Analysis of trends and applications of Multi-Criteria Decision-Making methods

ABSTRACT

Multi-Criteria Decision-Making (MCDM) methods provide effective tools for evaluating, comparing, and ranking alternatives based on multiple criteria, thereby assisting decision-makers in making rational and well-founded choices. This study aims to categorize MCDM methods and explore the practical contexts in which they are applied by mining data from the keywords and abstracts of 14,089 scientific research articles in the Scopus database using text mining techniques. The analysis reveals the diversity of methods such as Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS), and fuzzy variants, and identifies their application contexts ranging from supply chain management and performance evaluation to energy and environmental management, among others. These findings provide a comprehensive overview of the prevalence and usage trends of MCDM methods, while also highlighting research gaps and potential future applications.

Keywords: *MCDM, systematic review, text mining.*

1. INTRODUCTION

Humans constantly make decisions, and decision-making is inherently complex and challenging. MCDM methods represent a crucial field in research and practice, addressing complex decision-making problems where multiple criteria must be considered simultaneously. MCDM assists decision-makers in ranking or selecting the best alternatives based on numerous, often conflicting, criteria. MCDM can be considered both old and new; old because it dates back to the 1700s, and new because the group of MCDM methods has continuously evolved over time.[1] During its development process, to enhance decision-making capabilities under uncertainty, one of the significant advancements in this field is the development of fuzzy multi-criteria decision-making (F-MCDM), which incorporates fuzzy logic to handle ambiguity and imprecision in criteria evaluation.[2,3] In decision-making problems, fuzzy goals and constraints are represented as fuzzy sets within the space of alternatives, making fuzzy logic particularly adept at addressing complex decision-making issues, especially in scenarios where conventional methods may prove inadequate. While MCDM methods are widely applied across various domains, selecting the most suitable MCDM method for a specific problem remains a significant challenge. The diversity of Fuzzy MCDM (FMCDM) methods, each with unique assumptions and operational mechanisms, implies that no single method can be deemed 'universal'. For example, the Fuzzy Analytic Hierarchy Process (FAHP) is effective for pairwise comparisons of criteria but struggles with large-scale problems. In contrast, the Fuzzy Technique for Order Preference by Similarity to the Ideal Solution (Fuzzy-TOPSIS) is more appropriate for problems that involve evaluation based on proximity to an ideal solution. To address complex problems more effectively, MCDM methods are also often combined into integrated models. Vincke categorizes MCDM methods into three main components: multiple attribute utility theory, outranking methods, and interactive methods.[4] However, a more algorithmic approach groups these methods into distance-based, outranking, and pairwise comparison methods.[5] BaydaS et al.[6] argue that the algorithms of different MCDM methods do not always yield the same optimal solution or hierarchical ranking, highlighting a critical issue in the absence of a standardized evaluation framework for comparing MCDM methods. The urgency of this need is underscored by our refined research focus on utilizing MCDM. Previous literature reviews have attempted to address this issue. For instance, Kaya et al. reviewed 245 papers published between 2000 and 2017, analyzing FMCDM methods in the context of energy policy-making,[5] the study found that the FAHP, either as a standalone tool or integrated with other MCDM methods, was the most commonly used, and Type-1 fuzzy sets were the most preferred type of fuzzy sets. Both single and

integrated MCDM methods have been extensively used in the field of corporate sustainability, with single MCDM methods showing a dominant presence.[6,7] In the context of medical decision-making, particularly during the COVID-19 pandemic, the use of MCDM methods has been critical in optimizing treatment processes and resource management. Notably, methods such as AHP, TOPSIS, and PROMETHEE (Preference Ranking Organization Method For Enrichment Evaluation) have proven highly beneficial in supporting decision-making under the urgent circumstances of the pandemic.[8] These findings are consistent with research that highlights the prominence of AHP and TOPSIS in healthcare settings.[9] In addition, VIKOR, AHP, ANP, PROMETHEE, and hybrid methods have been widely employed in studies focusing on low-carbon transport and green logistics, showcasing the versatility and adaptability of MCDM approaches in sustainable development.[10] To address the research gap, this study consolidates all previously published studies available in the Scopus database up until 9:30 AM on September 19, 2024 (GMT+7). By doing so, it aims to provide a comprehensive overview of the application trends of MCDM methods across various fields.

2. METHODOLOGY

2.1. Methodology

This study employs text mining techniques for knowledge discovery through Python programming, a reliable and technology-driven approach that effectively extracts insights from large datasets.[11,12] Compared to other text mining tools such as Gephi or VoSViewer, Python programming allows us to fully understand and control the underlying algorithms, offering the advantage of customizing functions without the limitations commonly encountered with pre-built software.

We employed statistical descriptive analysis techniques and co-occurrence analysis, supplemented by Latent Dirichlet Allocation (LDA). LDA, a widely used method in machine learning and text mining, is an unsupervised statistical model that identifies hidden topics within a collection of textual documents without human intervention. Recent studies have demonstrated the effectiveness of LDA in uncovering latent topics in various research contexts.[13,14] In the visual representation shown in Figure 1, rectangles are used as iterative markers, where 'M' denotes documents, and 'N' represents the frequency of topics within those documents. Observable words, indicated as 'w' are derived from the topic distribution 'z'. In this framework, 'β' signifies the word distribution across topics, 'θ' describes the distribution of topics over documents, and 'α' indicates the word distribution within specific topics. LDA analysis was performed on all abstracts using multiple Python libraries, with PyLDAvis utilized to assess the mean separation between topics.

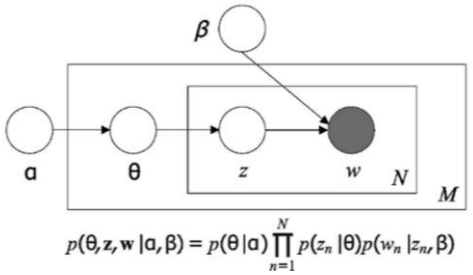

Figure 1. Latent Dirichlet Allocation model[14].

2.2. Dataset

The data source for this study consists of keywords and abstracts extracted from final articles and conference papers indexed in Scopus to ensure a certain level of reliability. The search syntax used is as follows:

(TITLE-ABS-KEY (mcdm) OR TITLE (multiple-criteria AND decision AND making)) AND (LIMIT-TO (DOCTYPE , 'cp') OR LIMIT-TO (DOCTYPE , 'ar')) AND (LIMIT-TO (LANGUAGE , 'English')) AND (LIMIT-TO (SRCTYPE , 'p') OR LIMIT-TO (SRCTYPE , 'j')) AND (LIMIT-TO (PUBSTAGE , 'final')).

Before analysis, the data was normalized by converting all keywords and methods to lowercase to ensure a more accurate match with the terms in the CSV file. Additionally, numbers, punctuation, and non-essential words (e.g., am, is, are) were removed using the stopwords library, which is believed to streamline and simplify the analysis process. Finally, keywords such as 'decision making', 'decision-making', 'decision makings', and 'mcdm' (which convey similar meanings) were excluded due to their general nature.

3. RESULTS AND DISCUSSION

The recent surge in research on Multi-Criteria Decision-Making (MCDM) is notable (Figure 2). In 2003, only 41 studies related to MCDM were recorded. By 2013, this number had risen to 369 publications, and by the end of 2023, the

count had reached 1,964, with a continued upward trend expected into 2024. Figure 3-Data analysis reveals that MCDM research is most prevalent in the fields of Computer Science (5,817 documents), Engineering (5,727 documents), Mathematics (3,050 documents), Business, Management and Accounting (2360 documents) highlighting the methods' widespread application in addressing technical problems, optimization, and mathematical modeling. Significant research activity is also observed in Business, Management, and Accounting (2,427 documents), Environmental Science (2,265 documents), and Energy (1,602 documents), underscoring the importance of MCDM in performance evaluation and sustainable decision-making within these domains. In contrast, fields such as Nursing (15 documents), Dentistry (5 documents), and Veterinary (5 documents) show limited MCDM research, indicating untapped potential in these areas. MCDM research involves a diverse group of authors from various countries. Notably, Asian authors are prominent, with India leading with 2,901 published works, followed by China with 2,019, and Iran with 1,465. In Southeast Asia, Malaysia ranks 7th in the publication ranking at the time of data extraction (548 documents). Research from Vietnam is recorded with 285 published works.

MCDM has become a crucial tool in various research fields and practical applications. From the keyword frequency chart, it is evident that the AHP and Fuzzy AHP are the most widely used methods, extensively applied in research related to supplier selection, optimization, and decision support systems. These methods facilitate the evaluation and ranking of alternatives based on multiple criteria, aiding decision-makers in selecting the most optimal option. Additionally, methods such as Entropy, VIKOR, and TOPSIS are also employed to address complex issues in areas such as sustainable development and risk management.

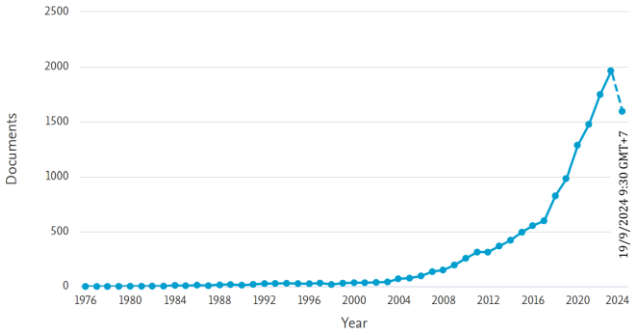

Figure 2. Documents by years (Source: Scopus).

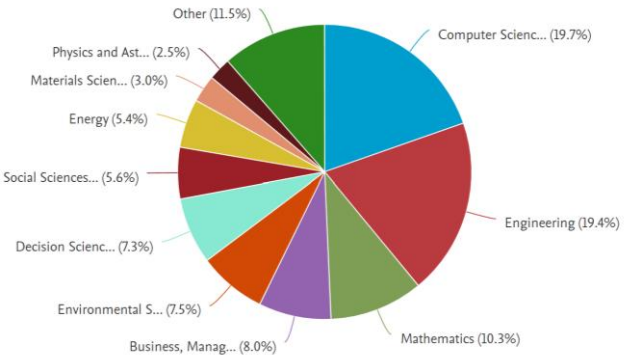

Figure 3. Documents by areas (Source: Scopus).

In the visualization (Figure 4), nodes are color-coded to represent different groups of methods. For instance, methods within the 'Pairwise comparison' group might be represented by one color, while methods in the 'Outranking' group could be shown in a different color. The lines connecting the nodes indicate the co-occurrence of methods within the same summary. The proximity of nodes may reveal the degree of relatedness between methods; nodes that are closer together might appear together more frequently.

In the field of MCDM, methods are often categorized into various groups based on their approaches. The 'Pairwise comparison' group includes methods such as the AHP, which has appeared 6,020 times, highlighting its popularity. AHP, along with variants like the ANP with 819 occurrences, Fuzzy AHP with 407 occurrences, and simpler methods like the Simple Additive Weighting (SAW) with 521 occurrences, plays a crucial role in evaluating criteria through pairwise comparisons between factors. AHP is particularly noted for its capability to handle complex issues, hierarchical goal settings, and criteria comparisons based on weights, especially when combined with fuzzy methods to better manage uncertainty.

The graph technique implemented in this code utilizes NetworkX to visualize the co-occurrence of MCDM methods based on their presence in abstracts. By representing each method as a node and connecting them with edges when they appear together, this approach provides insights into relationships and interactions among various decision-making methodologies, enhancing understanding and identifying research trends.

Figure 5-The 'Outranking' group focuses on evaluating and ranking options by comparing their advantages and disadvantages, with prominent methods such as PROMETHEE (535

occurrences) and ELECTRE (366 occurrences). These methods are widely applied in decision-making situations involving conflicting criteria, helping to identify superior options by eliminating weaker alternatives. Less commonly used methods like ORESTE, PRAGMA, and QUALIFLEX, with fewer than 30 occurrences each, reflect their specialized nature and limited practical application. The 'Distance-based' group features notable methods like TOPSIS (3,164 occurrences) and VIKOR (1,034 occurrences). TOPSIS is widely used for identifying the ideal solution by calculating the distance of each option from the best and worst alternatives. The Fuzzy TOPSIS method, with 462 occurrences, extends traditional TOPSIS by incorporating fuzzy factors to handle uncertainty, making it suitable for scenarios involving ambiguous or unclear data. Grey Analysis, with only 1 occurrence, is less applied, indicating limitations in practicality or popularity. The 'Others' group encompasses various methods, with Grey Relational Analysis (GRA) having the highest frequency (5,542 occurrences), demonstrating significant interest in research. Data Envelopment Analysis (DEA), with 4,004 occurrences, highlights its prominent role in evaluating performance and efficiency. Methods such as the Best-Worst Method (BWM) with 447 occurrences, Additive Ratio Assessment (ARAS) with 197 occurrences, and Evaluation based on Distance from Average Solution (EDAS) with 223 occurrences also receive notable attention due to their simplicity and effectiveness in comparing and evaluating options. Less common methods like MAUT, COMET, and REMBRANDT, with fewer than 50 occurrences each, reflect their specificity and limited adoption in practice.

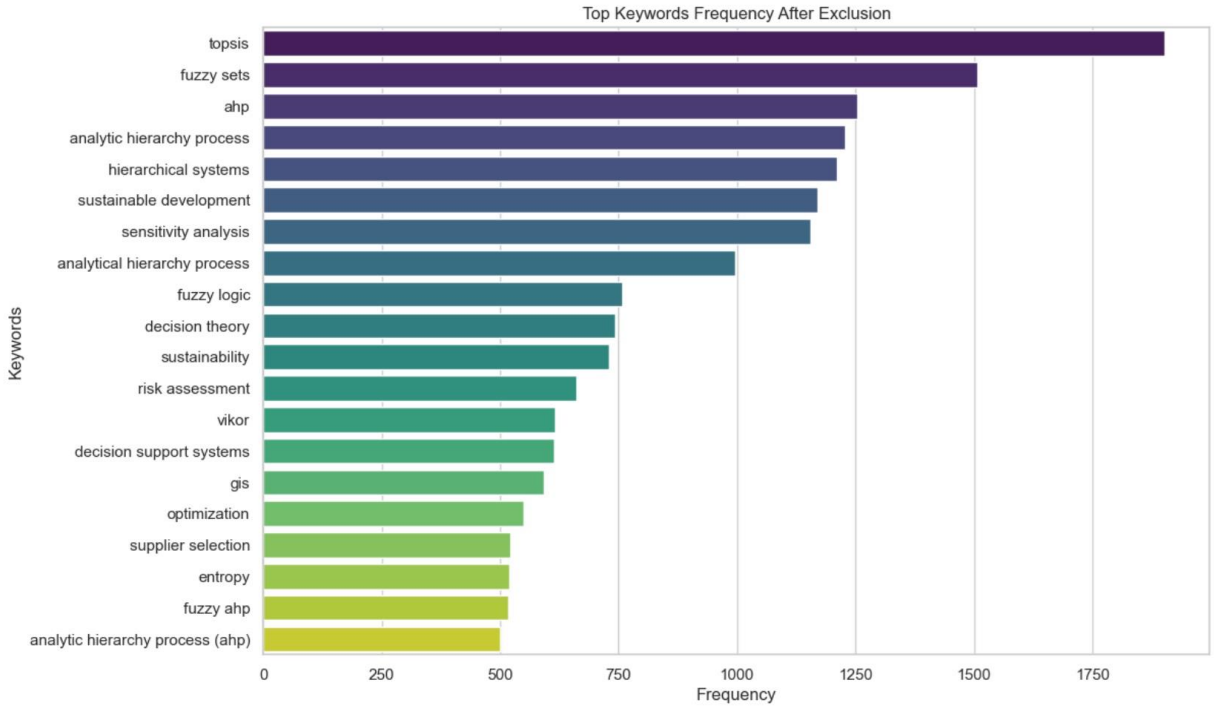

Figure 4. Top keywords frequency after exclusion

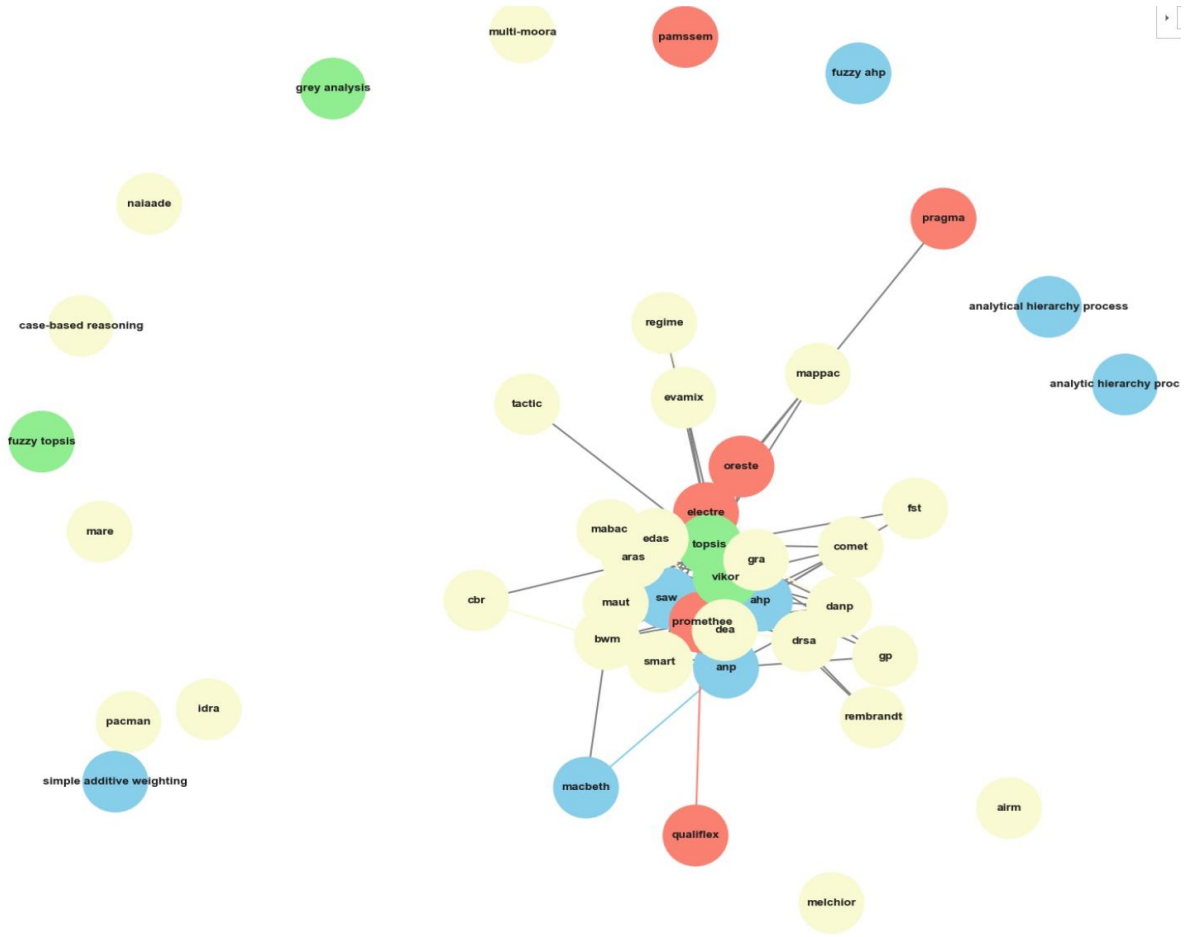

Figure 5. Co-occurrence Network of MCDM.

In this study, we applied topic analysis using the Latent Dirichlet Allocation (LDA) model to explore the main themes within abstracts related to MCDM. The LDA model is an unsupervised machine learning technique commonly used for text analysis, designed to uncover latent topics based on the distribution of keywords within the documents.

- Topic #1: 0.013* “criteria” + 0.011* “study” + 0.008* “selection” + 0.008*"method" + 0.007* “supply” + 0.006* “process” + 0.006* “used” + 0.006* “supplier” + 0.006* “service” .
- Topic #2: 0.032* “fuzzy" + 0.023* “method" + 0.016* “proposed” + 0.015* “criteria” + 0.015* “decision” + 0.009* “based” + 0.009* “paper” + 0.009* “alternatives” + 0.008* “approach” .
- Topic #3: 0.025* “decision” + 0.012* “criteria” + 0.011* “problem” + 0.011* “making” + 0.009* “multiple” + 0.008* “problems” + 0.008* “system” + 0.008* “methods” + 0.007* “paper” .
- Topic #4: 0.015* “energy” + 0.009* “study” + 0.007* “using” + 0.007* “water” + 0.006* “power” + 0.006* “results” + 0.006* “used” + 0.006* “analysis” + 0.005* “environmental” .
- Topic #5: 0.011* “model” + 0.010* “criteria” + 0.009* “decision” + 0.009* “study” + 0.008* “process” + 0.007* “performance” + 0.007* “evaluation” + 0.006* “research” + 0.006* “factors” .

The indicators and keyword weights within each topic provide valuable insights into the research trends and applications of MCDM methods across various fields.

- Methods for criteria selection and evaluation in supply chain and services:

Topic 1 from the LDA analysis highlights the prevalence of keywords such as ‘criteria’ ‘selection’, and ‘supplier’, suggesting the significant role of MCDM methods in selection and evaluation within supply chains. Methods like AHP, ANP, and SAW are widely used to identify, compare, and evaluate criteria related to suppliers, service performance, and supply chain management. These methods help businesses not only select appropriate suppliers but also optimize management processes, reduce risks, and enhance operational efficiency.

- Fuzzy methods in decision making:

Topic 2 indicates that fuzzy methods such as Fuzzy AHP, Fuzzy TOPSIS, and other variants play a crucial role in tackling decision-making problems under uncertainty or when dealing with hard-to-quantify information. The use of fuzzy methods allows for the integration of complex and ambiguous criteria into the decision-making process, leading to more accurate and relevant outcomes. This is particularly important in fields requiring the handling of incomplete or highly variable data. The analysis results show that the widespread use of fuzzy methods in research underscores the importance of combining qualitative and quantitative factors in decision-making.

- General MCDM Methods for Multi-Criteria and Systemic Decision-Making:

Topic 3 focuses on keywords such as ‘decision’, ‘criteria’, and ‘methods’ emphasizing the role of MCDM methods like TOPSIS, VIKOR, and ELECTRE in addressing general multi-criteria decision-making problems. These methods are not only applied in academic research but also in business, engineering, and industrial practices. They enable decision-makers to compare, rank, and choose among alternatives while considering multiple criteria simultaneously. The high applicability and adaptability of these methods make them popular choices for tackling complex and multidimensional problems.

- Evaluation methods in energy and environmental issues:

Topic 4 underscores the application of MCDM methods in the fields of energy and the environment, with keywords related to ‘energy’, ‘water’, and ‘environmental’. Methods like PROMETHEE and Grey Analysis are often used to assess environmental impacts, manage energy resources, and analyze sustainable development strategies. The presence of these methods in research indicates the growing trend of applying MCDM to address global issues related to environmental protection and efficient resource use.

- Performance evaluation and decision-making models:

Topic 5 addresses performance evaluation models such as DEA (Data Envelopment Analysis) and ARAS (Additive Ratio Assessment). These methods help analyze and assess the performance of organizations, projects, and other factors in the decision-making process. DEA is particularly used to measure the operational performance of decision-making units in various fields such as banking, education, and healthcare, due to its ability to compare the relative efficiency of similar units. These methods not only aid in performance evaluation but also provide valuable information on influencing factors, thereby helping to improve decision-making processes.

4. CONCLUSION

The analysis results reveal the diversity and widespread application of Multi-Criteria Decision-Making (MCDM) methods in both research and practical applications, underscoring their importance in supporting effective and accurate decision-making. Evidence suggests that methods like Entropy, VIKOR, and TOPSIS are also employed to address complex issues in fields such as sustainable development and risk management. Methods such as AHP, TOPSIS, and PROMETHEE have proven their significance in tackling complex multi-criteria problems, particularly in areas like supply chain, services, energy, and environmental management. AHP and Fuzzy AHP stand out for their capability in pairwise comparisons and handling uncertainty, enhancing decision quality in complex scenarios.

The Outranking methods, such as PROMETHEE and ELECTRE, continue to demonstrate effectiveness in ranking and selecting alternatives when criteria are conflicting. TOPSIS and VIKOR, within the Distance-based group, have expanded their applicability, especially in scenarios that require balanced solutions across multiple criteria.

These methods are not only easy to understand but also widely applicable across various domains.

However, to enhance practical application, future research should focus on integrating traditional methods with emerging technologies like machine learning and big data analytics to optimize real-time decision-making processes. Combining methods such as DEA with Fuzzy AHP or TOPSIS could improve the accuracy and reliability of results. Additionally, developing hybrid methods that leverage the strengths of multiple techniques presents a promising direction.

While listing and analyzing MCDM methods can provide an overview, there is often a lack of in-depth analysis regarding the effectiveness and limitations of each method within specific contexts. This can diminish the practical value and specificity needed for subsequent research.

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