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Lean Manufacturing Implementation Through Fuzzy Multi Criteria Decision-Making: A Literature Review

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ABSTRACT

Lean manufacturing is a systematic approach to reduce waste and increase productivity. In its implementation, lean manufacturing is often faced with complexity in its application due to inappropriate decision-making. Therefore, a more structured approach, such as the integration of the Fuzzy Multi Criteria Decision-Making (FMCDM) method, is a solution to assist decision-making within the lean framework and ensure proper lean implementation. This research aims to explore the application of FMCDM by using a Systematic Literature Review (SLR) approach, successfully analyzing 185 articles published between 2000 and 2025 focusing on integrating FMCDM and lean manufacturing. The results of the literature review show that the integration of FMCDM and lean manufacturing is still limited but has increased since 2023, with FMCDM being used for three primary purposes, namely evaluation of factors and risks in lean implementation, selection of appropriate lean tools and strategies, and assessment of lean level. This research identifies research gaps and offers practical recommendations to improve lean manufacturing effectiveness through a more adaptive and structured decision-making approach. Thus, this research is expected to significantly contribute to developing lean manufacturing theory and practice, particularly in FMCDM-based decision-making.

Keyword: Fuzzy, Lean Manufacturing, Multi Criteria Decision-Making

ABSTRAK

Lean Manufacturing merupakan pendekatan sistematis yang bertujuan untuk mengurangi pemborosan dan meningkatkan produktivitas. Namun, dalam praktiknya, penerapan *lean manufacturing* sering kali menghadapi kompleksitas akibat pengambilan keputusan yang kurang tepat. Oleh karena itu, diperlukan pendekatan yang lebih terstruktur, seperti integrasi metode *Fuzzy Multi-Criteria Decision Making* (FMCDM), sebagai solusi untuk mendukung pengambilan keputusan dalam kerangka *lean* dan memastikan implementasinya secara optimal. Penelitian ini bertujuan mengeksplorasi penerapan FMCDM melalui pendekatan *Systematic Literature Review* (SSLR), dengan menganalisis 185 artikel yang diterbitkan antara tahun 2000 hingga 2025 yang berfokus pada integrasi FMCDM dan *lean manufacturing*. Hasil kajian menunjukkan integrasi antara FMCDM dan *lean manufacturing* masih terbatas, tren penerapannya terus meningkat sejak tahun 2023. FMCDM digunakan untuk tiga tujuan utama, yaitu evaluasi faktor dan risiko dalam penerapan *lean*, pemilihan strategi *lean* yang tepat, serta penilaian tingkat keberhasilan *lean*. Penelitian ini bertujuan untuk mengidentifikasi celah dalam kajian sebelumnya sekaligus merumuskan rekomendasi praktis guna mengoptimalkan efektivitas *lean manufacturing* melalui pendekatan pengambilan keputusan yang lebih adaptif dan terstruktur. Dengan pendekatan tersebut, penelitian ini diharapkan dapat memberikan kontribusi yang berarti bagi pengembangan teori maupun praktik *lean manufacturing*, khususnya dalam pengambilan keputusan berbasis FMCDM.

Keyword: *Fuzzy, Lean Manufacturing, Multi Criteria Decision-Making*

1. Introduction

Lean is a philosophy described by Womack and Jones as lean thinking[1], [2]. Womack explains how principles towards managers, employees, suppliers, and customers can bring mass production out of waste and make it leaner [3]. Implementing Lean can reduce waste and increase productivity by identifying and eliminating non-value added [4],[5]. The significance of lean lies its ability to generate more value by using fewer resources, thus becoming an important strategy for organizations that want to remain competitive and quickly respond to market demands [6].

Lean manufacturing is a systematic approach that aims to identify and eliminate waste. It is deeply rooted in the Toyota Production System that emerged in Japan in the mid-20th century[7]. he origins of lean manufacturing can be traced to innovations implemented at Toyota between the 1930s and 1970s, focusing on increasing efficiency and reducing waste in the production process [8]. This approach was significantly influenced by the need for Japanese manufacturers to recover from World War II's devastation and compssete in a global market dominated by mass production techniques [9]. Lean manufacturing principles were formalized and popularized in the 1990s through a book entitled "The Machine That Changed the World" written by Womack, which highlighted the effectiveness of lean manufacturing compared to traditional mass production methods [10].

The evolution of lean manufacturing has been characterized by its ability to adapt and develop not only in the automotive industry, such as Toyota. The application of lean principles has been successfully implemented in many manufacturing industries, including the healthcare industry, which provides empirical evidence on the impact of lean on operational performance, occupational health and safety [11], [12]. Like the healthcare industry, the construction industry has also undergone a significant transformation in recent years, especially with adopting lean principles in its operations, which has become lean construction [13]. On the other hand, the management field has seen the benefits of lean implementation with reduced operational costs and improved service delivery. The application of lean management is seen in service industries such as hotels, restaurants or catering, where lean practices can effectively minimize food waste and improve efficiency and productivity in hospitality operations[14], [15].

Lean manufacturing, suitable for various manufacturing situations, applies the same principles driven by customer value [16]. Based on these principles [17], lean manufacturing offers an easy structure to create a detailed lean implementation framework. These principles are: determining value from the customer's perspective and not from the company's perspective [18]; identifying all the steps required to design, order, and produce goods across the value stream to highlight non-value-added waste; creating a value stream that flows smoothly without interruption [19]; producing only what the customer pulls [20]; and striving for perfection by continuously removing layers of waste[21]

In various industries, lean implementation has the same goal, which is to improve responsiveness to customer demand. By reducing lead times and improving the flow of materials and information, lean can better meet customer needs and increase the company's competitive advantage [25], [26]. Another essential goal of lean implementation is reducing waste and improving product quality, which is done by detecting waste and preventing waste [27]. These include overproduction, waiting, transportation, overprocessing, inventory, motion and defects[28], [29]. Eliminating these seven types of waste and preserving resources is the key to success in implementing lean manufacturing[30], [31]. Waste can be eliminated by many process steps, from developing the initial product and process design, how to design to operating the design [32].

The steps in waste elimination can be implemented with several lean tools and methodologies. Value stream mapping is one of the most prominent tools to help identify non-value-added activities and facilitate future state [33], [34]. In addition, the 5S methodology, which provides a framework for organizing and maintaining a clean and efficient workplace, is critical for reducing waste [35]. Another effective tool is kaizen which emphasizes the importance of involving all employees in the process of identifying and eliminating waste by fostering a culture where employees are encouraged to suggest improvements; organizations can leverage the collective knowledge and experience of their workforce, leading to innovative solutions and improved operational efficiency[36]–[39]. In addition, there are other tools such as just in time, total quality management, total productive maintenance, pull flow, Kanban, single minute exchange of dies (SMED), labor engagement, and others [40], [41].

In lean manufacturing, several cases involve decision-making, such as choosing the right alternative by evaluating several alternatives [42]. However, this decision-making is often not well considered, resulting in the implementation of lean not maximized. Decision-making based on a limited set of alternatives can conventionally be done with the multi-criteria decision-making (MCDM) method [43], [44]. In lean manufacturing, decision-making is based on subjective criteria, so it requires integration between Fuzzy Logic and conventional MCDM to eliminate uncertainty in subjectivity [45]. Fuzzy logic(Zadeh, 1996, 1997) is an analytical method that incorporates uncertainty into decision models. While MCDM is one of the most accurate decision-making methods [46], [47]. Where in its calculation, MCDM considers different qualitative and quantitative criteria in considering the best solution [48].

In lean manufacturing, the implementation of Fuzzy MCDM is used in many cases, such as determining waste or the causes of waste. Research conducted by Agazhie et al. [49] applying FTOPSIS and FAHP in the context of the sewing section in the clothing industry showed that the use of fuzzy techniques successfully identified the leading causes of lean waste and applying reduction methods by employing better waste cause identification methodologies. Another implementation is measuring leanness or lean level. Leanness or lean level in this context refers to measuring lean manufacturing practices [50]–[52]. Research conducted by [53], proposed a comprehensive framework for evaluating leanness developed using fuzzy DEMATEL to determine the significance and causal connections among lean practices. These practices encompass supplier-related issues, manufacturing operations, marketing, just-in-time (JIT) systems, cost and financial management, employee involvement, management responsibilities, and quality management within Turkey's plastics industry.

Another study conducted by Sharma et al. [54] employed the DEMATEL method to analyze the causal relationships between 17 lean practices in a machine tool manufacturing company. These practices included JIT (Just-in-Time), 5S, VSM (Value Stream Mapping), information technology, SMED (Single-Minute Exchange of Die), visual control, CIM (Computer-Integrated Manufacturing), ERP (Enterprise Resource Planning), job scheduling, standardized work, training, fixed-position layout, cellular manufacturing, poka-yoke, innovative processes and automation, TQM (Total Quality Management), and concurrent engineering. On the other hand, fuzzy MCDM is also used to determine the lean tools. Like other research conducted by Bhalaji [55], he used fuzzy VIKOR to examine lean implementation by analyzing risk factors and identifying the best lean manufacturing process. Fuzzy VIKOR is also applied to select the best lean facilitator. This facilitator selection problem is often controlled by uncertainty in practice, so Fuzzy VIKOR is suggested to handle both qualitative and quantitative criteria in selecting facilitators [56].

This research explores the application of Fuzzy Multi-Criteria Decision Making (FMCDM) as a decision-making method in dealing with the complexity of a lean manufacturing environment. Through a Systematic Literature Review, this research seeks to map existing knowledge and find unexplored research gaps related to applying FMCDM-based lean manufacturing. The review shows that the integration of FMCDM and lean manufacturing is still limited, so this research focuses on uncovering the main implementation themes in various cases. This research will contribute to practical recommendations to improve lean manufacturing effectiveness through a more adaptive decision-making approach by integrating FMCDM methods.

2. Research Methodology

Systematic literature review (SLR) in this research focuses on the use of Fuzzy MCDM in lean implementation; searching from databases such as Google Scholar, Science Direct, etc., with the keywords "Systematic literature review" and "lean manufacturing", no articles will be found about it. The objectives of this lean review research are as follows: (1) What is the role of Fuzzy MCDM in lean implementation? (2) how is the application of Fuzzy MCDM in lean done?

An SLR was conducted to achieve the objectives of this study. SLR differs from traditional desk reviews with a scientific, transparent and replicable process to minimize bias through in-depth literature searches, providing an audit trail [57], as well as applying explicit, reproducible methods to examine relevant research and achieve comprehensive accuracy while reducing bias [58], [59]. This methodology allows researchers to clearly articulate the study's inclusion and exclusion criteria, thus providing a more transparent explanation of the methodology used [60]. This method is presented and aligned with many high-quality scientific journals such as [61]–[64] . The flowchart of the SLR method can be seen in Figure 1.

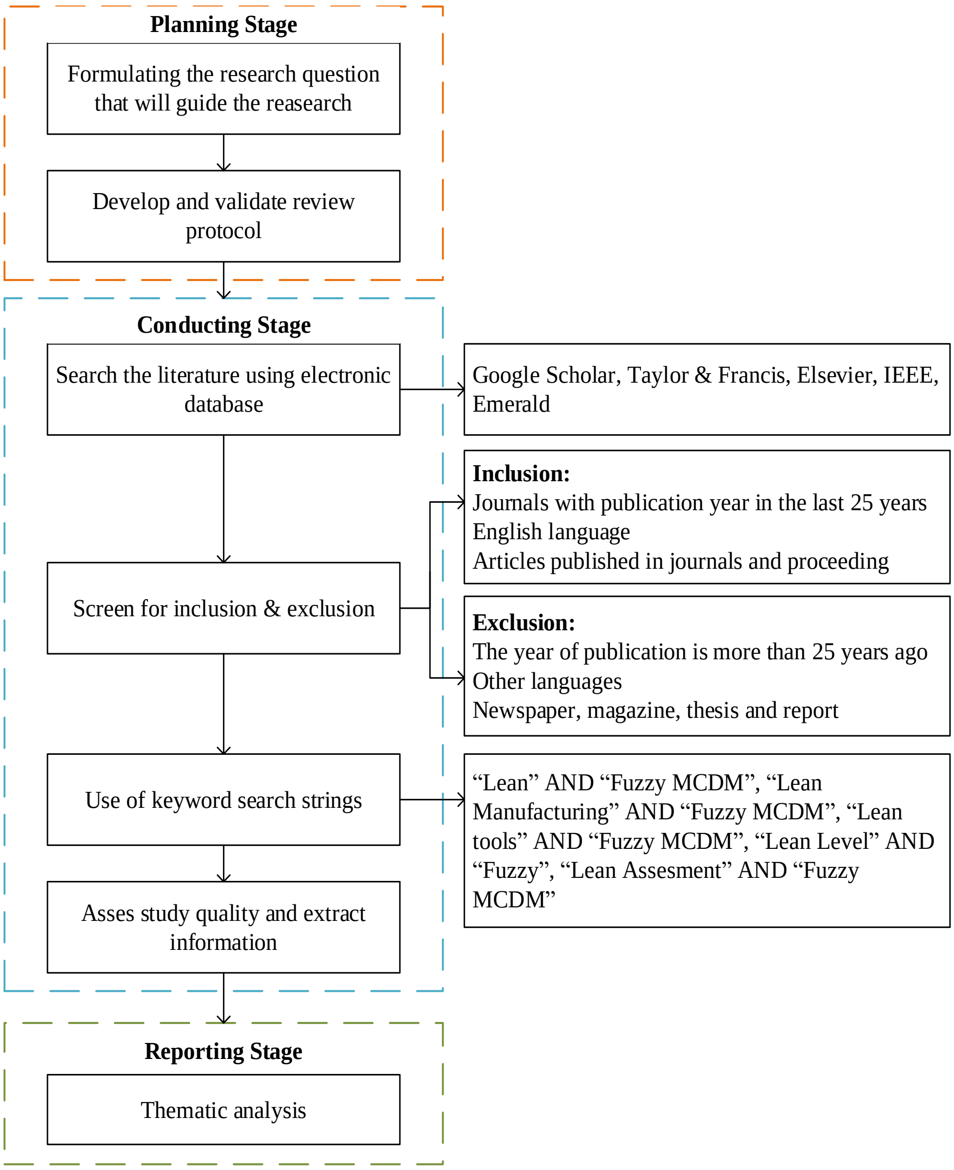

Figure 1. SLR stages of research

Table 1. Inclusion and exclusion criteria for literature review

Inclusion criteria	Exclusion criteria
Year of publication last 25 years	Year of publication more than 25 years ago
Journal	Newspapers, magazines, reports and gray literature (conferences, master theses, doctoral dissertations, textbooks, reports, working papers from research groups, technical reports, etc.)
English	Other languages
Well-known databases: emerald, google scholar, IEEE, science direct and Taylor & Francis	Non-academic database

In the planning stage, the first step of the SLR stage is formulating the research question that will guide the research. At this stage, the literature review focuses on the research question, which becomes the leading guide in the entire literature review process. The selection of studies and data analysis to formulate the results aims to answer the research question. However, novice researchers often make a mistake, namely choosing a research question that is too broad [65]. Too broad questions make the literature review unfocused because there is too much data to analyze. Questions such as the trend of using Fuzzy MCDM in lean cases form the basis of this entire literature review process.

Then, the review protocol was developed and validated. A review protocol is essential for a transparent, systematic and replicable ongoing literature review [66]. Review protocols are carried out by establishing research objectives, research questions, inclusion and exclusion criteria, screening procedures and reporting [67], [68]. Before a review protocol is implemented, it must be thoroughly validated. In this study, the protocol was validated by the supervisor and peers. Since literature reviews develop knowledge, it is important to carefully evaluate and critique protocols to improve the quality of research [69].

The next stage is the conducting stage. In this stage, we started by searching for literature using electronic databases. Electronic databases are the primary source for collecting published literature [70]. Since there is no single database that covers all available material, the literature search was conducted in several databases. Some of the electronic databases used in this study are Google Scholar, Taylor & Francis, Elsevier, IEEE and Emerald. In this study, only English-language literature with a publication year of no more than 25 years was used. Furthermore, "gray literature" such as newspapers, news, theses, and reports were not included in this study.

The literature search focused on "lean" AND "fuzzy". Then it combined them with various keywords such as "lean manufacturing" AND "fuzzy MCDM", "lean level" AND "fuzzy", and "lean assessment" AND "fuzzy". This study did not include articles that use fuzzy outside of fuzzy MCDM. The researcher ensured no significant human errors in selecting terms, databases, periods, or other relevant factors. Next, we assessed the quality of the studies and extracted information from the articles found. The quality of these studies was assessed based on their index and relevance by reviewing the abstracts. A review of the abstraction was done to determine the focus of each study and identify the purpose of applying Fuzzy MCDM to lean methods. The last stage is the reporting stage. In this stage, thematic analysis is conducted by extracting emerging themes from the literature, grouping them and ultimately synthesizing them into more structured analytical themes [71].

3. Results and Discussion

Based on a search with the keywords "Lean manufacturing" and "Fuzzy MCDM", the resulting articles from various electronic databases show a significant volume of literature. Taylor & Francis (tandfonline.com) produced 18,985 articles; Google Scholar (scholar.google.com) produced 15,111 articles; Emerald (emeraldinsight.com) produced 3,118 articles; Elsevier (sciencedirect.com) produced 1,488 articles; IEEE (ieeexplore.ieee.org) with 67 articles. This categorization approach is the basis for evaluating research trends integrating lean manufacturing with fuzzy MCDM methods. This process also provides findings that align with other systematic literature reviews (SLR) while underscoring the diversity and depth of literature available in the field.

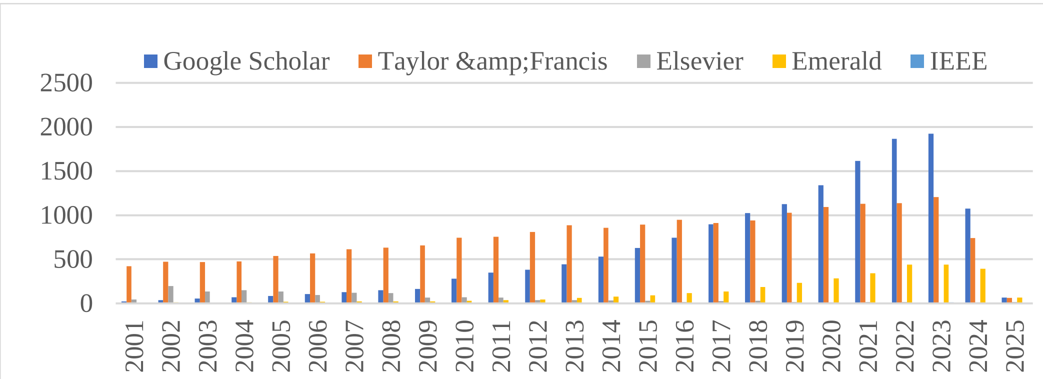

Figure 2. Categories of Articles Integrating Lean Manufacturing and Fuzzy MCDM Based on Publication Year

As early as 2001-2005, the number of related publications was low, indicating that the integration of lean manufacturing and fuzzy MCDM had not been widely explored. However, starting in 2006, a significant increase occurred until the peak around 2015-2018. This shows that the topic is getting more attention from researchers. After reaching the peak, there was a decrease in the number of publications in the following years, although it remained higher compared to the beginning of the period. The literature review was conducted again by re-examining the literature based on keywords, titles, and abstracts to avoid exclusion criteria.

Based on keywords, titles and abstracts, the articles yielded a total of 185 articles. The majority of these articles, 57, were sourced from Emerald. Most of the articles were sourced from Emerald, where Emerald is one of the publishers that contribute significantly to the lean manufacturing research field. In addition, 27 articles (14.59%) were retrieved from Taylor & Francis database, Google Scholar contributed 35 (18.91%), Taylor & Francis (T&F) and Elsevier each contributed 32 articles (17.29%), and IEEE contributed 4 articles (2.16%). These findings show varying levels of representation across different databases, emphasising the importance of using multiple sources to ensure a thorough literature review.

A review of the implementation of fuzzy MCDM within the framework of lean manufacturing reveals three main themes. The first theme examines the classification and application of fuzzy MCDM methods in general decision-making processes. The second theme explores the role and application of fuzzy MCDM methods in supporting lean manufacturing implementation, including risk identification, the selection of lean strategies and tools, and the evaluation of lean implementation levels. The third theme provides a literature mapping of various studies on the application of fuzzy MCDM in the context of lean manufacturing.

3.1. Fuzzy MCDM and Its Categories

Fuzzy MCDM is used to evaluate alternatives based on predefined criteria with its ability to handle uncertainty and ambiguity in the decision-making process which is especially important in contexts where the available data uses linguistic values[72], [73]. Various categories in fuzzy multi-criteria decision-making have been developed to handle various decision-making problems. These categories include pairwise comparison-based methods, outranking methods, distance-based methods, and others, each of which has advantages and disadvantages depending on the context of the problem. A comparison of these methods, including an analysis of their advantages and disadvantages, as well as their real-life implementation, can be found at [75], [76].

Some methods commonly used in Fuzzy MCDM are the Analytic Hierarchy Process (AHP), the Analytic Network Process (ANP), and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) by incorporating the concept of fuzzy sets. In addition, there are also other methods such as fuzzy VIKOR (Multicriteria Optimization and Compromise Solution), fuzzy ELECTRE (Elimination and Choice Expressing the Reality), fuzzy PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation), fuzzy Axiomatic Design (AD), and fuzzy DEMATEL (Decision-Making Trial and Evaluation Laboratory). These methods help achieve more sensitive and accurate solutions in dealing with complex decision-making problems [45], [77]. Fuzzy MCDM can be classified based on 4 categories[45], [77], [78].

Table 2. Categories of FMCDM Methods

FMCDM Categories	FMCDM Methods	Aplication
Pairwise Comparison based Methods	F-AHP F-ANP F-MACBETH	The pairwise comparison method is used to determine the relative importance of alternatives and criteria by utilizing a pairwise comparison matrix.
Outranking Methods	F-PROMETHEE F-ELECTRE	Outranking relations are utilized to assess and compare alternatives.
Distance Based Methods	F-VIKOR F-TOPSIS	Distance-based methods are employed to evaluate alternatives based on how close they are to ideal solutions.
Other Methods	F-AXIOMATIC DESIGN	Used to identify whether criteria exhibit conjunctive (combined) or disjunctive (separate) behaviors.
	F-DEMATEL	Used to analyze the interconnections between criteria and to identify which criteria act as causes and which are effects.
	F-CHOQUET INTEGRAL	Used to evaluate and rank criteria and alternatives by representing them both semantically (in words) and quantitatively (in numbers).

3.2. The Role of Fuzzy MCDM in Lean Implementation

The role of fuzzy MCDM in lean implementation aims to help make more effective and accurate decisions to solve various challenges during the lean implementation process. To understand the complexity of the problem, this research seeks to identify and categorize the objectives of applying fuzzy MCDM in solving problems faced in lean implementation. One of the uses of Fuzzy MCDM is to identify factors and risks in implementing lean manufacturing so that considerations for implementing lean manufacturing can be decided as in research [79]–[81]. Like the research conducted by Bhalaji, this research tries to identify risk factors in implementing a lean manufacturing system in a medical equipment manufacturing company located in India using fuzzy VIKOR. This research suggests that customers changing supply schedules and improper operating procedures are the most influential risk factors in lean manufacturing implementation decisions.

Another role of fuzzy MCDM is in the process of selecting the right strategies and tools in implementing lean tools[82]–[84] . The lean manufacturing philosophy helps manufacturing industries in improving their productivity aspects by identifying and eliminating waste using certain tools/techniques. Research conducted by Kumar [5], It presents an integrated framework with a fuzzy AHP approach for implementing lean in the steel processing industry. By utilizing fuzzy AHP and complex assessment, this study successfully identified the most suitable lean tools to be implemented. The results showed success in reducing waste with scale waste reaching 50%, miss roll defect at 72.7% and size variation defect at 62%.

In assessing the extent of lean implementation, fuzzy MCDM can also be applied (lean level). Lean manufacturing is gaining popularity as an approach to improve industrial performance, but its implementation takes a long time and continuous improvement; therefore, measuring the level of lean implementation periodically is necessary. Such complex assessments often use the help of fuzzy MCDM in the process [77], [85], [86]. Such as research conducted by [87], where the improvement of lean implementation can be measured by lean maturity level (LML) where the weighting of criteria that affect LML is carried out. In this study, 9 main criteria and 14 sub-lean criteria were weighted with the help of fuzzy AHP. This research successfully measured the level of maturity in the company's implementation, set at 64%.

3.3. Application of Various Fuzzy MCDM Methods in Lean

This theme discusses applying various Fuzzy MCDM methods in lean manufacturing based on their role in lean tool selection, risk analysis and lean maturity level evaluation. Several studies prove the importance of MCDM techniques and their application in lean in their literature, such as the use of Fuzzy AHP to evaluate criteria weights, Fuzzy TOPSIS to rank alternatives, Fuzzy DEMATEL to analyze cause-effect relationships between factors and Fuzzy VIKOR to find a compromise solution close to the ideal, which can be seen in Table 3.

Table 3. Literature Survey on Application of Fuzzy MCDM Techniques in Lean Manufacturing

No.	Methodology	Lean tools /Techniques	Application	Ref
1	Fuzzy NGM-VIKOR	-	Risk analysis in lean implementation	[79]
2	Fuzzy AHP, Process Activity Mapping	VSM	Lean tools selection	[82]
3	Fuzzy DEMATEL, FTA, TOC, Balanced Scorecard	Kaizen	Lean tools Selection	[83]
4	Fuzzy TOPSIS	VSM, 5S, TPM, Kanban, Kaizen	Ranking of lean tools	[84]
5	Fuzzy AHP	Kaizen, 5S, Ergonomics	Lean maturity level (Leannes)	[87]
6	Fuzzy TOPSIS	5S, Kaizen, TPM, Poka-yoke, Line Balancing	Ranking of lean tools based on material flow	[88]
7	Fuzzy AHP-COPRAS	VSM, PDCA	Lean tools selection based on waste	[89]
8	Fuzzy AHP, FMEA, QFD	VSM, Kaizen, 5S	Lean tools selection based on waste associated risks, failure mode and effects analysis	[90]
9	Fuzzy TOPSIS	VSM, Mistake-proof Processing	Lean tools selection	[91]
10	Fuzzy TOPSIS	-	Lean performance evaluation (Leannes)	[92]

No.	Methodology	Lean tools /Techniques	Application	Ref
11	Fuzzy AHP, Fuzzy Delphi, Fuzzy TOPSIS, Fuzzy QFD	5S, TPM	Failure mode ranking and lean tools selection	[93]
12	Fuzzy TOPSIS	-	Lean Maturity Level (Leannes)	[94]
13	Fuzzy DEMATEL	-	Evaluation of critical factors or risks in lean implementation	[95]
14	Fuzzy-AHP, QFD, PPROMETHEE	Kaizen, Kanban	Lean tools selection with restricted resources	[96]

Table 4 shows the fuzzy methods applied in the lean manufacturing framework. Among them, Analytical Hierarchy Process (AHP) proposed by [87] which is a structured approach to decision-making in complex problems. AHP organizes the decision-making criteria as a hierarchy and aims to measure the relative priority for a set of available alternatives based on paired judgments from decision-makers. Fuzzy TOPSIS is often used to rank lean tools, utilizing fuzzy logic and conventional TOPSIS to evaluate lean tool alternatives more accurately. Fuzzy DEMATEL, an effective method for analyzing cause-effect relationships between factors in the context of lean manufacturing, is often used to identify key factors that affect the implementation of lean tools. Finally, Fuzzy VIKOR prioritises risks that may arise during lean implementation.

4. Conclusion

This study reviews the literature on lean manufacturing with Fuzzy Multi Criteria Decision Making (FMCDM) approach, by selecting 185 articles in the time span of 2000-2025. It can be seen that publications increased significantly in 2023, reflecting the growing interest in the integration of lean manufacturing with the FMCDM approach. Based on the literature analysis, it was found that FMCDM is applied in lean manufacturing decision making for three main reasons, namely evaluation of factors in lean implementation, selection of appropriate lean tools, and identification of lean implementation levels. This research is a new gateway in contributing to the development of lean manufacturing theory and practice by relying on structured decision-making aspects. By identifying research gaps and offering new perspectives, this research is expected to continue and continue to inspire developers of lean manufacturing theory and practice.

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