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Artificial Intelligence-Assisted Multi-Criteria Decision-Making Methodology: From Research Trends to the Future Roadmap

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Bibliometric analysis, Web of Science, Machine learning, Artificial intelligence, Multi-criteria decision-making

Abstract: Bibliometric analysis is a popular methodology in recent years that provides valuable insights for literature and researchers by visualizing interesting trends, relationship patterns, and information flow in research areas. This study aims to evaluate the publication trends, author contributions, institutional collaborations, and citation dynamics of this field by examining the integration of Multi-Criteria Decision Making (MCDM) and Artificial Intelligence (AI) with bibliometric analysis methods. This integration optimizes complex decision-making processes and provides faster, consistent, and effective solutions. The analysis was performed using performance analysis and science mapping techniques. Data were collected from the WoS database and 993 articles covering the period from 1992 to 2024 were analyzed. Co-citation, keyword co-occurrence, and co-authorship analyses were visualized with VOSviewer software. Accordingly, India, China and Iran stand out as the countries with the most publications, while the Indian Institute of Technology has the highest contribution. 'Annals of Operations Research' and 'Expert Systems with Applications' were among the most frequently cited journals. University of Technology Sydney and King Abdulaziz University stood out in institutional collaboration. This study is a pioneering study that conducts bibliometric analysis for AI-MCDM methods, especially in terms of the subject, scope and some of the findings obtained, and has produced valuable insights through data analytics.

Yapay Zekâ Destekli Çok Kriterli Karar Verme Metodolojisi: Araştırma Eğilimlerinden Gelecek Yol Haritasına

Anahtar Kelimeler
Bibliyometrik analiz, Web of Science, Makine öğrenimi, Yapay zekâ, Çok kriterli karar verme

Öz: Bibliyometrik analiz, son yıllarda araştırma alanlarında ilginç eğilimleri, ilişki desenlerini ve bilgi akışını görselleştirerek literatür ve araştırmacılar için değerli bilgiler sağlayan popüler bir yöntemdir. Bu çalışma, Çok Kriterli Karar Verme (ÇKKV) ve Yapay Zekâ (AI) entegrasyonunun bibliyometrik analiz yöntemleriyle incelenerek, bu alanın yayın eğilimlerini, yazar katkılarını, kurumsal iş birliklerini ve atıf dinamiklerini değerlendirmeyi amaçlamaktadır. Bu entegrasyon, karmaşık karar verme süreçlerini optimize ederek ve daha hızlı, tutarlı ve etkili çözümler sunmaktadır. Analiz, performans analizi ve bilim haritalama teknikleri kullanılarak yapılmıştır. Veriler, WoS veritabanından toplanmış ve 1992-2024 yıllarını kapsayan 993 makale analiz edilmiştir. Ortak atıf, eş birliktelik ve ortak yazar analizleri VOSviewer yazılımı ile görselleştirilmiştir. Buna göre, Hindistan, Çin ve İran en fazla yayına sahip ülkeler olarak öne çıkarken, Indian Institute of Technology en yüksek katkıyı sağlamaktadır. 'Annals of Operations Research' ve 'Expert Systems with Applications' en sık atıf yapılan dergiler arasında yer almıştır. University of Technology Sydney ve King Abdulaziz University, kurumsal iş birliği alanında öne çıkmıştır. Bu çalışma, özellikle konu, kapsam ve elde edilen bazı bulgular açısından, AI-ÇKKV yöntemleri için bibliyometrik analiz yapan öncü bir çalışmadır ve veri analitiği ile çok değerli içgörüler üretmiştir.

1. INTRODUCTION

Artificial Intelligence (AI) has become a very important decision support system today thanks to its ability to detect meaningful patterns in large and complex data sets, to solve problems quickly and accurately, and the advanced predictive accuracy of machine learning. AI-based systems, which can carry out tasks at high levels of difficulty even autonomously, have made radical transformations in every conceivable field, accelerating efficiency, accuracy, prediction, and innovation. It is thought that artificial intelligence, which is considered a branch of engineering, will one day reach a very advanced level of intelligence beyond predictions with speed, capacity, and software developments, and will be a decision support mechanism needed in almost every field [1].

Decision making is a rational implementation process where decision makers (DMs) are faced with operational decisions and choose among various options to achieve certain goals or address the interests of stakeholders [2]. A decision-making methodology that emerged in the fields of operations research and applied mathematics and has found widespread use in the field of computer and artificial intelligence in recent years is Multi-Criteria Decision Making (MCDM). MCDM is a systematic approach that has hundreds of types in different approaches where multiple criteria and alternatives are taken into account, processes crisp, fuzzy or probability data, and can simultaneously solve complex problems such as data transformation, weighting, and basic calculation equations [3-4]. An important advantage of MCDM methods is that they can simultaneously address benefit-oriented and cost-oriented criteria with different weight coefficients. Thus, the decision maker will have the ability to easily choose the most appropriate one among the alternatives. In this context, MCDM is not only an academic tool but also an indispensable method of decision-making practices.

It is clear that MCDM methods, which can normally be applied with difficulty for each problem separately in human execution, can be used to solve hundreds of problems simultaneously thanks to the autonomous and powerful processing power ability of artificial intelligence. In this sense, MCDM-AI integration can be a vital solution support or assistant. The integration of AI and MCDM methods is a hybrid approach that will be increasingly used to overcome complex problems in modern decision-making processes. The combination of powerful data processing capabilities of AI and systematic analysis and evaluation skills of MCDM provides fast, consistent and optimized solutions to multi-dimensional and dynamic problems. This integration, which was founded in the 1990s, has gained momentum with the developments in computer-based algorithms, programming, software and especially artificial intelligence and machine learning in recent years.

However, the lack of comprehensive bibliometric analyses in the literature regarding the emphasis on the AI-MCDM title is very striking. Bibliometric studies provide guidance for researchers by using quantitative methods to understand the development of scientific literature and research trends. These analyses help discover new research areas by encouraging interdisciplinary collaborations. They also support policy makers and research institutions in making strategic decisions in resource allocation. Analysis of trends in research outputs stimulates scientific innovation by providing information on innovative technologies and fields. Finally, it increases the impact of research and strengthens academic networks by mapping international collaborations [5-9].

This study aims to analyze the scientific production at the intersection of AI and MCDM, and to reveal the historical development, basic trends, and future research opportunities of this integration. Within the scope of the study, articles published from 1992 to 2024 were collected from the Web of Science (WoS) database and examined with bibliometric analysis methods. Using performance analysis and science mapping techniques, this study identifies important authors, journals, institutions, and countries in the literature; while also revealing the basic dynamics of the field with co-citation, keyword co-occurrence, and co-authorship analyses.

In this context, the study aims to both fill the knowledge gap in the literature and provide an awareness for understanding the current and potential effects of AI-MCDM integration on decision-making processes and valuable insights in the background.

2. METHODOLOGY

2.1. Aim

This study aims to offer a comprehensive analysis of the integrated application of MCDM and AI by exploring publication trends, author patterns, institutional contributions, and citation dynamics through bibliometric techniques. While numerous studies have examined MCDM and AI individually in recent years, research that combines these two fields remains relatively scarce in the existing literature. The fusion of MCDM and AI methods provides significant advantages in contemporary decision-making processes, particularly for addressing complex problems involving the interplay of multiple factors. This synergy not only enhances the efficiency of decision-making but also yields more accurate, optimized, and reliable outcomes. In this regard, the study seeks to illuminate the overarching trends in the joint application of these fields, as revealed through bibliometric analysis.

2.2. Method

In this study, bibliometric analysis was employed to provide an overview of the MCDM-AI field. Bibliometric analyses conducted to identify key topics and trends in a research field provide valuable insights for shaping future research directions and addressing existing gaps [10]. Bibliometric analysis combines two key approaches: science mapping analysis and performance analysis [11]. Performance analysis assesses the contributions of

research entities, science mapping aims to explore the relationships among these entities [12]. Science mapping, also known as bibliometric mapping, provides a visual representation of the connections between fields, specialties, disciplines, and individual works or authors [13]. In this regard, this study utilizes bibliometric analysis to present key authors, leading journals, organizations, and countries related to this field. Additionally, through science mapping, co-citation, co-occurrence of keywords analysis, and co-authorship analysis are provided.

2.3. Analysis Technique

Various software programs, such as VOSviewer [14], BibExcel [15], CitNetExplorer [16], SciMAT [17], RStudio Bibliometrix (Bibliometrix), and CiteSpace [18] are used to perform bibliometric analysis. In this study, the relationships between terms and the visualization of bibliometric networks were analyzed using the VOSviewer 1.6.16 software [14]. VOSviewer, with its detailed visual representations of the literature, facilitates a deeper exploration of research trends related to material selection [19].

2.4. Data Collection

In this study, the WOS database was used to gather the necessary data. WOS is among the most commonly utilized databases in the field of scientometrics [20]. Several procedures were followed to collect the data from WOS. Initially, keywords related to MCDM and AI topics were created, and a search was conducted in the topic section, yielding 1248 studies. To enhance the quality of the study and considering the role of high-quality journals in academic development [21], only journals indexed in SSCI (211), SCIE (863), and ESCI (147) were included. Given that English is the dominant language of publication (99%), only English-language articles were considered in this study (N=1245). No time constraints were imposed on data collection. Only articles were included in the analysis (N=993). The data was collected on 14/12/2024. After applying the filtering process, 993 articles were included in the analysis. The list of terms used for the query and the methodology are presented in Figure 1.

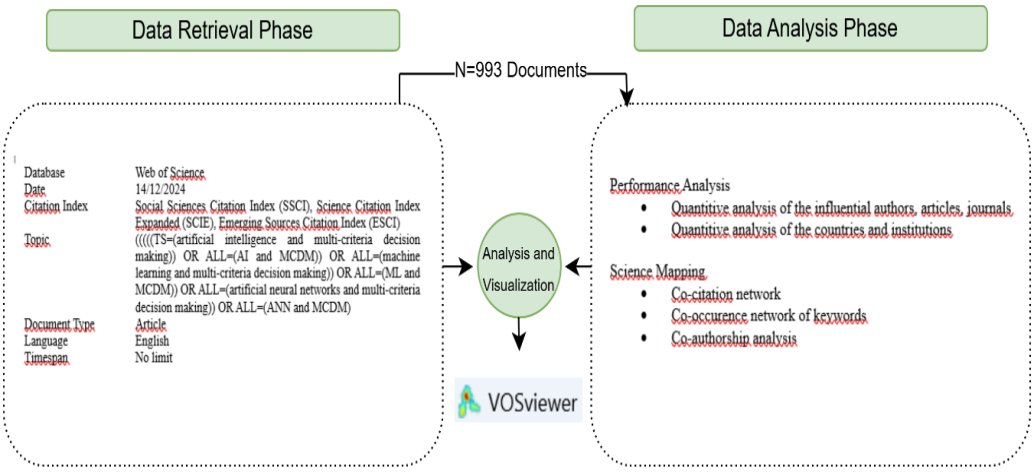

Figure 1. Research methodology

3. APPLICATION

3.1. Performance Analysis

In this section, a performance analysis has been conducted to present an overview of the studies in the MCDM-AI field, key authors, leading journals, organizations, and countries.

3.1.1. Publication trend

The trend of total publications and citations over time in the MCDM-AI field is shown in Figure 2.

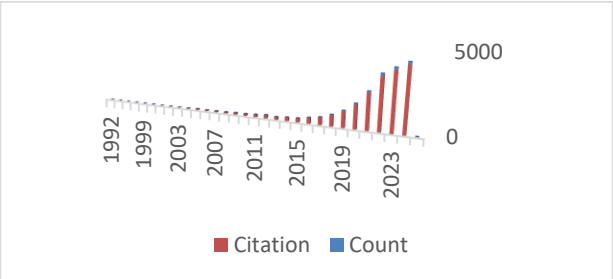

Figure 2. Number of publications and citations over time

According to Figure 2, the first publication in this field appeared in 1992. The study titled "Integrating Case-Based Reasoning In Multicriteria Decision Support Systems" was published by [22]. Another key study, titled "Feedforward Artificial Neural Networks For Solving Discrete Multiple Criteria Decision-Making Problems," was published by [23]. It can be observed that the number of MCDM-AI studies has gradually increased over the years. A noticeable upward trend emerged particularly

from 2018 onwards, with a peak in the number of publications observed in 2024. On the other hand, the total number of citations (excluding self-citations) for the 993 studies reviewed is 19.286, with an h-index of 66. Until 2012, the citation count was relatively low (N=227), but a sharp increase in citations started in 2018 (N=717), reaching its highest point in 2024 (N=4178).

3.1.2. Leading countries and institutions

An analysis was conducted to evaluate the contributions of prominent countries and institutions to the MCDM-AI field. In the initial phase, the contributions of various countries were examined, identifying a total of 93 countries involved in this domain. The publication counts of the top 10 contributing countries are presented in Table 1.

Table 1. The top 10 productive countries

Countries	N	%
India	222	21.83
Peoples R Chına	183	17.99
Iran	133	13.08
USA	116	11.41
Saudi Arabia	72	7.08
Taiwan	69	6.78
Australia	60	5.90
England	58	5.70
Turkiye	53	5.21
Malaysia	51	5.01

The analysis reveals that India ranks first with 222 publications, followed by People's Republic of China in second place with 183 publications, and Iran in third with 133 publications. Other notable countries in terms of publication count include the USA (n = 116), Saudi Arabia (n = 72), Taiwan (n = 69), Australia (n = 60), England (n = 58), Turkey (n = 53), and Malaysia (n = 51). Figure 3 presents the top 10 most productive institutions among the 200 organizations in the relevant field. The Indian Institute of Technology System (IIT) ranks first with 36 publications and 411 citations. In second place is the National Institute of Technology (NIT) System, with 34 publications and 672 citations, followed by the University of Tehran, also with 34 publications, but 604 citations, securing the third position. Additionally, 178 universities have published fewer than 10 articles.

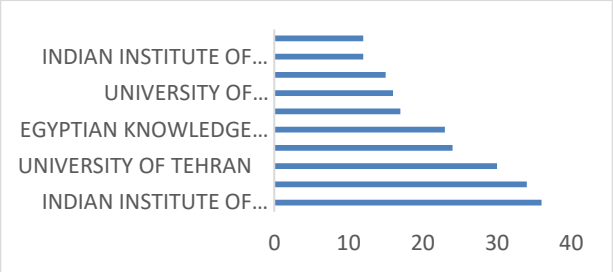

Figure 3. The most productive institutions

3.1.3. Leading authors, articles, and journals

This section provides an overview of studies on the topic of MCDM-AI, the authors responsible for these works, and the journals in which they were published. Between 1992 and 2024, a total of 200 authors contributed to 664 publications. Notably, only 7 authors (3.5%) produced 10 or more publications. Table 2 lists the top 10 researchers in this field.

Table 2. The top authors and their publication details

Rank	Author	Country/Institution	PYS	TP	TC	h-index	C/P
1	Pradhan, Biswajeet	Australia / University of Technology Sydney	2000	678	41817	112	61.68
2	Pamucar, Dragan	Serbia/ University of Belgrade	1991	486	12261	58	25.23
3	Wang, Chia-Nan	Taiwan/National Kaohsiung University of Science and Technology	2002	258	2464	28	9.55
4	Zaidan, A. A.	Australia / P Jain School of Global Management	2009	226	5888	57	26.05
5	Albahri, A.S.	Iraq/ Imam Ja'afar Al-Sadiq University	2018	142	3288	44	23.15
6	Albahrey, Osamah Shihab	Malaysia/ Universiti Pendidikan Sultan Idris	2018	122	3332	47	27.31
7	alamoodi, abdullah	Malaysia/ Universiti Tenaga Nasional	2019	96	2306	30	24.02
8	Dang, Thanh-Tuan	Taiwan/National Kaohsiung University of Science and Technology	2019	51	792	18	15.53
9	Nguyen, Ngoc-Ai-Thy	Taiwan/National Kaohsiung University of Science and Technology	2020	23	572	14	24.87
10	Maghsoodi, Abtin Ijadi	New Zealand /The University of Auckland	2018	21	457	14	21.76

Note: PYS (Publication Year Start), TP (Number of Publication), TC (Tocal Citations without self citation), C/P = citations per paper (TC/TP).

The rankings in Table 2 are based on the number of publications. According to this, Pradhan, Biswajeet is the most prolific author with 678 publications, followed by Pamucar, Dragan with 486 publications, and Wang, Chia-Nan with 258 publications, securing the third position. In terms of citation count, the top three authors are Pradhan, Biswajeet (n=41.817), Pamucar, Dragan (n=12.261), and Zaidan, A. A. (n=5.888). When evaluating the h-index, Pradhan, Biswajeet (n=112) ranks first, followed by Pamucar, Dragan (n=58) in second place, and Zaidan, A. A. (n=57) in third.

The top 10 most highly cited and influential papers in the field of MCDM-AI are presented in Table 3. The ranking is based on the number of citations. The most cited paper is "Pymoo: Multi-Objective Optimization in Python," published by [24]. The second most cited paper, with 424 citations, is "A comparative assessment of flood susceptibility modeling using Multi-Criteria Decision-Making Analysis and Machine Learning Methods," authored by [25]. These papers were published in the IEEE Access and the Journal of Hydrology, respectively.

Table 3. The top 10 most cited publications

Rank	Title	First Author	Year	Source	TC
1	"Pymoo: Multi-Objective Optimization in Python"	Blank [24]	2020	IEEE Access	872
2	"A comparative assessment of flood susceptibility modeling using Multi-Criteria Decision-Making Analysis and Machine Learning Methods"	Khosravi [25]	2019	Journal of Hydrology	424
3	"A GIS-based flood susceptibility assessment and its mapping in Iran: a comparison between frequency ratio and weights-of-evidence bivariate statistical models with multi-criteria decision-making technique"	Khosravi [26]	2016	Natural Hazards	325
4	"Flash-Flood Susceptibility Assessment Using Multi-Criteria Decision Making and Machine Learning Supported by Remote Sensing and GIS Techniques"	Costache [27]	2020	Remote Sensing	163
5	"GIS-based landslide susceptibility modeling: A comparison between fuzzy multi-criteria and machine learning algorithms"	Ali [28]	2021	Geoscience Frontiers	130
6	"Benchmarking Methodology for Selection of Optimal COVID-19 Diagnostic Model Based on Entropy and TOPSIS Methods""	Mohammed [29]	2020	IEEE Access	113
7	"Building supply-chain resilience: an artificial intelligence-based technique and decision-making framework"	Belhadi [30]	2021	International Journal of Production Research	108
8	"Accurate multi-criteria decision making methodology for recommending machine learning algorithm"	Ali [31]	2017	Expert Systems with Application	103
9	"Landslide susceptibility assessment at the Wuning area, China: a comparison between multi-criteria decision making, bivariate statistical and machine learning methods"	Hong [32]	2019	Natural Hazards	89
10	"A comparison among fuzzy multi-criteria decision making, bivariate, multivariate and machine learning models in landslide susceptibility mapping"	Pham [33]	2012	Geomatıcs Natural Hazards & Risk	85

The leading 10 journals in the field of MCDM-AI are ranked by publication count in Figure 4. According to this ranking, *Annals of Operations Research* (n=101) holds the first position, followed by *International Journal of Machine Learning and Cybernetics* (n=32), *IEEE Access* (n=29), and *Expert Systems with Applications* (n=24). Furthermore, 94.5% of the journals have published 10 or fewer articles. The analysis reveals that these top 10 journals account for 36.67% of the total publications during the study period. The contribution of *Annals of Operations Research* to the field is particularly notable.

Figure 4. Top 10 most leading journals

3.2. Science Mapping

Bibliometric methods can be utilized at the levels of titles, keyword lists, publication abstracts, and even entire citation records to analyze trends related to specific topics and topic categories [14]. This section will present the science mapping analysis, including the results of co-occurrence of keywords analysis, co-citation analysis, and co-authorship analysis.

3.2.1. Top keywords for MCDM-AI field

This analysis was performed to identify the most frequently used keywords in studies within the MCDM-AI field. A total of 3.416 indexed keywords were found across 993 documents, as provided by VOSviewer. A threshold of 5 occurrences was applied, with 111 keywords meeting this criterion (Figure 5). The analysis resulted in 11 distinct clusters, which are depicted in similar colors. The node size represents the frequency of the keywords, while the proximity of the nodes within each cluster indicates the frequency of their co-occurrence.

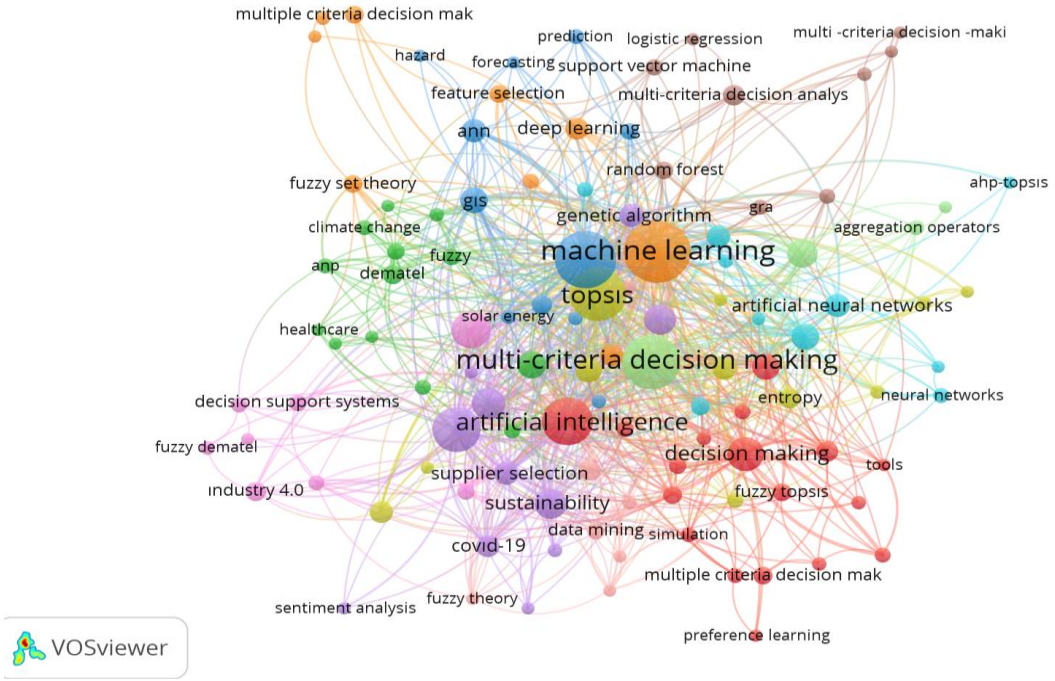

Figure 5. Keyword cloud

VOSviewer has organized the 111 keywords into 11 distinct clusters. Cluster 1, indicated in red (18 items), includes keywords such as AI, artificial intelligence, decision making, fuzzy AHP, fuzzy TOPSIS, and simulation. Cluster 2, indicated in green (13 items), contains terms like analytic hierarchy process, ANP, DEMATEL, fuzzy, neural network, and sensitivity analysis. Cluster 3, indicated in blue (11 items), features keywords such as ANN, data envelopment analysis, MCDM, hazard, PROMETHEE, and prediction. Cluster 4, also indicated in green (11 items), highlights terms like "CoCoSo", "CRITIC", "entropy", "machine learning" (ML), "multi-criteria decision making", "multi-criteria decision-making", "supply chain management", and "TOPSIS". Similarly, Cluster 5 (11 items), Cluster 6 (10 items), Cluster 7 (9 items), Cluster 8 (9 items), Cluster 9 (8 items), Cluster 10 (7 items), and Cluster 11 (4 items) form a total of 11 clusters. The top 10 most frequently used keywords have been ranked according to their total connection strength (Table 4).

Table 4. Top 10 keywords

Keywords	Occurences	Total Link Strengths	Cluster membership
Machine learning	124	184	7
topsis	89	184	4
mcdm	104	182	3
Multi-criteria decision making	95	122	4
Artificial intelligence	73	111	1
Multi-criteria decision-making	65	111	4
Decision making	36	75	1
Ahp	31	67	5
Artificial neural network	42	65	6
sustainability	30	52	5
Fuzzy logic	21	49	6

Machine learning and topsis have the highest value, with a total connection strength of 184 and 124 and 89 co-occurrences, respectively. Other nodes with high total link strengths include mcdm (n=182), Multi-criteria decision making (n=122), Artificial intelligence (n=111), Multi-criteria decision-making (n=111).

3.2.2. Co-citation analysis

Co-citation analysis is used to examine the relationships between authors, topics, journals, and keywords [34]. This section provides the co-citation analysis in two stages: author and journal co-citation analysis.

3.2.2.1. Co-citation of authors and journals

Author co-citation analysis involves mapping the prominent and influential authors in the field within a network. In this study, a citation threshold of 20 was set as the minimum, and only authors with a minimum of 20 citations were included in the analysis. Out of a total of 34.376 citations, 166 authors surpassed this threshold, and the density visualization of these 166 authors is shown in Figure 6.

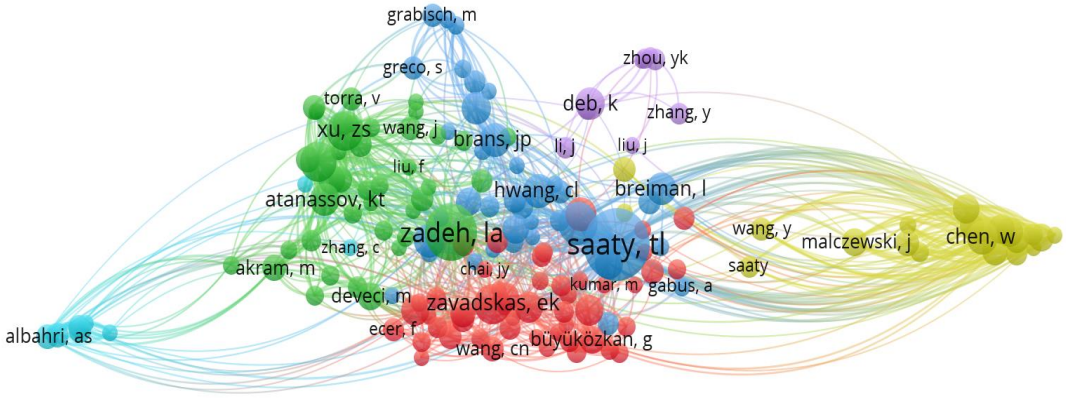

Figure 6. Author co-citation network

Based on this analysis, the author co-citation network is divided into six clusters: Cluster 1 (49 items), Cluster 2 (41 items), Cluster 3 (38 items), Cluster 4 (21 items), Cluster 5 (9 items), and Cluster 6 (8 items). Authors who are frequently co-cited are grouped together in the same cluster. The largest clusters are labeled in red (Cluster 1), while the most-cited authors are identified in black. Table 5 lists the top authors with the highest citation counts associated with the themes of the research clusters. Saaty, T.L., a member of Cluster #3, has the highest citation count (n=366). Zadeh, L.A. (n=232), and Opricovic, S. (n=128), from Clusters #2 and #3, are ranked second and third, respectively. Xu, Z.S. (n=116) and Yager, R.R. (n=116), members of Cluster #2, are tied for fourth place in citation count.

Table 5. Most cited authors

Author	Number of citations	Total link strength	Cluster membership
Saaty, tl	366	3110	3
Zadeh, la	232	2387	2
Opricovic, s	128	1381	3
Xu, zs	116	1795	2
Yager, rr	116	1668	2

A journal co-citation occurs when two articles from different journals are cited together in a third publication [34]. The threshold was established at 20, and among 16,418 journals, 402 surpassed this limit. Figure 7 illustrates the co-citation of journals in the field of MCDM-AI.

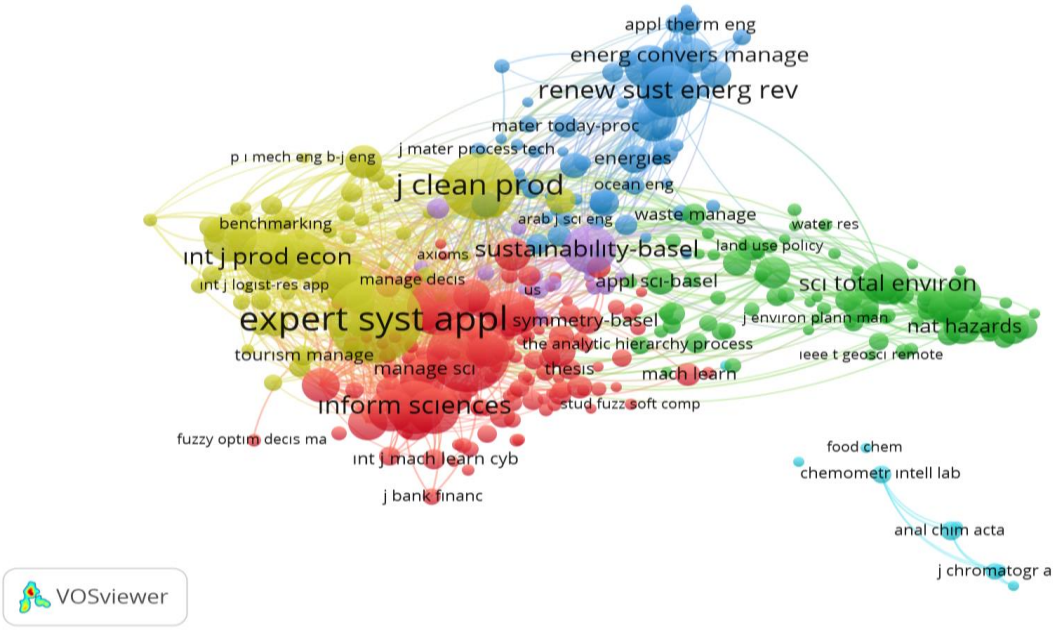

Figure 7. Journal co-citation network

This map clearly demonstrates the division into six clusters, each represented by a different color. The three largest circles on this color-coded map correspond to "*Expert Systems with Applications"*, "*European Journal of Operational Research* (EUR J Open Res)", and "*Journal of Cleaner Production"* (J Clean Prod), indicating that these journals have the highest citation counts and the largest networks.

In Cluster 4, "*Expert Systems with Applications"* is connected to 395 other journals, including "*Applied Mathematical Modelling"*, "*International Journal of Information Management"*, and "*Annals of Operations Research"*. In Cluster 1, "*EUR J Open Res"* ranks second with a total of 398 connections, with journals such as "*Soft Computing"*, "*Information Control"*, "*IEEE Access"*, and "*Information Sciences"* among its connections. Lastly, "*J Clean Prod"*, located in Cluster 4, has a connection strength of 393 and is linked to journals like "*Sustainable Production" and "Consumption*, *Journal of Manufacturing Systems"*, "*Transportation Research E-Logistics"*, and "*Production and Operations Research"*.

3.2.3. Co-authorship analysis

Co-authorship analysis explores the relationships and collaborations between researchers [12]. The analysis was conducted to identify which researchers, countries, and institutions are collaborating with each other.

3.2.3.1. Co-authorship networks for authors, countries and instutions

During the analysis period, among the 3.379 authors working on MCDM-AI topics, the minimum publication threshold was set to 2, and the minimum citation count required for an author was set at 30. A total of 182 authors exceeded these thresholds (Figure 8).

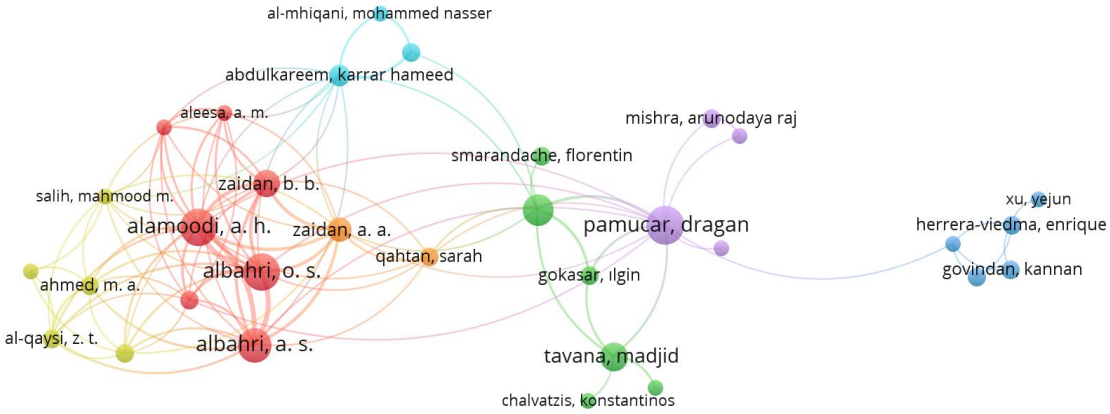

Figure 8. Author co-authorship network

The authors addressing the topic of MCDM-AI are grouped into seven clusters based on the author co-authorship network map. Figure 8 illustrates these clusters, where nodes are connected when collaborative work occurs. Each cluster consists of at least two authors. In the above network map, Alamoodi, AH (citations: 167, documents: 11, total link strength: 47), Albahri, OS (citations: 167, documents: 11, total link strength: 47),

and Albahri, AS (citations: 134, documents: 10, total link strength: 42) exhibit stronger connection strengths compared to other authors. The higher connection strength is further confirmed by their placement within the red circles. The density map indicates that the blue, green, yellow, and red colors represent no density, low density, moderate density, and high density, respectively.

Among the 97 countries contributing to the field of MCDM-AI, 78 nations have published a minimum of two papers, while 62 countries have published at least five papers. The analysis was conducted based on countries with a minimum of five publications. Figure 9 presents the country co-authorship network within the field of MCDM-AI.

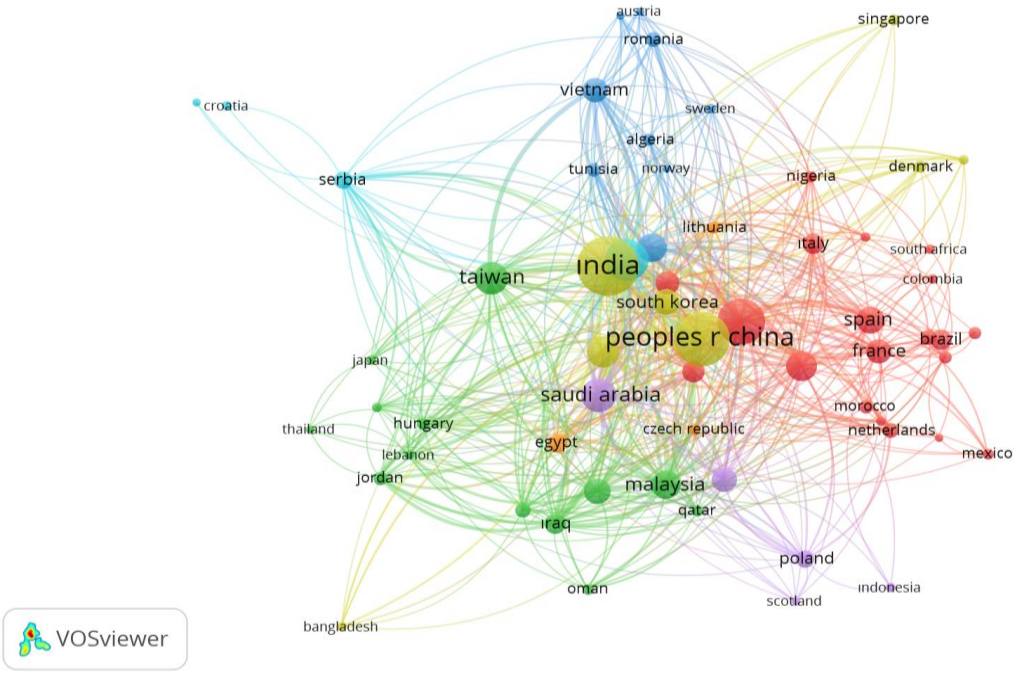

Figure 9. Country co-authorship network

The network is composed of seven clusters. India, with 222 documents, 52 connections, and a total connection strength of 221, along with the People's Republic of China, which has 183 documents, 40 connections, and a total connection strength of 206, and Iran, with 133 documents, 44 connections, and a total connection strength of 198, are the top three countries demonstrating the highest level of collaboration.

An analysis was conducted to explore the collaborative efforts of institutions within the MCDM-AI field. Among 1.582 research institutions, 87 have published at least five papers. The analysis identified 12 clusters (Figure 10). The University of Technology Sydney, with 16 documents, 807 citations, 15 links, and a total connection strength of 38, ranks first. King Abdulaziz University follows in second place with 17 documents, 246 citations, 27 links, and a total connection strength of 36.

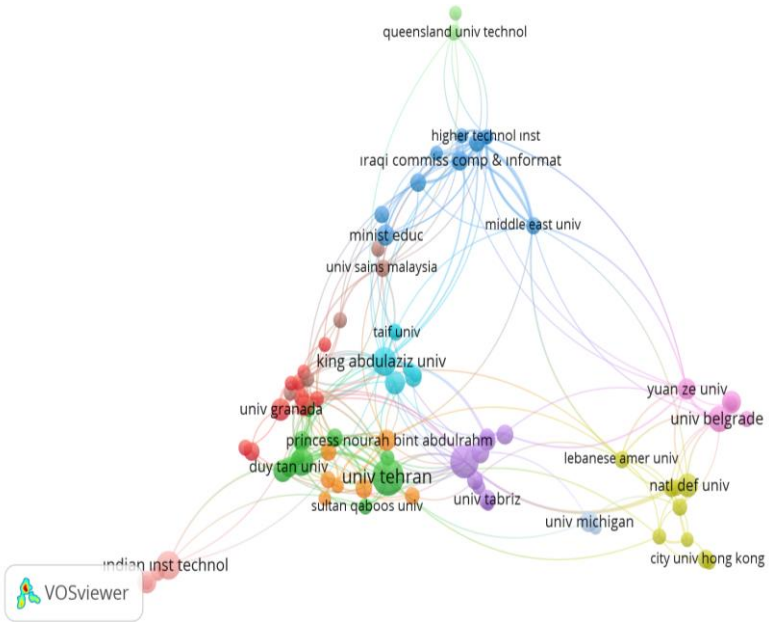

Figure 10. Institutes' co-authorship network

4. RESULT AND DISCUSSION

AI refers to the application of computers to model cognitive behavior with minimal human intervention, and it is generally considered to have originated with the invention of robots [1]. AI is a rapidly advancing technological field that is demonstrating its impact across various aspects of life. Since 2010, a number of AI technologies have emerged, driven by innovative advancements in computer hardware and internet Technologies [35]. These AI technologies have been incorporated into diverse fields such as communication [36], health [37], sustainability [38], etc. In recent years, another important area where artificial intelligence has been integrated is MCDM. MCDM evaluates various qualitative and quantitative criteria that need to be considered in order to find the most optimal solution [39]. The increasing complexity of problems has enhanced the importance of these methods. On the other hand, the integration of MCDM and AI is considered significant for managing complex decision-making processes more effectively and efficiently. In recent years, it has become possible to access numerous studies where these two fields are used in an integrated manner [2, 40-44]. The integration of MCDM and artificial intelligence enables the rapid and accurate analysis of complex data, thereby providing a more solid foundation for the decision-making process. Furthermore, this integration allows for the optimization of the balance among complex criteria, enhancing the consistency of the decision-making process.

This study presents a bibliometric analysis of the MCDM-AI integration, aiming to provide insights into key trends, developments, and opportunities in the research activities at the intersection of these two fields. The methodology of the research consists of two main stages: performance analysis and science mapping. In the performance analysis section, key authors, leading journals, organizations, and countries related to this field are presented. Through science mapping, co-citation analysis, co-occurrence of keywords analysis, and co-authorship analysis are provided. According to the performance analysis results, the quantity of publications and citations in the MCDM-AI field has seen a significant increase, particularly since 2018, reaching its peak in 2024. India has been identified as the leading country in this field, with the “Indian Institute of Technology System” (IIT System) ranking first for the highest number of publications. Furthermore, it was found that most of the universities in the top 10 are based in Saudi Arabia and India. The most influential author in this field has been identified as Pradhan, Biswajeet. The articles titled "Pymoo: Multi-Objective Optimization in Python" and "A Comparative Assessment of Flood Susceptibility Modeling Using Multi-Criteria Decision-Making Analysis and Machine Learning Methods" were found to have a high impact. Additionally, the most influential journal in this field is *Annals of Operations Research*, which accounts for 36% of the total publications in the top 10 journals. According to the science mapping analysis results, frequently used terms in both integrated areas include "Machine Learning," "TOPSIS," and "MCDM." Co-citation analysis results show that Saaty, TL holds the highest connection strength among authors. *Expert Systems with Applications* is the journal with the highest connection strength. According to the co-authorship analysis, Alamoodi, AH, Albahri, OS, and Albahri, AS exhibit stronger connection strengths compared to other authors. Similar to the performance analysis results, the leading three countries in the MCDM-AI field are India, the People's Republic of China, and Iran. In terms of institutional collaborative efforts, the University of Technology Sydney and King Abdulaziz University rank at the top with the highest connection strength.

In the literature, although there have been a significant number of recent studies on the applications of artificial intelligence (AI) in the MCDM field, only one study has been identified that presents the general trends of integration between the two areas. In the study conducted by Düzen et al. [45], a bibliometric analysis of the combined use of machine learning and MCDM was performed. It has been determined that some key findings obtained through performance analysis and science mapping analysis are consistent with the results of the aforementioned study. Our study covers the literature from a wider period without any time limitation (1992-2024). It is the pioneer study to perform bibliometric analysis for AI-MCDM methods in terms of title emphasis. Moreover, our study shows that it contributes to the field from different perspectives in terms of the most influential author, institutional contribution, leading country, distribution in literature, and general, theoretical, and methodological terms. These findings show that the study is a road map in the literature.

5. CONCLUSION

This study evaluated the integration of MCDM and AI with bibliometric analysis, revealing important trends, developments and opportunities in the combined use of these two fields. The study showed that this integration has increased rapidly, especially since 2018, and reached its peak in 2024. India, China and Iran stand out as the leading countries in this field, while the Indian Institute of Technology (IIT) provided the highest publication contribution.

It was determined that keywords such as "Machine Learning," "TOPSIS," and "MCDM" with performance analysis and science mapping methods are strong connection points in the integrated use of this field. Pradhan, Biswajeet in particular were identified as the leading authors in this field, and Annals of Operations Research and Expert Systems with Applications were the most widely cited journals. In addition, University of Technology Sydney and King Abdulaziz University were at the forefront of institutional collaboration.

These findings prove that the combined applications of MCDM and AI provide more solid foundations for decision-making processes by analyzing complex data sets quickly and accurately. This integration not only increases the effectiveness of decision-making processes, but also provides an important roadmap for shaping the

future directions of the literature in this field. The research covers a wider period (1992-2024) in the literature and is a pioneering study in this field, especially at some points. Moreover, it constitutes a roadmap for the future applications of these methods.

In this context, the study has made significant contributions to both theoretical and applied literature in the integration of MCDM and AI and has established a basis for future research.

5.1. Limitations of Study and Future Research

The limitations of this study can be expressed as follows. The use of data obtained from only one database (WOS) may have limited the scope of the research. Additionally, the study focused solely on journal articles, excluding conference proceedings, book chapters, or other types of academic publications. Furthermore, it should be noted that the dataset and sample would vary depending on the selected keywords. Moreover, since the analysis only includes studies published up to a certain date, significant research conducted after the publication of this study could not be included in the analysis. Future research could allow for a more comprehensive analysis by expanding beyond the Web of Science database. Additionally, multidisciplinary approaches integrating methods from different disciplines, alongside MCDM and AI, could be explored.

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