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SURVEY OF MULTI-CRITERIA DECISION MAKING (MCDM) METHODS FOR EVALUATING BARRIERS IN DECISION-MAKING PROCESSES

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Abstract – *This study analyzes the trends in applying multi-criteria decision-making methods to assess decision-making barriers through text mining techniques, including keyword frequency analysis, Latent Dirichlet Allocation modeling, and t-distributed Stochastic Neighbor Embedding. The results indicate that multi-criteria decision making is most commonly applied in fields, such as engineering, supply chain management, and sustainable development, with popular methods like Analytic Hierarchy Process, Fuzzy Analytic Hierarchy Process, Technique for Order of Preference by Similarity to Ideal Solution, and Decision-Making Trial and Evaluation Laboratory. Decision-Making Trial and Evaluation Laboratory tends to be applied independently rather than in combination with other methods. The study also reveals strong connections between these methods, with the Analytic Hierarchy Process playing a central role, frequently integrated with other approaches to optimize decision-making processes. Future recommendations include expanding the data collection scope and applying machine learning techniques to enhance analysis accuracy, while further exploring the potential applications of multi-criteria decision making in emerging fields.*

Keywords: barriers, decision making, multi-criteria decision making (MCDM), text-mining.

I. INTRODUCTION

Decision-making is one of the most essential and significant tasks in management. It plays a critical role in determining the success or failure of organizations by guiding them toward achieving their goals, optimizing resources, and improving overall performance. Every decision made at various levels within an organization influences its operational efficiency, strategic direction, and long-term sustainability. A correct decision leads to successful outcomes, while incorrect decisions can result in losses, inefficiencies, and missed opportunities. Thus, the quality of decision-making directly impacts the effectiveness of management. However, decision-makers are likely to be biased [1]. Decision-making is often fraught with difficulties and easy to make mistakes [2] because human decision-makers frequently struggle due to numerous factors such as insufficient information, time constraints, and the inherent complexity of situations. Mistakes come with a cost in money and time [1]. Unfortunately, most of the problems in the world involve multiple data points with varying characteristics; for instance, some are objective and precise, while others are subjective or uncertain [3]. In an increasingly dynamic and uncertain business environment, decision-makers must navigate competing priorities, ambiguity, and conflicting interests. These challenges result in a high risk of errors, leading to decisions that are suboptimal or, in some cases, detrimental to the organization.

To address the inherent complexities of decision-making, researchers and practitioners have created various tools and frameworks to help managers navigate these challenges. One such tool is multi-criteria decision-making (MCDM), which has its roots in decision theory and has been developed to tackle complex issues involving multiple criteria [3]. The historical roots of MCDM can be traced back to the 18^{th} century

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when Benjamin Franklin employed a decision-making framework involving multiple objectives. While the concept has ancient origins, contemporary MCDM research gained formal recognition in the late 1950s with Charnes and Cooper's pioneering work on goal programming. Since then, MCDM has experienced substantial growth, evidenced by the prolific publication of over 15,000 scholarly articles and countless books on the subject [4]. The field has evolved into a cornerstone sub-discipline within management science and operations research, establishing its own distinct identity and significance. In real-world decision-making, a single criterion is often insufficient to guide choices effectively. Instead, complex scenarios demand the consideration of multiple, often competing factors. MCDM provides a systematic framework for evaluating and ranking alternative options by comprehensively assessing both quantitative and qualitative dimensions. Unlike traditional decision-making methodologies that prioritize a singular objective, MCDM is indispensable when decision-makers must balance and weigh various, sometimes conflicting, criteria to arrive at informed judgments. In essence, the main aim of MCDM is to assist decision-makers in achieving the optimal outcome by balancing all relevant criteria and ensuring that the decision aligns with the organization's strategic goals.

Barrier is a fence or other obstacle that prevents movement or access. Barriers are often multifaceted, involving obstacles in the adoption process due to various shortcomings [5]. The complexity of ranking these barriers arises from the need to balance multiple, often conflicting criteria. MCDM methods are particularly effective for handling this complexity as they systematically compare and evaluate different factors, allowing for a structured and comprehensive analysis. This makes MCDM well-suited for identifying which barriers have the most significant impact on decision-making processes. To illustrate this, the following are examples of MCDM applications in barrier prioritization studies: (1) the use of the Best Worst Method (BWM) to prioritize sustainable manufacturing barriers [5]; (2) the application of Decision-Making Trial and Evaluation Laboratory (DEMATEL) with priority weights to evaluate potential barriers to implementing solar drying techniques [6]; (3) barrier analysis for solar energy development in Iran using the fuzzy AHP-TOPSIS method [7]; and (4) the prioritization of barriers to Industry 4.0 adoption in Indian manufacturing industries using Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) [8]. By identifying and evaluating these barriers, organizations can take proactive measures to mitigate their impact, thus improving decision quality and minimizing errors.

There are over 200 MCDM methods [9], and there is a wide array of them available, each with its own strengths and weaknesses. The diversity of MCDM methods highlights the importance of selecting the appropriate method for the specific decision-making context because appropriate methods are required to address the issues effectively for a specific context, as not all methods are suitable for every situation. The choice of method should be guided by the nature of the decision, the type of data available, and the decision-makers' preferences and constraints. Despite the availability of numerous methods, the application of MCDM in practice is often subjective. This subjective use of MCDM tools can lead to inconsistent results, as different methods may yield different recommendations for the same decision problem. Despite the advancement of numerous sophisticated MCDM methods, none can be regarded as a 'universal method' suitable for all decision-making situations [9], and the choice of MCDM methods is likely to be uncertain [10]. Therefore, a key objective is to survey previous studies that have applied MCDM methods in analyzing decision-making barriers, with the overarching goal of MCDM to focus on understanding which methods are most effective in different contexts. Prior studies [11–14] have conducted surveys on the methods and applications of MCDM. For instance, in the field of sustainable engineering, a study covering the period from 2008 to 2018 analyzed 108 articles indexed

in the Web of Science through manual review [11]. Chowdhury et al. [12] manually reviewed 52 articles published in research on corporate sustainability, during the period 2007–2019 extracted from Google Scholar and Web of Science; Research on MCDM techniques for energy policy and decision-making problems from 1986 to 2017 was also conducted through manual reading of the results, combined with regression analysis to make predictions [13]; Or Sotoudeh-Anvari [14] reviewed 72 papers published in 37 leading peer-reviewed journals indexed in Web of Science that used MCDM methods in different areas of COVID-19 pandemic. It can be observed that the studies delve deeply into specific issues to analyze and explore which particular methods are used for each case. Despite this focus, previous studies remain limited in addressing the application of MCDM methods to evaluate barriers in decision-making. This research therefore aims to explore the trends in the application of MCDM methods for addressing barriers in decision-making. By utilizing text mining techniques along with advanced analytical methods such as Latent Dirichlet Allocation (LDA) for topic modeling and t-distributed Stochastic Neighbor Embedding (t-SNE) for dimensionality reduction and visualization, the study seeks to systematically analyze large volumes of research literature to identify patterns and trends in the usage of specific MCDM methods across diverse contexts. Building on these findings, the secondary aim of this research is to provide a clearer understanding of how MCDM methods can be applied more objectively and effectively to overcome decision-making barriers, thereby enhancing their utility in addressing complex decision-making challenges.

II. RESEARCH METHODS

A. *Methodology*

This study employs text mining methods to conduct knowledge discovery. Compared to traditional document review approaches, text mining is considered more efficient. This technique is supported by several analytical software tools, just to name a few, Loureiro et al. [15] used Gephi to identify research trends and relationships, while Srivastava et al. [16] employed VoSViewer to evaluate research domains. However, a limitation of these applications is the lack of detailed information about the algorithms they utilize, with only brief introductions to the software and its usage provided. Consequently, self-coding was adopted in this study. Python programming is believed to offer greater flexibility, a deeper understanding of the algorithms, and higher customizability compared to using software tools, especially when handling complex or unique text mining tasks, thanks to the extensive library support available.

Specifically, in this study, alongside descriptive statistics, the machine learning model LDA was employed, as it is considered one of the most widely used models for knowledge discovery in systematic reviews [17]. Some even argue that this model, proposed in 2003, is ‘the most effective for measuring and visualizing data’ [18]. The foundation of this theory can be viewed through the framework of Bayesian networks. A Bayesian network is a probabilistic model that represents the relationships between random variables within the process in terms of their probabilities. The LDA operates through a generative process using two main distributions: the topic distribution for documents (θ_d) and the word distribution per topic (φ). First, from a set of documents, each document is assigned a topic distribution (θ_d) from a Dirichlet distribution with parameter α. Next, for each word in the document, a topic (Z_n) is chosen from the assigned topic distribution (Figure 1). The word (W_n) is then generated based on the word distribution of that topic (θ_d), which itself is drawn from a Dirichlet distribution with parameter β. Through this process, LDA helps uncover latent structures (referred to as ‘latent topics’) within the documents, allowing researchers to gain a better understanding of the main topics that are not explicitly stated in the text content.

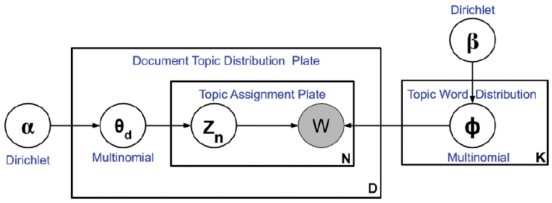

Fig. 1: Diagrammatic representation of the LDA generative algorithm [19]

To further enhance the efficiency of the model, the study combines LDA with t-SNE, a data dimensionality reduction method introduced in 2008, to enhance the efficiency of machine learning models. t-SNE uses the t-distribution instead of the Gaussian distribution to describe similarities among data in a low-dimensional space and relies on a joint probability distribution function, replacing conditional probability, to represent the low-dimensional neighborhood relationships among data [20]. t-SNE is particularly sensitive to local structures, making it one of the best approaches for data visualization and aiding in the understanding of theoretical attributes within datasets. Explanation of the principle behind this algorithm, t-SNE calculates the probability p_{ij} that document i considers document j as its 'neighbor', based on the distance between their document vectors (using cosine or Euclidean distance). For example, if two documents A and B have similar content (many common keywords), the distance between their vectors will be small, resulting in a high probability p_{AB}. Conversely, if documents A and C are quite different (few common keywords), the distance will be large, and the probability p_{AC} will be low. In the next step, when reducing dimensions to 2D or 3D for visualization, t-SNE recalculates the probability q_{ij} that two documents in the lower-dimensional space are 'neighbors' but this time using a t-distribution. For instance, if documents A and B remain close after the reduction, the probability q_{AB} will be high, while if A and C are still distant, q_{AC} will be low. t-SNE's objective is to make the low-dimensional probabilities q_{ij} as close as possible to the original high-dimensional probabilities p_{ij}, ensuring that if two documents are close in the original space (indicating similar content), they will also be close in the map visualization.

In all analytical techniques, the data is cleaned, specifically by normalizing the data through the removal of excess whitespace to ensure consistency during data retrieval and processing. Next, keywords are standardized by converting all text to lowercase, eliminating unnecessary differences between uppercase and lowercase letters, thereby avoiding duplication.

B. Data

The Scopus database is considered relatively reliable and offers broader coverage compared to Web of Science. It includes a wider range of journals, disciplines, and sources, making it a valuable resource for comprehensive literature reviews across various fields of research. The data was extracted from the Scopus database, extracted at 10:00 AM on September 19, 2024 (GMT+7). The articles selected have titles containing 'MCDM', 'multiple-criteria decision making', 'multiple-criteria decision-making', or 'multiple criteria decision-making' combined with titles that include the word 'barrier'. The rationale behind searching within the title lies in its ability to narrow the focus to articles that are directly relevant to the specific topic of interest, as the title typically provides a concise reflection of the study's main content. The decision to select only the title to refine the search results has been applied in previous studies [21, 22]. This research filtered the documents to include only research papers and conference papers written in English. The reasoning for this selection is based on the fact that research articles typically undergo a peer review process, ensuring the quality and accuracy of the published information; conference papers are also carefully reviewed before being presented at reputable conferences, providing up-to-date and novel insights.

The search yielded 263 documents as of the extraction time. After filtering according to the criteria, 244 documents were obtained. All documents had their keywords and abstracts extracted as text for the purpose of data mining.

III. RESULT AND DISCUSSION

The trend in research on MCDM and its associated barriers, as depicted in Figure 2, shows a notable evolution over time. From 1994 to 2014, the number of publications remained relatively low and stable, suggesting that the investigation into barriers within MCDM processes was not a major focus during this period. However, starting around 2015, there has been a gradual increase in the number of publications, reflecting a growing interest in understanding and addressing the challenges associated with MCDM. The most significant surge occurs from 2019 to 2023, when the number of publications rises sharply, indicating this increase may be attributed to the expanding application of MCDM across various industries and fields, which necessitates a deeper exploration of its limitations.

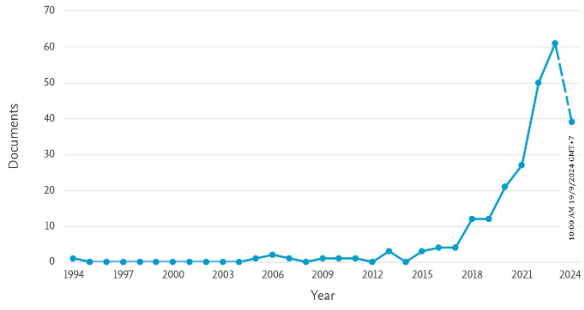

Fig. 2: Documents by years

The application of MCDM in analyzing barriers shows a significant concentration in certain fields, as reflected by the data (Figure 3). Engineering (18.1%) leads in the utilization of MCDM methods, likely due to the sector's complex decision-making requirements in infrastructure development, project management, and technical innovations, where multiple conflicting criteria must be evaluated. Business, Management, and Accounting (14.5%) also exhibit a high application of MCDM, particularly in strategic decision-making, resource allocation, and risk management, where identifying and addressing barriers is crucial for optimizing outcomes. Similarly, Computer Science (13.1%) leverages MCDM in areas, such as system optimization, artificial intelligence, and machine learning, where decisions must balance technical and operational challenges. Environmental Science (11.2%) demonstrates substantial use of MCDM, especially in evaluating sustainability, environmental impact, and economic trade-offs, which are critical in addressing the barriers to effective environmental management. On the other hand, disciplines such as Chemistry (0.3%), Arts and Humanities (0.3%), and Biochemistry, Genetics, and Molecular Biology (0.3%) show minimal application of MCDM, possibly due to the nature of research in these fields, which may rely less on multi-criteria evaluation frameworks or face fewer barriers that require complex decision-making tools. This distribution suggests that MCDM is most relevant in sectors with inherently complex decision environments, where multiple criteria and barriers must be systematically assessed.

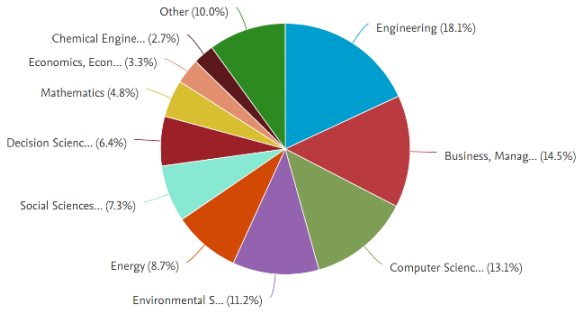

Fig. 3: Documents by areas

Continuing the analysis of frequently occurring keywords, after excluding general terms such as 'MCDM', 'decision making', 'multi-criteria decision making', and 'barriers', the research obtained the following results:

The keyword analysis (Figure 4) indicates a strong focus in MCDM research on evaluating barriers to sustainable development, with particular emphasis on supply chain management and waste management issues. A notable area of interest is developing countries, which face unique challenges that have attracted considerable research attention. Traditional MCDM methods such as AHP, fuzzy AHP, and DEMATEL are commonly applied to identify, prioritize, and analyze complex barriers in these contexts. These methods have proven especially useful in exploring the challenges hindering the adoption of advanced technologies like Industry 4.0 and blockchain. The prominence of the keyword 'India' points to a geographic region where MCDM is being extensively applied to address these issues, reflecting the country's growing importance in the global discourse on sustainable development. Additionally, the presence of 'sensitivity analysis' among the top keywords suggests an increasing focus on evaluating the robustness of research outcomes by examining how input variations affect the results. This trend underscores a growing commitment to enhancing the reliability and accuracy of MCDM research.

The data will be categorized following the study of Song et al. [23] and Krstić et al. [24], which classify methods into three main groups: pairwise comparison, outranking, and distance-based methods.

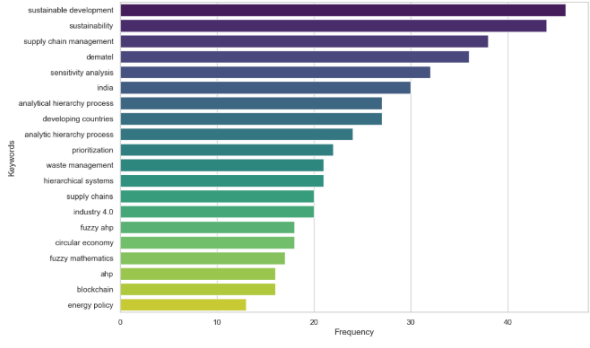

Fig. 4: Keyword frequency

The discovered topics include:

The results of the LDA analysis have indicated

Topic #1: Risk assessment and energy
0.008*"risk" + 0.007*"energy" + 0.005*"analysis" + 0.005*"method" + 0.005*"results" + 0.005*"study" + 0.004*"cumulative" + 0.004*"used" + 0.004*"using"
Topic #2: Waste management, sustainable development
0.008*"study" + 0.006*"industry" + 0.005*"lack" + 0.004*"waste" + 0.004*"literature" + 0.004*"management" + 0.004*"sustainable" + 0.003*"countries" + 0.003*"healthcare"
Topic #3: Supply chain management and system implementation
0.013*"study" + 0.009*"industry" + 0.007*"supply" + 0.007*"implementation" + 0.006*"chain" + 0.006*"management" + 0.005*"research" + 0.005*"results" + 0.005*"lack"
Topic #4: Energy and sustainable environment
0.011*"study" + 0.007*"research" + 0.006*"energy" + 0.005*"implementation" + 0.005*"environmental" + 0.005*"sustainable" + 0.005*"fuzzy" + 0.005*"process" + 0.005*"lack"
Topic #5: Assessment and adoption of new technologies in the supply chain
0.012*"study" + 0.008*"adoption" + 0.007*"supply" + 0.006*"energy" + 0.006*"fuzzy" + 0.005*"chain" + 0.005*"industry" + 0.005*"method" + 0.005*"approach"

five main research directions in which researchers utilize MCDM methods to address barriers in various fields.

Topic 1 – Risk assessment and energy: Key terms include 'risk', 'energy', 'analysis', and 'method'. This indicates that researchers focus on using MCDM to assess risks related to energy, including analyses and multi-criteria methods for decision-making in high-risk areas.

Topic 2 – Waste management and sustainable development: Pertaining to waste management and sustainable development, MCDM aids in evaluating and optimizing management options, particularly in industrial sectors and healthcare.

Topic 3 – Supply chain management and system implementation: Keywords related to supply chain and system management suggest that studies employ MCDM to optimize and assess the implementation of solutions within the supply chain.

Topic 4 – Energy and sustainable environment: This research utilizes MCDM methods to propose sustainable solutions in energy and environmental management.

Topic 5 – Assessment and adoption of new technologies in the supply chain: MCDM methods are applied to evaluate and optimize the acceptance and implementation of new technologies in the supply chain, particularly concerning energy and technology.

The distance between clusters indicates that the documents within each cluster contain very distinct topics (Figure 5). In other words, these documents share little commonality in content. The significant gaps between clusters also suggest minimal linkage or overlap among the topics. This implies that these topics seldom co-occur within a single document. Clusters with more widely dispersed data points may indicate greater

diversity within the topic, featuring various different variations.

The results from the graph (Figure 6) indicate common combinations among the methodological groups: AHP serves as the central connecting node. Its links to numerous other network nodes demonstrate its popularity when considered for use in combination with other methods.

TOPSIS stands out as a representative of the distance-based group, particularly when combined with other groups. It is evident that AHP and TOPSIS (the distance-based group, shown in green) are frequently used together. AHP aids in analyzing and ranking criteria based on their importance, while TOPSIS calculates the distance between alternatives and the ideal solution. This combination facilitates a comprehensive decision-making process, where AHP determines the weights of the criteria and TOPSIS evaluates the alternatives based on their proximity to the ideal solution.

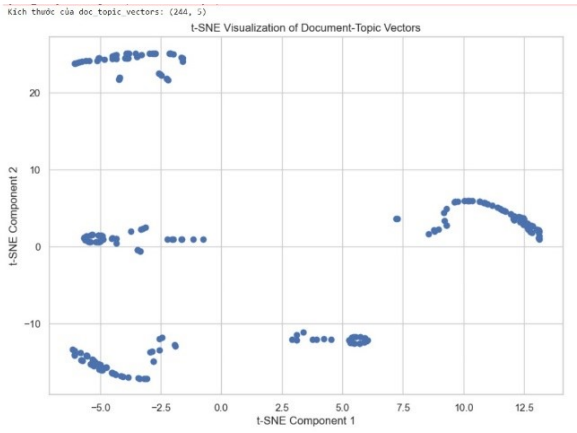

Fig. 5: t-SNE visualization of document topic

The combination of AHP and ANP is also notable. Both methods share a theoretical foundation but serve different purposes in decision analysis, with AHP focusing on hierarchical structures and ANP emphasizing the network relationships among factors.

In specific situations, simple additive weighting (SAW) may replace AHP. While SAW can substitute AHP in certain scenarios, the choice of the appropriate method depends on the characteristics of the problem, the nature of the criteria, and the specific requirements of the decision-maker. If factors are complex, interactions among criteria are significant, or sensitivity is critical, AHP may be the better choice.

ELECTRE and PROMETHEE can be used interchangeably. The Electre and Promethee methods are often employed as substitutes in studies that require the comparison and ranking of alternatives based on unclear or conflicting criteria. However, since they belong to the same Outranking group, researchers frequently combine them with methods from other groups, such as AHP or TOPSIS, to enhance the decision-making process. AHP can be used to determine the criteria weights before employing Promethee or Electre to rank the options.

Multi-Attribute Border Approximation Area Comparison (MABAC) and Generalized Preference (GP) often combine well with other analytical methods to improve the accuracy and feasibility of decisions but can operate independently in certain situations. Best-Worst Method (BWM) is primarily used to determine the weights of criteria and is often combined with other methods to evaluate and rank the alternatives. DEMATEL is often used to analyze and model the relationships between factors, aiming to identify the elements that have the most significant influence on the system. In contrast, AHP focuses on ranking and comparing alternatives under conditions of uncertainty. This difference may reduce the feasibility of combining the two methods within the same study, resulting in a lack of coherence in the abstract.

IV. CONCLUSION AND RECOMMENDATIONS

This study aligns with previous research, as the results indicate that AHP (including fuzzy AHP) is the most popular MCDM method applied. The survey results indicate significant advancements in the application of MCDM methods to analyze barriers in decision-making across various fields. MCDM has emerged as a crucial tool, widely

Fig. 6: Co-occurrence methods map

utilized in industries with complex requirements for assessing and optimizing conflicting factors. One of the leading fields in MCDM application is engineering, with a representation of 18.1%, reflecting the demand for multi-criteria analysis in project management, infrastructure development, and technical improvements. The frequency keyword analysis reveals that researchers are particularly focused on evaluating barriers to sustainable development, especially in areas such as supply chain management and waste management. This reflects a global concern regarding environmental issues and sustainable development, particularly in developing countries like India, where MCDM is extensively applied. Research in this context primarily centers on advanced technology factors such as Industry 4.0 and blockchain, enabling nations to address emerging challenges.

LDA analysis has clearly identified five main thematic groups. The areas of risk assessment and energy, waste management and sustainable development, supply chain management, sustainable energy, and new technologies all demonstrate strong links with MCDM methods. This highlights the high applicability of MCDM in evaluating and optimizing multi-criteria decisions across various industries, particularly in addressing environmental challenges and advancing technology.

The relationships among MCDM methods were also analyzed through a graph, illustrating common combinations between different methodological groups. AHP plays a central role in many studies, often combined with other methods such as TOPSIS and ANP to enhance accuracy and analytical capabilities in the decision-making process. The integration of AHP with TOPSIS creates a comprehensive process where AHP determines the weights of criteria, while TOPSIS assesses alternatives based on their distance to the ideal solution. Additionally, the combination of AHP and ANP clarifies the complex network relationships among decision factors.

Other methods, such as ELECTRE and PROMETHEE, while interchangeable in some situations, are also frequently combined with other methods like AHP or TOPSIS to enhance the effectiveness of the decision-making process. MABAC and GP demonstrate potential when combined with other methods to improve accuracy, while BWM is primarily used to determine criterion weights and is often integrated with other methods for evaluating and ranking alternatives.

Despite providing a comprehensive overview of the development and application of MCDM methods in analyzing decision-making barriers, this study has notable limitations. First, the analysis based on frequency keywords and LDA modeling primarily focuses on the available literature, leading to the risk of overlooking other important aspects that keywords or algorithms may not adequately capture. For instance, several studies might use different terminology to express the same concept or approach a problem from varying perspectives not encompassed by the analyzed keywords, resulting in an incomplete representation of the actual research landscape. Furthermore, results from statistical models such as LDA or t-SNE heavily depend on input data and the chosen number of topics, which can affect the objectivity of the findings. Consequently, selecting a non-optimal number of topics or keywords may diminish the representativeness of the identified themes. Additionally, this study does

not include an in-depth analysis of fields outside of engineering, business, and management, potentially overlooking the full application potential of MCDM in other sectors such as healthcare, education, or public policy. Finally, it should also be acknowledged that limiting the search terms to only titles, without including keywords or abstracts, presents a shortcoming, as it may overlook a few studies during the search process.

To further advance this research, several future directions could be considered. First, integrating advanced text analysis methods, such as deep learning, could enhance the capability to detect themes and more accurately evaluate research trends. Second, expanding the scope of data collection to include studies from various languages, as well as broadening the search criteria to encompass keywords, may provide a more comprehensive view of MCDM development globally. Finally, future research should focus on in-depth analyses of the relationships between MCDM methods and each research area, it emphasizes the need for more detailed studies on how MCDM methods relate to various research areas.

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