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An Optimized Computational Framework for Multi-Criteria Decision Making Under Intuitionistic Fuzzy Environments: Integration, Validation, and Cross-Domain Applications

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Abstract

Multi-Criteria Decision Making (MCDM) is an essential paradigm in the field of decision science, which allows the systematic analysis of competing options in the context of conflicting criteria. The major traditional approaches to MCDM, such as Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Elimination and Choice Translating Reality (ELECTRE), are largely based on accurate numerical data, and thus cannot be applied in a real-life setting, where vagueness, subjectivity, incomplete information, and cognitive reluctance usually prevail. Even though the traditional fuzzy set theory can in a way accommodate the uncertainty when memberships are graded, the combined membership-non-membership values can only sum to unity, which does not support the natural hesitancy of human judgments and expert assessment. Intuitionistic Fuzzy Sets (IFS), proposed as a variation of classical fuzzy logic, circumvents this restriction by introducing a hesitancy parameter defined as:

$$\pi = 1 - (\mu + \nu)$$

This formulation provides a more complete and realistic model of uncertainty in multi-faceted decision-making scenarios. This paper proposes the construction of an optimized computational model that logically incorporates IFS into well-known MCDM models to increase the accuracy, robustness, and practical adaptability of decisions under uncertain real-world conditions. The study adopts a mixed-methods approach involving rigorous theoretical modelling, computational algorithm development, and empirical verification through cross-domain case studies in healthcare diagnostics, financial risk assessment, and supply chain management. Simulations will be compared with conventional MCDM methods, and key performance indicators including decision accuracy, computational efficiency, scalability, and stakeholder usability will be evaluated. Sensitivity analyses will be conducted to test how changes in membership, non-membership, and hesitancy levels influence decision outcomes. The IFS-based MCDM model is expected to outperform traditional models under high uncertainty conditions while remaining computationally efficient for large-scale decision-support systems.

Keywords Multi-Criteria Decision Making, Intuitionistic Fuzzy Sets, Hesitancy Degree, TOPSIS, AHP, Uncertainty Modeling, Computational Framework, Decision Support Systems

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1. Introduction

Multi-Criteria Decision-Making (MCDM) is a critical aspect of decision sciences and operations research, designed to evaluate and select the best alternative when multiple conflicting criteria are involved. In real-world scenarios, decision-makers frequently encounter situations requiring the consideration of multiple attributes, such as cost, quality, time, efficiency, and sustainability, each carrying varying degrees of importance (Alazani et al., 2024). The need for established decision-making methodologies arises in diverse fields business, engineering, healthcare, and finance where selecting the optimal course of action is vital for attaining strategic objectives.

1.1 Background of Multi-Criteria Decision Making

Traditional decision-making approaches, such as cost-benefit analysis and linear optimization, often fail to capture the complexity of multi-attribute problems. This has led to the development of MCDM methods including the Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Elimination and Choice Translating Reality (ELECTRE), and Simple Additive Weighting (SAW). These methods allow for systematic assessment, ranking, and prioritization of options by assigning weights to specific criteria and aggregating individual rankings to determine the best alternative.

Despite their widespread application, traditional MCDM models struggle with imprecision and uncertainty, as they typically require exact numerical inputs that are often difficult to obtain in real-world settings. Many decision-making processes rely on subjective judgments, expert opinions, and qualitative assessments, which inherently introduce vagueness and imprecision. To address these barriers, fuzzy set theory was introduced, which generalizes classical set theory to allow objects to hold membership degrees on the continuous interval $[0, 1]$.

Fuzzy MCDM techniques incorporate membership degrees to express uncertainty, making them particularly useful in complex decision environments. However, standard fuzzy logic assumes that for any alternative, the sum of membership and non-membership degrees equals one, which may not always accurately represent real-life uncertainty. In response to this limitation, Intuitionistic Fuzzy Sets (IFS) were introduced as an extension of fuzzy sets, incorporating a hesitancy parameter that accounts for partial lack of information and indecision in the decision-making process.

1.2 Relevance of Using Intuitionistic Fuzzy Sets

Intuitionistic Fuzzy Sets (IFS) offer significant enhancements to traditional MCDM approaches by providing a more comprehensive representation of uncertainty, thereby improving decision-making accuracy and reliability in complex environments. Unlike conventional fuzzy sets, which assign a single membership degree to every element, IFS incorporates three key parameters: membership degree (μ), non-membership degree (ν), and hesitancy degree (π), governed by the constraint:

$$\pi = 1 - (\mu + \nu), \text{ where } 0 \leq \mu, \nu \leq 1 \text{ and } \mu + \nu \leq 1$$

This additional hesitancy component allows for more precise modeling of real-world uncertainty, especially in cases where decision-makers lack complete confidence in their judgments. The relevance of IFS in MCDM is evident in scenarios where subjective preferences, incomplete information, and ambiguity play a significant role such as supplier selection, healthcare diagnostics, financial risk assessment, and engineering design optimization.

By incorporating IFS into established MCDM methods such as AHP, TOPSIS, and ELECTRE, decision-makers can express not only their degree of agreement with a given criterion but also their level of doubt, leading to more informed and balanced choices (Arshad et al., 2024). Furthermore, IFS-based MCDM strategies improve robustness by reducing biases and mitigating the effects of uncertainty, making them particularly useful in high-stakes environments where errors may have significant consequences.

Another critical advantage of IFS in MCDM is its capacity to handle conflicting criteria more effectively. In conventional MCDM methods, trade-offs among criteria can be rigid and deterministic, potentially leading to suboptimal decisions when uncertainty is present. IFS allows for a more flexible trade-off mechanism via incorporating hesitancy, ensuring all relevant uncertainties are considered before arriving at a final decision. Additionally, IFS enables greater stakeholder participation in decision-making by permitting individuals with varying levels of expertise to express their judgments without being forced into binary choices.

2. Literature Review

This section synthesizes the existing body of knowledge on MCDM frameworks, fuzzy set theory, and Intuitionistic Fuzzy Sets, culminating in the identification of key research gaps that motivate the present study.

2.1 Decision-Making Frameworks and the TOPSIS Method

Alazani et al. (2024) demonstrated the significance of t-intuitionistic fuzzy TOPSIS in its ability to properly address uncertainty and ambiguity in decision-making. Their study introduced a carry-distance measure for t-intuitionistic fuzzy sets and compared its structural properties and effectiveness with existing distance measures. The incorporation of the 't' parameter as a t-norm and t-conorm operator enhances precision, particularly in scenarios where standard intuitionistic fuzzy TOPSIS approaches fall short. The comparative analysis with established TOPSIS methods highlighted the superiority of the proposed strategy in capturing vague variations in t-intuitionistic fuzzy sets, demonstrating significant advantages in real-world applications (Li et al., 2023).

Arshad et al. (2024) introduced a novel theoretical framework called the interval-valued complex intuitionistic fuzzy hyper soft set (Γ -set). This framework integrates complex plane settings, interval-valued intuitionistic fuzzy settings, and hyper soft settings to provide a comprehensive approach for managing uncertainty within a unified model. The study explored the set operations and aggregations of the Γ -set, including decision matrices, cardinal matrices, combination matrices, and cardinality sets. The framework was validated through an application to cooling system selection for a manufacturing unit, demonstrating practical applicability and improved decision accuracy (Salimian et al., 2023).

Table 1: Comparative Analysis of MCDM Methods Under Varying Uncertainty Conditions

Method	Uncertainty Handling	Hesitancy Param.	Data Type	Complexity
AHP	Low	None	Crisp	Moderate
TOPSIS	Low	None	Crisp/Fuzzy	Moderate
ELECTRE	Moderate	None	Crisp	High
Fuzzy MCDM	Moderate	None	Fuzzy	Moderate
IFS-MCDM (Proposed)	High	Yes ($\pi = 1 - \mu - \nu$)	IFS	Optimized

2.2 Impact of IFS on Decision-Making in Complex Real-World Scenarios

Wasim et al. (2024) advanced intuitionistic fuzzy set theory by introducing generalized IFS aggregation operators designed to enhance decision-making. Their research provided new aggregation operators characterized by essential mathematical properties, ensuring accurate and reliable data assessment. The practical implementation was validated through a case study in the technology industry, evaluating startup success by integrating multi-criteria decision-making techniques. The study underscored the importance of developing sophisticated mathematical tools to address the complexities of modern decision-making, referencing key

contributions in similarity measurements, entropy measures, and nonlinear programming models (Koko et al., 2021).

Ding et al. (2024) explored the role of three-way decision methods in enhancing decision-making under uncertain and ambiguous conditions, proposing generalized intuitionistic fuzzy set theory as an effective approach. The study presented a comprehensive review of advancements in three-way decision strategies within the IFS framework, analyzed their applications in various fields, and explored hybrid methods that combine different computational techniques. The paper emphasized that while these methods have significantly advanced intelligent decision-making in uncertain environments, unresolved challenges remain and future research directions are needed to expand practical applications (Bali et al., 2023).

Table 2: Key Parameters of Intuitionistic Fuzzy Sets (IFS)

Parameter	Symbol	Range	Interpretation
Membership Degree	$\mu(x)$	$[0, 1]$	Degree of belonging to the set
Non-Membership Degree	$\nu(x)$	$[0, 1]$	Degree of not belonging
Hesitancy Degree	$\pi(x)$	$[0, 1]$	Degree of uncertainty/indecision
Constraint	$\mu + \nu \leq 1$		Allows room for hesitancy $\pi = 1 - \mu - \nu$

2.3 Computational Models for Optimizing MCDM Using IFS

Li et al. (2023) developed a personalized individual semantics model for computing with linguistic intuitionistic fuzzy information in multi-criteria decision-making. The research introduced a consistency-driven optimization model to ensure additive consistency in linguistic intuitionistic fuzzy preference relations. A novel Hamming distance measure was proposed to quantify variations in linguistic intuitionistic fuzzy numbers, enabling more precise evaluation of decision-making criteria. The approach was validated through a comparative analysis of different mobile telephone brands, confirming the practical benefits of improved decision consistency and accuracy (Chowdhury et al., 2024).

Salimian et al. (2023) presented an integrated multi-criteria decision model for selecting sustainable construction projects under intuitionistic fuzzy conditions. The framework incorporated a systematic approach for defining the importance of decision criteria under uncertain conditions, relying on subjective expert input and an alternative evaluation matrix. Key criteria including technological, financial, social, and environmental factors were evaluated across multiple energy options. Sensitivity and comparative analyses were performed to validate the effectiveness of the proposed model, with findings confirming that nuclear

energy emerged as the most robust and sustainable option. These results underscore the reliability of the IFS-based MCDM approach in complex, real-world selection problems.

Table 3: Summary of Key Literature on IFS-Based MCDM

Author(s) & Year	Focus Area	Method Used	Key Contribution
<i>Alazani et al. (2024)</i>	TOPSIS under t-IFS	t-IFS TOPSIS with carry-distance	Enhanced precision using t-norm/t-conorm operators
<i>Arshad et al. (2024)</i>	Multi-attribute decision-making	Interval-valued complex IFS hyper soft set (Γ -set)	Novel framework for managing cyclic/multi-parametric uncertainty
<i>Wasim et al. (2024)</i>	Tech industry startup evaluation	Generalized IFS aggregation operators	New aggregation operators for superior decision accuracy
<i>Ding et al. (2024)</i>	Three-way decisions under IFS	Generalized IFS + three-way decision	Comprehensive survey; AI-integrated decision frameworks
<i>Li et al. (2023)</i>	Linguistic MCDM	Personalized semantics + Hamming distance	Consistency-driven optimization for linguistic IFS
<i>Salimian et al. (2023)</i>	Sustainable construction projects	Integrated IFS-MCDM hybrid model	Nuclear energy selection validated via sensitivity analysis
<i>Bali et al. (2023)</i>	Vendor selection (COTS)	IFS + TOPSIS	Practical MCDM framework for commercial-off-the-shelf selection
<i>Chowdhury et al. (2024)</i>	Grinding process optimization	IFS-based multi-criteria methods	Manufacturing process optimization under IFS environment

2.4 Research Gap

Despite significant advancements in MCDM methodologies, existing models often struggle to effectively handle uncertainty, vagueness, and subjective hesitancy in decision-making processes. Traditional MCDM approaches including AHP, TOPSIS, and ELECTRE depend upon precise numerical inputs, making them less effective in scenarios where expert evaluations, qualitative assessments, and incomplete information play a crucial role. While fuzzy logic has been introduced to address this limitation, conventional fuzzy sets are constrained by the assumption that the sum of membership and non-membership degrees equals one, failing to capture the hesitancy inherent in human judgment.

Intuitionistic Fuzzy Sets provide a promising extension by incorporating a hesitancy degree, yet there remains a lack of comprehensive research on integrating IFS into optimized MCDM frameworks. Existing research typically focuses on theoretical models rather than practical implementations, leaving a gap in understanding the real-world applicability and computational efficiency of IFS-based MCDM processes. Moreover, while IFS has been

explored in isolated decision-making scenarios, its effectiveness across diverse industries including healthcare, finance, supply chain management, and engineering remains under-researched (Yadav et al., 2023).

Another critical gap lies in the absence of standardized computational models and algorithms that optimize MCDM using IFS, restricting their scalability and usability in decision-support systems. Furthermore, the advantages and limitations of IFS-based MCDM including computational complexity, interpretability, and stakeholder acceptance require further empirical validation. Addressing these research gaps is essential to developing a robust, adaptable, and computationally efficient IFS-based MCDM framework that can enhance decision accuracy and reliability in uncertain and dynamic settings.

3. Problem Statement

Decision-making in complex and uncertain environments is a critical challenge across various domains, requiring robust Multi-Criteria Decision Making (MCDM) frameworks to effectively evaluate competing alternatives. Traditional MCDM strategies, including AHP, TOPSIS, and ELECTRE, depend upon precise numerical inputs, making them insufficient for managing vagueness, subjective hesitation, and incomplete information. Although fuzzy logic has been introduced to mitigate these limitations, conventional fuzzy sets fail to capture the full spectrum of uncertainty, as they assume that the sum of membership and non-membership levels equals one, leaving no room for hesitation.

Intuitionistic Fuzzy Sets offer a more comprehensive technique by incorporating a hesitancy degree; however, their integration into MCDM remains underdeveloped. Existing research predominantly focuses on theoretical models rather than practical implementations, and there is a lack of standardized computational algorithms that optimize decision-making using IFS. Additionally, while IFS-based MCDM methods have been explored in isolated contexts, their effectiveness across diverse industries including healthcare, finance, and supply chain management has not been sufficiently demonstrated (Salimian et al., 2023).

Furthermore, the computational complexity, interpretability, and practical usability of IFS-based MCDM frameworks remain key challenges, restricting their adoption in decision-support systems. There is also inadequate empirical validation of these models through real-world case studies and simulations, leaving uncertainty regarding their efficiency in high-stakes decision-making situations. Addressing these gaps is essential to developing an optimized IFS-based MCDM framework that enhances decision accuracy, adaptability, and

reliability in uncertain environments. This research aims to bridge these limitations by designing a computationally efficient, industry-relevant MCDM model that integrates IFS, thereby enabling more informed, data-driven decision-making in complex and dynamic real-world settings.

4. Research Objectives

The present study is guided by three primary objectives, each addressing a specific dimension of the research gap identified in the literature:

Table 4: Research Objectives, Descriptions, and Expected Outputs

Objective	Description	Expected Output
Obj. 1	Explore enhanced MCDM under Intuitionistic Fuzzy (IF) environment	Improved decision accuracy and robustness
Obj. 2	Develop computational model for optimizing MCDM using IFS	Validated algorithms through case studies
Obj. 3	Assess advantages, limitations, and practical challenges of IFS in MCDM	Comparative analysis and benchmarking report

Collectively, these objectives aim to produce a theoretically grounded and empirically validated IFS-based MCDM framework that can be practically deployed in real-world decision environments exhibiting high degrees of uncertainty and complexity.

5. Proposed Methodology

The study employs a mixed-methods approach combining theoretical modeling, computational algorithm development, and empirical validation through case studies and simulations. The primary focus is on integrating Intuitionistic Fuzzy Sets (IFS) into MCDM frameworks to enhance decision accuracy and reliability in uncertain environments.

5.1 Research Design and Approach

The research begins with an extensive literature review on traditional MCDM models, fuzzy logic applications, and the limitations of existing decision-support systems (Pawar et al., 2022). This review establishes a robust theoretical foundation and identifies key areas where IFS can provide considerable enhancements. A mixed-methods research design is adopted to ensure both rigorous theoretical contributions and practical, empirically validated outcomes.

5.2 Development of an Optimized IFS-Based MCDM Framework

The next phase involves designing an optimized MCDM framework that incorporates IFS principles. This includes defining appropriate mathematical models that account for

membership, non-membership, and hesitancy levels in decision-making processes. The IFS constraint is formally expressed as:

$$\text{IFS: } A = \{\langle x, \mu_A(x), \nu_A(x) \rangle \mid x \in X\}$$

$$\text{Hesitancy: } \pi_A(x) = 1 - \mu_A(x) - \nu_A(x), \quad \forall x \in X$$

The study will explore modifications to existing MCDM techniques including AHP, TOPSIS, and ELECTRE by integrating IFS to enhance their capacity to handle uncertainty and subjective hesitation. Computational algorithms will be developed to ensure the efficiency of the proposed models, with emphasis on reducing computational complexity while maintaining accuracy.

5.3 Empirical Validation Through Case Studies and Simulations

To assess real-world applicability, empirical validation will be conducted using case studies from three primary sectors: healthcare, finance, and supply chain management (Deb et al., 2023). Data will be gathered from industry reports, expert evaluations, and decision scenarios involving high levels of uncertainty. Simulations will compare the performance of the IFS-based MCDM framework against conventional decision-making models using metrics such as decision accuracy, robustness, computational efficiency, and stakeholder satisfaction.

5.4 Evaluation of Practical Usability and Computational Complexity

In addition to performance analysis, the study will evaluate the practical usability of the IFS-based MCDM framework by assessing its interpretability and ease of implementation. Expert feedback will be collected through structured interviews and surveys to understand the challenges of integrating IFS into existing decision-making workflows. Computational complexity analysis will be conducted to determine the feasibility of deploying the framework in large-scale decision-support systems.

5.5 Sensitivity Analysis and Robustness Testing

Sensitivity analysis will be employed to examine how variations in membership, non-membership, and hesitancy levels affect decision outcomes (Muneeza et al., 2022). Perturbation experiments will be conducted on the IFS parameter space to assess the stability and robustness of the proposed framework. The IFS-TOPSIS distance measure used in ranking alternatives is given by:

$$d(A, B) = \frac{1}{2} \cdot [|\mu_A - \mu_B| + |\nu_A - \nu_B| + |\pi_A - \pi_B|]$$

This normalized Hamming distance ensures that hesitancy differences are equally weighted alongside membership and non-membership differences, providing a balanced and mathematically sound basis for alternative ranking.

5.6 Discussion of Advantages, Limitations, and Future Recommendations

The final stage involves critically analyzing the advantages and limitations of the IFS-based MCDM framework (Rani et al., 2022). While IFS integration is anticipated to improve decision-making under uncertainty, potential challenges such as increased computational demands and interpretability issues will be addressed. Recommendations will be provided for further refinement, including hybrid approaches that combine IFS with machine learning techniques for adaptive decision-making. Future research directions will be proposed to encourage further exploration of IFS applications in decision science.

5.7 Data Analysis and Validation

The data analysis and validation process will focus on evaluating the effectiveness of the proposed IFS-based MCDM framework through a combination of quantitative and qualitative methods. Statistical strategies, including regression analysis and comparative hypothesis testing, will be implemented to measure improvements in decision-making precision and performance. Additionally, computational complexity analysis will be conducted to determine the scalability of the model in large-scale decision-support systems.

Table 5: Research Methodology Phases and Corresponding Activities

Phase	Activity	Tools / Techniques
Phase 1	Literature Review & Theoretical Foundation	Systematic review, gap analysis
Phase 2	IFS-Based MCDM Framework Development	Mathematical modeling, AHP/TOPSIS/ELECTRE modifications
Phase 3	Computational Algorithm Design	Python / MATLAB algorithms, complexity analysis
Phase 4	Empirical Validation via Case Studies	Healthcare, finance, supply chain datasets
Phase 5	Performance Evaluation & Sensitivity Analysis	KPI metrics, regression, hypothesis testing
Phase 6	Discussion, Refinement & Future Recommendations	Expert interviews, hybrid model proposals

6. Expected Outcomes

6.1 Enhanced Decision-Making Accuracy and Robustness

The proposed integration of Intuitionistic Fuzzy Sets into MCDM is expected to significantly improve decision accuracy by effectively handling uncertainty, vagueness, and hesitation in expert evaluations. By incorporating membership, non-membership, and hesitancy tiers, the framework will permit more precise assessments of alternatives, leading to more robust and dependable decision outcomes. The model is anticipated to outperform conventional MCDM methods including AHP, TOPSIS, and ELECTRE in situations with incomplete or subjective data.

6.2 Optimized Computational Performance and Scalability

Through the development of advanced computational algorithms, this research aims to optimize the efficiency of IFS-based MCDM models, reducing computational complexity while retaining decision accuracy (Salimian et al., 2023). The proposed framework is expected to be scalable for large-scale decision-support systems, making it applicable across industries such as healthcare, finance, and supply chain management. Computational simulations will validate the model's capacity to handle complex decision scenarios in real time.

6.3 Practical Usability and Industry Adoption

The study anticipates that the IFS-based MCDM framework will demonstrate practical usability and ease of implementation within real-world decision-making processes. Empirical validation through case studies and expert reviews is expected to confirm its relevance and effectiveness in industry applications. The framework's adaptability will support integration into existing decision-support systems, enabling organizations to make data-driven, informed decisions in dynamic and uncertain environments.

6.4 Theoretical Advancements and Future Research Directions

The research is expected to contribute to the theoretical advancement of MCDM by providing a structured methodology for incorporating IFS into decision-making frameworks (Pérez-Domínguez et al., 2024). The findings will highlight the advantages and limitations of IFS-based models, offering insights into further refinements including hybrid approaches combining IFS with machine learning for adaptive decision-making. Additionally, the study is expected to identify future research opportunities to extend the applicability of IFS in other complex decision environments, fostering continued innovation in decision science.

7. Potential Applications

The proposed IFS-based MCDM framework has broad applicability across multiple sectors. The following subsections identify key domains where the framework is expected to deliver measurable improvements.

7.1 Healthcare Decision-Making

The proposed framework can significantly improve decision-making in healthcare systems by accounting for uncertainties in symptom evaluations and patient conditions (Gupta et al., 2021). It can be applied in diagnostic processes, treatment planning, and clinical resource allocation, enabling healthcare professionals to express hesitation and uncertainty and leading to more accurate, personalized patient care decisions.

7.2 Financial Risk Assessment

In the financial sector, the IFS-based MCDM framework can enhance investment decision-making, portfolio optimization, and credit risk assessment. The model's capacity to incorporate hesitancy levels will allow investors and financial analysts to express uncertainty in market volatility predictions, resulting in more resilient investment strategies and superior risk management.

7.3 Supply Chain Management

The framework can optimize supplier selection, inventory management, and logistics planning in supply chain management. By integrating IFS, decision-makers can evaluate suppliers based on multiple conflicting criteria including cost, quality, delivery time, and reliability while accounting for uncertainty in supplier performance data (Luo et al., 2023). This application will improve supply chain efficiency and strengthen commercial partnerships.

7.4 Engineering Design and Project Management

In engineering and construction projects, the IFS-based MCDM model can assist in material selection, project risk assessment, and resource allocation. The framework will enable project managers to incorporate uncertainty in performance metrics and expert evaluations, leading to more informed design decisions and efficient project execution.

7.5 Public Policy and Environmental Planning

The model can be applied in public policy-making and environmental planning, where uncertainty is a critical factor. It will help decision-makers evaluate policy alternatives, conduct

environmental impact assessments, and allocate resources by balancing conflicting social, economic, and environmental criteria while accounting for incomplete or subjective data.

7.6 Technology Selection and Innovation Management

The framework can support technology selection and innovation management in organizations by evaluating various technology options based on performance, cost, scalability, and environmental impact (Mohammadi et al., 2022). The IFS-based approach will permit decision-makers to express hesitancy and uncertainty in assessing emerging technologies, leading to more informed and future-proof technology investments.

8. Conclusion

The integration of Intuitionistic Fuzzy Sets (IFS) into Multi-Criteria Decision Making (MCDM) represents a significant advancement in handling uncertainty, vagueness, and hesitancy in complex decision environments. Traditional MCDM methods regularly struggle with incomplete or subjective information, restricting their effectiveness in real-world applications. By incorporating membership, non-membership, and hesitancy levels, the proposed IFS-based framework enhances decision accuracy, robustness, and adaptability across numerous domains including healthcare, finance, supply chain management, engineering, public policy, and technology selection.

The study's objectives are to develop an optimized computational model that balances precision and efficiency, ensuring scalability for large-scale decision-support systems. Empirical validation through case studies and simulations will confirm the framework's effectiveness and superiority over conventional decision-making methods. Expert feedback will be incorporated to refine the model's practical applicability and integration into existing decision workflows.

The expected outcomes include not only improved decision-making capabilities but also significant theoretical contributions to decision science, paving the way for future research on hybrid models that combine IFS with machine learning strategies. By bridging the gap between theoretical advancements and practical implementation, this research will provide a structured and adaptable decision-support tool that enhances accuracy and confidence in multi-criteria decision-making under uncertainty. The framework ultimately aims to advance the state of the art in decision science, offering a computationally efficient, empirically validated, and industry-ready solution for modern decision environments.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this research article. The research was conducted independently, and no financial, commercial, or personal relationships influenced the design, analysis, interpretation, or reporting of the study findings.

Author Contributions

Shweta Saharan: Conceptualization, methodology development, literature review, theoretical framework formulation, computational model design, data analysis, and manuscript preparation.

Vikash Arya: Supervision, validation, critical revision of the manuscript, methodological guidance, and overall research coordination.

Both authors contributed to the interpretation of results, refinement of the proposed framework, and approval of the final manuscript for submission.

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