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Research Article

Supplier Selection Using Fuzzy Analytical Hierarchy Process: A Bibliometric Analysis

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Abstract

The success of the supply chain is significantly dependent on the increasing selection of suppliers. Therefore, organizations must establish assessment criteria to expedite supplier selection. Various decision-making processes have been extensively employed, such as Multi-Criteria Decision Making (MCDM), a prominent method for selecting the best alternative. The criteria used to determine this alternative process was Fuzzy weight because it reduced subjective judgments of the weighted criteria set by the decision-maker. Therefore, this research aimed to present an orderly overview as a guide to earlier research on the Fuzzy Analytical Hierarchy Process (AHP) method in supplier selection, developed a categorization structure with important aspects and identified areas for further analysis. PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses), which combined quantitative and qualitative methods, was used to perform a comprehensive mapping analysis of supplier selection with Fuzzy AHP (FAHP). The quantitative analysis was conducted with the utilization of two software, namely Publish or Perish (PoP) and VOSviewer. The result showed a significant number of articles on supplier selection that consider environmental factors with sustainable development goals (SDGs). It also demonstrated that preliminary research focused on supplier selection methods with the use of mathematical methods. Therefore, future research streams included strategy-oriented supplier selection, and green and sustainable practices, which are still in the early stages of the cycle.

Keywords: Supplier Selection; MCDM; Fuzzy AHP; PRISMA; PoP and VOSviewer.

1. Introduction

The foundation of operational activity in every manufacturing organization is the supply chain, which facilitates competitive advantage (Kayapinar Kaya & Aycin, 2021). All changes in production tend to manifest along the supply chain. The working environment in the twenty-first century was characterized by globalization, rapid technical growth, and changes in response to customer demand. An increasing number of industries are making efforts to improve their respective reputation in global trade, aiming to produce high-quality goods and services that are practically connected to suppliers as raw materials providers.

Suppliers constitute the fundamental unit of the supply chain and are regarded as an essential aspect of this network. These individuals play an essential role in industry success, reacting to market rivalry, as well as enhancing customer satisfaction (Lotfi et al., n.d.). It is becoming more and more clear that choosing the right suppliers is essential to the supply chain's performance. The selection process is crucial for realizing industry success and competitiveness (Gernowo & Surarso, 2022). Therefore, choosing the ideal suppliers is an essential objective for businesses, and to move the selection process forward, a set of evaluation criteria is

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needed. These criteria must reflect industry strategy, the characteristics of the products or services, and be in line with the supply chain framework.

A variety of decision-making processes have been widely adopted in supplier selection. The Multi-Criteria Decision Making (MCDM), is a prominent method which addresses decision-making challenges by evaluating multiple criteria to choose the finest option. MCDM is a mathematical method used to make decisions in complex circumstances by analyzing and rating many options and competing criteria (Gernowo & Surarso, 2022). This method entailed weighing several criteria simultaneously when assessing and selecting among different alternatives. Decision-makers tend to benefit from the application of MCDM, when faced with complex issues including numerous objectives, criteria, and constraints. This method frequently incorporates mathematical models, optimization methods, and occasional subjective assessments. MCDM is regularly used in the following disciplines, engineering, management, economics, environmental science, and public policy. Over the past few decades, MCDM has been integrated with various methods, to enhance its effectiveness and enable it to handle a wider range of scenarios.

A typical example (Yadav & Sharma, 2015) was the Analytical Hierarchy Process (AHP) method proposed by Saaty, (1980), which focused on weighting criteria. MCDM offered a comprehensive framework for making successful judgments in complex decision-making scenarios, such as supplier selection. Meanwhile, using AHP to make decisions entailed subjective judgments and qualitative assessments, which introduced uncertainty and ambiguity. A decisive value may not adequately capture this complexity, rather extending MCDM with Fuzzy logic had been a common practice since 1994 (Mardani et al., 2015). Fuzzy AHP (FAHP), a popular hybrid Fuzzy-MCDM method, provides more accurate and persuasive ranking outcomes.

Fuzzy AHP incorporated the concept of Fuzzy logic, enabling the representation of imprecise or uncertain information (Zadeh, 1988). The method effectively managed the inherent vagueness in human judgments using Fuzzy sets and comparison matrices. It also enabled decision-makers to communicate choices in a flexible and subtle way, leading to more resilient and reliable outcomes. Therefore, Fuzzy AHP enhanced the method by addressing the limitations associated with qualitative assessments, uncertainty, and ambiguity, thereby improving the accuracy and persuasiveness of decision rankings.

Fuzzy AHP method is an adaptation of the conventional AHP, integrating Fuzzy sets into the pairwise comparison matrix. This method was widely used in several publications related to supplier selection. For example, S. Deshmukh and Sunnapwar (2019) adopted Fuzzy AHP to identify the best green supplier. Widyatama et al., (2019) applied the method in designing supplier performance evaluation system. Fuzzy AHP is highly effective in evaluating supplier performance by offering Fuzzy weight values for recognized criteria, including reducing the personal judgments of decision-makers (Gernowo & Surarso, 2022). It is commonly used for weighing criteria and can be effortlessly combined with other supplier selection methods.

This research presented a comprehensive overview to serve as a guide to previous invesitgations on Fuzzy AHP method in supplier selection. A structured categorization framework, focusing on important aspects, including identifying areas for further investigation, was established. Furthermore, articles published based on several perspectives including the respective primary fields, such as business, science, engineering, or technology were examined.

The literature on the descriptors of Fuzzy AHP had been reviewed systematically in this research by using multiple academic databases. Following a structured analysis of the collected articles, a total of 97 articles published from 2013 were investigated. The following research questions, how does the combination of Fuzzy AHP methods in supplier selection impact supply chains?, which countries had conducted research on Fuzzy AHP?, and which authors had published the most relevant articles? were addressed.

The other part of the study was arranged as follows: Section 2 offered a synopsis of the structure and literature review, along with details of the methods adopted. In Section 3, the results and examination of the review were presented, following the objectives and queries. Finally, Section 4 concluded all discussion accompanied with an explanation of the limitations and recommendations for future research.

2. Research Method

2.1. Review Protocol

This research adopted both quantitative and also qualitative methods to conduct a broad mapping analysis of supplier selection using Fuzzy AHP. Quantitative analysis was conducted using two software tools, namely Publish or Perish (PoP) and VOSviewer. Meanwhile, the qualitative content analysis was carried out to establish research guidelines for forthcoming investigations by analyzing and examining the most recent keyword tendencies and subjects. The systematic mapping procedure is shown in Fig. 1, depicting the sequential phases carried out to finally identify major keywords used in the literature on the observed topic.

2.1. PRISMA Protocol

This present research followed PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) method for article selection (García-Holgado et al., 2020). Fig. 2 showed the search terms protocol, literature sources, research selection criteria, and methods. The search terms including those related to supplier selection AND (Fuzzy OR AHP) combined using Boolean operators AND and OR. The core research question and review method, along with

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document type was used to filter the data. (e.g., articles), source (e.g., journals), and also language (e.g., English).

The literature review discussed the aspects of choosing the supplier that answer the investigated questions. This review comprised research from thousands of articles published in scholarly journals between 2013 and 2023. The articles accessible online, were available on the Scopus database. However in order to ensure the standard of assessment while discovering the cited papers, only articles in international publications, written in English were considered.

The search was conducted twice, using two combined terms namely supplier selection, Fuzzy AHP and supplier selection, Fuzzy AHP respectively, to ensure a reproducible and unbiased article search process. PoP software was used to capture all articles that met the established qualifications. Articles were gathered from the Semantic Scholar database.

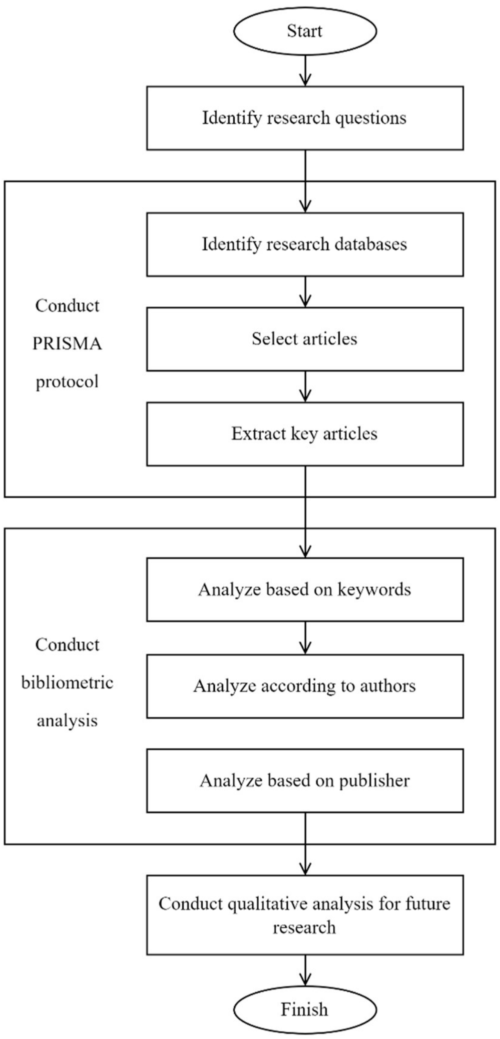

Fig. 1. Systematic mapping stages

Based on the restrictions capability of PoP, those two determined terms generate approximately 1,000 articles. Despite efforts to remove duplicated articles with the aid of Ms. Excel, there were over 1,000 articles remaining, posing challenges for thorough exploration. These exact 1,629 articles were then filtered. The first curation step reduced the selection to 1,079 articles by restricting the publication year to 2013-2023, ensuring novelty and relevance. Additionally, the titles and abstracts of the publications were examined, resulting in 57 pertinent articles. Although 8 of the articles were inaccessible, 49 others were left for further analysis. Fig. 2 shows the detailed framework of the articles search and collection method used in this research.

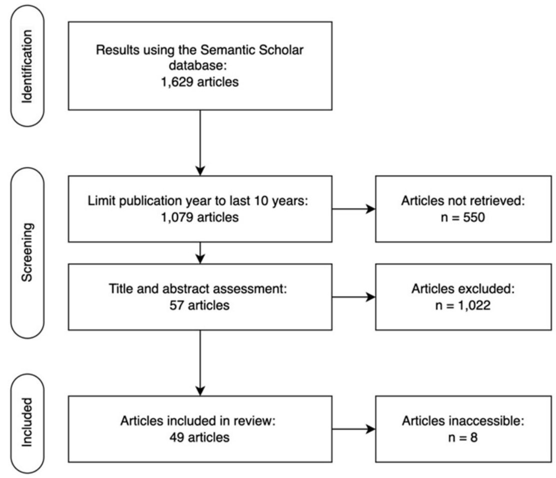

Fig. 2. The framework of article collection and extraction

VOSviewer software was used to evaluate the final set of 49 articles gathered. Based on bibliographic information, a map was generated using VOSviewer. The keyword co-occurrence criteria in the software were used with varying occurrence rates. This criteria assesses how frequently certain keywords or terms appear collectively in the articles. VOSviewer determined the co-occurrence and terms that showed up simultaneously were regarded as connected or associated. The 49 articles were then analyzed, leading to the identification of 128 keywords. Furthermore, to obtain maximum results, the thesaurus feature was adopted to eliminate or combine similar keywords, resulting in a more concise list of 97 keywords. The keywords were further refined by the limitation to those that appeared at least twice, thereby enhancing the visibility connection and increasing the level of importance. In the final filtration stages, 19 keywords were found, as shown in Table 1, sorted based on the connection strength in the last column.

Table 1

Keyword Occurrences and Total Link Strength

No.	Keyword	Occurrences	Total Link Strength
1	Fuzzy AHP	25	53
2	Supplier Selection	25	52
3	AHP	16	39
4	MCDM	14	36
5	SCM	7	17
6	Sensitivity Analysis	4	11
7	Supplier Evaluation	3	11

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8	Fuzzy Logic	4	10
9	Sustainable Supplier Selection	5	10
10	Fuzzy	4	9
11	Consistency	2	8
12	Fuzzy TOPSIS	3	7
13	Interval Type-2 Fuzzy Set	3	7
14	TOPSIS	3	6
15	Service	2	5
16	Global Supply Chain Management	2	5
17	Green Supplier Selection	2	5
18	GSCM	2	5
19	Industry 4.0	2	4

The sum of all weights of the links or connections allied to a specific keyword in the table is called Total Link Strength. This metric was commonly applied in network analysis, to comprehend the importance or centrality of nodes. VOSviewer calculated the Total Link Strength for each node or keyword by summing the weights of all associated connections. Nodes with higher Total Link Strength ratings were more central or influential in the network, as these are strongly connected to the others.

Table 1 shows that two keywords namely Fuzzy AHP and supplier selection, both had the highest strength and occurrences. The second strongest group comprised the following keywords AHP and MCDM with AHP being more frequently found in the articles. High Total Link Strength keywords can be indicative of significant ideas or themes frequently connected to the others. However, several keywords with the second weakest connection and occurrences, such as Service, Global Supply Chain Management, Green Supplier Selection, and GSCM, were identified, while Industry 4.0 was at the bottom of the list.

3. Results and Discussion

3.1. Keywords Analysis

The keywords were visualized in Figs. 3 and 4. Meanwhile, in Fig. 3 the density network depicts the top keywords, where the thickness and color intensity of each keyword area showed the repetition rate. Related topics were signified by the closeness of the collective keywords. Darker blue colors denote less repetition, while bright yellow depicts higher occurrence. The network analysis showed that supplier selection and AHP had the same occurrence rate as MCDM and Fuzzy AHP, suggesting equivalent research focus on these topics.

Fig. 4 shows the keyword co-occurrence network, used to discover terms appearing in two or more publications. It was also used to identify keywords co-occurring in two publications in each period, depiciting four clusters with various color schemes. In this network, each node represents a keyword, with the size inversely correlated to the frequency of the co-occurrence. Larger nodes implied more frequent co-occurrence of the keyword. In this case, the following keywords supplier selection, Fuzzy AHP, MCDM, and AHP appeared regularly, reflecting the quantitative results in Table 1. Moreover, the analysis identified a total of 19 keywords based on occurrences and total link strength with the least frequent occurrences found in keywords such as Service, Global Supply Chain Management, Green Supplier Selection, GSCM, and Industry 4.0.

In Fig. 4, the network showed closely related keywords to the main search focus of Fuzzy AHP, organized into four main clusters represented by different colors namely red, yellow, green, and blue. The red cluster focused on the connection among Fuzzy AHP, MCDM, Sustainable Supplier Selection and Fuzzy Logic, Global Supply Chain Management and Service, sorted according to the scale of the relationship showed by the size of the circle. The yellow cluster shows the close connection between Fuzzy AHP with SCM and Fuzzy TOPSIS. The green cluster connected Fuzzy AHP to Fuzzy, GSCM, Green Supplier Selection, Industry 4.0, and Interval Type-2 Fuzzy Set. Finally, the blue cluster represented the relationship between Fuzzy AHP and AHP, Supplier Evaluation, Consistency, Sensitivity Analysis, and TOPSIS.

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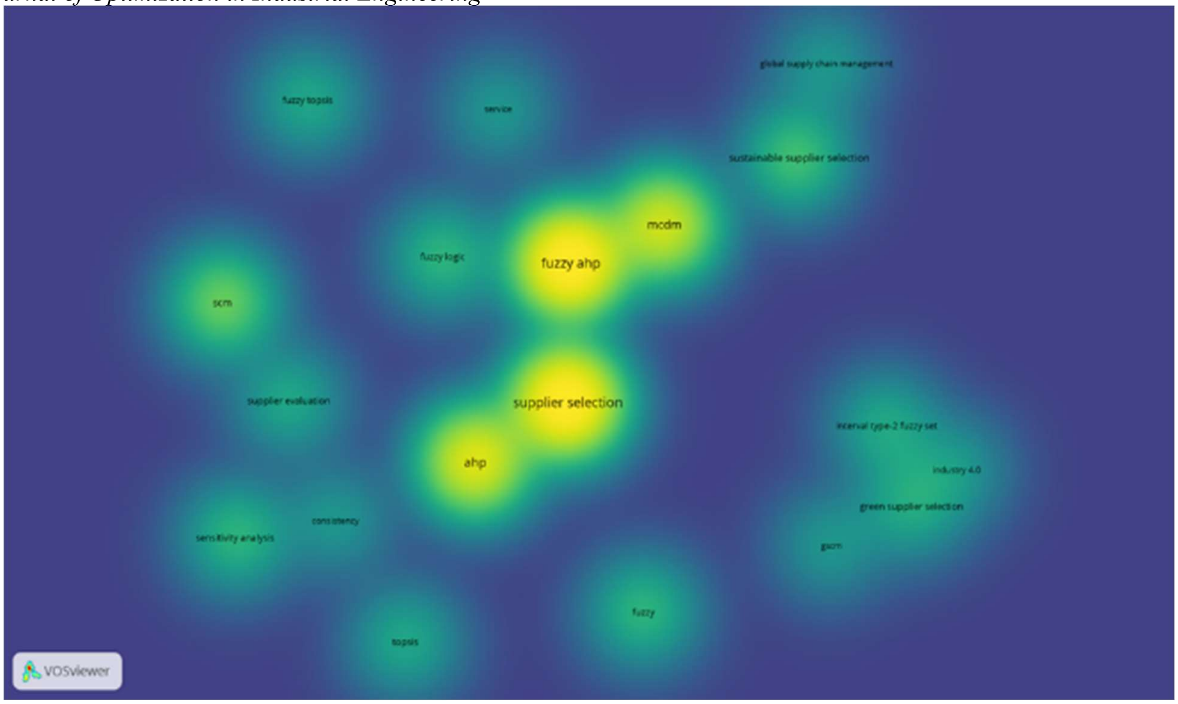

Fig. 3. The density network for the top keyword

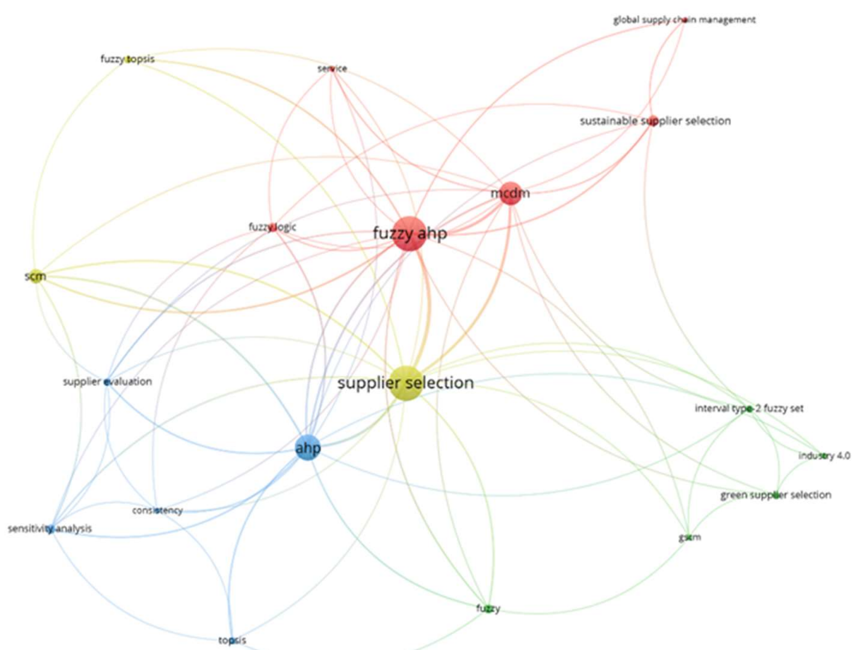

Fig. 4. Keyword co-occurrence network

This visual representation aids in identifying significant research areas for future investigations in supplier selection. The distance between keywords in the visualization was affected by the density, in which the higher the density, the closer the distance between the two vertices. Based on Fig. 4, the node representing Fuzzy AHP is close to these two Supplier Selection and MCDM. Additionally, a node of Fuzzy AHP is also connected with Fuzzy Logic, Fuzzy TOPSIS, and Interval Type-2 Fuzzy Sets. The combination of Fuzzy AHP with other supplier selection methods will be explained in more details in Table 4. The keyword Supplier Selection itself is connected to Service, Supplier Evaluation, Supply Chain Management, and Industry 4.0. The term MCDM is relevant for Sustainable Supplier Selection and Global Supply Chain Management. In addition, the the network associated with the term AHP closely resembles Fuzzy AHP for other keywords.

In Fig. 5, the overlay visualization showed a growing interest in the research on topics associated with these keywords, from 2016 to 2021. The nodes in yellow hue represent the most recent research conducted in 2021, while the nodes in darker colors, such as purple, blue,

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and green, depict earlier keywords discovered between 2016 and 2020. The research on Industry 4.0 specifically in the context of selecting green suppliers is still in the early stages. This showed multiple research gaps that needed to be addressed in the future.

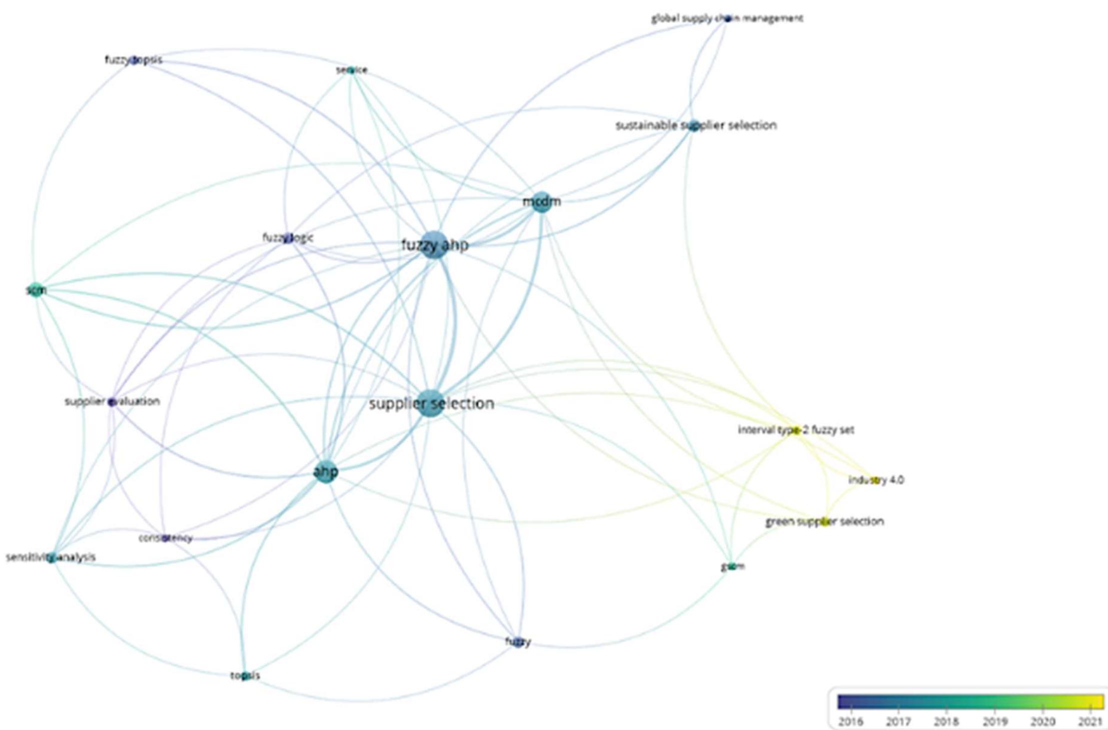

Fig. 4. Most cited keywords and year of publication

3.2. Analysis of Research Method

The combination of Fuzzy AHP with Fuzzy TOPSIS (FTOPSIS), and Fuzzy AHP with Goal Programming (GP) is the most popular method in supplier selection literature. The difference between Fuzzy AHP and FTOPSIS lies in the focus. Fuzzy AHP algorithm applications relied on pairwise comparisons, while FTOPSIS focused on the measured distance of alternatives from the ideal solution. In the case of combining Fuzzy AHP and GP, Fuzzy AHP was initially applied to obtain the weight of the criteria, followed by GP method to find the optimal order allocation solution for suppliers. There are several other combinations in supplier selection, and 38 others were shown in Table 4.

3.2.1. Problem Domain

In recent years, several literature reviews had been conducted on supplier selection and were discussed sequentially. First, Govindan et al. (2015) examined various publications between 1997 and 2011, specifically addressing green purchasing and supplier selection processes. It was reported that AHP was the most commonly used MCDM method for evaluating green suppliers. Furthermore, Fuzzy AHP was widely used in environmental management systems. Another research by Yildiz and Yayla (2015) examined 91 analyses on general supplier selection published from 2001 to 2014. The analyses showed that quality and cost are the most important elements in the case of supplier selection. Additionally, this research did not specifically focus on the selection of suppliers, considering sustainability or green aspects (Govindan et al., 2015).

In the following year, Wetzstein et al. (2016) examined some articles on supplier selection from the year of 1990 and 2015, in the subsequent year. Potential research areas related to green and sustainability issues were identified. The research clearly showed the prevalent use of mathematical methods. It was advocated that future research needed to include strategy-oriented supplier selection, as well as green and sustainable practices, which are still in the primary phases of growth. Another research by Karsak and Dursun (2016) analyzed 149 publications from 2001 to 2013, concentrating on non-deterministic investigative methods, such as stochastic/Fuzzy, in the occurrence of inaccurate data. The investigation focused on the relevance of supplier selection methods capable of considering imprecise and qualitative data, aiming to have a better consideration of the evaluation and selection procedure, while providing a hands-on reference for research and practitioners on the use of non-deterministic approaches and analysis.

In 2017, only one review paper focused on the problem of supplier selection. Simić et al. (2017) managed a full analysis of supplier selection and evaluated publications over the past 50 years, based on Fuzzy set principle, models, and hybridization.

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Furthermore, 54 publications from peer-reviewed journals were analyzed, evaluating Fuzzy supplier selection strategies by combining individual and integrated methods. Alkahtani and Kaid (2018) researched a selection of journal papers published between 1995 and 2018, centering on prevalent supplier selection trends, study gaps, and the selection criteria. This research provided valuable insights into the evolving supplier selection field. Ocampo et al. (2018) examined 240 peer-reviewed journals published between 2006 and 2016, exploring the use of various methods for supplier selection and review, involving single and mix methods. The research also stated the relevance of uncertainty, risk analysis, and sustainability variables in the unique supplier selection criteria. Meanwhile, between 2009 and 2020, Ograh et al. (2021) identified 41 research from 12 peer-reviewed journals, with 31 papers focusing on integrating green practices into supplier selection. The research provided insight on the strategies used to promote green incorporation while considering the different stages of supplier selection process.

Considering another literature review by Resende et al. (2021), 14 publications were analyzed to explore quantitative models assisting supplier selection in the Industry 4.0 era. Majority of the research in the review focused on models designed by integrating MCDM and artificial intelligence (AI) methods. Specifically, criteria closely associated Industry 4.0 such as knowledge sharing, capacity technology, cooperation, and digital involvement, were commonly identified. Therefore, the technological investigation concentrated on the significance of integrating MCDM and AI methods to develop decision-making support tools, particularly dashboards, in this modern era. The investigation also showed that 64% of research linked two or more methods in decision models, with Fuzzy logic often considered as a significant component. Specifically, the blend of Fuzzy logic with MCDM-AI method was the most regularly used, accounting for 50% of all applications.

Table 2

Problem domain and related references

Problem Domain	References
Literature review (LR) (11)	(Saputro et al., 2022), (Masudin et al., 2022), (Resende et al., 2021), (Ograh et al., 2021), (Ocampo et al., 2018), (Alkahtani & Kaid, 2018), (Simić et al., 2017), (Karsak & Dursun, 2016), (Wetzstein et al., 2016), (Yildiz & Yayla, 2015), (Govindan et al., 2015)
Deterministic optimization models (DO)	(Gernowo & Surarso, 2022), (Unal & Temur, 2022), (Fagundes, Hellingrath, et al., 2021), (Fagundes, Keler, et al., 2021), (Kayapinar Kaya & Aycin, 2021), (Ozkan & Aydin, 2020), (Agrawal & Kant, 2020), (Shafi Salimi & Edalatpanah, 2020), (Karabayir et al., 2020), (Ecer, 2022), (Tavana et al., 2021), (Çalık, 2021), (Widyatama et al., 2019), (Xu et al., 2019), (A. J. Deshmukh & Vasudevan, 2019), (S. Deshmukh & Sunnapwar, 2019), (Hu et al., 2020), (Manivel & Ranganathan, 2019), (Mondragon et al., 2019), (Zafar et al., 2019), (Awasthi et al., 2018), (Akbaş & Dalkilic, 2018), (Diouf & Kwak, 2018), (Kumar et al., 2018), (Sharawat & Dubey, 2018), (Secundo et al., 2017), (Özdemır, 2017), (Tooranloo & Iranpour, 2017), (Ajalli et al., 2017), (V. Jain et al., 2018), (V. Jain et al., 2018), (Pramanik et al., 2017), (Gold & Awasthi, 2015), (Mavi, 2015), (Yadav & Sharma, 2015), (Hamdan & Cheaitou, 2015), (Sivrikaya et al., 2015), (Sultana et al., 2015), (Rezaei et al., 2014), (Ishizaka, 2014), (Digalwar et al., 2014), (Junior et al., 2014), (Perić et al., 2013), (R. Jain et al., 2013), (Shaw et al., 2013), (Li et al., 2013), (Azadnia et al., 2013), (Ayhan, 2013)

Masudin et al. (2022) conducted an extensive review of 220 research journals on the issue of green procurement in supplier selection. The review comprised numerous journals published between 1994 and 2022. Similarly, Saputro et al. (2022) examined 326 journals issued between 2000 and 2001, exploring the leading scope of supplier selection, containing sourcing strategy, dimension of decision and ecosystem, selection criteria, and result method.

The analysis showed that 36.36% of all literature evaluations on supplier selection prioritized the green/sustainable process, while 63.63% discussed the same topic using various criteria and a combination of other methods. This showed that a few number of articles on supplier selection focused on environmental factors.

3.2.2. Deterministic and Optimization Models

This section discussed the deterministic optimization methods for supplier selection, using Fuzzy inference AHP method. Deterministic global optimization is a subfield of numerical optimization that focuses on finding a global solution with theoretical assurances of accuracy in a predefined tolerance. Articles with several citations were discussed, and a comprehensive Detail of other publications included in Table 2.

Ayhan (2013) examined how Fuzzy AHP method could be utilized to solve supplier selection challenges in gear motor industries. This research used AHP empowered with Fuzzy method. However, due to the nature of the problem being a single source type, complex model constructions were unnecessary, given that in such scenarios, one supplier may meet all the requirements of the buyer.

Rezaei et al. (2014) designed a novel two-phased funnel method for supplier selection, focusing on the suitability for airline retail industry. Sivrikaya et al. (2015) implemented a multi-criteria Fuzzy Analytic Hierarchical Process with Linear Programming (FAHP-LGP) model to evaluate the performance of apparel firms and distribute the purchase amount to the best-performing enterprises. Fuzzy AHP was used initially, to establish the weights of the criteria, followed by Goal Programming method to recognise the best solution for

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order allocation to providers. Galankashi, Helmi et al. (2016) exploited an integrated Balanced Scorecard-Fuzzy Analytic Hierarchical Process (BSC-FAHP) model to choose suppliers in the automotive industry. This innovative method modernized supplier selection process in the automobile sector, by combining various performance measurements to aid decision-makers.

Ajalli et al. (2017) adopted a hybrid method, combining Fuzzy AHP and COPRAS methods to balance and rank the criteria and options for supplier selection. The model identified the best suppliers and major criteria by considering elements significantly influencing supplier quality. This research combined Fuzzy AHP and COPRAS methods, using both for criterion weighting, and supplier rankings, resulting in negative and positive criteria. Diouf and Kwak (2018) recommended a novel structure for supplier selection and advance in the publishing and printing sectors. This framework incorporating Fuzzy set theory, AHP, DEA, and management evaluation, addressed subjectivity and ambiguity in expert assessments using Fuzzy AHP. It evaluated suppliers based on various factors and used DEA to assesses the relative efficiency. The managerial analysis provided valuable insights for decision-makers across diverse settings.

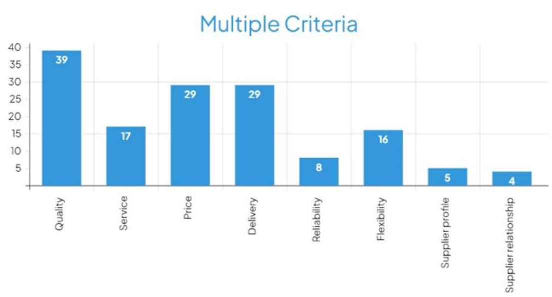

Fig. 5. System prototype architecture of FPV

Kayapinar Kaya and Aycin (2021) presented an actual case study to describe the practical application of the suggested framework. This model integrated the IT2F-AHP and COPRAS-G methods. Gernowo and Surarso (2022) introduced a web-based decision support system, employing Fuzzy AHP MOORA method to analyze system switch supplier selection. By conducting literature analysis, six supplier selection criteria were identified and subsequently selected by the decision-makers of industryy. The weight of each criterion was determied by the firm decision-makers, utilizing AHP pairwise comparisons. The deterministic optimization models for supplier selection, classified corresponding to numerous elements (sets) involving quality, service, price, delivery, flexibility, reliability, supplier profile, and relationship, are shown in Table 2.

Table 3

Problem field and associated references

Multiple Criteria	References
Quality (39)	(Gernowo & Surarso, 2022), (Unal & Temur, 2022), (Fagundes, Hellingrath, et al., 2021), (Kayapinar Kaya & Aycin, 2021), (Agrawal & Kant, 2020), (Ozkan & Aydin, 2020), (Karabayir et al., 2020), (Tavana et al., 2021), (Çalık, 2021), (Shafi Salimi & Edalatpanah, 2020), (A. J. Deshmukh & Vasudevan, 2019), (Manivel & Ranganathan, 2019), (Zafar et al., 2019), (S. Deshmukh & Sunnapwar, 2019), (Widyatama et al., 2019), (Awasthi et al., 2018), (Akbaş & Dalkilic, 2018), (Kumar et al., 2018), (Diouf & Kwak, 2018), (Secundo et al., 2017), (Tooranloo & Iranpour, 2017), (Ajalli et al., 2017), (V. Jain et al., 2018), (Pramanik et al., 2017), (Gold & Awasthi, 2015), (Yadav & Sharma, 2015), (Hamdan & Cheaitou, 2015), (Mavi, 2015), (Sultana et al., 2015), (Sivrikaya et al., 2015), (Rezaei et al., 2014), (Junior et al., 2014), (Digalwar et al., 2014), (Ishizaka, 2014), (Ayhan, 2013), (Li et al., 2013), (Shaw et al., 2013), (R. Jain et al., 2013), (Perić et al., 2013)
Service (17)	(Gernowo & Surarso, 2022), (Kayapinar Kaya & Aycin, 2021), (Çalık, 2021), (Ozkan & Aydin, 2020), (Manivel & Ranganathan, 2019), (Zafar et al., 2019), (Hu et al., 2020), (Kumar et al., 2018), (Ajalli et al., 2017), (Yadav & Sharma, 2015), (Sivrikaya et al., 2015), (Digalwar et al., 2014), (Ishizaka, 2014), (Ayhan, 2013), (Shaw et al., 2013), (Li et al., 2013), (R. Jain et al., 2013)
Price (29)	(Gernowo & Surarso, 2022), (Fagundes, Hellingrath, et al., 2021), (Kayapinar Kaya & Aycin, 2021), (Karabayir et al., 2020), (Shafi Salimi & Edalatpanah, 2020), (Agrawal & Kant, 2020), (A. J. Deshmukh & Vasudevan, 2019), (Manivel & Ranganathan, 2019), (Zafar et al., 2019), (Hu et al., 2020), (Akbaş & Dalkilic, 2018), (Kumar et al., 2018), (Diouf & Kwak, 2018), (Tooranloo & Iranpour, 2017), (Secundo et al., 2017), (Ajalli et al., 2017), (V. Jain et al., 2018), (Yadav & Sharma, 2015), (Gold & Awasthi, 2015), (Sultana et al., 2015), (Sivrikaya et al., 2015), (Rezaei et al., 2014), (Junior et al., 2014), (Ishizaka, 2014), (Ayhan, 2013), (Li et al., 2013), (Shaw et al., 2013), (R. Jain et al., 2013), (Perić et al., 2013)
Delivery (29)	(Gernowo & Surarso, 2022), (Fagundes, Hellingrath, et al., 2021), (Kayapinar Kaya & Aycin, 2021), (Agrawal & Kant, 2020), (Ozkan & Aydin, 2020), (Karabayir et al., 2020), (Çalık, 2021), (A. J. Deshmukh & Vasudevan, 2019), (Manivel & Ranganathan, 2019), (Widyatama et al., 2019), (Zafar et al., 2019), (Akbaş & Dalkilic, 2018), (Kumar et al., 2018), (Diouf & Kwak, 2018), (Tooranloo & Iranpour, 2017), (Ajalli et al., 2017), (V. Jain et al., 2018), (Galankashi, Helmi, et al., 2016), (Pramanik et al., 2017), (Yadav & Sharma, 2015), (Hamdan & Cheaitou, 2015), (Sivrikaya et al., 2015), (Rezaei et al., 2014), (Digalwar et al., 2014), (Junior et al., 2014), (Ishizaka, 2014), (Ayhan, 2013), (Shaw et al., 2013), (R. Jain et al., 2013)

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Reliability (8)	(Unal & Temur, 2022), (Fagundes, Hellingrath, et al., 2021), (Sharawat & Dubey, 2018), (Pramanik et al., 2017), (Junior et al., 2014), (Ishizaka, 2014), (Rezaei et al., 2014), (Perić et al., 2013)
Flexibility (16)	(Kayapinar Kaya & Aycin, 2021), (Ozkan & Aydin, 2020), (Karabayir et al., 2020), (Manivel & Ranganathan, 2019), (Widyatama et al., 2019), (Diouf & Kwak, 2018), (Kumar et al., 2018), (Tooranloo & Iranpour, 2017), (Galankashi, Helmi, et al., 2016), (Yadav & Sharma, 2015), (Mavi, 2015), (Sultana et al., 2015), (Gold & Awasthi, 2015), (Rezaei et al., 2014), (Shaw et al., 2013), (R. Jain et al., 2013)
Supplier profile (5)	(Karabayir et al., 2020), (Kumar et al., 2018), (Secundo et al., 2017), (Junior et al., 2014), (Li et al., 2013)
Supplier relationship (4)	(Karabayir et al., 2020), (Manivel & Ranganathan, 2019), (Junior et al., 2014), (Digalwar et al., 2014)

3.2.3. Operation Research Methods

Table 4 shows the categorized literature based on operations research (optimization) methods. Furthermore, Fuzzy AHP was the most commonly used method, followed by the hybrid of Fuzzy AHP and TOPSIS. The most recent research which adopted Fuzzy AHP was conducted in 2019, while the investigation incorporating TOPSIS was carried out in 2020. Generally, the table showed a preference for hybrid methods incorporating Fuzzy AHP, among authors.

Table 4

Classification of the papers according to the operations research methods

Methods	References
AHP, Fuzzy multi-criteria programming	(Perić et al., 2013)
AHP, Fuzzy TOPSIS	(Sharawat & Dubey, 2018)
AHP, Fuzzy AHP	(Mondragon et al., 2019), (A. J. Deshmukh & Vasudevan, 2019)
AHP, multi-objective fuzzy linear programming	(Shaw et al., 2013)
AHP, Spherical Fuzzy Sets	(Unal & Temur, 2022)
AHP, TOPSIS, QFD, Fuzzy	(Pramanik et al., 2017)
AHPSort II, Interval Type-2 fuzzy	(Xu et al., 2019)
Combining double quantitative fuzzy rough set, AHP	(Hu et al., 2020)
Computational Fuzzy AHP	(Fagundes, Keler, et al., 2021)
Fuzzy AHP	(Galankashi, Hisjam, et al., 2016), (S. Deshmukh & Sunnapwar, 2019), (Yadav & Sharma, 2015), (R. Jain et al., 2013), (Gold & Awasthi, 2015), (Widyatama et al., 2019), (Digalwar et al., 2014), (Ayhan, 2013)
Fuzzy AHP, Balanced Scorecard	(Galankashi, Helmi, et al., 2016)
Fuzzy AHP, Conjunctive Screening Method	(Rezaei et al., 2014)
Fuzzy AHP, COPRAS	(Ajalli et al., 2017)
Fuzzy AHP, COPRAS-G	(Kayapinar Kaya & Aycin, 2021)
Fuzzy AHP, DEA, Managerial Analysis	(Diouf & Kwak, 2018)
Fuzzy AHP, DEMATEL	(Agrawal & Kant, 2020)
Fuzzy AHP, D-Numbers	(Shafi Salimi & Edalatpanah, 2020)
Fuzzy AHP, extend analysis method	(Zafar et al., 2019)
Fuzzy AHP, Fuzzy ARAS	(Mavi, 2015)
Fuzzy AHP, Fuzzy MULTIMOORA	(Tavana et al., 2021)
Fuzzy AHP, Fuzzy TOPSIS	(Manivel & Ranganathan, 2019), (Karabayir et al., 2020), (Junior et al., 2014)
Fuzzy AHP, Goal Programming	(Sivrikaya et al., 2015), (Ozkan & Aydin, 2020)
Fuzzy AHP, MOORA	Al et al. (2022)
Fuzzy AHP, TOPSIS	(V. Jain et al., 2018)
Fuzzy AHP, VIKOR	(Awasthi et al., 2018)
Fuzzy AHP-Electre	(Özdemır, 2017)
Fuzzy Delphi, AHP-DEMATEL	(Kumar et al., 2018)
Fuzzy Delphi, Fuzzy AHP, Fuzzy TOPSIS	(Sultana et al., 2015)
Fuzzy Extended AHP, Computer-Based-Decision-Making	(Fagundes, Hellingrath, et al., 2021)
Fuzzy Extended AHP, Multiobjective Programming	(Li et al., 2013)
Fuzzy Logic, AHP, Fuzzy AHP, hybrid fuzzy AHP	(Ishizaka, 2014)
Fuzzy Logic, Fuzzy AHP	(Azadnia et al., 2013)
Fuzzy Pairwise, AHP	(Akbaş & Dalkilic, 2018)
Fuzzy TOPSIS, AHP, IP	(Hamdan & Cheaitou, 2015)
Hybrid Fuzzy Extended AHP	(Secundo et al., 2017)
Interval type-2 fuzzy AHP	(Ecer, 2022)
Interval-valued intuitionistic fuzzy AHP	(Tooranloo & Iranpour, 2017)
Pythagorean Fuzzy AHP, Fuzzy TOPSIS	(Çalık, 2021)

3.3. Cases Analysis

Table 5 provides an overview of the prevalent applications discussed in different research, offering insights into the characterization process. Several research had incorporated case studies. Regarding supplier selection using Fuzzy AHP, textile among oil and gas industries are acknowledged as the most common applications. According to the application

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model studied, components and raw materials dominate supplier selection categories based on product type, with a percentage of 32% and 21%, respectively. This percentage was calculated for 28 papers, clearly detailing the application model used. However, some papers provided limited information about the goods and services considered by suppliers. The geographical focus of the case studies were considered, revealing that India and Turkey were prominent regions featured inall application models.

Table 5

Applications of the model

Application	Product Category	Country	References
Agricultural Tools and Machinery Company	Machine	Turkey	(Çalık, 2021)
Apparel industry	Material	-	(Li et al., 2013)
Automobile Industry	Funding	India	(Kumar et al., 2018)
		-	(Galankashi, Helmi, et al., 2016)
Automotive industry	Component	-	(Junior et al., 2014)
	Component	India	(V. Jain et al., 2018)
Bakery Industry	Raw material	-	(Perić et al., 2013)
Battery Manufacturer	Raw material	Bangladesh	(Sultana et al., 2015)
Braking system material	Raw material	India	(Digalwar et al., 2014)
Computer Manufacturing	Component	-	(Ozkan & Aydin, 2020)
Construction Industry		Turkey	(Karabayir et al., 2020)
Electronic goods manufacturer	Outsourcing	United States	(Tavana et al., 2021)
	Material	-	(Awasthi et al., 2018)
Garment manufacturing	Material	India	(Shaw et al., 2013)
Gear motor company	Raw material	Turkey	(Ayhan, 2013)
Home Appliance Manufacturer	Green supplier	Turkey	(Ecer, 2022)
Hospital Pharmacy	Medicines	India	(Manivel & Ranganathan, 2019)
Indian manufacturing	Component	India	(S. Deshmukh & Sunnapwar, 2019)
		India	(R. Jain et al., 2013)
Leading car and truck manufacturing	Component	India	(Yadav & Sharma, 2015)
Metal Industry		Iran	(Ajalli et al., 2017)
Mobile Company	Vendor		(Sharawat & Dubey, 2018)
Oil and Gas Company	Component	Brazil	(Fagundes, Hellingrath, et al., 2021), Fagundes et al. (2021b)
	Component	Indonesia	(Widyatama et al., 2019)
	Component	Iran	(Azadnia et al., 2013)
Plastic Manufacturing		India	(A. J. Deshmukh & Vasudevan, 2019)
Semiconductor		Iran	(Galankashi, Hisjam, et al., 2016)
Textile Industry	Raw material	Pakistan	(Zafar et al., 2019)
	Technology		(Mondragon et al., 2019)
	Raw material	Turkey and Hungary	(Kayapinar Kaya & Aycin, 2021)
	Sub-contractor	Turkey	(Sivrikaya et al., 2015)
The Airline Industry	Retailer	Dutch	(Rezaei et al., 2014)
The Publishing and Printing Industries	Sub-contractor	Korea	(Diouf & Kwak, 2018)

Diouf and Kwak (2018) proposed a new framework to address the simultaneous selection and development of suppliers, focusing on the publishing and printing industries. The best suppliers for publication industries were ranked and selected using Fuzzy AHP and data envelopment analysis (DEA). In addition to ranking suppliers, managerial and strategical analyses was suggested to provide a thorough evaluation of the crucial factors influencing supplier selection. The results of DEA were made available for direct supplier development without the need for further classification. This research showed that the projected framework for the publishing and printing industries efficiently covered both supplier development and selection.

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3.4. Journal Analysis

This present research stated that the 49 selected articles reviewed were published from 41 different journal sites, as shown in Table 6. Meanwhile, Advances in Intelligent Systems and Computing, Benchmarking: An International Journal, International Journal of Services and Operations Management, Journal of Intelligent and Fuzzy Systems, Lecture Notes in Mechanical Engineering, Lecture Notes on Multidisciplinary Industrial Engineering, Neural Computing and Applications have published several research on this topic. The remaining journal each contributed one article.

Table 6

The publication list

Journal/Conference Name	Number of Articles
2017 Electric Electronics, Computer Science, Biomedical Engineering's Meeting, EBBT 2017	1
Advances in Intelligent Systems and Computing	3
Alexandria Engineering Journal	1
Applied Mechanics and Materials	1
Applied Soft Computing Journal	1
Benchmarking: An International Journal	2
Business Process Management Journal	1
Expert Systems with Applications	1
Gazi University Journal of Science	1
IEEE Latin America Transactions	1
IEEE Transactions on Engineering Management	1
IEOM 2015 - 5th International Conference on Industrial Engineering and Operations Management, Proceeding	1
IFAC-PapersOnLine	1
Information Sciences	1
International Conference on Industrial Enterprise and System Engineering (IcoIESE 2018)	1
International Journal of Computer Integrated Manufacturing	1
International Journal of Integrated Supply Management	1
International Journal of Machine Learning and Cybernetics	1
International Journal of Management Science and Engineering Management	1
International Journal of Managing Value and Supply Chains	1
International Journal of Operational Research	1
International Journal of Procurement Management	1
International Journal of Production Economics	1
International Journal of Services and Operations Management	2
International Journal of Supply Chain Management	1
International Journal of Systems Science: Operations and Logistics	1
Journal of Fuzzy Extension and Applications	1
Journal of Intelligent and Fuzzy Systems	2
Lecture Notes in Mechanical Engineering	2
Lecture Notes on Multidisciplinary Industrial Engineering	2
Logistics	1
Mathematical Problems in Engineering	1
MIT International Journal of Mechanical Engineering	1
Neural Computing and Applications	2
Operational Research	1

3.5. Year-based Publication

Articles related to supplier selection and Fuzzy AHP were classified annually as shown in Fig. 5. However, only 49 articles published from 2013 to the present were included. The total of papers issued in international journals on this topic remained relatively low until 2018, averaging approximately 4 to 6 articles per year. The contribution had been quite prominent since then and a significant increase was recorded in 2019 and 2020. The peak was recorded in 2019, when 8 articles were published and then a slight decrease was experienced in 2020. Subsequently, the number of articles has remained the same even in the current year.

The inconsistent distribution over the years, along with the diverse range of topics, suggested several research gaps in supplier selection field which needed to be addressed using Fuzzy AHP or other methods. These results also showed that research had been rarely conducted recently. Considering the unique and specific characteristics of case studies from various countries, provided valuable insights and contributions to this area of research.

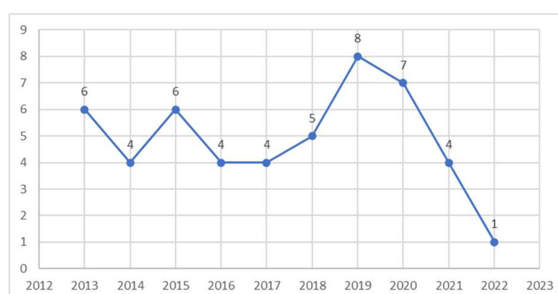

Fig. 6. Classification of the papers based on year

4. Conclusion

In conclusion, this research conducted a bibliometric analysis of Fuzzy AHP in the discipline of supplier selection and investigated the writing sources that applied MCDM method. The analysis showed that the textile as well as oil and gas industries were the most common empirical examples. In addition, case studies

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for selecting suppliers of components and raw materials dominated other domains according to product type, with a percentage of 32% and 21%, respectively. Regarding the locations of the case study, India and Turkey were reportedly leading, appearing in all application models.

The experiments conducted showed that 36.36% of all reviewed papers on supplier selection focused on the green/sustainable aspect, while the remaining 63.63% applied other various criteria. This showed the limited number of articles addressing environmental considerations in supplier selection, showing the need for future research following the accomplishment of SDGs set by the United Nations. Moreover, there were numerous opportunities for additional case studies, particularly in areas that had never explored, such as suppliers for service businesses or various types of unconventional manufacturing sectors including paper production industries whose raw material supply needed to meet environmental sustainability.

The use of VOSviewer significantly facilitated the progress of this research, including the construction and visualization of a citation network. Both qualitative and quantitative methods were recommended in future analyses, while also considering other aspects such as the impact factor of articles. Exploring case studies from various countries offered unique insights into supplier selection analysis, enriching the field in ways that previous investigations might not have captured.

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