

Article

A Hybrid Triangular Fuzzy Full Consistency Method (FUCOM) with TOPSIS to Assess Suppliers in Supply Chains

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Abstract

Supplier assessment plays a pivotal role in various sectors and is a key component of supply chain management (SCM); however, it combines complexities and challenges associated with uncertainty and dynamic requirements. Several studies have applied various methods to assess suppliers; however, their calculations are complex. Therefore, this work introduces a new hybrid method, depending on the full consistency method (FUCOM) with triangular fuzzy numbers (TrFNs) to consistently prioritize supplier assessment criteria, using the distance from the ideal assessment criterion to assess various suppliers, as well as to handle uncertainty. The proposed method is applied to a practical case study, and the results show that it prioritizes the assessment criteria, reflecting stakeholder preferences. Moreover, it enables decision makers to construct a set of decision matrices and take into account various viewpoints, and it uses simple, detailed steps with TOPSIS, thus avoiding confusion. Additionally, the results indicate that the use of the FUCOM-TrFNs provides consistent weights and a robust tool for imprecise problems, with fewer comparisons and less confusion during calculations. Ultimately, the findings provide valuable insights for assessing and selecting suitable suppliers with a more applicable method.

Keywords: supply chain management (SCM); triangular fuzzy numbers (TrFNs); full consistency method (FUCOM)

1. Introduction

In SCM, decision makers need to select sustainable suppliers to achieve a competitive advantage [1]. Determining the right supplier can improve long-term relationships and performance improvement, reduce costs, enhance operational performance, reduce procurement costs, and improve customer satisfaction. SCM requires coordination among its suppliers and maintaining relationships with good suppliers to support the entire chain. Working with unsuitable suppliers, results in inconsistent product quality, delayed deliveries, and the possible loss of competitive advantage in the market [2]. In supplier selection, purchasing managers identify and choose the most suitable suppliers to source the raw materials. Hawkins et al. [3] noted that the evaluation of suppliers' performance plays an important role in mitigating the risk. Suppliers act as agents to fulfill a firm's requirements, helping to achieve sustainability in the SCM [4,5]. One of the most important challenges in SCM is selecting sustainable suppliers [6]. Supplier evaluation and selection can be considered as a multi-criteria decision-making problem, which involves economic, environmental, and social factors [7].



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Recent trends in business and industry consider the process of determining suitable suppliers as a main determinant of a firm's operational success. The supplier assessment process aims to build a competitive supply chain network by establishing beneficial business relationships with reliable suppliers. Several tools and methods are applied for supplier selection in SCM [8–10], including the analytical hierarchy process (AHP), analytical network process (ANP), fuzzy techniques, linear/nonlinear programming, optimization technique, multi-criteria decision-making (MCDM) models, technique for order preference by similarity to ideal solution (TOPSIS), data envelopment analysis (DEA), and importance–performance analysis (IPA). Despite these methods and efforts, there is a need for new methods to consistently prioritize the assessment criteria and reflect the main preferences of stakeholders, as well as handle uncertainty. Several studies have addressed the problem of supplier assessment [1,6,11–14]. However, these efforts do not consistently prioritize the assessment criteria or take into account their distance from the ideal assessment criterion. On the other hand, several studies have applied various integrated methods, such as the analytic hierarchy process (AHP) and best–worst method (BWM), to prioritize the assessment criteria [15–17] however, these efforts require multiple calculations. Thus, this work aims to address the various perspectives of SCM and suppliers and introduce a hybrid method that uses the fuzzy full consistency method (FUCOM) to provide consistent prioritization of the supplier assessment criteria, to reflect the stakeholders' preferences, and then applies the TOPSIS-based method to assess various suppliers, taking into account the costs and benefits criterion, as well as the uncertainty. The proposed method is applied to a practical case study, and the results show the following: the proposed method takes into account the priority of the assessment criteria, reflecting stakeholders' preferences; the results indicate that the use of the FUCOM-based method provides consistent weights simply, thus reducing the calculation process and the number of the pairwise comparisons to $n - 1$; additionally, this work provides the detailed steps of the TOPSIS method; and finally, the proposed method enables decision makers to construct a set of decision matrices and take into account various viewpoints, using a more applicable method.

This work is organized as follows. The first section provides the introduction; the second section presents the literature review; the third section discusses the research method; the fourth section addresses the research method's implementation and its results; the fifth section discusses the results and findings; and the sixth section presents the conclusions and future work. Figure 1 highlights the structure of this work.

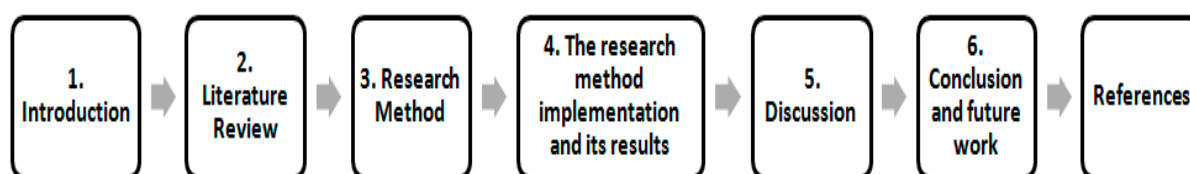


Figure 1. The structure of this work.

2. Literature Review

SCM is designed to manage all elements and parts along the supply chain based on a unified strategy, including logistics, production systems, supplier selection, inventory management, customer relationship management, human resource management, information systems, and performance management [18,19]. It strategically coordinates several business processes to optimize decisions, achieve customer satisfaction, and improve the overall performance. SCM is accomplished through five phases [20]:

1. Planning Phase: This phase aims to explore and understand market trends, plan for resources according to requirements, develop strategies, and set budgets.

2. Sourcing Phase: This phase aims to establish relationships with suitable and reliable suppliers, manage inventory levels, discuss contracts, manage relationships, optimize costs, and ensure quality control.
3. Manufacturing Phase: this phase aims to transform the raw materials into finished products, ensuring quality, managing inventory and packaging, and guaranteeing minimum waste and resource consumption.
4. Delivery Phase: This phase focuses on the transportation and delivery of products or services to customers, considering different factors such as transportation costs, delivery speed, and customer preferences.
5. Return Phase: This phase handles the product returns from the customers, including product faults and customer disappointment, aiming to maintain customer loyalty.

SCM aims to maximize customer value and achieve a sustainable competitive advantage. The suppliers play an important role in introducing resources and services according to users' requests. Purchasing decisions are important, as the aim is to increase purchasing.

2.1. Supplier Assessment, Selection, and Integration Concepts

There are three concepts related to suppliers: assessment, selection, and integration.

- The process of suppliers' assessment and selection

The process of suppliers' assessment and selection is a critical component of the purchasing process. A suitable supplier can help to reduce the cost, improve profits, and improve the quality of the products. The main objective of supplier selection is to find the supplier who will provide the right products/services at a minimum price, in the right quantities, and at the right time. The supplier selection process is a strategic activity within SCM that involves the following [20]:

1. Identification of the business requirements.
2. Identification of the criteria used in the evaluation and selection process.
3. Determination of the priority of the evaluation criteria.
4. Determination of the alternative suppliers.
5. Assessment of the alternative suppliers.
6. Choice of the most suitable supplier.

The process of assessing and selecting the most suitable supplier begins by identifying sourcing needs and defining the criteria suppliers must meet, such as quality standards, costs, delivery capabilities, and ethical considerations. Recently, businesses have paid special attention to key decisions that can improve a company's results, with successful supplier selection enhancing organizational performance [21].

- Supplier integration

Supplier integration with firms can be accomplished through the collection of cross-processes and activities involving multiple organizational levels: tactical, operational, and strategic. Supplier integration involves three levels [22,23]:

- Information Integration: This involves collaboration, communication, and information sharing about new technologies, as well as complete and reliable information on related sales data, inventory levels, and order status.
- Operational Integration: This involves collaborative processes development, resource management, and the coordination of decision-making, including collaborative planning, forecasting, vendor-managed inventory, and early supplier involvement in new product development.
- Relational Integration: This involves a strategic connection between organizations and the supply chain, emphasizing trust, commitment, and long-term relationships.

2.2. Assessment Criteria for Suitable Suppliers in SCM

The performance of potential suppliers is evaluated using multiple criteria rather than solely cost. According to [24], there are two types of suppliers in SCM: (1) single sourcing, where only one supplier can fulfill an organization's requirements and demands; and (2) multiple sourcing, where more than one supplier can meet the demands and requirements. Selecting potential suppliers is a strategic decision for any company, involving various criteria that influence supplier outcomes. The selection process lays the foundation for long-term partnerships that can significantly influence a business's success or failure. Business priorities and policies play a vital role in determining the assessment criteria [14,25,26]. The process of evaluating and ranking suppliers depends on the decision maker's choice of assessment criteria. The definition and weighting of these criteria are key steps in the supplier selection process. According to [27,28], there are three supplier assessment criteria: quality, cost, and delivery. As [29,30] pointed out; the most important criterion for selecting the optimal supplier is quality. As Khedr and Rani [20] indicated, there are five primary attributes for evaluating effective suppliers: quality of service (QoS), cost, location, reputation, and professionalism. Ware et al. [8] emphasized that cost, quality, service, and risk factors are important assessment criteria. Further, Abuzaid et al. [9] determined that the main criteria for the assessment and selection of suppliers include: better price (cost), quality, delivery, technological capability, flexibility, relationship, financial issues, and environmental aspects related to green practices. Table 1 presents the varied assessment criteria and their sub-criteria [9,31–35].

Table 1. Criteria and sub-criteria for selecting suppliers.

Suppliers' Assessment Criteria	Sub-Criteria
Price (Cost)	Competitive pricing of goods/services
	Discounts
	Tariff and taxes
	Total logistics/freight cost
Quality	Continuous improvement
	Conformance for certifications
	Reliability of the products/services
	Consistency of processes and services
Delivery/Services	Delivery on time
	Compliance with order quantities
	Stable supplement
	Real-time updates on order processing status
	Reliability
Technological Capability	Research and improvement ability
	Technical expertise
	Innovation capabilities
Flexibility	Immediate response to requirements
	Acceptance of changes
	Ability to handle conflicts with partners

Table 1. *Cont.*

Suppliers' Assessment Criteria	Sub-Criteria
Relationship	Ability to maintain a long-term relationship
	Information sharing
	Open communication
	Honesty and integrity
Financial aspects	Past business performance
	Assets and liabilities
	Suitable financial status
	Profitability
	Disclosure of financial records
	Ability to withstand economic fluctuations
Environmental aspects	Continuous delivery of products and services
	Certification of environmental management
	Use of hazardous substances in production
	Application of environmentally friendly packaging
Reputation	Environmental assessment programs
	Flexibility, environmental and financial stability, and social responsibility
Reliability	Ability to handle failures
	Fast recovery from interruptions to complete the task
	Maintenance of continuous service even in the event of disruptions
Social Responsibility	Socially responsible practices
	Human rights policies
	Safe working conditions
	Fair wages and benefits for their partners
Innovation and Adaptability	Embracing new technologies
	Agility in adapting to changing market demands
	Continuous improvement and provision of best practices
Collaboration and Communication	Maintenance of effective communication channels
	Willingness to collaborate
Ethical Practices	Clear policies and procedures to ensure ethical behavior
Risk Management	Ability to identify and mitigate potential risks
	Robust risk management strategies
Reporting and Transparency	Transparency practices
	Provision of reports to facilitate understanding and monitoring
Community Engagement	Inclusion of local communities, support for social initiatives, and contribution to the local economy

Table 1. *Cont.*

Suppliers' Assessment Criteria	Sub-Criteria
Location	Transport conditions
	Geographical distance
	Traffic infrastructure
	Road speed

2.3. Uncertainty in Supplier Assessment

The uncertainty in the process of supplier assessment is mainly due to the lack of knowledge and information, which directly affects SCM. This uncertainty can be considered from two perspectives:

- Uncertainty related to the priority of requirements/assuagement criteria (stakeholders' preferences and requirements)

User requirements contain uncertainty related to users' ratings, the priority of the service levels, and the priority of the requirements. This uncertainty is due to incomplete, imprecise, conflicting, not fully reliable, or evolving information. In addition, highly changing requirements add a new level of uncertainty. Suppliers that are selected based on limited information cannot satisfy users. There is a lack of knowledge about the evaluation criteria, such as the cost, performance, reliability, privacy, security, location, reputation, quality of service (QoS), and availability levels of the services. These challenges highlight the need for advanced methods, such as fuzzy systems (FSs), intuitionistic fuzzy systems (IFSs), and fuzzy theory, which can be adapted to handle the uncertainty of users' satisfaction in order to determine a sustainable provider.

- Uncertainty related to the various viewpoints of decision makers

There is uncertainty in the supplier assessment process due to conflicting sources, incomplete information, and a lack of knowledge. According to [10,36], there are five sources of uncertainty in the decision-making process:

- Uncertainty associated with human error.
- Uncertainty due to data collection tools.
- Uncertainty associated with the lack of data and information.
- Uncertainty due to data analysis methods.
- Uncertainty due to the interpretation process of data and information.

2.4. The Effect of Suitable Suppliers' Integration on the SCM and Overall Organizational Performance

The integration of suitable suppliers can support SCM tasks and the overall organizational performance [23].

SCM tasks and components are affected by suppliers' integration, and there are several benefits from involving suitable suppliers. Three basic dimensions are as follows:

1. Efficiency: the collaboration and integration of a suitable supplier can lead to the effective coordination of orders, raw material availability, and production or shipping schedules, the reduction in shortages or overstocks, the elimination of redundancies, and the reduction in production cycles.
2. Effectiveness is "the degree to which the channel accomplishes its objectives," which includes maximizing customer value and achieving the capacities required for customer satisfaction and cost reduction.

3. Product innovation: is the introduction of new products and services. The integration of suitable suppliers and their involvement in product design and the determination of raw materials can support inter-organizational learning and product innovation.

Suitable supplier integration can benefit the overall organizational performance, including [21,23,37]

- Increased profitability.
- The firm's sustainability.
- Increased sales and market share.
- Improved competitive advantage.
- Improved financial and market performance.

2.5. Methods of Supplier Assessment and Selection

The assessment and rating methods for selection can be classified into quantitative and qualitative.

1. Qualitative methods depend on visualizing methods and tools for brainstorming alternative solutions. These methods are applied to develop a clear understanding of a situation and explore, discover, and describe reasons and motives.
2. Quantitative methods depend on mathematics, physics, and the statistical sciences to assess the data collected in numerical form, in order to quantify a problem and categorize, rank, or measure it in units.

Quantitative methods are more structured than qualitative ones. Both methods can be used in integrated models for the supplier assessment and selection process [38] and various methods have been applied [21], as summarized in Table 2.

Table 2. Methods applied for the supplier assessment and selection process.

Categories	Example of Methods
Fuzzy Theory-Based Methods	Fuzzy systems (FSs)
	Intuitionistic Fuzzy Systems (IFSs)
	Neutrosophic Sets (NSs)
Multi-Criteria Decision-Making Methods	Analytic Hierarchy Process (AHP)
	Analytic Network Process (ANP)
	Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)
	Preference Ranking Organization Method for Enrichment Evaluations
	Multi-Attribute Utility Theory (MAUT)
Mathematical Programming Methods	Linear Programming,
	Goal programming
	Multi-objective Linear Programming
Cost-Based Methods	Data Envelopment Analysis
	Activity-Based Costing (ABC)
	Total Cost of Ownership (TCO)
Artificial Intelligence-Based Methods	Case-Based Reasoning
	Artificial Neural Network

Table 2. Cont.

Categories	Example of Methods
Combined Approaches	Mathematical programming +TCO
	AHP + Linear Programming
	MAUT + LP
	ANP + TOPSIS or Fuzzy TOPSIS

Table 3 provides a comparison between the most common methods for prioritizing assessment criteria and the FUCOM with TrFNs, which is used as part of the proposed method [10,39–41].

Table 3. Comparison between the most common methods to prioritize assessment criteria.

Method	Principles	No. of Pairwise Comparisons	Main Advantages	Main Disadvantages
FUCOM with TrFNs	Extends classical FUCOM by using triangular fuzzy numbers (TrFNs) to handle uncertainty and linguistic judgments	$(n - 1)$	- Handles uncertainty and vagueness in expert opinions. - Combines FUCOM's advantages of consistency and minimal comparisons.	- Increased mathematical complexity from fuzzy operations. - Results are fuzzy numbers: need an extra defuzzification step to compute crisp weights.
FUCOM (Classical)	Compute weights for criteria by applying pairwise comparisons	$(n - 1)$	- Reduces pairwise comparisons $(n - 1)$. - Computes the DFC to validate results.	- Focuses on expert judgment. - Does not handle imprecise or linguistic data.
Analytic Hierarchy Process (AHP)	Uses hierarchical structuring and extensive pairwise comparisons to compute weights and check consistency	$(n(n - 1)/2)$	- Well known and accepted. - Hierarchical structure is well-suited for complex decisions.	- A high number of comparisons results in inconsistencies. - Time-consuming.
Best-Worst Method (BWM)	Identifies the best (most important) and worst (least important) criteria; then, pairwise comparisons are made between these two extremes and all others to find the optimal weights.	$(2n - 3)$	- Has fewer comparisons than the AHP. - Gives consistent results.	- The choice of the single best and worst criterion can be subjective and impactful. - Less flexible if the decision context changes the extremes.

2.6. Basic Definitions

Definition 1. Let $\bar{A} = (l, m, u)$ be a triangular fuzzy number (TrFN), and R represent a set of real numbers; the membership function $\mu_{\bar{A}}(x): R \rightarrow [0, 1]$ is represented as follows [42]:

$$\mu_{\bar{A}}(x) = \begin{cases} 0 & x < l \\ \frac{x-l}{m-l} & l \leq x < m \\ \frac{u-x}{u-m} & m \leq x \leq u \\ 0 & x > u \end{cases}, \text{ where } (-\infty < l \leq m \leq u < \infty). \quad (1)$$

TrFNs represent values with just three dimensions to handle uncertainty; they are simpler than trapezoidal fuzzy numbers, intuitionistic fuzzy numbers, and neutrosophic sets, enabling the decision makers to perform efficient arithmetic operations.

2.7. The Basic Arithmetic Operations of TrFNs

The basic arithmetic operations of TFNs can be accomplished [42] as follows:

Let $\bar{a} = (l_{\bar{a}}, m_{\bar{a}}, u_{\bar{a}})$ and $\bar{b} = (l_{\bar{b}}, m_{\bar{b}}, u_{\bar{b}})$; then,

$$\bar{a} + \bar{b} = (l_{\bar{a}} + l_{\bar{b}}, m_{\bar{a}} + m_{\bar{b}}, u_{\bar{a}} + u_{\bar{b}}), \quad (2)$$

$$\bar{a} - \bar{b} = (l_{\bar{a}} - l_{\bar{b}}, m_{\bar{a}} - m_{\bar{b}}, u_{\bar{a}} - u_{\bar{b}}), \quad (3)$$

$$\bar{a} \times \bar{b} = (l_{\bar{a}} \times l_{\bar{b}}, m_{\bar{a}} \times m_{\bar{b}}, u_{\bar{a}} \times u_{\bar{b}}), \quad (4)$$

$$\frac{\bar{a}}{\bar{b}} = \left(\frac{l_{\bar{a}}}{u_{\bar{b}}}, \frac{m_{\bar{a}}}{m_{\bar{b}}}, \frac{u_{\bar{a}}}{l_{\bar{b}}} \right), \quad (5)$$

$$\bar{a} \times \gamma = (l_{\bar{a}} \times \gamma, m_{\bar{a}} \times \gamma, u_{\bar{a}} \times \gamma), \text{ where } \gamma \geq 0, \quad (6)$$

$$\bar{a}^{-1} = \left(\frac{1}{u_{\bar{a}}}, \frac{1}{m_{\bar{a}}}, \frac{1}{l_{\bar{a}}} \right). \quad (7)$$

Definition 2. Let $\bar{A} = (l, m, u)$ be a TrFN; then, the graded mean integration representation (GMIR) can be computed as [43,44]

$$\text{GMIR} = \frac{l + 4m + u}{6}. \quad (8)$$

3. The Research Method

This work introduces a new hybrid method using FUCOM with TrFNs to consistently prioritize supplier assessment criteria that reflect stakeholders' preferences. Then it applies the TOPSIS-based method to assess suppliers, taking into account the cost and benefit criteria, as well as uncertainty. The integration of the FUCOM and the TOPSIS-based methods reduces limitations and combines the advantages of each method; using a TOPSIS-based method without integrating FUCOM with TrFNs cannot reflect the priority of each criterion [16,45–48]. The FUCOM has been applied to prioritize assessment criteria as part of the assessment process [10,41].

The FUCOM was introduced by [49] as a new model to compute the weights of the assessment criteria, focusing on the consistency of the first and second prerequisites and the deviation from full consistency (DFC) metric. The lower value of the total DFC concludes the higher reliability of the results [10]. The FUCOM has multiple advantages over other decision-support methods, such as the AHP and the best–worst method (BWM), and has been employed by researchers, such as [36]. The advantages of FUCOM include the following:

- It reduces the number of pairwise comparisons and calculations.
- It validates its output by computing the deviation from full consistency (DFC).
- It simplifies the pairwise comparison by disregarding unnecessary comparisons.
- The integration of FUCOM can improve decision-making efficiency by providing consistently prioritized weights.

The simplified form of FUCOM provides a straightforward method for prioritizing assessment criteria and overcoming problems with the AHP. As described by [10], the simplification of FUCOM makes it more effective for decision-making with fuzzy numbers.

The proposed hybrid method consists of two parts, and each contains the following steps:

Part 1: Fuzzy Full Consistency Method (FUCOM) phases

Step 1.1: Determine the supplier assessment criteria (SAC) as follows:

$$\text{SAC} = \{\text{SAC}_1, \text{SAC}_2, \text{SAC}_3, \dots, \text{SAC}_n\}. \quad (9)$$

Step 1.2: Sort the supplier assessment criteria according to the stakeholders' preferences from the most to least significant.

The decision maker sorts the assessment criteria based on their own knowledge, ordering them from the most to least significant according to their preference. The superiority and equality between criteria are denoted by the symbols “>” and “=” as follows:

$$SAC_{J(1)}((>) \vee (=))SAC_{J(2)}((>) \vee (=)) \dots \dots \dots ((>) \vee (=))SAC_{J(K)}, \quad (10)$$

where k represents the rank of the assessment criterion.

Step 1.3: Apply the fuzzy FUCOM concept and perform pairwise comparisons.

Here, one performs pairwise comparisons between the sorted assessment criteria. The fuzzy priority of each criterion is relative to the other criteria.

$(p_{k/(k+1)}), k = 1, 2, \dots, n$, where the value of k denotes the rank of the criteria

The comparative priority $(p_{k/(k+1)})$ indicates the superiority of the criterion $C_{J(k)}$ over criterion $c_{j((k+1))}$. In this way, the vector of comparative priorities for the decision-making criteria is obtained as follows:

$$P = (p_{1/2}, p_{2/3}, \dots, p_{k/(k+1)}). \quad (11)$$

The second comparative priority of the criteria $((p_{(k+1)/(k+2)}))$ is calculated to evaluate the satisfaction of the second FUCOM prerequisite.

Step 1.4: Compute the fuzzy weights of the decision criteria and confirm the fuzzy FUCOM prerequisites.

The final weights of the criteria are as follows:

$$\bar{w} = (w_1, w_2, \dots, w_n)^T. \quad (12)$$

Here, w_1 represents the weight of the most important criterion from the decision makers' perspective, which is identified as the first criterion; this is calculated first. Then, using Equation (10), by dividing the weight of the most important criterion (w_i) by the priorities of the other criteria $(p_{k/(k+1)})$, the final weights of the remaining criteria are calculated.

$$\sum_k \frac{1}{p_{k(k+1)}} * w_i = 1 \Rightarrow \frac{1}{\sum_k \frac{1}{p_{k(k+1)}}} \forall k \quad (13)$$

$$w_k = \frac{w_i}{p_{k(k+1)}} \forall k \quad (14)$$

Step 1.5: Test the consistency of the fuzzy FUCOM using the DFC value.

The DFC in the FS-FUCOM can be calculated, where $n - 1$ is the total number of pairwise comparisons conducted using the FUCOM approach.

$$\frac{w_k}{w_{(k+1)}} = p_{k/(k+1)} \Rightarrow \frac{w_k}{w_{(k+1)}} - p_{k/(k+1)} = 0 \quad (15)$$

$$\frac{w_k}{w_{(k+2)}} = p_{k/(k+1)} * p_{(k+1)/(k+2)} \Rightarrow \frac{w_k}{w_{(k+2)}} - p_{k/(k+1)} * p_{(k+1)/(k+2)} = 0 \quad (16)$$

$$\sum \left(\frac{w_k}{w_{k+1}} - p_{k/(k+1)} \right)^2 \quad (17)$$

$$DFC = \frac{1}{n-1} \sum_k \left(\frac{w_k}{w_{k+1}} - p_{k/(k+1)} \right)^2 \quad (18)$$

Definition 3. If the DFC is $Z \neq 0$, the smaller the DFC, the higher the reliability and consistency of the results, which shows the better satisfaction of the FUCOM prerequisites [10].

Part 2: Applying the Fuzzy Positive Ideal Solution (Fuzzy FPIS) and the Negative Ideal Solution (FNIS)

Step 2.1: Establish a set of decision matrices that represent the viewpoints of each decision maker in the decision-making group.

Let k be the number of the decision-making experts within the decision-making group.

Each decision maker/expert can construct the decision matrix as follows:

- Rows represent alternative suppliers.
- Columns represent assessment measures.

$$\bar{a} = \{a_{ij}\}_{m \times n} = \begin{bmatrix} a_{11} & \dots & a_{1j} \\ a_{21} & \dots & a_{2j} \\ \vdots & \ddots & \vdots \\ a_{i1} & \dots & a_{ij} \end{bmatrix} \quad (19)$$

Step 2.2: Compute the mean value for the viewpoints of the decision makers in the group.

The arithmetic mean operator (AMO) can be computed as [16]:

$$AMO = \left(\frac{1}{k} \sum_{k=1}^k \bar{l}_{ij}, \frac{1}{k} \sum_{k=1}^k m_{ij}, \frac{1}{k} \sum_{k=1}^k u_{ij} \right). \quad (20)$$

Step 2.3: Compute the weighted matrix by applying the fuzzy FUCOM weights for each assessment criterion for every alternative within the decision matrix.

Apply the fuzzy FUCOM weights of Equation (13) as follows:

$$AMO * \bar{w} = \begin{bmatrix} a_{11} * w_j & \dots & a_{1j} * w_j \\ a_{21} * w_j & \dots & a_{2j} * w_j \\ \vdots & \ddots & \vdots \\ a_{i1} * w_j & \dots & a_{ij} * w_j \end{bmatrix}. \quad (21)$$

Step 2.4: Compute the normalized decision matrix (NDM).

The NDM can be determined as follows:

$$NDM_{Benefits} = \left(\frac{\bar{l}_{ij}}{\bar{u}^+}, \frac{\bar{m}_{ij}}{\bar{u}^+}, \frac{\bar{u}_{ij}}{\bar{u}^+} \right), \text{ where } \bar{u}^+ = \text{Max} \{u_{ij}\} \text{ for Benefits}; \quad (22)$$

$$NDM_{Costs} = \left(\frac{\bar{l}^-}{\bar{l}_{ij}}, \frac{\bar{l}^-}{\bar{m}_{ij}}, \frac{\bar{l}^-}{\bar{u}_{ij}} \right), \text{ where } \bar{l}^- = \text{Max} \{\bar{l}_{ij}\} \text{ for Costs}. \quad (23)$$

Step 2.5: Compute the distance from each alternative to the fuzzy positive ideal solution (Fuzzy FPIS) and negative ideal solution (FNIS).

The Fuzzy FPIS and negative ideal solution (FNIS) are calculated through five computation processes to clarify and simplify the computation process, as well as avoid confusion during the calculations [16].

Firstly, we determine the value of the fuzzy positive ideal solution A^+ and fuzzy negative ideal solution A^- as follows:

$$A^+ = (a_1^+, a_2^+, a_3^+, \dots, a_m^+) \quad a_j^+ = (u_j^+, u_j^+, u_j^+), \text{ where} \quad (24)$$

$$u^+ = \max \{u_{ij}\} \quad \text{for } i = 1, 2, 3, \dots, n.$$

$$A^- = (a_1^-, a_2^-, a_3^-, \dots, a_m^-) \quad a_j^- = (i_j^-, i_j^-, i_j^-), \text{ where} \quad (25)$$

$$u^- = \min \{i_{ij}\} \quad \text{for } i = 1, 2, 3, \dots, n.$$

Secondly, we compute the distance.

The distance $\text{dist}(y_{ij}, a_j^+)$ represents the difference between $y_{ij} = (i_{ij}, m_{ij}, u_{ij})$ and $a_j^+ = (u_j^+, u_j^+, u_j^+)$. The distance $\text{dist}(y_{ij}, a_j^-)$ represents the difference between $y_{ij} = (i_{ij}, m_{ij}, u_{ij})$ and $a_j^- = (i_j^-, i_j^-, i_j^-)$:

$$\text{dist}(y_{ij}, a_j^+) = \sqrt{\frac{1}{3} \left[(i_{ij} - u_j^+)^2, (m_{ij} - u_j^+)^2, (u_{ij} - u_j^+)^2 \right]}; \quad (26)$$

$$\text{dist}(y_{ij}, i_j^-) = \sqrt{\frac{1}{3} \left[(i_{ij} - i_j^-)^2, (m_{ij} - i_j^-)^2, (u_{ij} - i_j^-)^2 \right]}. \quad (27)$$

Thirdly, we compute the square value of $\text{dist}(y_{ij}, a_j^+)$ and $\text{dist}(y_{ij}, i_j^-)$, where the following is established:

$$\begin{aligned} \text{dist}(y_{ij}, a_j^+)^2 &= \left(\sqrt{\frac{1}{3} \left[(i_{ij} - u_j^+)^2, (m_{ij} - u_j^+)^2, (u_{ij} - u_j^+)^2 \right]} \right)^2, \\ \text{dist}(y_{ij}, a_j^+)^2 &= \left(\left(\frac{1}{3} \left[(i_{ij} - u_j^+)^2, (m_{ij} - u_j^+)^2, (u_{ij} - u_j^+)^2 \right] \right)^{\frac{1}{2}} \right)^2, \\ &\xrightarrow{\text{yields}} \text{dist}(y_{ij}, a_j^+)^2 = \frac{1}{3} \left[(i_{ij} - u_j^+)^2, (m_{ij} - u_j^+)^2, (u_{ij} - u_j^+)^2 \right]. \end{aligned} \quad (28)$$

$$\begin{aligned} \text{dist}(y_{ij}, i_j^-)^2 &= \left(\sqrt{\frac{1}{3} \left[(i_{ij} - i_j^-)^2, (m_{ij} - i_j^-)^2, (u_{ij} - i_j^-)^2 \right]} \right)^2, \\ \text{dist}(y_{ij}, i_j^-)^2 &= \left(\left(\frac{1}{3} \left[(i_{ij} - i_j^-)^2, (m_{ij} - i_j^-)^2, (u_{ij} - i_j^-)^2 \right] \right)^{\frac{1}{2}} \right)^2, \\ &\xrightarrow{\text{yields}} \text{dist}(y_{ij}, i_j^-)^2 = \frac{1}{3} \left[(i_{ij} - i_j^-)^2, (m_{ij} - i_j^-)^2, (u_{ij} - i_j^-)^2 \right] \end{aligned} \quad (29)$$

Fourthly, we compute the summation of $\text{dist}(y_{ij}, i_j^-)^2$ and $\text{dist}(y_{ij}, a_j^+)^2$ as follows:

$$\sum_i^m \left(\text{dist}(y_{ij}, a_j^+) \right)^2; \quad (30)$$

$$\sum_i^m \left(\text{dist}(y_{ij}, a_j^-) \right)^2. \quad (31)$$

Finally, we compute the square root of $\sum_i^m \left(\text{dist}(y_{ij}, a_j^+) \right)^2$ and $\sum_i^m \left(\text{dist}(y_{ij}, a_j^-) \right)^2$ to find d_i^+ and d_i^- as follows:

$$d_i^+ = \sqrt{\sum_i^m \left(\text{dist}(y_{ij}, a_j^+) \right)^2}; \quad (32)$$

$$d_i^- = \sqrt{\sum_i^m \left(\text{dist}(y_{ij}, a_j^-) \right)^2}. \quad (33)$$

Step 2.6: Compute the closeness index of each alternative.

This phase aims to compute the closeness index (CI) of each candidate supplier as follows:

$$CI = \frac{d_i^-}{d_i^- + d_i^+}. \quad (34)$$

A higher CI value means a more productive supplier.

Step 2.7: Rank and assess the alternative suppliers.

Here, we rank the alternative suppliers from the highest to the lowest value and then determine the most suitable supplier.

4. The Research Method Implementation and Its Results

A home appliance company that trades and manufactures electrical appliances wants to maintain its supply chain by establishing a long-term relationship with a suitable supplier. It wants to determine the most suitable supplier from five alternatives based on four assessment criteria according to the following requirements: (1) reliability, (2) reputation, (3) real-time updates on order processing status, and (4) honesty. The decision matrix is constructed by four decision makers and experts using the linguistic scales in Table 4 [50].

Table 4. Linguistic scale.

Linguistic Variables	Fuzzy Numbers
Equally Significant	(1,1,1)
Low Significance	(0.67,1,1.5)
Fairly Significant	(1.5,2,2.5)
Very Significant	(2.5,3,3.5)
Absolutely Significant	(3.5,4,4.5)

Part 1: Fuzzy Full Consistency Method (FUCOM) phases

Step 1.1: Determine the supplier assessment criteria (SAC) based on the given case using Equation (9). According to the given case,

SAC = {Reliability : SAC₁, Reputation : SAC₂, Real time updates SAC₃, Honesty: SAC₄}.

Step 1.2: Sort the supplier assessment criteria according to the stakeholders' preferences from the most to least significant.

The decision maker sorts the supplier assessment criteria depending on their requirements from the most to least significant using Equation (10).

$k = 1, 2, 3, 4$, where $k = 4$ represents the rank of the assessment criterion.

SAC 2 > SAC 3 > SAC 1 > SAC 4

Step 1.3: Apply the fuzzy FUCOM concept and perform pairwise comparisons.

Perform pairwise comparisons using Equation (11) as follows:

SAC 2	SAC 3	SAC 1	SAC 4
(1,1,1)	(0.67,1,1.5)	(1.5,2,2.5)	(2.5,3,3.5)
	(0.67,1,1.5)	(1,2,3.73)	(1,1.5,2.33)
		(0.67,2,5.6)	(1,3,8.69)

Step 1.4: Compute the fuzzy weights of the decision criteria and confirm the fuzzy FUCOM prerequisites.

The weight of the most important criterion (w_i) is computed as $\frac{1}{\sum_k \frac{1}{P_{k(k+1)}}$

$$\frac{1}{\frac{1}{(1,1,1)} + \frac{1}{(0.67,1,1.5)} + \frac{1}{(1.5,2,2.5)} + \frac{1}{(2.5,3,3.5)}} = \frac{1}{(2.28, 2.83, 3.49)} = (0.286, 0.353, 0.438).$$

Compute the crisp values for weights using Equation (8):

$$w_{SAC2} = (0.286, 0.353, 0.438) = 0.356.$$

The weights of the remaining criteria are calculated using Equation (14) as follows:

$$w_{SAC3} = \frac{(0.286, 0.353, 0.438)}{(0.67, 1, 1.5)} = (0.190, 0.353, 0.653) = 0.375;$$

$$w_{SAC1} = \frac{(0.286, 0.353, 0.438)}{(1.5, 2, 2.5)} = (0.114, 0.176, 0.292) = 0.185;$$

$$w_{SAC4} = \frac{(0.286, 0.353, 0.438)}{(2.5, 3, 3.5)} = (0.081, 0.117, 0.219) = 0.128.$$

The final weights of the criteria are as follows:

$$\bar{w} = (0.356, 0.375, 0.185, 0.128)^T.$$

Figure 2 shows these weights.

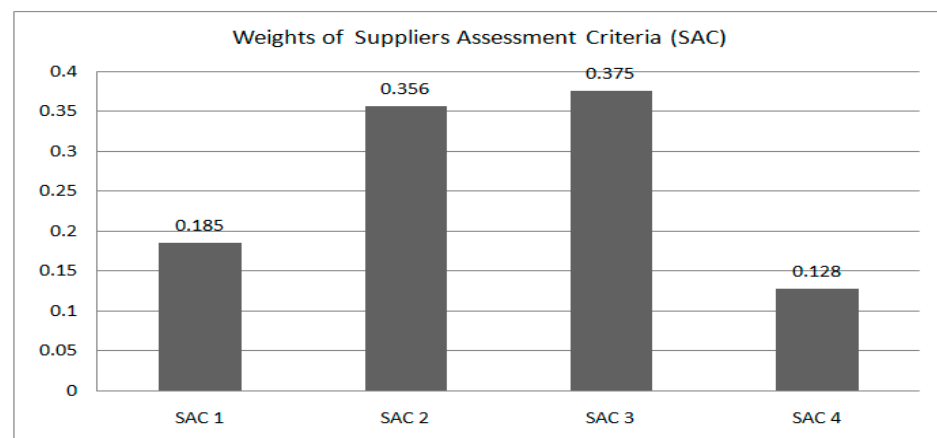


Figure 2. Weights of the supplier assessment criteria (SAC).

Compute the first prerequisite using $\sum \left(\frac{w_k}{w_{k+1}} - P_{k/(k+1)} \right)^2$:

Prerequisite 1:

$$\frac{w_{SAC2}}{w_{SAC3}} = \frac{(0.286, 0.353, 0.438)}{(0.190, 0.353, 0.653)} - (0.67, 1, 1.5) = (-0.233, 0, 0.8) = 0.09;$$

$$\frac{w_{SAC3}}{w_{SAC1}} = \frac{(0.190, 0.353, 0.653)}{(0.114, 0.176, 0.292)} - (1, 2, 3.73) = (-0.35, 0, 1.97) = 0.27;$$

$$\frac{w_{SAC1}}{w_{SAC4}} = \frac{(0.114, 0.176, 0.292)}{(0.081, 0.117, 0.219)} - (1, 1.5, 2.33) = (0.48, 0, 1.27) = 0.13.$$

Step 1.5: Test the consistency of the fuzzy FUCOM using the DFC value.

Apply Equation (18):

$$DFC = \frac{1}{n-1} \sum \left(\frac{w_k}{w_{k+1}} - P_{k/(k+1)} \right)^2.$$

According to the given numerical example with $n = 4$,

$DFC = \frac{1}{3} \sum (0.09 + 0.27 + 0.13)^2 = 0.08$, which indicates a higher reliability and consistency of results according to Definition 3.

Part 2: Apply the Fuzzy Positive Ideal Solution (Fuzzy FPIS) and Negative Ideal Solution (FNIS)-based Method

Step 2.1: Establish a set of decision matrices, which represent the viewpoints of each decision maker in the decision-making group.

Here, $k = 4$ is the number of the decision-making experts within the decision-making group.

Each decision maker/expert can construct the decision matrix by applying Equation (19) as follows:

- Rows represent alternative suppliers.
- Columns represent supplier assessment criteria (SAC).

Table 5 highlights decision matrices for experts.

Table 5. Decision matrices for experts.

Experts/Decision Makers		SAC 2	SAC 3	SAC 1	SAC 4
Decision Maker 1	Alt1	(1.5,2,2.5)	(0.67,1,1.5)	(1,1,1)	(2.5,3,3.5)
	Alt2	(2.5,3,3.5)	(0.67,1,1.5)	(2.5,3,3.5)	(3.5,4,4.5)
	Alt3	(1.5,2,2.5)	(1,1,1)	(1.5,2,2.5)	(2.5,3,3.5)
	Alt4	(3.5,4,4.5)	(1.5,2,2.5)	(2.5,3,3.5)	(3.5,4,4.5)
	Alt5	(2.5,3,3.5)	(1,1,1)	(2.5,3,3.5)	(3.5,4,4.5)
Decision Maker 2	Alt1	(1.5,2,2.5)	(1,1,1)	(0.67,1,1.5)	(2.5,3,3.5)
	Alt2	(2.5,3,3.5)	(1,1,1)	(1,1,1)	(2.5,3,3.5)
	Alt3	(2.5,3,3.5)	(2.5,3,3.5)	(0.67,1,1.5)	(2.5,3,3.5)
	Alt4	(3.5,4,4.5)	(2.5,3,3.5)	(1,1,1)	(3.5,4,4.5)
	Alt5	(1.5,2,2.5)	(0.67,1,1.5)	(1.5,2,2.5)	(1.5,2,2.5)
Decision Maker 3	Alt1	(1.5,2,2.5)	(1.5,2,2.5)	(1,1,1)	(0.67,1,1.5)
	Alt2	(2.5,3,3.5)	(1.5,2,2.5)	(2.5,3,3.5)	(1,1,1)
	Alt3	(3.5,4,4.5)	(1,1,1)	(3.5,4,4.5)	(1.5,2,2.5)
	Alt4	(2.5,3,3.5)	(2.5,3,3.5)	(3.5,4,4.5)	(1,1,1)
	Alt5	(1,1,1)	(1.5,2,2.5)	(2.5,3,3.5)	(1.5,2,2.5)
Decision Maker 4	Alt1	(3.5,4,4.5)	(2.5,3,3.5)	(2.5,3,3.5)	(1.5,2,2.5)
	Alt2	(1,1,1)	(1.5,2,2.5)	(2.5,3,3.5)	(1,1,1)
	Alt3	(1.5,2,2.5)	(2.5,3,3.5)	(2.5,3,3.5)	(3.5,4,4.5)
	Alt4	(1,1,1)	(1.5,2,2.5)	(3.5,4,4.5)	(1,1,1)
	Alt5	(2.5,3,3.5)	(1.5,2,2.5)	(2.5,3,3.5)	(3.5,4,4.5)

Step 2.2: Compute the arithmetic mean value of the decision makers' viewpoints in the decision-making group.

The arithmetic mean operator (AMO) can be computed by applying Equation (20) as shown in Table 6.

Table 6. The arithmetic mean value of the decision makers' viewpoints.

Alternatives	SAC 2	SAC 3	SAC 1	SAC 4
Alt1	(2,2.5,3)	(1.417,1.75,2.125)	(1.292,1.5,1.75)	(1.792,2.25,2.75)
Alt2	(2.125,2.5,2.875)	(1.167,1.5,1.875)	(2.125,2.5,2.875)	(2,2.25,2.5)
Alt3	(2.25,2.75,3.25)	(1.75,2, 2.25)	(2.042,2.5,3)	(2.5,3,3.5)
Alt4	(2.625,3,3.375)	(2,2.5,3)	(2.625,3,3.375)	(2.875,3.25,3.625)
Alt5	(1.875,2.25,2.625)	(1.167,1.5,1.875)	(2.25,2.75,3.25)	(2.5,3,3.5)

Step 2.3: Compute the weighted matrix by applying the fuzzy FUCOM weights for each assessment criterion for every alternative within the decision matrix.

Apply the fuzzy FUCOM weights from Table 7 Use Equation (21) to compute the weighted decision matrix using the fuzzy FUCOM weights as shown in Table 8.

Table 7. Fuzzy FUCOM weights.

Assessment Criteria	Fuzzy Values for Weights	Crisp Values for Weights Using Equation (8)	Orders
SAC 1	(0.114, 0.176, 0.292)	0.185	3
SAC 2	(0.286, 0.353, 0.438)	0.356	2
SAC 3	(0.190, 0.353, 0.653)	0.375	1
SAC 4	(0.081, 0.117, 0.219)	0.128	4

Table 8. The weighted decision matrix.

Alternatives	SAC 2	SAC 3	SAC 1	SAC 4
Alt1	(0.228,0.435,0.875)	(0.405,0.617,0.930)	(0.245,0.529,10.142)	(0.145,0.263,0.602)
Alt2	(0.242,0.435,0.839)	(0.333,0.529,0.821)	(0.403,0.882,10.877)	(0.162,0.263,0.547)
Alt3	(0.256,0.478,0.949)	(0.500,0.706,0.985)	(0.387,0.882,10.959)	(0.202,0.351,0.766)
Alt4	(0.299,0.522,0.985)	(0.572,0.882, 10.314)	(0.498,10.059,20.202)	(0.232,0.380,0.793)
Alt5	(0.214,0.391,0.766)	(0.333,0.529,0.821)	(0.427,0.970,20.122)	(0.202,0.351,0.766)

Step 2.4: Compute the normalized fuzzy decision matrix.

In the numerical example, the assessment process depends on the benefits criteria.

Compute the normalized weighted fuzzy decision matrix using Equation (22) as shown in Table 9.

Table 9. The normalized weighted fuzzy decision matrix.

Alternatives	SAC 2	SAC 3	SAC 1	SAC 4
Alt1	(0.103,0.197,0.397)	(0.183,0.280,0.422)	(0.111,0.240,10.518)	(0.065,0.119,0.273)
Alt2	(0.109,0.197,0.380)	(0.151,0.240,0.372)	(0.182,0.4,0.852)	(0.073,0.119,0.248)
Alt3	(0.116,0.216,0.430)	(0.226,0.320,0.447)	(0.175,0.4,0.889)	(0.091,0.159,0.347)
Alt4	(0.135,0.236,0.447)	(0.259,0.4, 0.596)	(0.226,0.480,1)	(0.105,0.172,0.359)
Alt5	(0.097,0.177,0.347)	(0.151,0.240,0.372)	(0.193,0.440,0.963)	(0.091,0.159,0.347)

Step 2.5: Compute the distance from each alternative to the fuzzy ideal.

To compute $\text{dist}(y_{ij}, a_j^+)^2 \left(\text{dist}(y_{ij}, a_j^-) \right)^2$, use Equations (28) and (29).

To compute $\sum_i^m \left(\text{dist}(y_{ij}, a_j^+) \right)^2$ and $\sum_i^m \left(\text{dist}(y_{ij}, a_j^-) \right)^2$, use Equations (30) and (31).

Table 10 highlights distances based on the positive ideal solution of alternatives; Table 11 highlights distances based on the negative ideal solution of alternatives.

Table 10. Distances based on the positive ideal solution of alternatives.

Alternatives	$\text{dist}(y_{ij}, a_j^+)^2$ For Each Assessment Criteria from the Positive Ideal Solution				$\sum_i^m \left(\text{dist}(y_{ij}, a_j^+) \right)^2$
	SAC 1	SAC 2	SAC 3	SAC 4	
Alts 1	0.603	0.506	0.533	0.726	2.368
Alts 2	0.586	0.563	0.350	0.733	2.232
Alts 3	0.573	0.455	0.350	0.653	2.031
Alts 4	0.545	0.357	0.289	0.632	1.823
Alts 5	0.639	0.563	0.321	0.653	2.176

Table 11. Distances based on the negative ideal solution of alternatives.

Alternatives	$\text{dist}(y_{ij}, a_j^-)^2$ For Each Assessment Criteria from the Negative Ideal Solutions				$\sum_i^m \left(\text{dist}(y_{ij}, a_j^-) \right)^2$
	SAC 1	SAC 2	SAC 3	SAC 4	
Alts 1	0.042	0.061	0.079	0.087	0.269
Alts 2	0.038	0.043	0.248	0.035	0.346
Alts 3	0.052	0.078	0.267	0.029	0.426
Alts 4	0.059	0.143	0.357	0.032	0.591
Alts 5	0.030	0.043	0.320	0.290	0.683

To compute d_i^+ and d_i^- , we use Equations (32) and (33). Table 12 represents the values of d_i^+ and d_i^- .

Table 12. The d_i^+ and d_i^- for each alternative.

Alternatives	$d_i^+ = \sqrt{\sum_i^m \left(\text{dist}(y_{ij}, a_j^+) \right)^2}$	$d_i^- = \sqrt{\sum_i^m \left(\text{dist}(y_{ij}, a_j^-) \right)^2}$
Alts 1	1.538	0.518
Alts 2	1.493	0.603
Alts 3	1.425	0.652
Alts 4	1.350	0.768
Alts 5	1.475	0.826

Step 2.6: Compute the closeness index of each alternative.

Use Equation (34) to compute the closeness index of each alternative, as shown in Table 13.

Step 2.7: Rank and assess the alternative suppliers.

In this step, the alternative suppliers are ranked from the highest values to the lowest based on the value of the closeness index, as shown in Table 14.

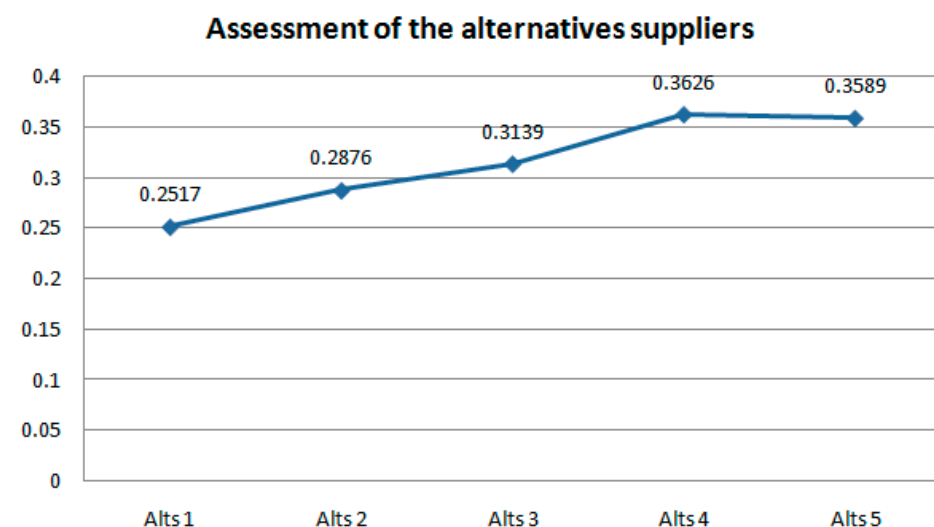
Table 13. Closeness index of each alternative.

Alternatives	Closeness Index of Each Alternative
Alts 1	0.2517
Alts 2	0.2876
Alts 3	0.3139
Alts 4	0.3626
Alts 5	0.3589

Table 14. Ranking of the alternative suppliers.

Alternatives	Ranking and Assessment	Determination of the Best
Alts 1	5	Alts 4
Alts 2	4	
Alts 3	3	
Alts 4	1	
Alts 5	2	

Figure 3 visualizes and clarifies the closeness index values for assessing the alternative suppliers.

**Figure 3.** Assessment of the alternative suppliers.

5. Discussion

The proposed hybrid method depends on the triangular fuzzy numbers with FUCOM to provide consistent prioritization of the assessment criteria, which can reflect the main preferences of stakeholders and make use of the advantages of the FUCOM; then, it applies the FPIS- and FNIS-based method to handle the uncertainty of decision makers during the assessment process. Figure 3 shows that the best supplier is alternative 4 (Alt4), and the alternatives can be ranked from the most suitable to the least as alternative 4 > alternative 5 > alternative 3 > alternative 2 > alternative 1. The results show that the proposed hybrid method takes into account the priority of stakeholders' preferences and enables the decision maker to handle uncertainty during the assessment process. The proposed method not only ranks the various alternatives but can also clarify the differ-

ences between alternatives, providing an accurate assessment of each alternative in terms of the requirements.

The main contributions can be summarized as follows:

1. The proposed method provides consistent prioritizing of the assessment criteria using FUCOM with TrFNs, which reflects the main preferences and requirements simply.
2. The proposed hybrid method enables the decision-making group to construct a set of decision matrices, take into account the various viewpoints of decision makers, and compute the mean value using the AMO.
3. The proposed hybrid method uses five detailed and clear steps to compute the FPIS and FNIS to simplify the computation process, as well as avoid confusion during the calculation process [16].
4. The proposed method ranks the suppliers according to their distance from the ideal assessment criterion, using FUCOM-TriFN with TOPSIS.
5. The use of FUCOM with TriFN makes it a robust tool for imprecise problems with fewer comparisons.
6. The integration of FUCOM with TOPSIS into supplier assessment and selection enables the proposed method to achieve the following goals:
 - (a) Take into account the costs and benefits criterion, as well as handle uncertainty using TriFN.
 - (b) Consistently prioritize the assessment criteria.
 - (c) Handle two types of uncertainty in SCM:
 - A. Uncertainty related to stakeholders' ratings and priority of requirements/assuagement criteria;
 - B. Uncertainty due to incomplete, imprecise, lack of knowledge, conflicting, not fully reliable, or evolving information, in addition to the highly changing requirements.

6. Conclusions and Future Work

SCM faces complexities and challenges in determining the most suitable supplier due to uncertainty, a dynamic environment, and the increasing number of suppliers competing with each other to offer ongoing promotions and offers through modern technology and various social media tools. Several efforts have failed to consistently prioritize the assessment criteria and reflect the main preferences of stakeholders while taking into account the costs and benefits criterion, as well as handling uncertainty. On the other hand, several studies have integrated TOPSIS with various traditional methods to prioritize the assessment criteria using the AHP; however, these efforts require multiple calculations. This work introduced a new hybrid method, depending on FUCOM with TrFNs to consistently prioritize the supplier assessment criteria to reflect stakeholders' preferences, and applied the TOPSIS-based method to assess various suppliers, taking into account the costs and benefits criterion, as well as the uncertainty. The proposed method was applied to a practical case study, and the results show that it can prioritize the assessment criteria while reflecting stakeholders' preferences. The proposed method enables the decision-making group to construct a set of decision matrices, taking into account the various viewpoints of decision makers and computing the mean value using the AMO. Moreover, it uses detailed and clear steps to compute the FPIS and FNIS to simplify the computation process, as well as to avoid confusion during calculation. Additionally, the results indicate that the use of the FUCOM-based method provides consistent weights simply, which reduces the calculation process, enabling the decision maker to handle supplier assessment and selection using a more applicable method. The main limitation of this method is the mathematical equations, which may require specialist knowledge. These limitations can be overcome

in future work by introducing the proposed framework as a computer program, which enables users to input the data and retrieve the evaluations. In addition, the integration of advanced analytical techniques, such as machine learning or artificial intelligence, into the proposed model could lead to further improvements in its ability to handle uncertainty and complexity. For future work, researchers can (1) apply new mathematical methods under a neutrosophic environment to provide more accurate results; (2) present the proposed method as programming source code; (3) provide integration of the proposed model with advanced analytical techniques, such as machine learning or artificial intelligence, to handle uncertainty; and (4) incorporate more user feedback for continuous improvement and refinement of its analysis capabilities.

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