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RESEARCH ARTICLE

An Interval-Valued Pythagorean Fuzzy AHP and COPRAS Hybrid Methods for the Supplier Selection Problem

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Abstract

Companies must be able to identify their suppliers appropriately and effectively in order to survive in the competitive market conditions. In order to fulfill and surpass the expectations of the consumers and clients, companies need to interact with the relevant suppliers. It is a tough manner for companies to select the best supplier from a large number of relevant alternatives. The selection process of the appropriate supplier involves multiple interacting and competing factors. Generally, the selection process and its results cause a waste of time and money. For this purpose, MCDM methodologies are utilized to manage this complex process efficiently. MCDMs allows for consistent and accurate decision-making as well as the selection of the most appropriate supplier. MCDM is one the most preferred tool to select the best alternative under the conflicting and competitive criteria when the evaluations are made in crisp numbers. Therefore, MCDM methods are preferred in various applications in academia and real life. However, the evaluations could not be always possible with crisp numbers, especially in vague environments or evaluations needs qualitative data. This study is one of the first to combine the AHP and COPRAS supplier selection methods with interval-valued Pythagorean fuzzy (IPF) logic. The effectiveness of these IPF-AHP and IPF-COPRAS evaluations for the supplier selection problem is compared and examined. The experimental results of case scenarios show that IPF is an effective way to apply in decision-making applications. In addition, sensitivity analysis is conducted to evaluate the proposed methodologies. According to sensitivity analysis, the IPF-AHP and IPF-COPRAS be able to illustrate the effects of small changings in criteria weights. Therefore, companies can use the IPF-AHP and IPF-COPRAS to assist their decision-makers in identifying and selecting the best suppliers.

Keywords Multi-criteria decision-making (MCDM) · Analytic hierarchy process (AHP) · Complex proportional assessment (COPRAS) · Supplier selection · Supply chain management (SCM)

1 Introduction

Businesses have had to make tough choices to enhance organizational structures, reduce expenses, and produce high-quality items in a competitive market. Evaluating various elements, exactly comparing alternatives, and making consistent and successful judgments have become critical and difficult for enterprises. This is one of the first studies to combine AHP and COPRAS supplier selection techniques with interval-valued Pythagorean fuzzy (IPF) logic. Comparing and analyzing the effectiveness of these IPF-AHP and IPF-COPRAS evaluations for the supplier selection problem. The efficient use of a company's limited resources such as human, financial, and intellectual properties is contingent on making the optimal choice from the alternatives available. MCDM is a structured process that helps companies select the best supplier by considering multiple criteria. It offers benefits such as improved decision-making, increased transparency, better risk management, increased efficiency, and better supplier relationships. MCDM helps companies make informed decisions, reduce time and resources required for supplier selection, and build better relationships with suppliers by identifying and managing risks associated with supplier selection. In this direction, procedures such as MCDM are utilized to select the most appropriate solution for the objective while considering competing criteria.

Extended author information available on the last page of the article

In supplier selection, there may be criteria that contradict each other, such as when a company wants to select a supplier who offers the lowest price while also ensuring that the supplier has a good reputation for quality. In this case, price and quality are diametrically opposed criteria. MCDM techniques provide a structured approach to supplier selection decision-making, taking into account multiple criteria and ensuring that all are taken into account. Companies can prioritize the most important criteria and determine their appropriate weighting in the decision-making process by breaking them down into smaller, manageable components. MCDM techniques are mathematical models that aid decision-making when multiple contradicting criteria are applied to analyze feasible solutions [1]. They facilitate accurate decision-making in fields where identifying the best alternative is challenging [2]. MCDM-based methods assist the selection of the optimal alternative, which is determined by examining the weights associated with each criterion.

Selecting a supplier is one of the most crucial business decisions. Quantitative and qualitative factors play a role in the strategic importance of supplier selection for numerous businesses. Since a poor supplier selection could reduce supply chain efficacy and result in a loss of competitive advantage, it is important to carefully select suppliers. Thus, selecting the most qualified candidate from a pool of candidates is a difficult multi-criteria decision-making process.

Businesses must choose appropriate suppliers to maintain production and meet client needs. Supply chains have challenges in obtaining commodities from the right source at the right time and at the lowest price. Decision-makers must choose the right supplier to manage the supply chain from production to consumption. A reliable supplier also helps organizations meet their manufacturing goals. The right supplier improves production flexibility and quality. Thus, consumer satisfaction, purchasing costs, and the company's competitiveness can improve. Supplier-supplied raw materials and production capacity determine enterprise product quality [3]. As a result, organizations have prioritized evaluating various suppliers and choosing the best one based on predetermined criteria [4].

Selecting the wrong supplier can cost the organization money, time, clients, and reputation. Thus, providers should be selected using scientific and required criteria. Strategic decisions that meet the goal grow the company.

The primary objective of supplier selection is to select a supplier that is compatible with the organization and provides the greatest value [3]. In this instance, MCDM techniques are used to determine the most suitable alternative for achieving the goal, taking into account competing criteria. This study investigated the MCDM Problem of selecting the best supplier. Before analyzing potential suppliers, the necessary criteria were established.

Weights for these criteria were determined using the AHP approach. Following that, each alternative supplier was evaluated quantitatively and qualitatively. The COPRAS approach was used to determine the best acceptable supplier alternative throughout the option evaluation process. The crisp numbers may not reflect the decision maker's judgments accurately. For example, "Very Strongly Important (VSI)" is shown by 7 on a linguistic scale from integer numbers between 1 and 9. However, VSI could be defined more accurately using a triangular fuzzy number that assigns VSI around 7 such as (6.5, 7.0, 7.5).

This definition better illustrates decision-makers' judgments. To manage the lack of knowledge and uncertain data regarding decision-making, most MCDMs uses fuzzy logic models such as type-2 fuzzy, intuitionistic fuzzy, Pythagorean fuzzy, and neutrosophic fuzzy. The first fuzzy set applications represented membership functions as system complexity. After the first fuzzy set applications, fuzzy logic is extended to type-n fuzzy ideas (Zadeh, 1975). Atanossov (1999) introduces intuitionistic type-2 fuzzy (IFS2) sets with membership and non-membership functions. Yager (2013) extended IFT2 via Pythagorean Fuzzy Sets (PFS). PFS extends membership and non-membership functions to help decision-makers handle uncertainty better than fuzzy sets [5]. Thus, this study compares PFS-based MCDM algorithms for imprecise information. This study develops an interval-valued Pythagorean Fuzzy AHP (IPF-AHP) and IPF-COPRAS to pick the best supplier among multiple alternatives under conflicting criteria.

The remaining sections of the paper are organized as follows: In Sect. 2, a literature review of the different versions of AHP and COPRAS, Pythagorean fuzzy sets, and supplier selection is provided. Section 3 explains fuzzy sets with Pythagorean coefficients. The IPF-AHP and IPF-COPRAS procedures are described in Sect. 4. In Sect. 5, applications of the IPF-AHP and IPF-COPRAS are presented with a sensitivity analysis. Section 6 concludes this paper with its conclusions and recommendations for further research.

2 Literature Review

Numerous studies on supplier selection criteria, supplier selection, and evaluation have been published in the literature. Alkahtani et al. [6] developed an MCDM tool that requires answering two questions in order to select the best supplier for a business. To begin, the queries "What criteria should be used to evaluate each supplier?" and "How should the best supplier be selected?" were addressed. A literature review was undertaken on these two challenges, and many viable approaches were provided. Madic et al. [7] examined the COPRAS technique for supplier selection again. A construction and agricultural tools manufacturer employed this method. Results were also compared to previous studies. Rouyendegh et al. [8] investigated green supplier selection (GSS) for sustainability. They choose the finest green provider using IFTOPSIS. Wang Chen et al. [9] recommended fuzzy MCDM for green supplier selection and evaluation. They presented an economic and environmental approach. A case study established the practicality and importance of the approach. Percin [10] adapted MCDM to the cyclical supplier selection (CSS) problem of a cement company. He proposed a CSS strategy employing interval-valued intuitionistic fuzzy sets (IVIFS) with AHP and COPRAS. In addition, AHP and COPRAS were used in different application areas such as evaluating the website quality of banks by defining weights of evaluation criteria related to the quality of bank websites [11]. Several MCDM techniques are used to define sustainable supplier selection, such as FUCOM [12, 13]; therefore, the MCDM methodology for supplier selection has been published in the literature. The table below provides a summary of current research. Analyzing the studies reveals that the approaches are used independently or combination with one another.

In the literature, there are many studies in which AHP and COPRAS have been integrated to into supply chain management in terms of vendor, supplier, or location decisions. For example, Erdebilli et al. (2023) suggest integrating AHP-COPRAS for vendor selection in SCM [14]. In that study, firstly, the vendor selection criteria are established, and then the relative relevance of the various criteria is evaluated using the AHP. The next step is to assess the potential providers and choose the best vendor using the COPRAS approach [15]. However, in real-time, there may not always be precise information available to evaluate the criteria and alternatives. For this reason, researchers use fuzzy logic in the MCDM technique to handle uncertainty and imprecision in decision-making [16]. Fuzzy logic allows decision-makers to express judgments or preferences in linguistic terms rather than precise numerical values, which are often more realistic and practical. Fuzzy MCDM methods enable more realistic results in solving decision-making problems. Efficient energy use is crucial for economic development, but excessive fossil fuel use harms the environment [17]. Renewable energy emits low greenhouse gases, leading countries to increase usage. Sectoral specific and asymmetric foreign exchange volatility effects affect crude oil, coal, electricity, and petroleum products. A three-dimensional hexagonal structure of nano-inclusions demonstrated better wear resistance and a reduced friction coefficient in polymer films [18, 19]. Therefore, this proposed study provides a decision-making model for supplier selection problems through integrated AHP-COPRAS, which is extended by Pythagorean fuzzy logic. PFL relaxes the requirement that the sum of squares representing an element's membership degree and non-membership degree cannot be larger than 1. As a result, modeling uncertainty and ambiguity in decision-making processes is now more flexible as shown in Table 1. Therefore, a new approach is applied to select the most appropriate supplier for the entire supply chain.

The following criteria are presented in the literature review:

C1: Cost/price	C12: Environmental
C2: Quality	C13: Geographical location
C3: Lead/delivery time	C14: Sustainability
C4: Technology	C15: Performance
C5: Service	C16: Reputation
C6: Flexibility	C17: Cooperation
C7: Distance	C18: Green design
C8: Variety	C19: Green manufacturing system
C9: Technical competence/capability	C20: Management system
C10: Economic	C21: Other criteria
C11: Social	

3 Preliminaries and Methodology

In this section, the AHP and COPRAS procedures, which are both MCDM approaches, were used to evaluate the supplier selection alternatives available to a company. MCDM methodologies offer a structured approach to decision-making, considering all relevant factors, identifying important criteria, weighing them appropriately, identifying trade-offs, and reducing personal biases. However, MCDM can be complex, time-consuming, require significant data, be sensitive to criteria and weights, and may not always produce clear or unambiguous results. Brunelli [46] and Kulakowski [47] describe the phases of the generic AHP method. Alinezhad and Kahlili [15] present the phases and applications of the COPRAS method. In addition, approach-specific details have been provided first and foremost. This information was used to submit an application to identify the most qualified service provider. The interval-valued Pythagorean fuzzy AHP (IPF-AHP) and interval-valued Pythagorean fuzzy (IPF-COPRAS)

Table 1 Literature review of supplier selection with MCDM methods

Author	Title	Method	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21
Yazdi et al. [20]	Supplier Selection in the Oil and Gas Industry: A Comprehensive Approach for Multi-Criteria Decision Analysis	COPRAS, SWARA	✔	✔		✔		✔			✔							✔					✔
Pınar et al. [21]	q-Rung Orthopair Fuzzy TOPSIS Method for Green Supplier Selection Problem	q-Rung Orthopair Fuzzy TOPSIS	✔	✔		✔	✔							✔		✔			✔		✔		✔
Perçin [10]	Circular Supplier Selection Using Interval-Valued Intuitionistic Fuzzy Sets	IVIF AHP, IVIF COPRAS										✔	✔										✔
Tavana et al. [22]	An Integrated and Comprehensive Fuzzy Multicriteria Model for Supplier Selection in Digital Supply Chains	BWM, Fuzzy COPRAS, Fuzzy TOPSIS, Fuzzy MULTIMOORA				✔		✔			✔								✔				✔
Kumari and Mishra [23]	Multi-Criteria COPRAS Method Based on Parametric Measures for Intuitionistic Fuzzy Sets: Application of Green Supplier Selection	COPRAS		✔																✔		✔	✔
Rouyendegh et al. [8]	Intuitionistic Fuzzy TOPSIS Method for Green Supplier Selection Problem	Intuitionistic Fuzzy TOPSIS	✔	✔		✔	✔							✔		✔			✔		✔		✔
Alkahtani et al. [6]	Comparison and Evaluation of Multi-Criteria Supplier Selection approaches: A Case Study	AHP, Fuzzy AHP, Fuzzy TOPSIS	✔				✔										✔						
Petrović et al. [24]	Comparison of Three Fuzzy MCDM Methods for Solving the Supplier Selection Problem	Fuzzy SWARA, Fuzzy TOPSIS, Fuzzy WASPAS, Fuzzy ARAS	✔		✔														✔				✔
Stević et al. [25]	A Novel Multi-Criteria Decision-Making Model: Interval Rough SAW Method for Sustainable Supplier	SAW										✔	✔	✔									
Liu et al. [26]	A Fuzzy Three-Stage Multi-Attribute Decision-Making Approach Based on Customer Needs for Sustainable Supplier Selection	Fuzzy VIKOR		✔	✔							✔	✔	✔								✔	✔

Table 1 (continued)

Author	Title	Method	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21
Sarkar et al. [27]	An Integrated Fuzzy Multiple Criteria Supplier Selection Approach and Its Application in A Welding Company	DANP, Fuzzy TOPSIS, MSGP, FVIKOR	✔		✔	✔	✔				✔				✔						✔		✔
Ajalli et al. [28]	Application of Fuzzy AHP and COPRAS to Solve the Supplier Selection Problems	Fuzzy AHP, COPRAS	✔	✔	✔		✔				✔												
Daneshvar Rouyendegh and Gholamrezanezhad [29]	A MCDM Approach For Supplier Selection Process: A Pilot Study From Iran	TOPSIS	✔	✔	✔				✔														✔
Fallahpour et al. [30]	A Decision Support Model for Sustainable Supplier Selection in Sustainable Supply Chain Management	Fuzzy Preference Programming, Fuzzy TOPSIS	✔	✔	✔		✔	✔															
Yazdani et al. [31]	Integrated QFD-MCDM Framework For Green Supplier Selection	COPRAS	✔	✔	✔															✔			✔
Ecer and Pamucar [3]	Sustainable supplier selection: A novel integrated fuzzy best worst method (F-BWM) and fuzzy CoCoSo with Bonferroni (CoCoSo'B) multi-criteria model	Fuzzy BWM, Fuzzy CoCoSo	✔	✔	✔		✔	✔			✔				✔		✔					✔	✔
Wang Chen et al. [9]	A Fuzzy MCDM Approach for Green Supplier Selection From the Economic and Environmental Aspects	Fuzzy AHP, Fuzzy TOPSIS	✔	✔	✔	✔								✔									
Stević [32]	Supplier Selection Using AHP and COPRAS Method	AHP, COPRAS	✔		✔																		✔
Rouyendegh [33]	Developing an Integrated ANP and Intuitionistic Fuzzy TOPSIS Model for Supplier Selection	ANP, Intuitionistic Fuzzy TOPSIS	✔	✔	✔			✔		✔													
Orji and Wei [34]	An Innovative Integration of Fuzzy-Logic and Systems Dynamics in Sustainable Supplier Selection: A Case on Manufacturing Industry	Fuzzy TOPSIS		✔										✔						✔			✔

Table 1 (continued)

Author	Title	Method	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21
Rouyendegh and Saputro [35]	Supplier Selection Using Integrated Fuzzy TOPSIS and MCGP: A Case Study	Fuzzy TOPSIS, MCGP	✔	✔	✔	✔									✔			✔				✔	✔
Miloš Madić et al. [7]	Application of COPRAS Method for Supplier Selection	COPRAS	✔	✔	✔				✔	✔							✔						
Harikannan et al. [36]	Decision Making Model for Supplier Evaluation and Selection Using MCDM Methods	AHP, TOPSIS	✔	✔	✔		✔																
Dursun and Karsak [37]	A QFD-Based Fuzzy MCDM Approach for Supplier Selection	Fuzzy Weighted Average (FWA)	✔																				✔
Rouyendegh [38]	A Hybrid Intuitionistic MCDM Model for Supplier Selection	AHP, Intuitionistic Fuzzy TOPSIS	✔	✔	✔			✔		✔													
Kannan et al. [39]	Integrated Fuzzy Multi Criteria Decision Making Method And Multi-Objective Programming Approach for Supplier Selection and Order Allocation in A Green Supply Chain	Fuzzy AHP, fuzzy TOPSIS	✔	✔	✔	✔								✔									
Rouyendegh and Erkan [40]	Selecting the Best Supplier Using Analytic Hierarchy Process (AHP) Method	AHP	✔	✔	✔			✔		✔													
Ecer [11]	Multi-criteria decision making for green supplier selection using interval type-2 fuzzy AHP: a case study of a home appliance manufacturer	Fuzzy AHP	✔		✔		✔																✔
Boran et al. [41]	A Multi-Criteria İntuitionistic Fuzzy Group Decision Making For Supplier Selection With TOPSIS Method	Fuzzy TOPSIS	✔	✔	✔																		✔
Önüt et al. [42]	Long Term Supplier Selection Using A Combined Fuzzy MCDM Approach: A Case Study for A Telecommunication Company	Fuzzy ANP, Fuzzy TOPSIS	✔	✔	✔																		✔

Table 1 (continued)

Author	Title	Method	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21
Dağdeviren and Eraslan [43]	Supplier Selection Using PROMETHEE Sequencing Method	PROMETHEE	✓	✓		✓		✓	✓								✓						
Zolfani et al. [44]	A Hybrid MCDM Model Encompassing AHP and COPRAS-G Methods for Selecting Company Supplier in Iran	AHP, COPRAS-G	✓	✓		✓			✓									✓					✓
Chen et al. [45]	A Fuzzy Approach for Supplier Evaluation and Selection in Supply Chain Management	Fuzzy TOPSIS, FPIS, FNIS		✓							✓												✓

techniques are combined with the following interval-valued Pythagorean fuzzy sets prerequisites:

3.1 Preliminaries of Interval-Valued Pythagorean Fuzzy Sets

Yager (2013) defines PFS as the sum of membership degrees, $\mu_{\widetilde{p}}(x)$, and non-membership degrees, $v_{\widetilde{p}}(x)$, of a function $\widetilde{p}(x)$ might be greater than 1; however, the sum of squares of the $\mu_{\widetilde{P}}(x)$ and $v_{\widetilde{p}}(x)$ could be less than or equal to 1 [5].

Definition 1 A PFS, $\widetilde{p}$, is an object that has the form (Yager 2013):

$$\widetilde{p}_1 \widetilde{\oplus \widetilde{p}_2} \cong \left\{ \langle x, \mu_{\widetilde{P}}(x), v_{\widetilde{P}}(x) \rangle ; x \in X \right\},$$

where $\mu_{\widetilde{P}}(x) :\rightarrow [0,1]$ and $v_{\widetilde{P}}(x) :\rightarrow [0,1]$, $x \in X$ and $\forall x \in X$ holds that

$$0 \leq \mu_{\widetilde{P}}(x) + v_{\widetilde{P}}(x) \leq 1.$$

The degree of hesitancy condition is defined as

$$\pi_{\widetilde{P}}(x)^2 = 1 - \mu_{\widetilde{P}}(x)^2 + v_{\widetilde{P}}(x)^2.$$

Definition 2 Let $\widetilde{p_1} = \langle \mu_1, v_1 \rangle$ and $\widetilde{p}_2 = \langle \mu_2, v_2 \rangle$ be two PFNs and summation and multiplication of two PFN are

$$\widetilde{p}_1 \oplus \widetilde{p}_2 = \left(\sqrt{\mu_1^2 + \mu_2^2 - \mu_1^2 \mu_2^2}, v_1 v_2 \right),$$

$$\widetilde{p}_1 \oplus \widetilde{p}_2 = \left(\mu_1 \mu_2, \sqrt{v_1^2 + v_2^2 - v_1^2 v_2^2}, \right).$$

Definition 3 Let $\widetilde{P_1} = \langle \mu_1, v_1 \rangle$ be a PFNs and $\lambda > 0$ then operations could be defined as

$$\lambda \widetilde{p}_1 = \left(\sqrt{1 - \left(1 - \mu_1^2\right)^{\lambda}}, v_1^{\lambda} \right),$$

$$\widetilde{p}_1^{\lambda} = \left(\mu_1^2, \sqrt{1 - \left(1 - v_1^2\right)^{\lambda}} \right).$$

This study is operating in interval-valued fuzzy space; therefore, the hesitation degree should be extended for the lower and upper points of $\widetilde{P}$ as follows:

Definition 4 Let $\widetilde{P} = \langle [\mu_L, \mu_U], [v_L, v_U] \rangle$ be an interval-valued PFN and hesitancy degree of lower and upper points of $\widetilde{P}$, π_L and π_U, respectively, which are calculated as follows:

Table 2 Linguistic scale for performance weighting for IPFV

Linguistic terms	PF numbers			
	μ_L	μ_U	v_L	v_U
Extremely low important (ELI)	0.00	0.00	0.90	1.00
Very low important (VLI)	0.10	0.20	0.80	0.90
Low important (LI)	0.20	0.35	0.65	0.80
Below average important (BAI)	0.35	0.45	0.55	0.65
Average important (AI)	0.45	0.55	0.45	0.55
Above average important (AAI)	0.55	0.65	0.35	0.45
High important (HI)	0.65	0.80	0.20	0.35
Very high important (VHI)	0.80	0.90	0.10	0.20
Certainly high important (CHI)	0.90	1.00	0.00	0.00
Equal important (EI)	0.50	0.50	0.50	0.50

$$\pi_l^2 = 1 - \left(\mu_U^2 + v_U^2\right),$$

$$\pi_U^2 = 1 - \left(\mu_L^2 + v_L^2\right).$$

The decision-makers evaluate the alternatives and criteria using the linguistic scale. Table 2 displays the linguistic scale proposed by Karasan et al. (2019) for IPFNs.

In this study, decision-makers use the linguistic terms in Table 2 to select the best supplier from a group of PFS-evaluated options. The mathematical explanation of the supplier selection problem is defined as a set of decision-makers, $DM = \{DM_1 \ldots DM_k\}$, evaluate a set of alternatives, $A = \{A_1 \ldots A_n\}$, under the set of criteria, $C = \{C_1 \ldots C_m\}$.The opinion of the kth Decision-maker, o_{ij}^k, regarding the ith alternative under the jth criteria is defined as $o_{ij}^k = \langle \left[\mu_{L_{ij}}^k, \mu_{U_{ij}}^k\right], \left[v_{L_{ij}}^k, v_{U_{ij}}^k\right] \rangle$ and weight vector of decision-makers is defined as $w_{DM} = \{w_{DM_1} \ldots w_{DM_k}\}$ based on the IPFV. The membership degree of A_i under C_j given by DM_k is represented as $\left[\mu_{L_{ij}}^k, \mu_{U_{ij}}^k\right]$. The membership degree of A_i under C_j given by DM_k is represented as $\left[v_{L_{ij}}^k, v_{U_{ij}}^k\right]$.

3.2 Proposed IPF-AHP Method

The steps of the proposed IPF-AHP are derived from Karasan (2019) and Ayyildiz and Taskin Gumus (2021) as follows:

Step 1. Create an IPF Decision matrix for decision-makers' opinions.

Step 2. Applying Eqs. 1 and 2, compute the difference matrix between the lower and upper points of membership and non-membership:

$$d_{L_{ij}} = \mu_{L_{ij}}^2 - v_{L_{ij}}^2, \tag{1}$$

$$d_{U_{ij}} = \mu_{U_{ij}}^2 - v_{U_{ij}}^2. \tag{2}$$

Step 3. Construct the interval multiplicative matrix by applying Eqs. 3 and 4:

$$S_{L_{ij}} = \sqrt{1000^{d_{L_{ij}}}}, \tag{3}$$

$$S_{U_{ij}} = \sqrt{1000^{d_{U_{ij}}}}. \tag{4}$$

Step 4. Calculate the indeterminacy value of o_{ij} using Eq. 5:

$$h_{ij} = 1 - \left(\mu_{U_{ij}}^2 - \mu_{L_{ij}}^2\right) - \left(v_{U_{ij}}^2 - v_{L_{ij}}^2\right). \tag{5}$$

Step 5. Construct the unnormalized weights matrix by applying Eq. 6:

$$\tau_{ij} = \left(\frac{S_{L_{ij}} + S_{U_{ij}}}{2}\right) h_{ij}. \tag{6}$$

Step 6. Calculate normalized weight for each criterion using Eq. 7:

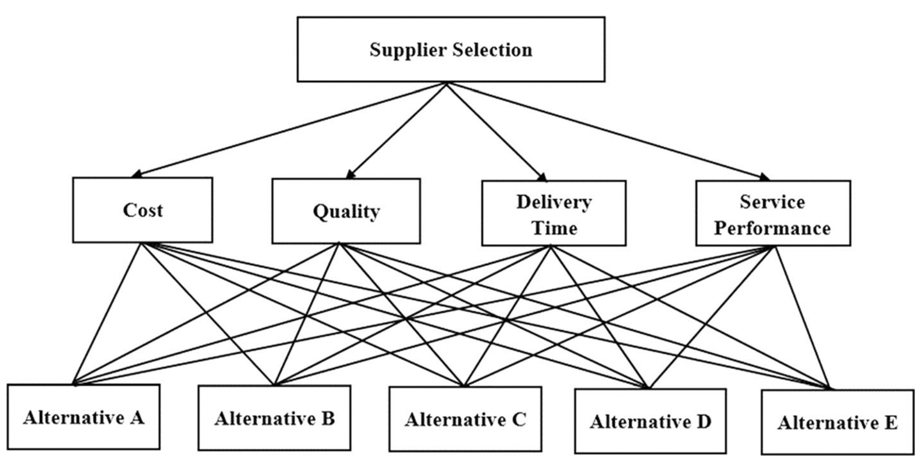


Fig. 1 Structural hierarchy of the problem

Table 3 Evaluation of criteria in linguistic variable

Goal	C_1	C_2	C_3	C_4
C_1	EI	AI	BAI	LI
C_2	AI	EI	AAI	HI
C_3	AAI	BAI	EI	AAI
C_4	HI	LI	BAI	EI

$$w_j^c = \left(\frac{\sum_{i=1}^{n}\tau_{ij}}{\sum_{i=1}^{n}\sum_{j}^{m}\tau_{ij}}\right). \tag{7}$$

Step 7. Apply Steps 1–6 for each alternative under each criterion and calculate normalized weight using Eq. 8:

$$w_i^a = \left(\frac{\sum_{j=1}^{m}\tau_{ij}}{\sum_{i=1}^{n}\sum_{j}^{m}\tau_{ij}}\right). \tag{8}$$

Step 8. Calculate priority weights for each alternative using Eq. 9:

$$p(A_i) = \sum_{j=1}^{m} w_i^A w_j^C, \forall i. \tag{9}$$

Step 9. Prioritize the alternatives in descending order of value $p(A_i)$.

3.3 Proposed IPF-COPRAS Method

Step 1. Create an IPF Decision matrix for decision-makers' opinions.

Step 2. Calculate criteria weights using Eq. 10:

$$w_j = \frac{\left(\mu_{U_j}^2+\mu_{L_j}^2\right)\left(2+\sqrt{1-\mu_{L_j}^2-v_{L_j}^2}+\sqrt{1-\mu_{U_j}^2-v_{U_j}^2}\right)}{\sum_{j=1}^{m}\left(\left(\mu_{U_j}^2+\mu_{L_j}^2\right)\left(2+\sqrt{1-\mu_{L_j}^2-v_{L_j}^2}+\sqrt{1-\mu_{U_j}^2-v_{U_j}^2}\right)\right)}. \tag{10}$$

Step 3. Applying Eqs. 1 and 2, respectively, calculate the difference matrix between the lower and upper points of the membership and non-membership.

Step 4. Construct the interval multiplicative matrix by applying Eqs. 3 and 4, respectively.

Step 5. Determine the indeterminacy value of o_{ij} using Eq. 5.

Step 6. Construct the unnormalized weights matrix by applying Eq. 6.

Step 7. Calculate normalized weight for each criterion using Eq. 7.

Step 8. Calculate weighted normalized matrix based on the criteria weights using Eq. 11:

$$D_{ij} = w_i^a w_j. \tag{11}$$

Table 6 Interval multiplicative matrix

Goal	C_1		C_2		C_3		C_4	
	$S_{L_{ij}}$	$S_{U_{ij}}$	$S_{L_{ij}}$	$S_{U_{ij}}$	$S_{L_{ij}}$	$S_{U_{ij}}$	$S_{L_{ij}}$	$S_{U_{ij}}$
C_1	1.000	1.000	1.000	1.000	0.537	0.468	0.267	0.167
C_2	1.000	1.000	1.000	1.000	1.862	2.138	3.748	5.974
C_3	1.862	2.138	0.537	0.468	1.000	1.000	1.862	2.138
C_4	3.748	5.974	0.267	0.167	0.537	0.468	1.000	1.000

Table 4 Evaluation of criteria in IPFV

	C_1				C_2				C_3				C_4			
	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U
C_1	0.5	0.5	0.5	0.5	0.45	0.55	0.45	0.55	0.35	0.45	0.55	0.65	0.2	0.35	0.65	0.8
C_2	0.45	0.55	0.45	0.55	0.5	0.5	0.5	0.5	0.55	0.65	0.35	0.45	0.65	0.8	0.2	0.35
C_3	0.55	0.65	0.35	0.45	0.35	0.45	0.55	0.65	0.5	0.5	0.5	0.5	0.55	0.65	0.35	0.45
C_4	0.65	0.8	0.2	0.35	0.2	0.35	0.65	0.8	0.35	0.45	0.55	0.65	0.5	0.5	0.5	0.5

Table 5 Differences matrix between upper and lower values of μ and v

Goal	C_1		C_2		C_3		C_4	
	$d_{L_{ij}}$	$d_{U_{ij}}$	$d_{L_{ij}}$	$d_{U_{ij}}$	$d_{L_{ij}}$	$d_{U_{ij}}$	$d_{L_{ij}}$	$d_{U_{ij}}$
C_1	0.000	0.000	0.000	0.000	− 0.180	− 0.220	− 0.383	− 0.518
C_2	0.000	0.000	0.000	0.000	0.180	0.220	0.383	0.518
C_3	0.180	0.220	− 0.180	− 0.220	0.000	0.000	0.180	0.220
C_4	0.383	0.518	− 0.383	− 0.518	− 0.180	− 0.220	0.000	0.000

Table 7 Indeterminacy values

Goal	C_1	C_2	C_3	C_4
C_1	1.000	0.800	0.800	0.700
C_2	0.800	1.000	0.800	0.700
C_3	0.800	0.800	1.000	0.800
C_4	0.700	0.700	0.800	1.000

Table 8 Unnormalized weights

Goal	C_1	C_2	C_3	C_4
C_1	1.000	0.800	0.402	0.152
C_2	0.800	1.000	1.600	3.402
C_3	1.600	0.402	1.000	1.600
C_4	3.402	0.152	0.402	1.000

Table 9 Normalized weights

C_1	0.126
C_2	0.363
C_3	0.246
C_4	0.265

Step 9. Calculate beneficiary and non-beneficiary indexes S_i^+ and S_i^- by applying Eqs. 12 and 13, respectively:

$$S_i^+ = \sum_{j=1}^{k} D_{ij}, i = 1, \ldots, k \,\text{beneficary criteria}, \quad (12)$$

$$S_i^- = \sum_{j=k}^{m} D_{ij}, i = k+1, \ldots, m \,\text{non} - \text{beneficary criteria}. \quad (13)$$

Step 10. Calculate the COPRAS index for the relative significance of alternatives using Eq. 14:

$$Q_i = S_i^+ + \frac{\sum_{i=1}^{n} S_i^-}{S_i^- \sum_{i=1}^{n} \frac{1}{S_i^-}}. \quad (14)$$

Step 11. Calculate the maximum relative significance values and performance index using Eqs. 15 and 16, respectively:

$$Q_{\max} = \max\{Q_1, \ldots, Q_n\}, \quad (15)$$

$$p(A_i) = \frac{Q_i}{Q_{max}} 100\%. \quad (16)$$

Table 10 Evaluation of alternatives respected to C_1

C_1	A_1	A_2	A_3	A_4	A_5	w_i	Rank
A_1	EI	LI	AI	AI	LI	0.087	4
A_2	HI	EI	HI	HI	AI	0.382	1
A_3	AI	LI	EI	HI	BAI	0.172	3
A_4	AI	LI	LI	EI	LI	0.067	5
A_5	HI	BAI	AI	HI	EI	0.292	2
CR =						0.072	

Table 11 Evaluation of alternatives respected to C_2

C_2	A_1	A_2	A_3	A_4	A_5	w_i	Rank
A_1	EI	AI	AAI	LI	VLI	0.039	2
A_2	AI	EI	AI	VLI	CLI	0.029	4
A_3	BAI	AI	EI	CLI	CLI	0.025	5
A_4	HI	VHI	CHI	EI	BAI	0.361	3
A_5	VHI	CHI	CHI	AAI	EI	0.546	1
CR =						0.082	

Table 12 Evaluation of alternatives respected to C_3

C_3	A_1	A_2	A_3	A_4	A_5	w_i	Rank
A_1	EI	BAI	HI	BAI	BAI	0.131	4
A_2	AAI	EI	CHI	AAI	BAI	0.324	2
A_3	LI	CLI	EI	LI	VLI	0.034	5
A_4	AAI	BAI	HI	EI	BAI	0.159	3
A_5	AAI	AAI	VHI	AAI	EI	0.352	1
CR =						0.067	

Table 13 Evaluation of alternatives respected to C_4

C_4	A_1	A_2	A_3	A_4	A_5	w_i	Rank
A_1	EI	AI	AI	AAI	BAI	0.200	2
A_2	AI	EI	AI	AAI	AI	0.165	3
A_3	AI	AI	EI	AAI	AI	0.165	3
A_4	BAI	BAI	BAI	EI	BAI	0.322	1
A_5	AAI	AI	AI	AAI	EI	0.148	5
CR =						0.056	

Step 12. Rank the alternatives in descending order of importance $p(A_i)$.

Table 14 Normalized alternatives' weights under each criterion

	C_1	C_2	C_3	C_4	$p(A_i)$
A_1	0.087	0.039	0.131	0.200	0.110
A_2	0.382	0.029	0.324	0.165	0.182
A_3	0.172	0.025	0.034	0.165	0.083
A_4	0.067	0.361	0.159	0.322	0.264
A_5	0.292	0.546	0.352	0.148	0.361

Table 15 The rank of the alternatives

A_i	A_5	A_4	A_2	A_1	A_3
Rank	1	2	3	4	5

Table 16 Evaluation of alternatives for each criterion in linguistic variable

	C_1	C_2	C_3	C_4
A_1	BAI	BAI	AAI	HI
A_2	VHI	BAI	VHI	AAI
A_3	AAI	BAI	LI	AAI
A_4	BAI	VHI	AAI	VHI
A_5	HI	CHI	VHI	AAI

4 Case Study with Applications and Results

This research was conducted for a military-focused research organization in Ankara, Turkey. Choose the correct source because military businesses manufacture delicate components. Thus, using the literature analysis and expert opinions, the application was designed according to the most important criteria.

Four criteria and five options are being explored to choose a provider. C1–C4 were cost, quality, delivery time, and service performance. In this regard, an interval-valued Pythagorean Fuzzy AHP (IPF-AHP) and IPF-COPRAS are developed and used to pick the best provider among 5 supplier alternatives (A1,…, A5) under conflicting criteria. According to Table 2, the decision-maker evaluates the alternatives using linguistic terms. For example, if the decision-maker assumes that A_1 is high important than A_5 under the same criterion, then the decision-maker must assign the *HI* from Table 2 to make evaluations accurately.

4.1 Application of IPF-AHP Method

Step 0. Create the hierarchical structure as shown in Fig. 1.

Step 1. Decision-maker uses Table 3 linguistic phrases to analyze criteria. Table 4 shows the IPFN-based pairwise comparison matrix.

Table 17 Evaluation of criteria in IPFV

	C_1				C_2				C_3				C_4			
	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U
A_1	0.35	0.45	0.55	0.65	0.35	0.45	0.55	0.65	0.55	0.65	0.35	0.45	0.65	0.8	0.2	0.35
A_2	0.8	0.9	0.1	0.2	0.35	0.45	0.55	0.65	0.8	0.9	0.1	0.2	0.55	0.65	0.35	0.45
A_3	0.55	0.65	0.35	0.45	0.35	0.45	0.55	0.65	0.2	0.35	0.65	0.8	0.55	0.65	0.35	0.45
A_4	0.35	0.45	0.55	0.65	0.8	0.9	0.1	0.2	0.55	0.65	0.35	0.45	0.8	0.9	0.1	0.2
A_5	0.65	0.8	0.2	0.35	0.9	1	0	0	0.8	0.9	0.1	0.2	0.55	0.65	0.35	0.45

Table 18 The weights of each criterion

Goal	C_1				C_2				C_3				C_4			
	LI				VHI				AAI				AAI			
	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U
IPFN	0.2	0.35	0.65	0.8	0.8	0.9	0.1	0.2	0.55	0.65	0.35	0.45	0.55	0.65	0.35	0.45
Rank	0.054				0.444				0.251				0.251			

Table 19 Differences matrix between upper and lower values of μ and v

Goal	C_1		C_2		C_3		C_4	
	$d_{L_{ij}}$	$d_{U_{ij}}$	$d_{L_{ij}}$	$d_{U_{ij}}$	$d_{L_{ij}}$	$d_{U_{ij}}$	$d_{L_{ij}}$	$d_{U_{ij}}$
A_1	− 0.18	− 0.22	− 0.18	− 0.22	0.18	0.22	0.38	0.52
A_2	0.63	0.77	− 0.18	− 0.22	0.63	0.77	0.18	0.22
A_3	0.18	0.22	− 0.18	− 0.22	− 0.38	− 0.52	0.18	0.22
A_4	− 0.18	− 0.22	0.63	0.77	0.18	0.22	0.63	0.77
A_5	0.38	0.52	0.81	1.00	0.63	0.77	0.18	0.22

Table 20 Interval multiplicative matrix

Goal	C_1		C_2		C_3		C_4	
	$S_{L_{ij}}$	$S_{U_{ij}}$	$S_{L_{ij}}$	$S_{U_{ij}}$	$S_{L_{ij}}$	$S_{U_{ij}}$	$S_{L_{ij}}$	$S_{U_{ij}}$
A_1	0.54	0.47	0.54	0.47	1.86	2.14	3.75	5.97
A_2	8.81	14.29	0.54	0.47	8.81	14.29	1.86	2.14
A_3	1.86	2.14	0.54	0.47	0.27	0.17	1.86	2.14
A_4	0.54	0.47	8.81	14.29	1.86	2.14	8.81	14.29
A_5	3.75	5.97	16.41	31.62	8.81	14.29	1.86	2.14

Table 21 Indeterminacy values

Goal	C_1	C_2	C_3	C_4
A_1	0.800	0.800	0.800	0.700
A_2	0.800	0.800	0.800	0.800
A_3	0.800	0.800	0.700	0.800
A_4	0.800	0.800	0.800	0.800
A_5	0.700	0.810	0.800	0.800

Table 22 The unnormalized weights

Goal	C_1	C_2	C_3	C_4
A_1	0.402	0.402	1.600	3.402
A_2	9.240	0.402	9.240	1.600
A_3	1.600	0.402	0.152	1.600
A_4	0.402	9.240	1.600	9.240
A_5	3.402	19.452	9.240	1.600

Table 23 The normalized weights

Goal	C_1	C_2	C_3	C_4
A_1	0.027	0.013	0.073	0.195
A_2	0.614	0.013	0.423	0.092
A_3	0.106	0.013	0.007	0.092
A_4	0.027	0.309	0.073	0.530
A_5	0.226	0.651	0.423	0.092

Step 2. The differences matrix between $D = \left(d_{ij}\right)_{mxm}$ the lower and upper points of the membership and non-membership by applying Eqs. 1 and 2 as shown in Table 5

Step 3. The interval multiplicative matrix is constructed by applying Eqs. 3 and 4 as represented in Table 6.

Step 4. The indeterminacy value matrix is created using Eq. 5 as shown in Table 7.

Step 5. The unnormalized weights matrix is created by applying the Eq. 6 as shown in Table 8.

Step 6. The normalized weight for each criterion is calculated using Eq. 7 as shown in Table 9.

Step 7. Steps 1–6 are applied for each alternative under each criterion. The calculation of how to obtain the weights is shown with respect to goal. Therefore, due to page and word limitations computations of Tables 10, 11, 12 and 13 are not shown in the manuscript. Tables 10, 11, 12 and 13 show the comparison matrixes and final weights of alternatives under each criterion. Normalized weights of each alternative under each criterion are calculated using Eq. 8

Step 8. Table 14 shows how Eq. 9 calculates alternate priority weights.

Step 9. Alternatives rank in descending order of importance $p(A_i)$ as shown in Table 15.

According to the results of the IPF-AHP methodology given in Table 15, the alternatives are ranked as A_5, A_4, A_2, A_1, and A_3. Therefore, the best alternative for supplier selection is found as A_5, and the worst alternative was A_3.

4.2 The COPRAS Approach Applied Into Practice

The IPF-AHP methodology was applied in order to derive the weights that should be assigned to the various viable options for the provider selection process. After that, the COPRAS approach was applied in order to calculate the weights of the various options.

Table 24 The normalized weights

Goal	C_1	C_2	C_3	C_4
A_1	0.001	0.006	0.018	0.049
A_2	0.033	0.006	0.106	0.023
A_3	0.006	0.006	0.002	0.023
A_4	0.001	0.137	0.018	0.133
A_5	0.012	0.289	0.106	0.023

Table 25 S_i^+, S_i^-, Q_i, and $p(A_i)$ values with ranking of alternatives

	S_i^+	S_i^-	$1/S_i^-$	Q_i	$p(A_i)$		Rank
A_1	0.007	0.067	14.837	0.008	26%	1.000	5
A_2	0.039	0.129	7.732	0.040	13.2%	0.463	3
A_3	0.012	0.025	40.344	0.012	3.9%	0.132	4
A_4	0.139	0.151	6.603	0.140	46.3%	0.039	2
A_5	0.301	0.129	7.732	0.302	100%	0.026	1

Step 1. Decision-maker uses Table 16 linguistic phrases to analyze criteria. Table 17 shows the IPFN-based pairwise comparison matrix.

Step 2. The weights of each criterion are calculated using Eq. 11 as shown in Table 18.

Step 3. The differences matrix between $D = (d_{ij})_{mxm}$ the lower and upper points of the membership and non-membership by applying Eqs. 1 and 2 as shown in Table 19.

Step 4. The interval multiplicative matrix is constructed by applying Eqs. 13 and 14 as represented in Table 20.

Step 5. The indeterminacy value matrix is created using Eq. 15 as shown in Table 21.

Step 6. The unnormalized weights matrix is created by applying the Eq. 16 as shown in Table 22.

Step 7. The normalized weights are calculated for each criterion using Eq. 17 as shown in Table 23.

Step 8. The weighted normalized weights based on the criteria weights are determined using Eq. 11 as shown in Table 24.

Step 9. The beneficiary and non-beneficiary indexes S_i^+ and S_i^- are calculated by applying Eqs. 12 and 13, respectively, as shown in Table 25. C_1 and C_2 are defined as beneficiary criteria. On the other hand, C_3 and C_4 are accepted as non-beneficiary criteria.

Step 10. The COPRAS index for the relative significance of alternatives is computed using Eq. 14 as shown in Table 25.

Step 11. The maximum relative significance values and performance index are calculated using Eqs. 15 and 16 as shown in Table 25.

Step 12. Alternatives are ranked in descending order of importance $p(A_i)$.

After finding the weight matrix, S_i^+ and S_i^- values have been calculated for each alternative. S_i^+ is equal to the sum of the weighted normalized values of C1 and C2 among the alternatives. The S_i^- value was derived from the aggregate of the weighted normalized values of the delivery time and service performance, which was determined to be the minimum among the alternatives. The option with a performance index of 100, represented by$p(A_5)$, is the finest option. The order of preference was determined by sorting the performance index values from greatest to least. The greatest alternative according to Table 25 was the A_5 with a performance index value of 100%, while the worst alternative was the A_1 with a performance index value of 56.53%. The alternatives are ranked in descending importance order as follows: A_5, A_4, A_2, A_3, and A_1 respectively.

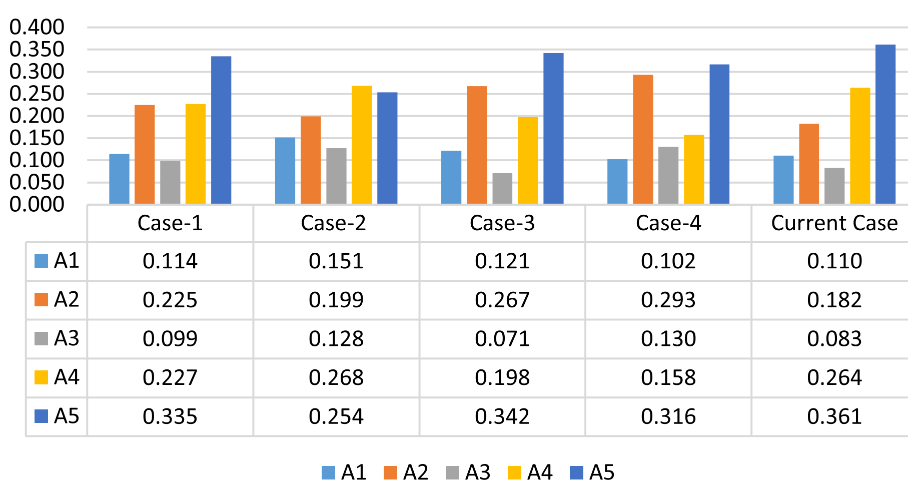
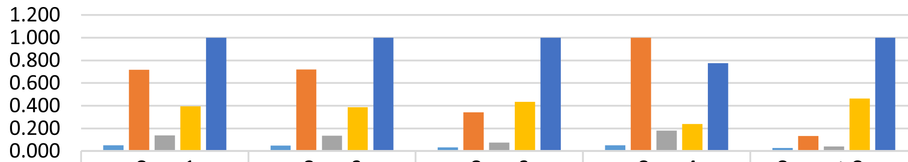


Fig. 2 Sensitivity analysis for IPF-AHP



	Case-1	Case-2	Case-3	Case-4	Current Case
A1	0.051	0.049	0.033	0.052	0.026
A2	0.718	0.719	0.343	1.000	0.132
A3	0.138	0.136	0.074	0.180	0.039
A4	0.393	0.385	0.433	0.238	0.463
A5	1.000	1.000	1.000	0.774	1.000

Fig. 3 Sensitivity analysis and results for IPF-COPRAS

Table 26 Weights of criteria for different cases for IPF-AHP

		C_1	C_2	C_3	C_4
Case-1	C_1	EI	AI	AI	AI
	C_2	AI	EI	AI	AI
	C_3	AI	AI	EI	AI
	C_4	AI	AI	AI	EI
Case-2		C_1	C_2	C_3	C_4
	C_1	EI	AI	AI	HI
	C_2	AI	EI	AI	HI
	C_3	AI	AI	EI	HI
	C_4	LI	LI	LI	EI
Case-3		C_1	C_2	C_3	C_4
	C_1	EI	AI	HI	AI
	C_2	AI	EI	HI	AI
	C_3	LI	LI	EI	LI
	C_4	AI	AI	HI	EI
Case-4	Goal	C_1	C_2	C_3	C_4
	C_1	EI	LI	LI	LI
	C_2	HI	EI	AI	AI
	C_3	HI	AI	EI	AI
	C_4	HI	AI	AI	EI
Current case	Goal	C_1	C_2	C_3	C_4
	C_1	EI	AI	BAI	LI
	C_2	AI	EI	AAI	HI
	C_3	AAI	BAI	EI	AAI
	C_4	HI	LI	BAI	EI

Table 27 Weights of criteria for different cases for IPF-COPRAS

	C_1	C_2	C_3	C_4
Case-1	AI	AI	AI	VHI
Case-2	AI	AI	VHI	AI
Case-3	AI	VHI	AI	A
Case-4	VHI	AI	AI	AI
Current case	LI	VHI	AAI	AAI

4.3 Sensitivity Analysis

A sensitivity analysis is carried out so that the degree to which the results are affected by changes in the parameters representing the various weight scenarios may be determined. In order to discover how the weights of the key criteria affect the ranks of the alternative choices, a sensitivity analysis must first be carried out. In order to accomplish this goal, we have created four unique scenarios by adjusting the relative importance of the major criteria. The following is a definition of the criteria that were obtained:

Case-1 All criteria has equal importance on each other
Case-2 C4 has higher importance than the other criteria
Case-3 C3 has higher importance than the other criteria
Case-4 C2 has higher importance than the other criteria

The results of the case scenarios are compared with the expert evaluations (Current Case) to show effectiveness of the proposed methodology. The various ranks derived from such case scenarios are used to examine the effects of the weighted criteria. The various weight cases that are employed in the sensitivity analysis for IPF-AHP and IPF-TOPSIS are shown in Tables 26 and 27.

As shown in Tables 26 and 27, criteria weights changed gradually. The results of sensitivity analysis are presented in Figs. 2 and 3 for IPF-AHP and IPF-COPRAS. In the current case of IPF-AHP, the best alternative is as A_5 that is followed by A_4, A_2, A_1, and A_3, respectively. On the other hand, the current case of IPF-AHP shows the rank of alternatives as A_5, A_4, A_2, A_3, and A_1, respectively. After the changes on each criterion, the weights of alternatives are changed. As shown in Fig. 3, Case-3 in which the C_2 has higher importance than the other criteria implies that rank of the alternatives is A_2, A_5, A_4, A_3, and A_1 in descending order. Similar results are appeared in the each cases of IPF-AHP and IPF-COPRAS.

According to the sensitivity analysis and results are shown in Figs. 2 and 3, the proposed IPF-AHP and IPF-COPRAS methods are robust and reliable. Therefore, sensitivity analysis shows that the ranking among A_5 could be accepted as robust to changes in most importance levels. On the other hand, it could be thought that the rankings among A_1, A_2, A_3, and A_4 are highly sensitive to changes in the different levels of criteria weights.

In this research, in order to identify and select the best-suited supplier among all five possible choices under four criteria, consistent and effective assessments are made utilizing the IPF-AHP and IPF-COPRAS methodologies. As a managerial implication of the results, it is recommended to put more attention on the most essential risk factors to select the most appropriate supplier. Table 9 implies that the most essential criterion is ''Quality.'' However, the fact that the quality conditions are extremely unpredictable and tough to foresee and avoid is well established. Therefore, the decision-makers could focus on the other variables which are controllable by managers to decide on the appropriate provider. In addition, from the management point of view, it is recommended to improve alternative diversity in order to increase flexibility in the decision-making process. On the other hand, from the practical consequences, choosing the best suitable supplier under the fuzzy environment could the research one step ahead. In a fuzzy environment, evaluating criteria or alternatives is difficult to quantify. The IPF-AHP and IPF-COPRAS capture a board frame to represent fuzzy judgments in order to minimize failure in supplier selection, which could result in increased costs and undesirable consequences. The IPF-AHP and IPF-COPRAS approaches are demonstrated to be a beneficial way to handle the fuzzy multiple attribute group decision-making problems more flexibly and fully, according to the sensitivity analysis results of the suggested methodology. Consequently, fuzzy logic and MCDM present unique study topics with a range of various managerial and practical implications.

5 Conclusion

In today's tough business environment, companies must make the best decisions to succeed. The best supplier choice affects the entire supply chain, thus firms must make this decision carefully. Supplier selection techniques help companies choose providers that meet quality standards [48]. Businesses have to select appropriate providers to meet consumer demands. Thus, MCDM is utilized to make consistent, effective decisions and choose the best provider. The literature research and expert feedback helped this study's application meet the most important criteria. Four criteria and five options were chosen for the most suitable provider. Supplier selection was solved using cost, quality, delivery time, and service performance.

MCDM and AHP were used to create a hierarchical model based on selection criteria. The expanded hierarchical model's findings help decision-makers choose providers by considering predetermined criteria. This instance used AHP to rank numerous criteria. After that, potential suppliers were assessed using the COPRAS method. Comparing options with a ratio showed how good or bad they were. Finally, after ranking the possibilities, the best provider was chosen. Based on the value of the performance index assigned to each alternative, the best supplier among the alternatives was found using the COPRAS technique. The options were identified as A_5, A_4, A_2, A_3, and A_1, respectively, based on the results collected from the test. As a result, A_1 was determined to be the most viable solution for supplier selection. Aside from that, the choices were rated based on both approaches, and the validity of the methodologies was compared. Eventually, a sensitivity analysis was undertaken to assess whether or not the reordering of the alternatives was a direct consequence of the adjustments that were made.

As further research directions, it could be grateful to investigate different methods of decision-making, and it would also be beneficial to broaden the scope of the study to include a larger number of participants in terms of the number of experts. In addition, additional research could investigate the influence that exogenous factors, such as the state of the economy or political unrest, have on the decisions made regarding which suppliers to work with. It is also essential to take into account the long-term repercussions of the decisions made regarding the selection of suppliers, including how those decisions will affect the overall performance and sustainability of the supply chain. In general, the findings of this study emphasize how critical it is to base decisions regarding supplier selection on methodologically sound research and in-depth analysis, and they provide insightful information that is useful to both researchers and practitioners.

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Declarations

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