| \right], i = 1, 2, \ldots, m \quad (15)$$

$$S_i^{-} = \frac{1}{2} \sum_{j=1}^{n} \left[|\mu_{ij}^{'} - \mu_j^{'-}| + |v_{ij}^{'} - v_j^{'-}| + |\pi_{ij}^{'} - \pi_{ij}^{'-}| \right], i = 1, 2, \ldots, m \quad (16)$$

Step 7: Calculation of the relative closeness coefficient to the intuitionistic ideal solution.

The relative closeness coefficient of an alternative with respect to the intuitionistic fuzzy positive ideal solution is calculated as follows:

$$C_i^{*} = \frac{S_i^{-}}{S_i^{*} + S_i^{-}},\ \ 0 \le C_i \le 1\ ,\ \ i = 1, 2, \ldots, m \quad (17)$$

Step 8: Ranking the alternatives.

Alternatives are ranked according to descending order of relative closeness coefficient value, which is calculated in step 7. Thus, the final assessment of all alternatives is completed in this step.

4. Application of measuring the performance of green supply chain management for tire manufacturers

This numerical and real case study is about the usage of the TOPSIS method combined with intuitionistic fuzzy set for the evaluation of drivers of GSCM performance of tire manufacturing companies in the group decision-making environment. These companies as the alternative companies are evaluated and ranked by intuitionistic fuzzy TOPSIS in terms of performance determination of GSCM. Firstly, experts from academic and this specific industrial domain help to determine the necessary drivers of GSCM. **Table 1** presents these five drivers, which are explained in Section 2 as criteria. After pre-evaluation, a committee composed of three decision-makers filled out the questionnaire about green drivers of six tire manufacturing companies competing in the same sector.

Also, the importance levels of ideas among decision-makers have been calculated by using Eq. 3 as the most important detail in this method. The proposed steps in the following are used to reach the best performance of green supply chain management.

Step 1: Determination of the weights of decision-makers.

Linguistic terms in **Table 2** are used to determine both the weights of decision-makers in the group and criteria. In the literature, it is possible to see that different linguistic terms can be applied. However, in this chapter, the linguistic terms, which Boran et al. [53] used in their research, are used. These linguistic terms seem appropriate.

The importance levels and weights of the decision-makers are calculated as in **Table 3**.

C1	Green design
C2	Green purchasing
C3	Green transformation
C4	Green logistics
C5	Reverse logistics

Table 1. Five drivers of GSCM activities.

Linguistic terms	Intuitionistic fuzzy number
Very unimportant	(0.1. 0.9. 0)
Unimportant	(0.35. 0.6. 0.05)
Medium level important	(0.5. 0.45. 0.05)
Important	(0.75. 0.2. 0.05)
Very important	(0.9. 0.1. 0)

Table 2. Linguistic terms for rating the importance of criteria and the decision-makers.

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Decision-maker 1	Decision-maker 2	Decision-maker 3
Very important	Important	Medium level important
0.4062	0.3563	0.2375

Table 3. The importance of decision-makers and their weights.

Decision-makers in this group have different levels of education, different working experiences and company positions.

Step 2: Conversion of decision-makers' evaluation about alternatives into aggregated intuitionistic fuzzy decision matrix.

The linguistic terms for evaluating alternatives on a per-criteria basis by three decision-makers were accepted as presented in **Table 4**.

Table 5 summarizes questionnaire evaluation about criteria of the alternatives by three decision-makers.

Linguistic terms	Intuitionistic fuzzy number
Very good (VG)	(0.75. 0.10. 0.15)
Good (G)	(0.65. 0.25. 0.15)
Fair (F)	(0.50. 0.50. 0.00)
Bad (B)	(0.25. 0.60. 0.15)
Very bad (VB)	(0.10. 0.75. 0.15)

Table 4. Linguistic terms for rating alternatives.

Decision-makers	Alternatives	C1	C2	C3	C4	C5
DM1	A1	G	G	G	G	G
	A2	G	G	G	F	G
	A3	G	G	G	G	G
	A4	G	G	G	F	G
	A5	F	B	F	F	F
	A6	F	F	F	F	F
DM2	A1	G	G	VG	F	G
	A2	G	G	VG	F	G
	A3	G	G	VG	F	G
	A4	VG	G	VG	F	G
	A5	B	F	F	B	B
	A6	F	G	G	F	F

Decision-makers	Alternatives	C1	C2	C3	C4	C5
DM3	A1	G	G	G	F	G
	A2	G	G	G	F	G
	A3	G	G	G	F	F
	A4	G	G	F	F	F
	A5	B	B	F	F	F
	A6	F	F	F	F	G

Table 5. Evaluation of alternatives according to criteria by decision-makers.

In order to ensure no losses occur in the decision-makers' opinion, the IFWA operator is used to construct the aggregated intuitionistic fuzzy decision matrix, shown in **Table 6**, with the help of the evaluation in **Table 5**.

Step 3: Calculation of the weights of criteria.

In the case of decision-making problems, the weight of each criterion is generally different from each other except for some specific evaluations. The most important reason for this is that the significance levels of criteria are different for each decision-maker. If the problem requires the determination of the importance of the decision-makers in a group, as in this study, the linguistic terms, shown in **Table 2**, and Eq. 3, are used together.

In addition, evaluation of decision-makers about the criteria is presented in **Table 7**. By using IFWA, the weights of criteria are calculated as follows:

—	C1	C2	C3	C4	C5
A1	(0.600, 0.250, 0.150)	(0.600, 0.250, 0.150)	(0.662, 0.180. 0.158)	(0.543, 0.377, 0.079)	(0.600, 0.250, 0.150)
A2	(0.600, 0.250, 0.150)	(0.600, 0.250, 0.150)	(0.662, 0.180. 0.158)	(0.500. 0.500. 0.000)	(0.600, 0.250, 0.150)
A3	(0.600, 0.250, 0.150)	(0.600, 0.250, 0.150)	(0.662, 0.180. 0.158)	(0.543, 0.100, 0.150)	(0.578, 0.295, 0.127)
A4	(0.662, 0.180. 0.158)	(0.600, 0.250, 0.150)	(0.643, 0.213, 0.144)	(0.500. 0.500. 0.000)	(0.578, 0.295, 0.127)
A5	(0.364, 0.557, 0.079)	(0.651, 0.562, 0.087)	(0.500. 0.500. 0.000)	(0.422, 0.534, 0.044)	(0.422, 0.534, 0.044)
A6	(0.500, 0.500, 0.000)	(0.538, 0.391, 0.071)	(0.538, 0.391, 0.071)	(0.500. 0.500. 0.000)	(0.526, 0.424, 0.050)

Table 6. Aggregated decision matrix.

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	DM 1	DM 2	DM 3
C1	VI	VI	I
C2	I	VI	I
C3	I	I	I
C4	M	M	M
C5	I	I	M

Table 7. Evaluation of criteria by decision-makers.

$$W = \left\{ \begin{array}{l} (0.876, 0.118, 0.006); \\ (0.820, 0.156, 0.024); \\ (0.750, 0.200, 0.050); \\ (0.500, 0.450, 0.050); \\ (0.705, 0.242, 0.052) \end{array} \right\}$$

Step 4: Construction of aggregated weighted intuitionistic fuzzy decision matrix.

It has become easier to calculate the aggregated weighted intuitionistic fuzzy decision matrix by determining the weight of each criterion. The final weighted combined decision matrix formed by the product operator (IFWA) defined in the intuitionistic fuzzy sets is given in **Table 8**.

—	C1	C2	C3	C4	C5
A1	(0.525, 0.338, 0.136)	(0.492, 0.367, 0.141)	(0.496, 0.344, 0.159)	(0.272, 0.658, 0.071)	(0.423, 0.432, 0.145)
A2	(0.525, 0.338, 0.136)	(0.492, 0.367, 0.141)	(0.496, 0.344, 0.159)	(0.250, 0.725, 0.025)	(0.423, 0.432, 0.145)
A3	(0.525, 0.338, 0.136)	(0.492, 0.367, 0.141)	(0.496, 0.344, 0.159)	(0.272, 0.658, 0.071)	(0.408, 0.466, 0.126)
A4	(0.579, 0.277, 0.144)	(0.492, 0.367, 0.141)	(0.482, 0.370, 0.147)	(0.250, 0.725, 0.025)	(0.408, 0.466, 0.126)
A5	(0.319, 0.609, 0.072	(0.288, 0.631, 0.082)	(0.375, 0.600, 0.025)	(0.211, 0.743, 0.045)	(0.298, 0.647, 0.056)
A6	(0.438, 0.559, 0.003)	(0.441, 0.486, 0.073)	(0.404, 0.512, 0.084)	(0.250, 0.725, 0.025)	(0.371, 0.564, 0.065)

Table 8. Aggregated weighted intuitionistic fuzzy decision matrix.

$r_1'^*$	(0.579, 0.277, 0.144)
$r_2'^*$	(0.492, 0.367, 0.141)
$r_3'^*$	(0.496, 0.344, 0.159)
$r_4'^*$	(0.272, 0.658, 0.071)
$r_5'^*$	(0.423, 0.432, 0.145)

Table 9. Intuitionistic fuzzy positive-ideal solution value.

Step 5: Calculation of intuitionistic fuzzy positive-ideal solution and intuitionistic fuzzy negative-ideal solution.

All the criteria discussed in the problem are beneficial. Intuitionistic fuzzy positive-ideal solution (A^*) and intuitionistic fuzzy negative-ideal solution (A^-) are calculated by taking into consideration the benefit and cost criteria, and shown in **Tables 9** and **10**.

Step 6: Calculation of positive and negative separation measures.

The separation measures between the alternatives and the positive intuitive fuzzy ideal solution and the negative intuitive fuzzy ideal solution are given in **Table 11**.

Step 7: Calculation of the relative closeness coefficient to the intuitionistic ideal solution.

The relative closeness coefficients are determined and shown with positive and negative separation measures in the same table.

Step 8. Ranking the alternatives.

$r_1'^-$	(0.319, 0.609, 0.072)
$r_2'^-$	(0.288, 0.631, 0.082)
$r_3'^-$	(0.375, 0.600, 0.025)
$r_4'^-$	(0.211, 0.743, 0.045)
$r_5'^-$	(0.298, 0.647, 0.056)

Table 10. Intuitionistic fuzzy negative-ideal solution value.

Alternatives	S_i^*	S_i^-	C_i^*
A1	0.061	1.09	0.9467
A2	0.129	1.04	0.8901
A3	0.095	1.06	0.9173
A4	0.127	1.05	0.8915
A5	1.152	0	0.0000
A6	0.768	0.48	0.3856

Table 11. Separation measures and the relative closeness coefficient of each alternative.

The relative closeness coefficients are used in the order of the alternatives. Six alternatives are ranked according to the descending order of C_i^* value. The alternative with the highest C_i^* value is the best alternative, while the alternative with the lowest value is the last alternative to be selected with the criterion-based evaluation. In this study, the best alternative was selected as alternate 1. While alternate 3 is in the second rank, six different tire manufacturing companies in the form of A1 > A3 > A4 > A2 > A6 > A5 were evaluated.

5. Conclusions and recommendations

In today's business environment, increasing practices of supply chain management with green perspectives have become remarkable and necessary. Thus, successful management of green activities in an uncertain future in a competitive environment has also become important to survive. This chapter explains an intuitionistic fuzzy group decision-making for green supply chain management performances of tire manufacturing companies using intuitionistic fuzzy TOPSIS. Dealing with uncertainties is the subject of this method. In addition to this characteristic, fuzzy average operator helps to combine ideas of decision-makers. On the other hand, if only TOPSIS used to make this evaluation, there would be a different solution. Because, even though TOPSIS has special distance calculations features while calculating the ideal optimal solution, it does not take into account decision-makers' ideas with the different importance levels. All these make the proposed method preferable.

In this chapter, to decide related criteria of GSCM, it is really important to investigate GSCM performances of Turkey's top tire manufacturing companies. This proposed approach can be applied for companies operating in different sectors. In future studies, various multi-criteria decision-making techniques can be combined with intuitionistic fuzzy sets to create hybrid techniques.

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