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Multi-Criteria Decision-Making Techniques: A Comprehensive Review of Methodologies and Applications

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Abstract

Multi-Criteria Decision Making (MCDM) is an essential framework in decision science, offering structured methodologies to handle complex decision-making processes including multiple, often conflicting criteria. This paper provides a comprehensive review of MCDM techniques, including the Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), VIšekriterijumsko KOmpromisno Rangiranje (VIKOR), and COmplex PRoportional ASsessment (COPRAS). It also discusses the integration of neutrosophic sets for handling uncertainty and vagueness in decision-making. The paper highlights the strengths and weaknesses of these methods, beside their applications in various fields such as environmental management, public health, and data center location selection. A comparative analysis of MCDM methods underscores the importance of hybrid approaches in enhancing decision accuracy and reliability. The findings of this paper are relevant to researchers and practitioners seeking to improve decision-making strategies across various sectors.

Keywords: Multi-Criteria Decision Making; MCDM; Analytic Hierarchy Process; AHP; TOPSIS; VIKOR; Neutrosophic Sets; Environmental Management; Decision Support Systems.

1 | Introduction

Multi-Criteria Decision Making (MCDM) is a dynamic framework in modern decision science, providing structured methodologies to manage complex decision-making scenarios including multiple, often conflicting criteria. The increasing complexity of decision problems in various fields, such as environmental management, public health, and information technology, needs robust methods to evaluate and prioritize varied factors systematically. This paper explores the concept of MCDM, detailing various methods and their applications in solving diverse decision-making problems.

MCDM techniques provide a structured approach to decision-making, helping the identification of viable solutions that consider all relevant criteria. These methodologies are particularly useful in environmental management due to their ability to oversee multiple criteria and trade-offs [1]. MCDM techniques can be broadly categorized into various methods, each with its unique approach to structuring decision problems and deriving solutions. Among the most prominent are the Analytic Hierarchy Process (AHP), VIšekriterijumsko KOmpromisno Rangiranje (VIKOR), COmplex PRoportional ASsessment (COPRAS),

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and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). These methods have been applied successfully across different domains to solve problems ranging from environmental planning to public health strategy optimization [2, 3].

The primary goal of this paper is to provide literature on MCDM methodologies, highlighting their applications, strengths, and weaknesses. This review will provide a foundation for understanding how MCDM can be applied to improve decision-making strategies in managing public health crises and selecting optimal locations for data centers. This paper seeks to create robust models that address the complexities and uncertainties in these fields by combining MCDM methodologies with neutrosophic sets.

In the context of public health, particularly during the COVID-19 pandemic, MCDM methodologies have been instrumental in evaluating and prioritizing response strategies. Decision-makers must balance multiple criteria, such as infection rates, healthcare capacity, economic impact, and social factors, to formulate effective strategies [4]. In information technology, selecting optimal data center locations involves evaluating a complex array of criteria, including energy availability, environmental conditions, network connectivity, and land costs. Traditional decision-making approaches often fall short of managing the uncertainties and vagueness associated with these criteria [5].

This paper will cover the historical development of MCDM, various MCDM techniques and methods, and their applications in different sectors. It will also compare different MCDM methods and discuss future trends in the field, including the integration of emerging technologies and the need for scalable and efficient algorithms.

2 | Historical Development of MCDM

The field of Multi-Criteria Decision Making (MCDM) has grown significantly over the past few decades as shown in Figure , reflecting the increasing complexity of decision-making scenarios in various domains. MCDM's origins can be traced back to the mid-20th century when foundational theories and initial applications were developed to enhance decision-making processes.

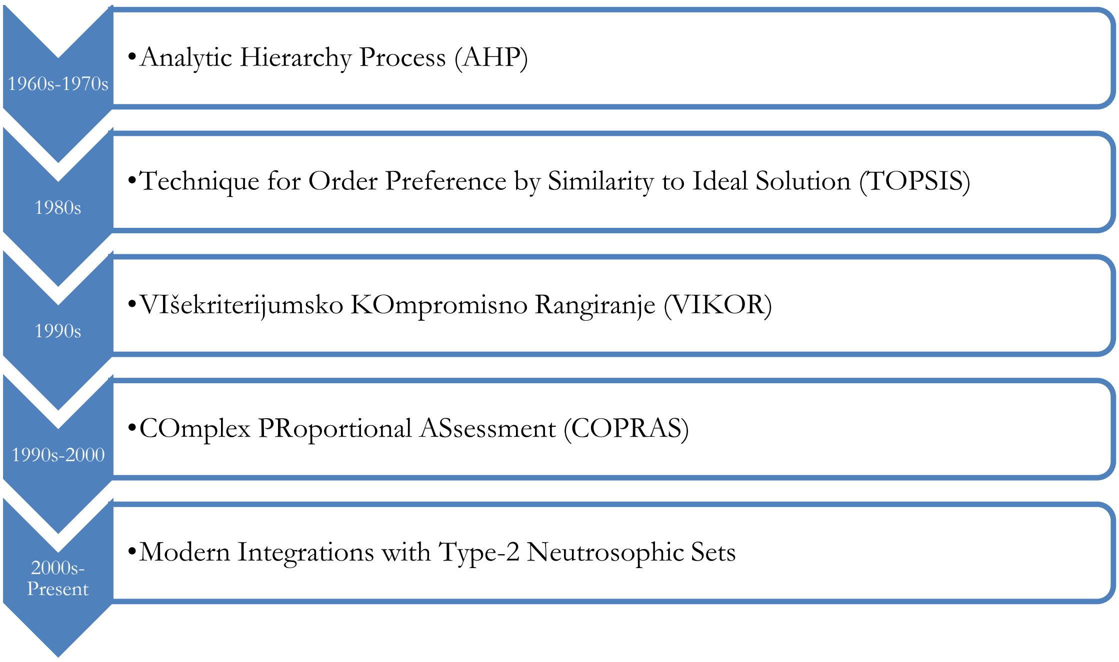

Figure 1. Timeline showing the development of major MCDM methods.

2.1 | Analytic Hierarchy Process AHP

The early development of MCDM was influenced by operations research and management science, disciplines that needed to apply mathematical and analytical methods to decision-making. One of the earliest and most powerful methods in MCDM is the Analytic Hierarchy Process (AHP), developed by Thomas L. Saaty in the 1970s. AHP provides a structured framework for decision-making by decomposing a complex problem into a hierarchy of more easily comprehensible sub-problems as shown in Figure , each of which can be analyzed independently [1]. This method has been widely used in various fields, including resource allocation, strategic planning, and conflict resolution.

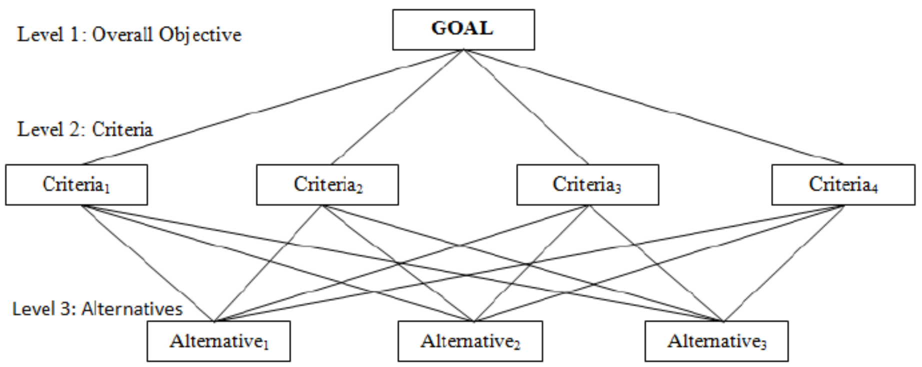

Figure 2. Diagram of an AHP hierarchy with criteria and alternatives [5].

2.2 | Entropy

The Entropy method, rooted in information theory, was introduced to the field of MCDM as a means of objectively determining the weights of decision criteria. Originally developed by Claude Shannon in 1948, In the context of MCDM, the Entropy measures the uncertainty or randomness of a system, providing a quantitative means of evaluating the distribution of information across several criteria. Within MCDM, the Entropy method calculates the relative importance of each criterion by analyzing the inherent data characteristics, thereby reducing subjectivity and potential biases associated with expert judgment [6].

This method reduces subjectivity, and potential biases associated with expert judgment by relying on the inherent information contained within the dataset. Over the years, it has been widely adopted in various decision-making applications, including environmental management, supply chain optimization, and public health [4, 7].

The integration of the Entropy method with other MCDM techniques, such as TOPSIS and VIKOR, has further enhanced its applicability and robustness. By combining the objective weighting capability of the Entropy method with the ranking and evaluation strengths of other MCDM methods, decision-makers can achieve more reliable and comprehensive outcomes.

2.3 | TOPSIS (Technique for Order Preference by Similarity to Ideal Solution)

Introduced by Hwang and Yoon in 1981, works on the principle that the best choice should be the one closest to the ideal solution and furthest from the negative ideal solution. This method is intuitive and straightforward, making it suitable for decision problems where the ideal and negative-ideal solutions can be clearly defined [5, 6].

The TOPSIS method is a robust and versatile tool in the field of MCDM, offering clear advantages in terms of simplicity, ease of use, and reliability. Its wide range of applications in manufacturing, healthcare, environmental management, and supply chain management underscores its effectiveness and adaptability. As

MCDM continues to evolve, the TOPSIS method will likely remain a fundamental technique for decision-makers dealing with complex, multi-criteria problems.

2.4 | VIšekriterijumsko KOmpromisno Rangiranje (VIKOR)

The VIKOR method, a popular tool within the Multi-Criteria Decision Making (MCDM) framework, has been extensively studied and applied across various disciplines. This review synthesizes the existing literature on the VIKOR method, focusing on its development, application, and comparative performance in MCDM contexts.

The VIKOR method, introduced by Opricovic and Tzeng, aims to provide a compromise solution for a problem with conflicting criteria, which is closer to the ideal solution. The method's basis lies in the concepts of compromise programming and the multi-criteria ranking index based on the measure of "closeness" to the ideal solution [8].

The method has been commonly applied in various fields. For example, it has been used in environmental management to assess and select the best environmental policies [9]. In supply chain management, VIKOR has helped evaluate and rank suppliers based on multiple criteria such as cost, quality, and delivery performance [10]. Additionally, the method has been used in the healthcare sector to prioritize medical treatments and technologies [11].

The VIKOR method remains a valuable tool in the MCDM field, offering a strong mechanism for deriving compromise solutions in the presence of conflicting criteria. Its applications in environmental management, supply chain management, and healthcare show its versatility and effectiveness. As the field of MCDM evolves, the VIKOR method is likely to continue playing a critical role in helping decision-makers navigate complex, multi-criteria problems.

2.5 | COmplex PRoportional ASsessment (COPRAS)

This method, developed by Zavadskas and Kaklauskas in 1996, assesses the significance and utility of alternatives by considering the proportionality of criteria values. COPRAS is effective in scenarios involving uncertainty and varying criteria importance, providing a robust framework for decision-makers to evaluate alternatives comprehensively [12]. The method is designed to rank and select from among various alternatives based on multiple criteria. This method considers both the positive and negative attributes of each alternative and uses relational assessment to provide a final ranking [13].

COPRAS has been applied in various fields, including construction, energy management, environmental sustainability, and supply chain management. In the realm of environmental sustainability, COPRAS is employed to assess and rank environmental policies and practices. A study by Banaitiene et al. utilized COPRAS to evaluate sustainable waste management strategies, integrating environmental, economic, and social criteria [14]. COPRAS is appreciated for its simplicity and ease of implementation. In a comparative study, Turskis and Zavadskas found that COPRAS outperformed other MCDM methods in terms of computational efficiency and ease of understanding, making it particularly useful in practical decision-making scenarios [15]. As MCDM continues to evolve, the COPRAS method is likely to remain an essential technique for decision-makers facing complex, multi-criteria problems.

2.6 | Integration Of Neutrosophic Sets

A more recent advancement in MCDM is the integration of neutrosophic sets to manage uncertainty and vagueness in decision-making. Neutrosophic sets, introduced by Florentin Smarandache, generalize the concept of fuzzy sets by incorporating the degree of truth, indeterminacy, and falsity. This approach has enhanced the robustness and reliability of MCDM methods in complex decision-making environments, such as public health and information technology [16].

Neutrosophic sets allow for a more nuanced representation of uncertainty, which is particularly useful in situations where decision-makers must navigate ambiguous or incomplete information [16]. By integrating neutrosophic sets with traditional MCDM methods, researchers have developed new frameworks that better capture the complexities of real-world decision problems. These integrated methods have shown promise in various applications, including risk assessment, strategic planning, and policy analysis.

The continuous evolution of MCDM reflects its critical role in addressing progressively complex and complicated decision-making problems. The integration of advanced mathematical and computational techniques continues to push the limitations of what can be achieved with MCDM, ensuring its relevance and applicability across various domains.

3 | Applications of MCDM

Multi-criteria decision-making (MCDM) methodologies have proven essential in tackling complex decision-making problems that involve multiple conflicting criteria. These methods have been successfully applied in various domains including environmental management, public health, and data center location selection. This section delves into the applications of MCDM, showing case studies, methodologies used, and the impact of these applications in real-world scenarios, using the information presented in Table 1.

Table 1. Application of MCDM.

Domain	Application	MCDM Methods Used	Criteria Considered	Reference
Environmental Management	Sustainable Waste Management	AHP	Environmental impact, Economic cost, social acceptance	Wang et al., 2020 [17]
	Climate Change Adaptation	Various MCDM Techniques	Cost-effectiveness, Feasibility, Impact on biodiversity, social acceptance	Lamichhane et al., 2022 [18]
Supply Chain Management	Supplier Selection	fuzzy ANP	Cost, Quality, Delivery performance, Risk	Büyüközkan and Çifçi, 2012 [19]
	Warehouse Location Selection	TOPSIS, FTOPSIS, FAHP	Proximity to markets, Transportation costs, Infrastructure, Environmental impact	Saha et al., 2023 [20]
Energy Management	Renewable Energy Project Evaluation	Various MCDM Techniques	According to the renewable energy sources	Shao et al., 2020 [21]
	Solar Plants Site	AHP, Fuzzy TOPSIS	Climate, geographical, Transportation, Environment, Cost	Ghasempour et al., 2019 [22]
Public Health	COVID-19 Response Strategies	Fuzzy Entropy, PROMETHEE-II	Public Health Impact, Economic Impact, Healthcare System Resilience, Community Engagement and Compliance	Jeon, J., et al. 2023 [23]

3.1 | Environmental Management

MCDM techniques help in evaluating and prioritizing different environmental policies and practices, considering multiple criteria such as environmental impact, economic cost, and social acceptance.

- Sustainable Waste Management: The Analytic Hierarchy Process (AHP) is employed to assess sustainable waste management practices by evaluating their environmental impact, economic cost, and social acceptance. This comprehensive approach guarantees that waste management strategies are effective, sustainable, and socially acceptable. For instance, Wang et al. (2020) utilized AHP to prioritize waste management options in urban settings, considering both the short-term and long-term environmental impacts. By incorporating stakeholder preferences and expert judgments, the AHP methodology facilitates the identification of waste management solutions that are environmentally sound and economically viable, thereby supporting sustainable urban development [17].

- Climate Change Adaptation: Various MCDM techniques evaluate the feasibility, cost-effectiveness, impact on biodiversity, and social acceptance of different climate change adaptation strategies. This helps identify the most viable options for mitigating the effects of climate change. Lamichhane et al. (2022) applied a range of MCDM methods to evaluate cross-sectoral strategies for climate change adaptation, showing the importance of integrating various criteria to achieve sustainable outcomes. Their approach includes assessing the resilience of ecosystems, the adaptability of infrastructure, and the socio-economic benefits of adaptation measures, ensuring a holistic evaluation of climate change strategies [18].

3.2 | Supply Chain Management

While supply chain management may seem tangential, its relevance to environmental decision-making lies in the adoption of green supply chain practices and the selection of environmentally friendly logistics solutions.

- Supplier Selection: The fuzzy Analytic Network Process (ANP) is used to select suppliers based on criteria such as cost, quality, delivery performance, and risk. This method helps identify the most dependable suppliers that can meet the company's requirements while minimizing risks. Büyüközkan and Çifçi (2011) showed the effectiveness of fuzzy ANP in evaluating green supply chain management practices, providing a structured framework to balance environmental and operational objectives. This method allows companies to include environmental considerations, such as carbon footprint and sustainability practices, into their supplier selection process, promoting greener supply chains [19].

- Warehouse Location Selection: Techniques like TOPSIS, fuzzy TOPSIS (FTOPSIS), and fuzzy AHP (FAHP) evaluate potential warehouse locations. These methods consider proximity to markets, transportation costs, infrastructure, and environmental impact, ensuring the optimal placement of warehouses. Saha et al. (2023) used these MCDM techniques to assess the suitability of various locations for automotive industry warehouses, emphasizing the need for a holistic evaluation to support strategic decisions. By including environmental criteria such as land use impact, energy consumption, and transportation emissions, these methods ensure that warehouse locations align with sustainable development goals [20].

3.3 | Energy Management

In the energy sector, MCDM techniques are vital for evaluating and selecting sites for renewable energy projects, considering various criteria associated with climate, geography, transportation, environment, and cost.

- Renewable Energy Project Evaluation: Various MCDM methods evaluate different renewable energy projects. This includes evaluating the suitability of sites for solar plants based on climate, geographical factors, transportation, environment, and cost considerations. Shao et al. (2020) reviewed the application of MCDM methods in renewable energy site selection, illustrating how these techniques can balance technical, economic, and environmental criteria to identify the best sites for solar, wind, and other renewable energy projects. By considering factors such as sunlight exposure, wind speed, grid connectivity, and environmental protection, MCDM ensures the sustainable development of renewable energy infrastructure [21].
- Solar Plants Site Selection: Specifically, AHP and fuzzy TOPSIS determine the most suitable sites for solar plants by evaluating factors such as climate conditions, geographical location, transportation infrastructure, environmental impact, and cost. Ghasempour et al. [22] applied these methods to identify optimal locations for solar energy projects, ensuring that selected sites maximize energy production while minimizing environmental impacts. The use of MCDM techniques in this context supports the transition to clean energy sources and helps in mitigating the environmental impacts associated with fossil fuels [22].

3.4 |Public Health

Public health decision-making, especially in response to crises like the COVID-19 pandemic, involves environmental considerations such as the impact of public health strategies on community well-being and resource allocation.

- COVID-19 Response Strategies: Fuzzy Entropy and PROMETHEE-II evaluate and prioritize different response strategies. This approach ensures a balanced consideration of public health impact, economic implications, and healthcare system resilience, leading to more effective and adaptable response strategies. Jeon et al. (2023) utilized these methods to assess various intervention strategies against COVID-19 in India, demonstrating how MCDM can support dynamic and context-specific decision-making in public health emergencies. By incorporating criteria such as healthcare capacity, economic stability, social compliance, and environmental sustainability, MCDM helps in developing comprehensive and balanced public health policies [23].

MCDM methodologies offer a structured and systematic framework for decision-making across various fields, each with significant environmental impacts. By evaluating multiple criteria and balancing conflicting factors, these techniques help decision-makers make more informed and effective choices. The applications mentioned earlier highlight the versatility and effectiveness of MCDM methods in tackling complex decision-making challenges in environmental management, supply chain management, energy management, and public health.

4| Comparative Analysis of MCDM Methods

Multi-Criteria Decision Making (MCDM) methods are essential tools for addressing complex decision-making problems involving multiple conflicting criteria. This section provides a comparative analysis of various MCDM methods, highlighting their strengths and weaknesses as shown in Table 2, and discussing the potential of hybrid approaches to enhance decision-making processes.

Table 2. Strengths and weaknesses of some widely used MCDM methods.

Method	Strength	Weakness
AHP	1. Intuitive and Simple: AHP is easy to understand and implement, making it accessible to decision-makers with varying levels of expertise. 2. Hierarchical Structure: It allows for the decomposition of complex problems into a hierarchy of sub-problems, facilitating a systematic evaluation. • Pairwise Comparisons: AHP's use of pairwise comparisons helps capture the relative importance of criteria and alternatives, providing a clear preference structure.	• Subjectivity: The reliance on expert judgment in pairwise comparisons can introduce subjectivity and potential bias. • Consistency Issues: Ensuring consistency in judgments can be challenging, especially in large-scale applications. • Scalability: AHP can become cumbersome when dealing with a large number of criteria and alternatives.
ENTROPY	• Objective Weighting: The Entropy method objectively determines the weights of criteria based on the variability of the data, reducing subjectivity and potential bias in the decision-making process. • Data-Driven: It relies on the actual distribution of data, providing a more accurate reflection of the importance of each criterion. • Versatility: This can be integrated with various MCDM methods (such as TOPSIS, and VIKOR) to enhance their robustness and accuracy.	• Data Dependency: The method's effectiveness is highly dependent on the quality and quantity of available data. Poor data quality can lead to misleading results. • Complexity: Understanding and implementing the Entropy method requires a good grasp of statistical concepts. • Computational Intensity: Calculating entropy values and weights can be computationally demanding, especially for large datasets.
TOPSIS	• Clarity and Simplicity: TOPSIS is straightforward to apply and understand. • Distance Measures: It uses Euclidean distance to determine the closeness of alternatives to the ideal solution, providing a clear ranking. • Practicality: Suitable for problems where the best and worst alternatives can be clearly defined.	• Normalization Sensitivity: The results can be sensitive to the method of normalization used. • Inter-criteria Correlation: TOPSIS does not account for correlations between criteria, which can affect the accuracy of the results. • Compromise Solution: It may not always provide a true compromise solution in highly conflicting scenarios.
VIKOR	• Compromise Solutions: VIKOR is designed to provide compromise solutions, making it suitable for scenarios with conflicting criteria. • Multi-criteria Balancing: It effectively balances and aggregates different criteria, providing a holistic evaluation. • Flexibility: Allows for different criteria weightings and sensitivity analyses.	• Complexity: The method can be complex and computationally intensive, especially for large datasets. • Subjectivity: Determining the weights of criteria can introduce subjectivity. • Parameter Sensitivity: Results can be sensitive to the choice of parameters, such as the compromise factor.
COPRAS	• Comprehensive Assessment: COPRAS considers both positive and negative attributes, providing a balanced evaluation. • Simplicity and Transparency: The method is relatively simple and transparent, making it easy to interpret results. • Applicability: Suitable for a wide range of decision-making problems, including those with varying criteria importance.	• Normalization Requirement: Requires careful normalization of criteria, which can affect results. • Subjectivity in Weighting: Like other methods, the assignment of weights can be subjective. • Scalability Issues: May become less efficient with a large number of alternatives and criteria.
Neutrosophic Sets Integration	• Handling Uncertainty: Neutrosophic sets effectively manage uncertainty, imprecision, and indeterminacy in decision-making. • Flexibility: They can be integrated with various MCDM methods to enhance robustness. • Comprehensive Representation: Provide a nuanced representation of truth, indeterminacy, and falsity.	• Complexity: Mathematical complexity can be a barrier to implementation. • Computational Intensity: Overseeing large datasets can be computationally demanding. • Interpretation Challenges: The interpretation of neutrosophic values can be challenging for non-experts.

4.1 | Hybrid Approaches

To overcome the limitations of individual MCDM methods, hybrid approaches have been developed, combining the strengths of multiple methods to enhance decision-making processes. These hybrid methods integrate various techniques to address the weaknesses and maximize the benefits, providing more robust, accurate, and adaptable decision-making frameworks.

One of the prominent hybrid approaches is the combination of AHP and TOPSIS. The Analytic Hierarchy Process (AHP) is renowned for its ability to break down complex decision problems into a hierarchical structure of criteria and sub-criteria, which are then evaluated through pairwise comparisons. This method excels in determining the relative importance of each criterion.

However, AHP alone can struggle with ranking alternatives when faced with large datasets. By integrating TOPSIS, which ranks alternatives based on their closeness to an ideal solution, the hybrid AHP-TOPSIS approach leverages the hierarchical structuring and precise weighting of AHP with the ranking efficiency of TOPSIS. This combination is particularly effective in scenarios where both qualitative and quantitative criteria are important, offering a comprehensive evaluation framework that ensures consistency and clarity in decision-making.

Fuzzy logic, when combined with AHP and TOPSIS, further enhances these methods by overseeing the vagueness and uncertainty inherent in human judgments. The Fuzzy AHP and Fuzzy TOPSIS hybrid approaches incorporate fuzzy logic to manage imprecise data, enabling decision-makers to capture the uncertainty and subjectivity of expert opinions more effectively. This is particularly valuable in fields such as risk assessment and strategic planning, where decisions must be made based on incomplete or ambiguous information. By using fuzzy sets to express the uncertainty in pairwise comparisons and alternative evaluations, these hybrid methods provide more realistic and flexible decision-making tools.

The VIKOR-COPRAS hybrid approach is another powerful combination that addresses the need for compromise solutions in complex decision scenarios. VIKOR focuses on identifying solutions that achieve a balance between conflicting criteria, making it suitable for problems where stakeholders have differing priorities. On the other hand, COPRAS evaluates alternatives based on both positive and negative attributes, providing a proportional assessment of each option. By combining these methods, the VIKOR-COPRAS hybrid offers a comprehensive decision-making framework that balances and integrates multiple criteria, ensuring that the selected solution is not only optimal but also acceptable to all stakeholders involved. This hybrid approach is particularly useful in fields like environmental management and urban planning, where decisions must satisfy a diverse range of criteria and stakeholder interests.

The integration of neutrosophic sets with traditional MCDM methods such as TOPSIS, AHP, and VIKOR represents a significant advancement in handling uncertainty and indeterminacy. Neutrosophic sets generalize the concept of fuzzy sets by incorporating degrees of truth, indeterminacy, and falsity, providing a more nuanced representation of uncertainty. When combined with MCDM methods, neutrosophic sets enhance the robustness and flexibility of decision-making processes. For example, in public health and environmental management, where decision-makers must navigate ambiguous or incomplete information, the use of neutrosophic sets allows for more comprehensive and reliable evaluations. This integration supports the development of models that can better capture the complexities of real-world decision problems, leading to more informed and accurate outcomes.

Entropy-based weighting is another innovative hybrid approach that combines the objective weighting capability of the Entropy method with the evaluation strengths of other MCDM techniques such as TOPSIS and VIKOR. The Entropy method objectively determines the weights of criteria based on the variability of the data, reducing subjectivity and potential biases. By applying these entropy-derived weights in methods like TOPSIS and VIKOR, decision-makers can achieve a more balanced and objective assessment of alternatives.

This hybrid approach is particularly effective in scenarios where an unbiased determination of criteria importance is critical, such as in technology selection and resource allocation.

The comparative analysis of MCDM methods highlights the strengths and weaknesses of each approach, providing insights into their suitability for different decision-making scenarios. Hybrid approaches, by combining the advantages of multiple MCDM methods, offer enhanced robustness, accuracy, and flexibility, making them particularly valuable in complex and uncertain environments. By leveraging the complementary strengths of various MCDM methods, hybrid approaches ensure more reliable and comprehensive decision-making outcomes, addressing the limitations of individual methods and meeting the diverse needs of stakeholders across different domains. This paper leverages these insights to develop advanced MCDM models that address contemporary challenges in environmental decision-making.

5 | Conclusion

The comparative analysis of Multi-Criteria Decision Making (MCDM) methods presented in this paper highlights the strengths, weaknesses, and potential of hybrid methods to overcome individual limitations. Each MCDM method—whether it is AHP, TOPSIS, VIKOR, COPRAS, or the integration of neutrosophic sets and Entropy—offers unique advantages tailored to specific decision-making contexts. By understanding these characteristics, decision-makers can select and apply the most appropriate methods to address complex problems, particularly in fields like environmental management, public health, and information technology.

Traditional MCDM methods such as AHP and TOPSIS are recognized for their simplicity and clarity, making them accessible tools for various applications. However, their limitations in handling large datasets and subjective judgments have prompted the exploration of hybrid approaches. The integration of fuzzy logic with AHP and TOPSIS enhances their ability to manage uncertainty and imprecise data, providing more realistic and flexible decision-making frameworks. Similarly, combining VIKOR and COPRAS ensures a balanced evaluation of alternatives, accommodating diverse stakeholder preferences and conflicting criteria.

Hybrid approaches, such as the combination of Entropy-based weighting with MCDM methods like TOPSIS and VIKOR, offer more objective and balanced assessments of criteria importance, enhancing the robustness and accuracy of decision-making processes. The incorporation of neutrosophic sets further addresses real-world complexities by offering a nuanced representation of uncertainty, enabling more informed and accurate outcomes across a range of sectors including public health, supply chain management, and data center location selection.

The findings of this paper underscore the importance of hybrid MCDM approaches in improving decision-making under uncertain and complex conditions. Future research should continue to explore these hybrid methods, particularly in integrating emerging techniques that better handle the dynamic nature of decision problems. By leveraging the insights gained from this analysis, decision-makers can enhance the effectiveness and reliability of their strategies, significantly contributing to sustainable development and strategic planning across various fields.

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Author Contributions

All authors contributed equally to this work.

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Data Availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there is no conflict of interest in the research.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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