Pamukkale Üniversitesi

Sosyal Bilimler Enstitüsü Dergisi

Pamukkale University Journal of Social Sciences Institute

ISSN 1308-2922 E-ISSN 2147-6985

Article Info/Makale Bilgisi
√Received/Geliş:11.06.2022 **√Accepted/Kabul:**29.12.2022
DOİ:10.30794/pausbed.1129214
Research Article/Araştırma Makalesi

Madenoğlu, F. S. (2023). "A Group Decision-Making Method for Ranking Problems Under Sustainability, Risks, and Intuitionistic Fuzzy Environment", *Pamukkale Social Sciences Institute Journal*, Issue 56, Denizli, pp.123-137.

A GROUP DECISION-MAKING METHOD FOR RANKING PROBLEMS UNDER SUSTAINABILITY, RISKS, AND INTUITIONISTIC FUZZY ENVIRONMENT

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Abstract

This paper presents a group decision-making mechanism to properly manage ranking problems in an intuitionistic fuzzy environment. TOPSIS ranking multi-criteria decision-making (MCDM) methods is utilized under the intuitionistic fuzzy set theory. This solution technique examines the sets of criteria employed in decision-making problems, the preferences of a group of decision-makers, and the importance levels of decision-makers. Managers use the ranking methods as a reliable technique for making supplier evaluation decisions. Furthermore, the supply chain suffers from the shortage of materials, transportation problems, etc. In the post COVID-19 era, the need for a practical and exhaustive tool is explicit. An illustrative case on a supplier selection problem considering sustainability and risks in the post-COVID-19 era is used to demonstrate the applicability of the proposed technique by detailing the procedure step by step. A comparative analysis of the results is carried out. The results are compared with the results of the MARCOS method. The results show that the presented methodology is applicable to the other areas as well.

Keywords: *Multi-criteria decision making, Intuitionistic Fuzzy Sets, TOPSIS, MARCOS, Sustainability, Risk.*

SÜRDÜRÜLEBİLİRLİK, RİSKLER VE SEZGİSEL BULANIK ORTAMDA SIRALAMA PROBLEMLERİ İÇİN GRUP KARAR VERME YÖNTEMİ

Öz

Bu makale, sezgisel bulanık bir ortamda sıralama problemlerini düzgün bir şekilde yönetmek için bir grup karar verme mekanizması sunmaktadır. Sezgisel bulanık küme teorisi kapsamında çok kriterli karar verme (ÇKKV) yöntemi olan TOPSIS kullanılmaktadır. Bu çözüm tekniğinde karar verme problemlerinde kullanılan birtakım kriterler, karar vericiler grubunun tercihleri ve karar vericilerin önem düzeyleri incelenmektedir. Yöneticiler, sıralama yöntemlerini tedarikçi değerlendirme kararlarını vermek için güvenilir bir teknik olarak kullanır. Ayrıca, COVID-19 döneminden sonra tedarik zinciri malzeme sıkıntısı, ulaşım sorunları vb. sıkıntılardan muzdariptir, pratik ve kapsamlı bir araca olan ihtiyaç açıktır. Prosedürü adım adım detaylandırarak önerilen tekniğin uygulanabilirliğini göstermek için, COVID-19 sonrası dönemde sürdürülebilirliği ve riskleri dikkate alan bir tedarikçi seçimi sorununa ilişkin örnek bir vaka kullanılmıştır. Sonuçların karşılaştırmalı analizi gerçekleştirilmiştir. Sonuçlar, MARCOS yönteminin sonuçları ile karşılaştırılmıştır. Sonuçlar, sunulan metodolojinin diğer alanlara da uygulanabilir olduğunu göstermektedir.

Anahtar Kelimeler: *Çok kriterli karar verme, Sezgisel Bulanık Kümeler, TOPSIS, MARCOS, Sürdürülebilirlik, Risk.*

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1. INTRODUCTION

Individuals are faced with many decision-making problems, such as determining the most appropriate house for hiring in their lives and organizations are faced with a wide variety of decisions, such as strategic, operational, and daily. Similarly, organizations carry out operational, tactical, and strategic decisions at different levels in supply chain management. Alternatives in decision environments are evaluated with the help of multiple conflicting evaluation criteria. In these circumstances, multi-criteria decision-making (MCDM) methods are the most appropriate tools for making decisions (Hwang and Yoon, 1981: 58), selecting the best alternative among the alternatives considering the opinions of decision-makers. In problem-solving situations, the evaluations of individual decision-makers and group decision-makers are taken into consideration. In multi-criteria group decision-making (MCGDM) involving a group of decision-makers, the aim is to find the most satisfactory decision for the decision-makers by integrating the individual views of the decision-makers.

It can be difficult to understand practical decision-making problems completely because of the complex and uncertain decision environment. The decision-makers make their decisions in an environment where there is incomplete and uncertain data regarding the evaluation of alternatives or evaluation criteria. The Fuzzy Set Theory (FST) introduced by Zadeh (1965) is to handle imprecise information in the decision-making process. The imprecise information decision environment and fuzzy multi-criteria decision-making methods provide the decision-makers or group of decision-makers with an opportunity to assess the alternative by considering the evaluation criteria by using linguistic terms that include words expressed by fuzzy numbers. Zadeh (1965) presented the classical fuzzy set theory, which doesn't consist of hesitation. The extended version of fuzzy set theory includes non-membership degrees and hesitation can be widely faced in real-life decision environments to deal with outranking problems. It was introduced by Atanassov (1986) and called the IFS theory. Both hesitation and vagueness can be handled with the proposed theory. The criteria have structural differences due to their nature. Some criteria (such as age) are shown by quantitative statements, and some criteria (such as appearance) are displayed by qualitative expressions. IFN provides for the common use of these two types of criteria. Differential criteria values are converted to IFNs. Thus, different criteria can be included in the ranking algorithms. In addition, evaluations of decision-makers are aggregated to construct a decision matrix.

During COVID-19, organizations gained a better understanding of the importance of supply chain management decisions, which has attracted a lot of attention from research and business. The primary objectives of supply chain management are to reduce manufacturing costs and risks, raise revenues, optimize inventories, business processes, and cycle times, and so enhance competitiveness, customer satisfaction, and profitability (Heizer and Render, 2004: 444–486). One of the most important steps to implement in the supply chain is excellent purchasing activity (Chou and Chang, 2008: 2241–2246). Because of factors such as globalization and risks, purchasing activity has received much interest in improving the supply chain value. The supplier selection decision-making process is the most crucial decision in supply chain management. In addition to the decision environment, there are other global situations that need to be addressed during the supplier selection decision-making process. The uncertainties that may arise from the nature of the supply chain and various extra risks (political, natural disasters, etc.) should be taken into account. A small disruption in some parts of the supply chain causes losses and problems in the whole supply chain. Therefore, in addition to the aim of maximizing the supply chain surplus, there should be an approach aimed at managing such risks by taking them into account. Besides, new legal obligations imposed by governments and the enhancement of environmental awareness necessitate the implementation of a sustainable supply chain management approach. In this context, the fact that stakeholders in the supply chain have green awareness and green practices and they carry out their operations by making risk assessments and managing all dimensions of the supply chain makes the company more competitive and stronger. Therefore, in an uncertain decision environment, sustainability and risk factors should be included in the supplier selection decision, which is a critical decision.

In this paper, the TOPSIS method under intuitionistic fuzzy environment is used to identify solutions among several criteria and alternatives. The main principle of this method is to provide the shortest distance between the positive ideal solution and the negative ideal solution. TOPSIS can immediately recognize the proper alternative, reduce the number of pairwise comparisons required, analyze both objective and subjective data, can be used in problem environments with many alternatives and attributes, and is based on an aggregating function that represents closeness to the ideal, which originated in the compromise programming method. In addition, since it is one of the most used MCDM techniques in the literature, the TOPSIS method is adapted for this study. The main contributions of this study to the related literature are given as follows:

1. In the study, multiple decision-makers are included in the decision-making process. In this way, different perspectives that make the multi-attribute group decision-making process more realistic and applicable are considered.
2. To consider the uncertainty and hesitation in the decision-making problem, the TOPSIS method is applied under an intuitionistic fuzzy environment. To the best of our knowledge, there is no paper that takes into account sustainability and risk for supplier selection problems under IFS theory in the literature.
3. A comparative study and a sensitivity analysis verify the validity and robustness of the results generated by the utilized method.

The following part of this paper is organized as follows: A literature review is presented in Section 2. Section 3 explains the research design, and Section 4 presents the case study. Finally, conclusions are presented in Section 5.

2. LITERATURE REVIEW

This paper presents the TOPSIS method among MCDM techniques, which include many decision alternatives and criteria. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was developed by Hwang and Yoon (1981). In a mathematical approach, TOPSIS is the most popular mathematical technique to solve MCDM problems (Salih et al., 2019). This method has been utilized for solving problems extensively in other fields with favorable findings. TOPSIS examines different alternatives based on different criteria. The key goal of this strategy is to identify the point closest to the positive-ideal solution (with the minimum gaps in the criteria) and the point furthest from the negative-ideal solution (obtaining the maximum levels in each criterion). An index is defined as that expresses the similarity to the positive ideal solution and the distance from the negative ideal solution. Then, the best alternative that is the most similar to the positive-ideal solution is selected. The similarity to the positive-ideal solution and the distance from the negative-ideal solution is expressed by an index. The best option that is the most similar to the positive-ideal solution is then chosen. The traditional TOPSIS approach is based on crisp data to evaluate the alternatives and determine the criteria weight. For decision-makers, assigning the crisp value of performance metrics to an alternative for the criteria is challenging. As a result, TOPSIS has been extended to handle decision problems in a fuzzy context and is now known as fuzzy TOPSIS (Kuo et al., 2007). Due to the increasing unpredictability and ambiguity of crisp data, human evaluations cannot be considered in real-life decision circumstances. Boran et al. (2009) then propose Intuitionistic Fuzzy TOPSIS, which is an extended form of Fuzzy TOPSIS. The fuzzy TOPSIS method was applied in a wide variety of real-life applications. Amiri (2010) utilized fuzzy AHP and fuzzy TOPSIS for project selection for oil-field development. Krohling and Campanharo (2011) applied fuzzy TOPSIS for the selection of the best alternatives for accidents with oil spills in the sea. Chamodrakas and Martakos (2012) proposed a fuzzy TOPSIS method to select energy-efficient networks in heterogeneous wireless networks. Kannan et al. (2013) combined a fuzzy MCDM method and a multi-objective programming approach for supplier selection and order allocation problems in a green supply chain environment. Kannan et al. (2014) adapted fuzzy TOPSIS to select green suppliers for a Brazilian electronics company. Sengül et al. (2015) utilized fuzzy TOPSIS to rank renewable energy supply systems in Turkey. Zyoud et al. (2016) presented a framework for water loss management in developing countries by using Fuzzy AHP with Fuzzy TOPSIS. Onu et al. (2017) suggested a fuzzy TOPSIS approach to evaluate sustainable acid rain control options. Chou et al. (2019) evaluated the human resources in science and technology for Asian countries using fuzzy AHP and fuzzy TOPSIS. Dhiman and Deb (2020) presented an application of fuzzy TOPSIS and fuzzy COPRAS for hybrid wind farms. Yazdi et al. (2020) proposed a fuzzy fault tree analysis based on modified fuzzy AHP and fuzzy TOPSIS for fire and explosions in the process industry. Bilgili et al. (2022) presented an intuitionistic fuzzy TOPSIS to evaluate renewable energy alternatives for sustainable development in Turkey..

There are not many studies in the literature that deal with the issue of sustainability in the supplier selection problem. For green supplier selection in the high-tech industry, Lee et al. (2009) proposed a model that includes the Delphi method and a fuzzy extended analytic hierarchy process. Kuo et al. (2010) developed an integrated model which contains an artificial neural network, data envelopment analysis, and an analytic network process for green supplier selection in an electronic company in Taiwan. The Fuzzy decision-making trial and evaluation laboratory (DEMATEL) method is used by Chang et al. (2011) to identify the supplier selection factors. Kumar et al. (2014) proposed green data envelopment analysis for supplier selection, and the proposed method was applied to an automobile spare parts manufacturer in India. Yazdani et al. (2017) developed an integrated framework for green supplier selection. They integrated DEMATEL and quality function deployment methods to determine decision criteria and applied COPRAS and MOORA methods to rank suppliers. The proposed framework is implemented for Iranian dairy companies for selecting green suppliers. Qin et al. (2017) proposed an extended TODIM within the interval type-2 fuzzy environment for green supplier selection. Yu et al. (2019) proposed an extended TOPSIS under an interval-valued Pythagorean fuzzy set to select a sustainable supplier. Rouyendegh et al. (2020) utilized intuitionistic fuzzy TOPSIS for green supplier selection. Chen et al. (2020) improved an integrated rough-fuzzy DEMATEL-TOPSIS approach for sustainable supplier selection. Silva et al. (2020) present a literature review on sustainability-related supplier risk management. The findings of this research are the increased prevalence of sustainable supply chain management and supply chain risk management, the scarcity of the social and economic dimensions of sustainability, the increased utilization of combined models, and fuzzy heuristic models with multi-criteria decision-making models. Saputro et al. (2022) reviewed 326 studies published from 2000 to 2021. They investigate these papers under sourcing strategy, decision scope and environment, selection criteria, and solution approaches. This research shows that there is a research gap still in integrated supplier selection, including risk mitigation, sustainability, and new technology adoption.

A limited number of publications in the literature have discussed sustainability and risk together. Chen and Zou (2017) proposed an integrated method that combined the GRA method with a generalized intuitionistic fuzzy set to provide supplier selection with risk aversion. Cost, high quality, good service performance, and a good supplier profile are critical criteria for the discussed case. Alikhani et al. (2019) generated a solution approach for supplier selection problems under sustainability and risk criteria simultaneously and applied it to an Iranian supermarket company. The risk factors for assessing the alternatives are quality, cost, long-term cooperation, bankruptcy, on-time delivery, supplier constraints, supplier's profile, continuity, second-tier supplier, contract, and opportunity. They proposed an improved super-efficiency DEA model to evaluate candidate suppliers using interval type-2 fuzzy sets. Yazdani et al. (2019) presented an integrated decision-making method that includes DEMATEL, FMEA, and EDAS to choose green suppliers considering risk factors. Defects in design, GHG pollution, water pollution, government regulation, financial risk, unemployment rate, and natural disasters are considered the main evaluation criteria in the analyzed case. Fagundes et al. (2021) presented a fuzzy extended analytic hierarchy process method for supplier selection considering supplier risks. The evaluation factors, which are delivery, performance, price, and financial, are used to evaluate supplier performance, and price and financial factors are considered as risk factors in this study.

In the literature review, the number of articles and the scope of discussing a supply chain management approach and supplier evaluation system considering risk and sustainability have shown that there is a research gap in this area.

3. RESEARCH DESIGN

3.1. Intuitionistic Fuzzy Sets

Atanassov introduced intuitionistic fuzzy sets in 1986 as an extended form of fuzzy set theory. Intuitionistic fuzzy sets are represented as follows:

$$A=\{(x, \mu_A(x), \nu_A(x) \mid x \in X \} \quad (1)$$

where $\mu_A(x)$, $\nu_A(x) \rightarrow [0,1]$ represent a membership and non-membership function, such that

$$0 \leq \mu_A(x) + \nu_A(x) \leq 1 \quad (2)$$

Hesitation degree or intuitionistic fuzzy index $\pi_A(x)$ is third parameter of intuitionistic fuzzy sets, whether x belongs to A or not.

$$\pi_A(x) = 1 - \mu_A(x) - \nu_A(x) \quad (3)$$

$\pi_A(x)$ represents hesitation degree for every $x \in X$ to subset A.

$$0 \leq \pi_A(x) \leq 1 \quad (4)$$

3.2. Intuitionistic Fuzzy Topsis

Boran et al. (2009) introduced intuitionistic fuzzy TOPSIS. A group of alternatives is $A=\{A_1,A_2,\ldots,A_m\}$ and a group of criteria is $X=\{X_1,X_2,\ldots,X_n\}$. The application procedure of this method is given as the following steps (Boran et al., 2009):

Step 1. Assign the decision-makers weights.

The decision group consists of *l* decision-makers, and the priority level of the decision-makers is expressed in intuitionistic fuzzy numbers as linguistic expressions. The intuitionistic fuzzy number $D_k = [\mu_k, v_k, \pi_k]$ defines the kth sequence of decision makers. The *k*th decision maker's weight can be calculated as follows:

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

$$\sum_{k=1}^{l}\lambda_k = 1 \quad (5)$$

Step 2. Set the aggregated intuitionistic fuzzy decision matrix, considering the opinions of decision makers.

Assume $R^{(k)}=(r_{ij}^{k})_{mxn}$ is an intuitionistic fuzzy decision matrix of each decision-maker. $\lambda = \{\lambda_1, \lambda_2, \ldots, \lambda_l\}$ is the set of the weights of decision makers, and the summation of these weights equals to one ($\lambda_k \in [0,1]$).. In group decision-making logic, a group decision is obtained by combining all the decision makers' opinions. The aggregated intuitionistic fuzzy decision matrix $R^{(k)}=(r_{ij}^{k})_{mxn}$ can be represented as follows:

$$\begin{aligned} r_{ij} &= IFWA_{\lambda}\,(r_{ij}^{(1)}, r_{ij}^{(2)}, \ldots, r_{ij}^{(l)}) \\ &= \lambda_1 r_{ij}^{(1)} \oplus \lambda_2 r_{ij}^{(2)} \oplus \lambda_3 r_{ij}^{(3)} \oplus \ldots \oplus \lambda_l r_{ij}^{(l)} \\ &= \left[1 - \Pi_{k=1}^{l}\left(1-\mu_{ij}^{(k)}\right)^{\lambda_k}, \Pi_{k=1}^{l}\left(v_{ij}^{(k)}\right)^{\lambda_k}, \Pi_{k=1}^{l}\left(1-\mu_{ij}^{(k)}\right)^{\lambda_k} - \Pi_{k=1}^{l}\left(v_{ij}^{(k)}\right)^{\lambda_k}\right] \end{aligned} \quad (6)$$

$$R=\begin{bmatrix} (\mu_{A_1}(x_1), v_{A_1}(x_1), \pi_{A_1}(x_1)) & \left(\mu_{A_1}(x_2), v_{A_1}(x_2), \pi_{A_1}(x_2)\right) & \ldots. & (\mu_{A_1}(x_n), v_{A_1}(x_n), \pi_{A_1}(x_n)) \\ \vdots & \vdots & \ddots & \vdots \\ (\mu_{A_m}(x_1), v_{A_m}(x_1), \pi_{A_m}(x_1)) & (\mu_{A_m}(x_2), v_{A_m}(x_2), \pi_{A_m}(x_2)) & & \mu_{A_m}(x_n), v_{A_m}(x_n), \pi_{A_m}(x_n)) \end{bmatrix} \quad (7)$$

Step 3. Determine the weights of criteria.

The criteria have different effects on the final rank, and we assign the weights of criteria. Let $w_j^k = [\mu_j^k, v_j^k, \pi_j^k]$ is an intuitionistic fuzzy number assigned to criterion X_j by the *k*th decision maker. The following formula is used to calculate the weights of criteria:

$$\begin{aligned} w_{ij} &= IFWA_{\lambda}\,(w_j^{(1)}, w_j^{(2)}, \ldots, w_j^{(l)}) \\ &= \lambda_1 w_j^{(1)} \oplus \lambda_2 w_j^{(2)} \oplus \lambda_3 w_j^{(3)} \oplus \ldots \oplus \lambda_l w_j^{(l)} \\ &= \left[1 - \Pi_{k=1}^{l}\left(1-\mu_j^{(k)}\right)^{\lambda_k}, \Pi_{k=1}^{l}\left(v_j^{(k)}\right)^{\lambda_k}, \Pi_{k=1}^{l}\left(1-\mu_j^{(k)}\right)^{\lambda_k} - \Pi_{k=1}^{l}\left(v_j^{(k)}\right)^{\lambda_k}\right] \end{aligned}$$

$$W=[w_1, w_2, w_3, \ldots, w_j] \quad (8)$$

Here $w^j = (\mu^j, v^j, \pi^j)$ (j=1,2,….,n).

Step 4. Determine the aggregated weighted intuitionistic fuzzy decision matrix.

After the weights of criteria are determined, the aggregated weighted intuitionistic fuzzy decision matrix is constructed as follows:

$$R \otimes W = \{(x, \mu_{A_i}(x).\mu_w(x), v_{A_i}(x) + v_m(x) - v_{A_i}(x).v_m(x)\rangle \mid x \epsilon X\} \quad (9)$$

and

$$\pi_{A_i.w}(x) = 1 - v_{A_i}(x) - v_m(x) - \mu_{A_i}(x).\mu_w(x) + v_{A_i}(x).v_m(x) \quad (10)$$

After that, the aggregated weighted intuitionistic fuzzy decision matrix can be constructed as follows:

$$R' = \begin{bmatrix} \left(\mu_{A_1w}(x_1), v_{A_1w}(x_1), \pi_{A_1w}(x_1)\right) & \left(\mu_{A_1w}(x_2), v_{A_1w}(x_2), \pi_{A_1w}(x_2)\right) & \cdots \left(\mu_{A_1w}(x_n), v_{A_1w}(x_n), \pi_{A_1w}(x_n)\right) \\ \vdots & \ddots & \vdots \\ \left(\mu_{A_mw}(x_1), v_{A_mw}(x_1), \pi_{A_mw}(x_1)\right) & \left(\mu_{A_mw}(x_2), v_{A_mw}(x_2), \pi_{A_mw}(x_2)\right) & \cdots \left(\mu_{A_mw}(x_n), v_{A_mw}(x_n), \pi_{A_mw}(x_n)\right) \end{bmatrix} \quad (11)$$

$$R' = \begin{bmatrix} r'_{11} & \cdots & r'_{1j} \\ \vdots & \ddots & \vdots \\ r'_{i1} & \cdots & r'_{ij} \end{bmatrix} \quad (12)$$

$r'_{ij} = (\mu'_{Ai}, v'_{Ai}, \pi'_{Ai}) = \left(\mu_{A_iw}(x_j), v_{A_iw}(x_j), \pi_{A_iw}(x_j)\right)$ is the component of weighted intuitionistic fuzzy decision matrix.

Step 5. Generate the intuitionistic fuzzy positive-ideal solution and the intuitionistic fuzzy negative-ideal solution.

Assume J_1 denotes the set of benefit criteria and J_2 denotes the set of cost criteria. A^+ is an intuitionistic fuzzy positive-ideal solution, and A^- is an intuitionistic fuzzy negative-ideal solution. Equation 13,14,15 are used to obtain A^+ and equation 13,16,17 are used to determine A^-.

$$A^+ = (\mu_{A^+w}(x_j), v_{A^+w}(x_j)) \text{ and } A^- = (\mu_{A^-w}(x_j), v_{A^-w}(x_j)) \quad (13)$$

Where

$$\mu_{A^+w}(x_j) = ((\max_i \mu_{A_i.w}(x_j) \mid j\epsilon J_1), (\min_i \mu_{A_i.w}(x_j) \mid j\epsilon J_2)) \quad (14)$$

$$v_{A^+w}(x_j) = ((\min_i v_{A_i.w}(x_j) \mid j\epsilon J_1), (\max_i v_{A_i.w}(x_j) \mid j\epsilon J_2)) \quad (15)$$

$$\mu_{A^-w}(x_j) = ((\min_i \mu_{A_i.w}(x_j) \mid j\epsilon J_1), (\min_i \mu_{A_i.w}(x_j) \mid j\epsilon J_2)) \quad (16)$$

$$v_{A^-w}(x_j) = ((\max_i v_{A_i.w}(x_j) \mid j\epsilon J_1), (\min_i v_{A_i.w}(x_j) \mid j\epsilon J_2)) \quad (17)$$

Step 6. Calculate the separation measures.

The distance between alternatives in an intuitionistic fuzzy set is measured by Hamming distance, and Euclidean distance and their normalized distance measures are also utilized. In this paper, the normalized Euclidean distance is used (Szmidt and Kacprzyk, 2002).

$$S^+ = \sqrt{\frac{1}{2n}\sum_{j=1}^{n}\left[\left(\mu_{A_i.w}(x_j) - \mu_{A^+w}(x_j)\right)^2 + \left(v_{A_i.w}(x_j) - v_{A^+w}(x_j)\right)^2 + \left(\pi_{A_i.w}(x_j) - \pi_{A^+w}(x_j)\right)^2\right]} \quad (18)$$

$$S^- = \sqrt{\frac{1}{2n}\sum_{j=1}^{n}\left[\left(\mu_{A_i.w}(x_j) - \mu_{A^-w}(x_j)\right)^2 + \left(v_{A_i.w}(x_j) - v_{A^-w}(x_j)\right)^2 + \left(\pi_{A_i.w}(x_j) - \pi_{A^-w}(x_j)\right)^2\right]} \quad (19)$$

Step 7. Obtain the relative closeness coefficient to the intuitionistic ideal solution.

Equation 20 is utilized to calculate the relative closeness coefficient for an alternative A_i to the intuitionistic fuzzy positive-ideal solution A^+.

$$C_{i^*} = \frac{S_{i^-}}{S_{i^*}+S_{i^-}} \quad where\ 0 \leq C_{i^*} \leq 1 \tag{20}$$

Step 8. Rank the alternatives.

The relative closeness coefficients of all alternatives are ranked according to descending order C_{i^*}'s.

4. CASE STUDY

A real-life case is presented to illustrate the decision making process and demonstrate the applicability of the proposed model. A steel manufacturer located in Turkey offers products to the international market. About ninety percent of the company's sales are made up of international customers. In order to be competitive in the global market, it is necessary to meet customer expectations and legal regulations. In addition, it adapts its supply chain management approach to its company within the framework of environmentally friendly production and a management approach that takes risks into account, which is one of the inevitable requirements of the age. The company carries out its production with an order-based production approach. It is very important to obtain the raw materials and semi-finished products to be supplied under the specified conditions (quality, time, price, etc.). For this purpose, it is desired to enhance green applications and handle supply chain risks for the post-COVID-19 era. As a result, the company raises its sustainability level and reduces global risks in order to raise environmental awareness and improve supply chain management in the global environment. To achieve the strategic goals of the company in the steel sector, they adapted the supplier evaluation and selection system. This firm determined a decision group consisting of three decision makers. ABC analysis refers to the inventory management technique used to identify items that make up a significant portion of the overall inventory value and classify them as critical, important, and moderately important. The product to be examined is determined by ABC analysis. The data to be used in the study was provided by the decision group.

The supplier evaluation criteria are determined by the decision group and the proposed methodology is applied to select suppliers. Four criteria are: economic (C1), environmental (C2), social (C3), and risk (C4). Zimmer et al. (2016) emphasize that price, delivery, and quality are important criteria to fulfill the aims of the company. In this study, these criteria are considered under the economic criteria. Environmental criteria cover environment-related certificates, pollution reduction, use of environmentally friendly materials, and recycling capability; social criteria consist of occupational health and safety management, standardized health and safety conditions, the interests and rights of employees, and employee welfare; risk criteria include currency risks, disruption risks, and operational risks. The degree of importance of each criterion is obtained by the decision makers' evaluation of the criteria separately by using linguistic expressions.

The application procedure of the methodology consists of the following steps:

Step 1. Assign the weights of decision makers.

The linguistic terms used to evaluate the importance level of decision-makers are given in Table 1. The manager determined the importance level of the decision makers in the decision process with the help of linguistic expressions used in determining the importance level presented in Table 1. The importance of decision-makers and their weights are shown in Table 2. Equation 5 is used to calculate the weights of decision makers.

$$\lambda_{DM1} = \frac{(0{,}9+0x(\frac{0{,}9}{(0{,}9+0{,}1)}))}{\left(0{,}9+0x\left(\frac{0{,}9}{(0{,}9+0{,}1)}\right)\right)+\left(0{,}75+0{,}05x\left(\frac{0{,}75}{(0{,}75+0{,}2)}\right)\right)+\left(0{,}75+0{,}05x\left(\frac{0{,}75}{(0{,}75+0{,}2)}\right)\right)} = 0{,}363$$

$$\lambda_{DM2} = \frac{(0{,}75+0{,}05x(\frac{0{,}75}{(0{,}75+0{,}2)}))}{\left(0{,}9+0x\left(\frac{0{,}9}{(0{,}9+0{,}1)}\right)\right)+\left(0{,}75+0{,}05x\left(\frac{0{,}75}{(0{,}75+0{,}2)}\right)\right)+\left(0{,}75+0{,}05x\left(\frac{0{,}75}{(0{,}75+0{,}2)}\right)\right)} = 0{,}318$$

$$\lambda_{DM3} = \frac{(0{,}75+0{,}05x(\frac{0{,}75}{(0{,}75+0{,}2)}))}{\left(0{,}9+0x\left(\frac{0{,}9}{(0{,}9+0{,}1)}\right)\right)+\left(0{,}75+0{,}05x\left(\frac{0{,}75}{(0{,}75+0{,}2)}\right)\right)+\left(0{,}75+0{,}05x\left(\frac{0{,}75}{(0{,}75+0{,}2)}\right)\right)} = 0{,}318$$

Table 1: Linguistic Terms for Rating the Importance of Criteria and Decision-Makers

Linguistic terms	Intuitionistic fuzzy numbers
Very important	(0.90,0.10)
Important	(0.75,0.20)
Medium	(0.50,0.45)
Unimportant	(0.35,0.60)
Very unimportant	(0.10,0.90)

Table 2: The Importance of Decision-Makers and their Weights

Linguistic terms	DM1 Very important	DM2 Important	DM3 Important
Weight	0.374	0.313	0.313

Step 2. Set the aggregated intuitionistic fuzzy decision matrix considering the opinions of decision-makers.

The linguistic terms for evaluating the alternatives are provided in Table 3. The decision makers evaluated the performance of the alternatives separately for each criterion with the help of alternative evaluation linguistic expressions given in Table3. The obtained ratings of the alternatives are shown in Table 4.

Table 3: Linguistic Expression for Rating the Alternatives

Linguistic terms	Intuitionistic fuzzy numbers
Extremely good (EG)/extremely high (EH)	[1.00,0.00]
Very very good (VVG)/very very high (VVH)	[0.90,0.10]
Very good (VG)/very high (VH)	[0.80,0.10]
Good (G)/high (H)	[0.70,0.20]
Medium good (MG)/medium high (MH)	[0.60,0.30]
Fair (F) /medium (M)	[0.50,0.40]
Medium bad (MB)/ medium low (ML)	[0.40,0.50]
Bad (B) /low (L)	[0.25,0.60]
Very bad (VB)/ very low (VL)	[0.10,0.75]
Very very bad (VVB)/very very low (VVL)	[0.10,0.90]

Table 4: The Ratings of the Alternatives

Criteria	Alternatives	Decision Makers		
		DM1	DM2	DM3
C1	A1	M	ML	L
	A2	M	M	M
	A3	VVL	VL	VL
	A4	VH	VH	VVH
C2	A1	MG	G	G
	A2	G	F	F
	A3	VG	VG	G
	A4	MB	F	F
C3	A1	G	VG	G
	A2	G	MG	MG
	A3	VG	G	VG
	A4	F	F	MG
C4	A1	H	H	H
	A2	MH	M	M
	A3	VL	VL	VL
	A4	VVH	VH	VH

The aggregated intuitionistic fuzzy decision matrix is constructed by using Equation 6 as follows:

$$R=\begin{matrix} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{matrix}\begin{matrix} C1 & C2 & C3 & C4 \\ \left[\begin{matrix} (0.397,0.489,0.114) & (0.667,0.232,0.101) & (0.736,0.160,0.103) & (0.700,0.200,0.100) \\ (0.500,0.400,0.100) & (0.585,0.311,0.104) & (0,640,0.259,0.101) & (0.539,0.360,0.101) \\ (0.100,0.801,0.099) & (0.772,0.125,0.103) & (0.772,0.125,0.103) & (0.100,0.750,0.150) \\ (0.840,0.100,0.060) & (0.466,0.434,0.100) & (0.534,0.365,0.101) & (0.844,0.100,0.056) \end{matrix}\right] \end{matrix}$$

Step 3. Determine the weights of the criteria.

The decision makers determined the importance level of the criteria by using linguistic expressions expressing the importance levels of the criteria given in Table 1. The importance levels of the decision makers are taken into account. Table 5 represents the importance level of the criteria as linguistic terms. Equation 8 is utilized to calculate the weights of the criteria.

Table 5: The Importance Level of Criteria

	DM1	DM2	DM3
C1	VI	VI	I
C2	I	I	M
C3	I	I	I
C4	VI	I	I

The weights of criteria are obtained as follows:

$$W=\begin{matrix} C1 \\ C2 \\ C3 \\ C4 \end{matrix}\begin{bmatrix} (0.866,0.125,0.009) \\ (0.688,0.259,0.053) \\ (0.750,0.200,0.050) \\ (0.821,0.156,0.024) \end{bmatrix}$$

Step 4. Determine aggregated weighted intuitionistic fuzzy decision matrix.

Equation 9, 10, 11, 12 are used to construct the aggregated weighted intuitionistic fuzzy decision matrix as a follows:

$$R' = \begin{matrix} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{matrix}\begin{matrix} C1 & C2 & C3 & C4 \\ (0.344,0.552,0.104) & (0.459,0.431,0.110) & (0.552,0.328,0.119) & (0.606,0.300,0.094) \\ (0.433,0.475,0.092) & (0.402,0.489,0.108) & (0,480,0.407,0.113) & (0.467,0.440,0.093) \\ (0.087,0.826,0.087) & (0.532,0.351,0.117) & (0.579,0.300,0.121) & (0.087,0.781,0.132) \\ (0.727,0.212,0.061) & (0.321,0.580,0.099) & (0.401,0.492,0.107) & (0.731,0.212,0.056) \end{matrix}$$

Step 5. Generate the intuitionistic fuzzy positive-ideal solution and intuitionistic fuzzy negative-ideal solution.

Environmental and social are the benefit criteria J1 = {C2, C3}, and economic and risk pollution control are the cost criteria J2 = {C1, C4}. The intuitionistic fuzzy positive-ideal solution and intuitionistic fuzzy negative-ideal solution are obtained as follows:

A^+ ={(0.087,0.826,0.087), (0.523,0.351,0.117),(0.579,0.300,0.121),(0.087,0.781,0.132)}
A- ={(0.727,0.212,0.061),(0.321,0.580,0.099),(0.401,0.492,0.107),(0.731,0.212,0.056)}

Step 6. Calculate the separation measures.

Negative and positive separation measures using Equation 19 and 18 are shown in Table 6.

Table 6: Separation Measures and Relative Closeness of Each Alternative

Alternatives	S^*	S^-	C_{i^*}
A_1	0.287	0.218	0.432
A_2	0.265	0.196	0.425
A_3	0.000	0.461	1.000
A_4	0.461	0.000	0.000

Step 7. Obtain the relative closeness coefficient to the intuitionistic ideal solution.

Equation 20 is utilized to calculate the relative closeness coefficient of each alternative and the results are given in fourth column of Table 6.

Step 8. Rank the alternatives.

The alternatives are ranked according to the relative closeness coefficient and the descending order of C_{i^*} $A_3>A_1>A_2>A_4$ is the ranking of alternatives.

4.1 Sensitivity Analysis and Validation of The Results

One of the issues that comes to mind applying the decision-making method is the effect of changing the parameters on the result. Another is the result of different decision-making approaches. In decision-making problems, it is very important to check the robustness of the results and to analyze the sensitivity of the obtained results to the changes in the input parameters. First of all, the effect of the change in model parameters on the result was examined. Afterwards, a comparison of the results obtained by applying a different method was presented.

The importance levels of the decision makers were determined according to the subjective evaluation of the manager and were used to combine the weighting coefficients of the criteria. Since the decision maker's importance level has an impact on the criterion weight calculation, it is necessary to examine the effect of the decision maker's importance level change on the final ranking.

The decision maker weights obtained by the evaluation of the manager used in the study are as follows. w_{DM1}=0.374, w_{DM2}=0.313, w_{DM3}=0.313. According to this data, the decision maker with the greatest influence on the evaluation is decision maker 1. In the analysis of the effect of the importance level of the decision maker on the final ranking, 125 different scenarios where all possible combinations of decision makers were examined. The change in the weights of the decision makers based on the scenario is given in Figure 1. After generating new 125 weight coefficient vectors, their effects on the final rank change obtained by the MCMD methodology were analyzed. The final ranking change is shown in Figure 2 according to the scenarios. When the effect of the change in the weights of the decision makers on the result was examined, it was seen that the relative closeness coefficient of each alternative changed. When the ranking of the alternatives is examined, it has been determined that the ranking of the other scenarios is the same as the main problem ranking, except three scenarios. A3 alternative is in the first place. A1, A2, and A4 are in decreasing order of importance. The A4 alternative is in the fourth, that is, the last place. In the different rankings, the alternatives in the second (A1) and third places (A2) exchanged their places. The presented results show that the change in the value of the weighting coefficients of decision makers in general may affect the final ranking results. In the discussed problem, changes of the weights of the decision makers' criteria caused minor changes in the final alternative ranks. These results show that the obtained solution is stable.

In the evaluations of the decision makers, the effect of changing the most important criterion on the result for the decision makers was examined. Fifteen scenarios were obtained by changing the importance level of one decision maker without changing the importance level of other decision makers. Although the relative closeness coefficient of each alternative changed in all scenarios, the final rank did not change.

In this study, the intuitionistic fuzzy MARCOS method (Ecer and Pamucar, 2022) has been used in comparison to deal with uncertainty and inaccuracy. Based on the obtained results, the alternative A3 is the best alternative according to both MCDM methods. The results showed that IF TOPSIS and IF MARCOS multi-criteria methods gave the same rank.

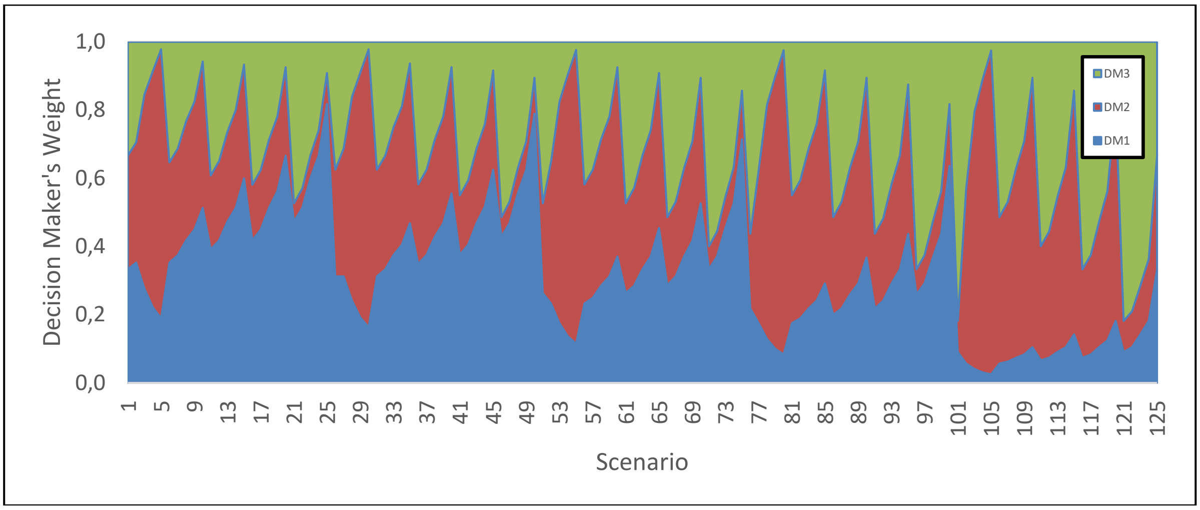

Figure 1. Decision maker’s weight through 125 scenarios

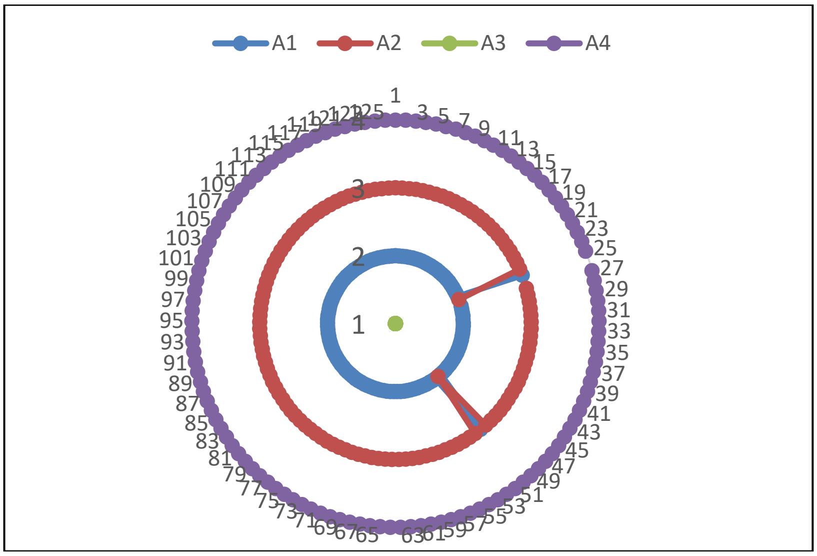

Figure 2. The change of DM's weight on change of final rankings

5.CONCLUSION

The eruption of the supply issue during the Covid era has enhanced understanding of the significance of risks and sustainability when evaluating and choosing suppliers. The issues that emerged on the discussion during and after the Covid period included evaluating all potential hazards that could arise in the world and paying attention to the problem of sustainability in order to assist risk reduction and comply to legal requirements.

This paper presents a multi-criteria intuitionistic fuzzy group decision-making method called IF-TOPSIS which aims to evaluate the most acceptable suppliers in supply chain management under sustainability and risks among alternatives regarding several criteria. The method allows decision-makers to express their opinions with linguistic expressions in evaluating alternatives to evaluation criteria. TOPSIS provides order preference by similarity to an ideal solution. The goal of this article is to establish a comprehensive approach to supply chain management in respect of collaborating with suppliers in alignment with the company's strategic goals, considering risks and sustainability for the post-COVID-19 era. Using intuitionistic fuzzy sets, supply chain management uncertainty is managed. The alternatives and the weights of supplier evaluation criteria are set as linguistic terms which defined by intuitionistic fuzzy numbers. The aggregated operation is conducted by using intuitionistic fuzzy averaging operator. The intuitionistic fuzzy positive-ideal solution and intuitionistic fuzzy negative-ideal solution are derived from the euclidean distance and the relative closeness coefficients of alternatives are calculated. The solutions have been sorted. Because decision makers' perceptions are ambiguous, the TOPSIS technique paired with intuitionistic fuzzy sets provides a high possibility of success for multi-criteria decision-making situations. The presented method ensures the selected supplier meets the expectations of decision makers.

The presented approach is applied to a manufacturing company in Turkey. To achieve company goals, supplier evaluation criteria were determined, considering the minimization of risks to be encountered in the global market and providing sustainable solutions. The ranking of suppliers was founded as a part of the application of the presented method. Thus, a sustainable and risk assessment system consistent with company goals has been adopted. The three decision makers' opinions were utilized to obtain the ranking results. In the results obtained, alternative 3 are ranked first, and A1, A2, A4 are ranked in decreasing order of importance. 125 experimental studies were conducted with all possible options to determine the final ranking influence of decision makers. The results of the experimental study performed gave the same order, supporting the results obtained. This supports that the approach used gives very consistent results for the problem. The effect of the change in the importance levels of the evaluation criteria, which is another parameter, on the result was examined. In this experimental study, fifteen scenarios were generated where the importance level of each decision maker is changed while the importance level of other decision makers remained the same. In the experimental study results, the final ranking is the same as the presented problem ranking. This supports the applicability and validity of the result obtained from the proposed approach for the firm. Additional comparative analysis was conducted to compare the presented approach with the MARCOS multi-criteria decision-making approach under the IF setting. Furthermore, a detailed sensitivity analysis has been conducted on the decision parameters. The results reveal that the presented MDCM approach is stable, valid, and feasible for the decision-making problems.

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Beyan ve Açıklamalar (Disclosure Statements)

1. Bu çalışmanın yazarları, araştırma ve yayın etiği ilkelerine uyduklarını kabul etmektedirler (The authors of this article confirm that their work complies with the principles of research and publication ethics).

2. Yazarlar tarafından herhangi bir çıkar çatışması beyan edilmemiştir (No potential conflict of interest was reported by the authors).

3. Bu çalışma, intihal tarama programı kullanılarak intihal taramasından geçirilmiştir (This article was screened for potential plagiarism using a plagiarism screening program).