Assessing the barriers to lean manufacturing adoption in the furniture industry of Bangladesh: a fuzzy-DEMATEL study

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Abstract

Purpose – The objective of this study is to investigate the barriers hindering the integration of lean manufacturing (LM) practices within the furniture industry of Bangladesh. The traditional operational paradigms in this sector have posed substantial challenges to the effective implementation of LM. In this study, the barriers of implementing LM in the furniture business are examined, aiming to provide a systematic understanding of the barriers that must be addressed for a successful transition.

Findings – The research reveals that "Fragmented Industry Structure," "Resistance to Lean Practices" and "Inadequate Plant Layout and Maintenance", emerged as the foremost barriers to LM implementation in the furniture industry. Additionally, "Insufficient Expert Management," "Limited Technical Resources" and "Lack of Capital Investment" play significant roles.

Research limitations/implications – The outcomes of this study provide valuable insights into the furniture industry, enabling the development of strategies for effective LM implementation. One notable challenge in lean implementation is the tendency to revert to established practices when confronted with barriers. Therefore, this transition necessitates informed guidance and leadership. In addition to addressing these internal challenges, the scope of lean implementation should be broadened.

Originality/value – This study represents one of the initial efforts to systematically identify and assess the barriers to LM implementation within the furniture industry of Bangladesh, contributing to the emerging body of knowledge in this area.

Keywords Lean manufacturing (LM), Fuzzy-DEMATEL, Decision-making, Furniture industry

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1. Introduction

Lean has its origins in Henry Ford, who established an impressive Highland Park Manufacturing Company's production process in 1913 (Diego Fernando and Rivera Cadavid, 2007). The term "lean" is derived from Japanese manufacturing and refers to a way of thinking that detests waste in all its forms and works tirelessly to eradicate errors (Dickson *et al.*, 2009). LM, often known as lean production, is a rigorous strategy to remove waste from a manufacturing process. Promote lean production as a multifaceted approach that integrates several management techniques, such as just-in-time manufacturing, quality control, workgroups, cellular manufacturing and management of supplier (Dhiravidamani *et al.*, 2018). The Japanese had instead created a new method of production management called LM (Wu, 2003). LM aims to produce excellent products in the most effective and inexpensive way possible by using fewer space, less inventory, less time to develop things and less human labor (Chauhan and Singh, 2012).

In Bangladesh, individuals typically opt for stylish furniture that is also long-lasting, cozy and simple to keep. People from various socioeconomic backgrounds react differently to the elements that influence their household goods purchasing decisions. Customers typically conduct pre-purchase research despite the fact that local and national brands are available to them. Because of this, retailers must fully comprehend the buying habits of their customers (Nigar, 2021). Bangladesh's furniture business has grown. The business standard reported that the country's furniture industry generates more than 10,000 crores in income annually (Gautam *et al.*, 2022). In addition to satisfying local clients' needs, manufacturers are currently exporting their products abroad. In order to lower production costs, speed up delivery and improve quality while maintaining competitiveness in a market that is becoming more globally diversified, wood manufacturers have been under pressure to embrace innovative manufacturing techniques and management strategies. Continuous improvement encourages a continual effort to improve quality and productivity for the wood products business. The complicated manufacturing structure of the furniture business, along with its many difficulties and other distinctive characteristics, make it a strong candidate for the adoption of LM. This study focuses on the areas that the furniture sector has to prioritize to successfully implement LM. Furniture sector managers and decision-makers can learn crucial lessons that will help them adopt LM effectively, particularly in emerging markets where resources are scarce (Debnath *et al.*, 2023a).

In Bangladesh's garments sector there are many works on it. Due to issues with their recent production planning and management methods, many private Bangladeshi garment manufacturing enterprises are either running well below their probable capacity or facing a high level of late deliveries (Chakraborttya and Paul, 2011). The Bangladeshi economy relies heavily on its garment industry, a dominant force in the country's exports. To address the challenges faced by this sector, LM principles and techniques have gained prominence (Bashar and Hasin, 2018). Similarly, the footwear industry in Bangladesh, benefiting from abundant raw materials and labor, presents opportunities for growth. Various engineers, researchers and institutions have developed lean goals and concepts, focusing on enhancing processes, products and services. Lean principles encompass a set of tasks aimed at delivering value to customers through accurate, sequential and timely execution (Science, 2017). The adoption of LM practices is now a focal point for businesses striving to reduce waste and enhance competitiveness. Bangladesh's industrial output has surged, and its small-scale industries have played a pivotal role in the nation's economic progress (Sushil *et al.*, 2020). The ready-made garments (RMG) sector generates more than 70% of Bangladesh's total export earnings and employs over 40% of the country's manufacturing workforce (Islam and Halim, 2022). As a result, government involvement is essential to ensure the sector's success. One of Bangladesh's major achievements is that

RMG enterprises produce goods at low labor prices. LM principles are widely used in many countries, and they are also used in Bangladesh's numerous textile factories (Karim and Rahman, 2012).

One of the primary factors contributing to the limited adoption of LM practices is a lack of awareness among manufacturers. When manufacturers lack adequate understanding and information about LM technologies, they are less inclined to invest in them. This diminished interest and reduced investment can, in turn, hinder the advancement of the manufacturing sector (Mathiyazhagan *et al.*, 2022). However, a lot of research has been done on the crucial variables and barriers to LM adoption (Maware and Parsley, 2022; Robertsone *et al.*, 2022; Qureshi *et al.*, 2022; Leite *et al.*, 2022; Abu *et al.*, 2022; Rathi *et al.*, 2022). LM implementation barriers based on the Malaysian wood and furniture industry have been identified by Abu *et al.* (2022), and their analyses highlighted four dominant challenges which are related to culture and human attitude issues, i.e. lack of employee commitment, lack of senior management's interest and support, difficult to implement stands out as the most significant. A framework for implementing sustainable lean manufacturing in the electrical and electronics component manufacturing industry has been developed by Mathiyazhagan *et al.* (2022).

As the literature review indicates, there exists a dearth of research specifically addressing the barriers to LM adoption within the Bangladesh's furniture industry. The present study seeks to bridge this gap by systematically identifying and analyzing these barriers, thereby contributing novel insights into the body of knowledge in the field of LM implementation. Several studies such as (Maware and Parsley, 2022; Robertsone *et al.*, 2022; Qureshi *et al.*, 2022) examined the benefits and drawbacks of LM adoption in manufacturing industries and textile industries, but few have modeled paths specific into the Bangladesh's furniture industry. The existing research on LM implementation generally lacks sector-specific modeling that accounts for Bangladesh's furniture sector's unique difficulties and potential. It is also significant to note that no earlier research has looked at the barriers associated with applying LM in the furniture industry of Bangladesh (Chowdhury *et al.*, 2015; Jannat *et al.*, 2009). The Bangladeshi furniture industry faces numerous barriers in implementing LM practices. These barriers include such as fragmented industry structures, resistance to lean practices, inadequate plant layout and maintenance, insufficient expert management, limited technical resources, inefficient production times and a lack of capital investment (Darabi *et al.*, 2023; Feldmann, 2022; Darabi *et al.*, 2023, ; Mawlood *et al.*, 2022). The corporations are excited to introduce LM in their industry. Following their analysis, the authors attempt to provide a framework for identifying the obstacles to implementing LM and attempt to respond to the subsequent research questions (RQs):

RQ1. What are the pivotal barriers to implement lean manufacturing in the furniture industries of Bangladesh?

RQ2. How can a framework be created to model and examine the interdependence of those barriers for implementing lean practices?

RQ3. How the proposed framework helps the furniture industry to adopt lean manufacturing in the furniture industry?

By looking at the barriers to LM in the furniture sector, the current study has theoretically enhanced the body of knowledge on LM in an effort to respond to those RQs. The goal is to overcome the barriers and implement a proper framework for lean in the furniture industry. For assessing the barriers, a novel framework incorporating questionnaires and a fuzzy-DEMATEL technique has been presented. The questionnaires and literature were utilized to determine the relevant barriers in the framework of Bangladesh's furniture industry. A fuzzy-

DEMATEL model has been presented to investigate the significant interactions between the obstacles. The fuzzy-DEMATEL technique was used for this investigation, because it can map the barriers with influential linkages from imprecise data. In terms of practical implications, the study's findings may assist furniture producers in making judgments about establishing distinctive lean implementations and changing current systems into competitive ones. The fuzzy-DEMATEL model also aids industrial managers in developing successful LM implementation strategies.

The following is an outline of the article: Section 2 offers a comprehensive analysis of existing literature on LM methods and the barriers to using LM techniques in the furniture sector. Section 3 describes the data gathering procedure as well as the computational phases of the proposed fuzzy-DEMATEL framework. The results of using the suggested framework are shown in Section 4 of the paper. Section 5 highlights the significance of the findings and the insights gained from the investigation. Section 6 concludes the study by discussing its weaknesses and extents for further study.

2. Literature review

2.1 Lean manufacturing in furniture industry of Bangladesh

Many wood products companies have already integrated LM components and tools in full or in part or they are considering doing so. In fact, the adoption of lean has helped a number of industry participants successfully alter their operations. Some received the Shingo Prize for operational excellence in manufacturing, the highest honor given each year to the top USA manufacturers (Horbach, 2013). The Bangladeshi furniture industry, a prominent player in the nation's economy, has been actively exploring the integration of LM principles and tools (Debnath *et al.*, 2023b). This strategic shift is aimed at addressing various challenges and enhancing the sector's overall efficiency. Within the Bangladesh's furniture industry, there are notable success stories where LM practices have brought about substantial improvements. While not on the same scale as global manufacturing giants, these achievements are significant within the context of the local industry.

One such example is HATIL Furniture, which has made remarkable strides in LM adoption. The company's commitment to lean principles resulted in impressive outcomes, including notable cost reductions and streamlined production processes (Habib *et al.*, 2023). The Bangladesh's furniture industry, with its unique strengths and challenges, has demonstrated its potential for growth (Habib *et al.*, 2023). Unlike larger manufacturing nations, Bangladesh's furniture sector offers distinct advantages, such as abundant raw materials, a strategic location and a skilled labor force. The nation hosts a substantial number of furniture companies, employing a significant workforce. This sector's growth trajectory aligns with Bangladesh's economic development plans, making it a pivotal player in the country's industrial landscape (Khan, 2019). Despite these promising prospects, the industry faces its own set of challenges (Ahsan *et al.*, 2022). This study on the Bangladeshi furniture industry is conducted in the context of addressing the specific challenges and opportunities within this industry. The Bangladesh's furniture sector holds significant economic potential due to its abundance of raw materials, skilled labor force and strategic location. However, despite its promise, this sector faces several unique challenges, including issues related to design, quality control, skilled manpower shortages, research and development, industry fragmentation and limited government support. Such as limited access to modern design, issues with quality control, skilled manpower shortages, inadequate research and development, fragmented industry structure, limited government support and many more (Debnath *et al.*, 2023b; Habib *et al.*, 2023). These barriers have underscored the need for LM practices as a means to address and overcome these

challenges effectively (Jahan *et al.*, 2022). As a result, the study aimed to fill this research gap by providing valuable insights into the barriers and opportunities for implementing LM practices within the context of Bangladeshi furniture manufacturing. So, the Bangladeshi furniture industry's journey toward LM signifies a proactive approach to addressing industry-specific challenges and enhancing competitiveness. While it may not match the scale of global furniture manufacturing giants, the industry's efforts to embrace lean principles are crucial for its sustained growth and contribution to Bangladesh's economy (Debnath *et al.*, 2023b).

2.2 Barriers for implementing lean in context of furniture industry of Bangladesh

The LM implementation barriers were explored through the extensive literature review. In order to identify the barriers, the authors conducted a thorough literature review. Between 2012 and 2022, the Scopus database, Web of Science and Google Scholar were used for this literature search. The LM implementation challenges and barriers were explored through the extensive literature review. In order to identify the challenges, the authors conducted a systematic literature review (SLR). Table 1 displays the SLR approach's inclusion and exclusion criteria. The inclusion and exclusion criteria are based on the studies of Keung *et al.* (2020).

After reviewing the relevant literature, the authors came up with a list of barriers from (Maware and Parsley, 2022; Platin and Konuk, 2022; Wicaksono *et al.*, 2022; Silvius *et al.*, 2021; Teknologi *et al.*, 2021; Abu *et al.*, 2021; Ratnasingam *et al.*, 2019; Inayatullah and Narain, 2017; Guerrero *et al.*, 2017; Belhadi *et al.*, 2016; Sharma *et al.*, 2016; Velarde *et al.*, 2011; Yu *et al.*, 2011), which consists of several barriers to LM implementation. The complicated manufacturing structure of the furniture business, along with its many difficulties and other distinctive characteristics, make it a strong candidate for the adoption of LM. This study focuses on the areas that the furniture sector has to prioritize to successfully implement LM. Furniture sector managers and decision-makers can learn crucial lessons that will help them adopt LM effectively, particularly in emerging markets where resources are scarce (Debnath *et al.*, 2023a). Identified barriers to the adoption LM were selected based on the mentioned articles are shown in Table 2. Authors have categorized the barrier table into three distinct contexts: managerial, technical and financial. These categorizations were determined through a comprehensive analysis of the barriers identified in the study. Each barrier was assessed based on its characteristics, including its relationship with management practices, technical aspects and financial implications. After careful consideration, the authors have assigned the barriers to the respective categories, ensuring that they align with the appropriate context.

Inclusion criteria	Exclusion criteria
Lean manufacturing implementation processes	Non-English research paper
Studies concentrating on the issues that furniture industries face while implementing lean manufacturing processes	Proxy and repetitive work
Barriers & challenges of lean manufacturing implementation	Inadequate and Incomplete data
Recent research during the years 2012 through 2022	Proceeding papers, editorial materials and thesis

Source(s): Authors' own contributions

Table 1. Criteria followed in SLR technique

3. Research methodology

The DEMATEL method was formerly applied in 1973, by the Geneva Research Center of the Battelle Memorial Institute. The DEMATEL technique is a more advanced way to create and examine a structural model for examining the interactions between influences among complicated criteria (Han and Deng, 2018). However, it is difficult to separate complex variables when making decisions in a fuzzy situation. In the current work, a fuzzy-DEMATEL technique is applied to generate a more accurate analysis. The furniture industry of Bangladesh, like many industries, involves complex and interrelated factors that

Table 2. Lean implementation barriers faced by Bangladeshi furniture industry

No.	Context	Barriers	Descriptions	References
1	Managerial	Insufficient expert management	This refers to a lack of knowledgeable leadership capable of driving lean initiatives effectively	Maware and Parsley (2022)
2		Resistance to change	It represents employee reluctance to adopt new lean technologies and procedures	Maware and Parsley (2022)
3		Rejection of lean practice	Resistance among employees and management to embrace lean manufacturing principles, resulting in reluctance to change existing processes	Darabi *et al.* (2023), Maware and Parsley (2022)
4		Unaware about the benefit	Lack of awareness or understanding of the advantages and potential improvements that lean practices can bring to the furniture industry	Teknologi *et al.* (2021)
5		Ineffective communication	Communication gaps and inefficiencies within the industry, hindering the successful implementation and coordination of lean initiatives	Sharma *et al.* (2016)
6	Technical	Lack of modern design	Outdated or traditional design approaches that are not aligned with modern lean manufacturing concepts and requirements	Ratnasingam *et al.* (2019)
7		Lack of quality control	Insufficient quality control processes and standards, leading to inconsistencies and defects in furniture production	Velarde *et al.* (2011)
8		Limited technical resources	It signifies a shortage of essential technical capabilities and resources required for lean implementation	Silvius *et al.* (2021)
9		Inefficient production time	This barrier pertains to suboptimal production processes that hinder lean practices	Belhadi *et al.* (2016)
10		Insufficient skilled manpower	Shortage of skilled and trained personnel capable of implementing and sustaining lean practices effectively	Inayatullah and Narain (2017)
11		Inadequate R&D and Innovation	Limited investment and focus on research, development and innovation within the industry, hindering lean advancements	Pirraglia *et al.* (2010)

(*continued*)

No.	Context	Barriers	Descriptions	References
12	Financial	Insufficient training	Lack of comprehensive training programs to educate the workforce about lean principles and methodologies	Guerrero *et al.* (2017)
13		Lack of capital cost	It signifies limited financial resources allocated to lean initiatives	Platin and Konuk (2022)
14		Fragmented industry structure	A fragmented and disorganized structure within the furniture industry, making collaborative lean efforts challenging	Feldmann (2022), Yu *et al.*(2011)
15		Inadequate plant layout and maintenance	This highlights issues with factory layouts and maintenance practices that hinder lean efficiency	Mawlood *et al.* (2022), Abu *et al.* (2021)
16		Limited government support	Inadequate support and policies from the government to facilitate and promote lean adoption and development in the sector	Wicaksono *et al.* (2022)

Source(s): Authors' own contributions

Table 2.

affect the adoption of LM. DEMATEL is particularly suited for analyzing complex systems with multiple interconnected variables (Jodlbauer and Tripathi, 2023). It allows us to examine the cause-and-effect relationships among barriers, providing insights into how each barrier influences others. This is valuable when dealing with intricate issues such as LM adoption. Fuzzy-DEMATEL extends the traditional DEMATEL method by accommodating fuzzy logic (Ahmed *et al.*, 2021). In real-world scenarios, data and relationships are often imprecise and uncertain. Fuzzy-DEMATEL can handle this fuzziness effectively, allowing for a more realistic representation of the system under study. FAHP, Fuzzy VIKOR and BWM methods may not offer the same level of flexibility in handling fuzzy data (Kushwaha and Talib, 2020; Raut *et al.*, 2019; Bouzon *et al.*, 2016; Prakash and Barua, 2015). Fuzzy-DEMATEL has been successfully applied in various studies involving complex decision-making problems, including those related to barriers and obstacles (Ponnambalam *et al.*, 2023; Murugan and Marisamynathan, 2022; Feldmann *et al.*, 2022; Govindan *et al.*, 2022). Its effectiveness in revealing hidden relationships and dependencies among variables makes it a suitable choice for our research context. Fuzzy-DEMATEL excels over methods like graph theory and fuzzy-TISM, due to its nuanced handling of uncertainties in causal relationships (Geekiyanage *et al.*, 2023). It utilizes fuzzy logic to capture subtle influences between factors, accommodating experts' subjective input for decisions. Unlike the binary graph theory and less flexible fuzzy-TISM, fuzzy-DEMATEL thrives in ambiguous contexts, ideal for analyzing complex and uncertain relationships (Kumar *et al.*, 2023). While the graph theory or fuzzy-TISM, FAHP, fuzzy-VIKOR and BWM methods are valuable in their own rights for multi-criteria decision-making, the specific characteristics of our research problem, which involve complex interrelationships and fuzzy data, make fuzzy-DEMATEL a suitable and advantageous choice for analyzing the barriers to LM adoption in the furniture industry of Bangladesh.

In order to identify the barriers to LM implementation in Bangladesh's furniture business, which is a developing economy, our study intention is to offer a framework. Lack of understanding of the connections between the barriers is preventing many furniture industries from successfully implementing the LM idea. Figure 1 depicts the stages of this study.

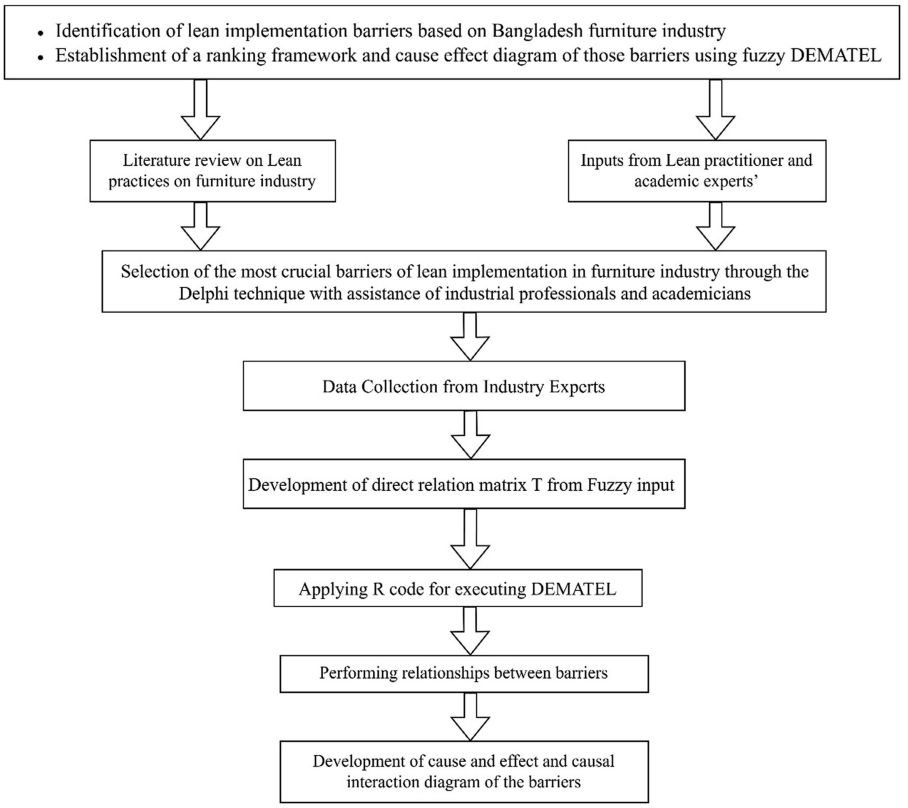


Figure 1.
Flowchart of the current research

Source(s): Author's own contributions

3.1 Study design, data collection and validation

The fuzzy-DEMATEL is used in this study to examine the main motivations for implementing LM. Three distinct methods of getting expert feedback were used in the data collection procedure. In the initial stage, a survey questionnaire (attached in appendix) was sent via Google Form to 21 experts with the intention of validating and improving the significant barriers that had been identified. During the data validation process in our study, a purposive sampling method was employed to select a group of 21 experts with diverse backgrounds in both industry and academia. The purposive sampling method, a non-probability sampling technique, involves the deliberate selection of specific respondents based on characteristics or attributes relevant to the research objectives (Moktadir *et al.*, 2018). To maintain the privacy of these experts, their names are not disclosed in this study. The carefully chosen individuals were actively involved and directly involved in the furniture sector. The specialists were chosen based on requirements that they are well knowledgeable about lean manufacturing and have working knowledge of the furniture sector, and at least six years of experience. The selection criteria for these experts were meticulously applied through panel sessions to ensure their qualifications for providing insights into the adoption of LM. The criteria for expert selection encompassed: (1) Expertise in LM adoption, (2) Sufficient understanding of lean concept and (3) Familiarity with the Bangladeshi furniture industry. The resulting panel of experts included individuals who held positions as

professors and industry executives, collectively amassing over a decade of experience in the domain of LM. Table 3 includes an overview of the profiles of the experts who took part in the study. Table 4 shows the finalized barriers of furniture industries that were developed by the experts.

Following the meticulous evaluation process and thorough consideration of expert suggestions, a total of 12 key barriers, aligned with the scope of this investigation, were identified. Initially, the experts considered the broader context of LM adoption and condensed the initial list of 16 barriers identified in the literature review to 13. In the subsequent round, the experts further refined the list of barriers, concentrating specifically on cognitive and human psychological factors, ultimately selecting 12 barriers. These barriers, presented in Table 4 introduced by the panel of experts by using the Delphi technique.

In this study, the three-stage Delphi methodology is used to pinpoint the important barriers affecting LM adoption. Figure 2 (adopted from H. M. Taqi *et al.*, 2023) illustrates the

Experts	Size of industry	Experience level	Professional role
1	Medium	10 years	Industrial Engineer, Researcher, PQR Furniture Industry
2	Large	12 years	Vice president, Lean Manufacturing department, PQR Furniture Industry
3	Large	15 years	Manufacturing Director, XYZ Furniture Industry
4	Medium	11 years	Manager, ABC Manufacturing Industry
5	Small	6 years	Head of procurement, ABC Manufacturing Industry
6	Large	9 years	Operation Specialist, ABC Manufacturing Industry
7	Medium	12 years	Senior Industrial Engineer, PQR Furniture Industry
8	Large	12 years	Manager, Industrial Engineering department, PQR Furniture Industry
9	Large	15 years	Manager, XYZ Furniture Industry
10	Medium	10 years	Researcher, R&D division, PQR Furniture Industry
11	–	7 years	Assistant Professor, X university
12	–	6 years	Assistant Professor, Y university
13	–	8 years	Professor, X university
14	–	7 years	Professor, X university
15	–	6 years	Professor, X university

Source(s): Authors' own contributions

Table 3.
Profiles of experts

Code	Barriers
A1	Fragmented industry structure
A2	Inefficient production time
A3	Insufficient skilled manpower
A4	Limited technical resources
A5	Lack of modern design
A6	Lack of quality control
A7	Insufficient expert management
A8	Resistance to change
A9	Unaware about the benefit
A10	Lack of capital cost
A11	Rejection of lean practice
A12	Inadequate plant layout and maintenance

Source(s): Authors' own contributions

Table 4.
The list of final barriers developed from experts' input

involved steps in the three-stage Delphi method. The figure illustrates how a thorough literature study is used to first identify the pertinent barriers.

3.2 Fuzzy-DEMATEL method

Fuzzy-DEMATEL technique includes seven basic steps:

Step 1: Objectives and evaluation criteria with respect to them are determined.

Step 2: Decision-makers are questioned to determine their judgments about the relationship between criteria. Since human judgments on evaluation criteria include uncertainty, five linguistic terms "Very high influence, High influence, Low influence, Very low influence, No influence" are determined. Then these linguistic terms are expressed as positive triangular fuzzy numbers as shown in Table 5. The answers of decision-makers in terms of linguistic terms are converted to triangular fuzzy numbers.

Step 3: Let $\widetilde{O}^k$ is the k. evaluators' fuzzy decision matrix about the criteria expressed in terms of fuzzy triangular numbers. $\widetilde{O}^k$ is normalized as follows:

$$\widetilde{O}^k = \begin{matrix} 0 & \widetilde{o}^k_{12} & \dots & \widetilde{o}^k_{1n} \\ \widetilde{o}^k_{21} & 0 & \dots & \widetilde{o}^k_{2n} \\ \dots & \dots & \ddots & \dots \\ \widetilde{o}^k_{n1} & \widetilde{o}^k_{n2} & \dots & 0 \end{matrix}, \quad \mathrm{k} = 1, 2, \dots, \mathrm{p} \tag{1}$$

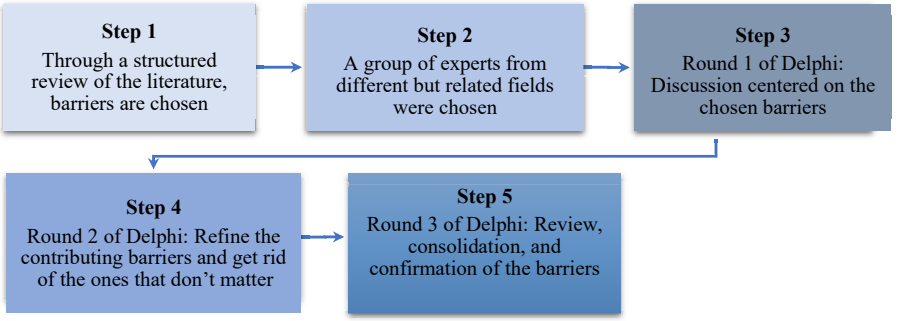


Figure 2.
Steps of the three-stage Delphi technique

Source(s): Figure courtesy of H. M. Taqi *et al.* (2023)

Linguistic terms	Triangular fuzzy numbers
No influence (N)	(0.00,0.00,0.25)
Very low influence (VL)	(0.00,0.25,0.50)
Low influence (L)	(0.25,0.50,0.75)
High influence (H)	(0.50,0.75,1.00)
Very high influence (VH)	(0.75,1.00,1.00)

Table 5.
Fuzzy linguistic scale

Source(s): Table courtesy of X

$$x^k = \max_{1 \le i \le n} \left(\sum_{j=1}^{n} r_{ij}^k \right) \tag{2}$$

$$\widetilde{o}_{ij}^{(k)} = \frac{\widetilde{Y}_{ij}^{(k)}}{x^{(k)}} = \left(\frac{a_{ij}^{(k)}}{x^{(k)}}, \frac{b_{ij}^{(k)}}{x^{(k)}}, \frac{c_{ij}^{(k)}}{x^{(k)}} \right) \tag{3}$$

Step 4: In this step, average value of p evaluators normalized fuzzy decision matrix is found.

$$\widetilde{O} = \frac{\widetilde{o}^{(1)} \oplus \widetilde{o}^{(2)} \oplus \ldots \oplus \widetilde{o}^{(p)}}{p} \tag{4}$$

$$\widetilde{O}^k = \begin{matrix} \widetilde{o}_{11} & \widetilde{o}_{11} & \ldots & \widetilde{o}_{ln} \\ \widetilde{o}_{21} & \widetilde{o}_{22} & \ldots & o_{2n} \\ \ldots & \ldots & \ddots & \ldots \\ \widetilde{o}_{n1} & \widetilde{o}_{n2} & \ldots & \widetilde{o}_{nm} \end{matrix}; \quad \widetilde{o}_{ij} = \frac{\sum_{k=1}^{p} \widetilde{o}_{ij}^{(k)}}{p} \tag{5}$$

Step 5: After finding initial direct relation matrix and normalizing it, total relation fuzzy matrix ($\widetilde{T}$) is defined as follows:

$$\widetilde{T} = \widetilde{O}.\left(I - \widetilde{O} \right)^{-1} \tag{6}$$

Step 6: In this step D and R are calculated. D is the sum of the row and R is the sum of the column of T. Then D and R are defuzzified separately. Best nonfuzzy performance (BNP) value was used as a defuzzification procedure. The BNP value can be found using the following equation:

$$BNP_{ij} = ((U_{ij} - L_{ij}) + (M_{ij} - L_{ij}))/3 + L_{ij} \tag{7}$$

BNP_{ij} represents the defuzzified value of D and R. We call defuzzified value of D and R as D and R, respectively.

In order to determine causal relationships between critical success factors, D + R and D − R are calculated. While D + R represents degree of central role (how much importance the criteria have), D − R shows the degree of relation. Relation divides the criteria in to cause and effect group. If D–R is positive then criteria belong to cause group. If D − R is negative then criteria belong to effect group.

Step 7: Causal diagram is constructed. In this diagram, the horizontal axis represents D − R while vertical axis represents D + R. In this diagram, the criteria above the horizontal axis mean that they belong to cause group. Criteria below the horizontal axis mean that they belong to effect group.

4. Analysis and results

4.1 Results of the study

This segment summarizes the results of using the fuzzy-DEMATEL method to understand the relations between the barriers to lean implementation in the Bangladesh's furniture

sector. An expert group comprised of academic and industrial specialists was formed to examine the interrelationship between the aspects related to the study work's aim (Step 1). The direct-relation matrix T is established, as shown in Table 6, based on expert responses. According to (Step 2) the language variable, the study examines the following responses to the human logic variable: no influence, very low influence, low influence, strong influence and very high influence. The linguistic scale is given in Table 5.

In the study, triangular fuzzy numbers are computed using the method of converting fuzzy data into crisp score (CFCS). The surveys are defuzzified to provide a crisp number. The initial direct-relation matrix F is computed by the logistic method to produce the initial direct-relation matrix F displayed in Table 7 (Step 3).

In (Step 4) with the use of the formula, the author creates a generalized direct-relation matrix S, whose main diagonal elements are all between 1 and 0. As shown in the generalized direct-relation matrix, presented as Table 8.

By applying equation to the generalized direct-relation matrix, the total-relation matrix M is obtained. Table 9 displays the total-relation matrix (Step 5). Within the total-relation matrix M, the sum of the rows and the sum of the columns are represented individually as D and R (Step 6). Following the DEMATEL method, the matrix is found from using R code.

Table 6.
Direct-relation matrix T

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
A1	0	VH	H	VH	VH	H	VL	VL	VL	VH	L	VH
A2	VH	0	H	H	VL	VL	VL	L	L	VL	H	H
A3	H	L	0	VL	L	VL	VL	VL	VL	H	L	VL
A4	VL	VL	L	0	VL	L	L	VH	L	VH	H	H
A5	VL	VL	VL	VL	0	VL	VL	VL	VL	VL	VL	VL
A6	H	VL	VL	VL	VL	0	VL	VL	L	L	VH	VH
A7	VH	H	H	VL	VL	VL	0	L	H	H	VH	L
A8	H	H	L	H	VL	L	H	0	VL	L	L	L
A9	L	VL	VL	H	VL	L	H	L	0	VL	H	VL
A10	H	VL	L	L	L	VL	L	L	VL	0	L	H
A11	VL	L	H	L	L	H	H	H	H	L	0	L
A12	VH	H	VL	L	VL	VL	VH	H	VL	H	H	0

Source(s): Authors' own contributions

Table 7.
Initial direct-relation matrix F

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
A1	0.00	0.97	0.75	0.97	0.97	0.75	0.25	0.25	0.25	0.97	0.50	0.97
A2	0.97	0.00	0.75	0.75	0.25	0.25	0.25	0.50	0.50	0.25	0.75	0.75
A3	0.75	0.50	0.00	0.25	0.50	0.25	0.25	0.25	0.25	0.75	0.50	0.25
A4	0.25	0.25	0.50	0.00	0.25	0.50	0.50	0.97	0.50	0.97	0.75	0.75
A5	0.25	0.25	0.25	0.25	0.00	0.25	0.25	0.25	0.25	0.25	0.25	0.25
A6	0.75	0.25	0.25	0.25	0.25	0.00	0.25	0.25	0.50	0.25	0.97	0.97
A7	0.97	0.75	0.75	0.25	0.25	0.25	0.00	0.50	0.75	0.75	0.97	0.50
A8	0.75	0.75	0.50	0.75	0.25	0.50	0.75	0.00	0.25	0.50	0.50	0.50
A9	0.50	0.25	0.25	0.75	0.25	0.50	0.75	0.50	0.00	0.25	0.75	0.25
A10	0.75	0.25	0.50	0.50	0.50	0.25	0.50	0.50	0.25	0.00	0.50	0.75
A11	0.25	0.50	0.75	0.50	0.50	0.75	0.75	0.75	0.75	0.50	0.00	0.50
A12	0.97	0.75	0.25	0.50	0.25	0.25	0.97	0.75	0.25	0.75	0.75	0.00

Source(s): Authors' own contributions

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
A1	0.00	0.13	0.10	0.13	0.13	0.10	0.03	0.03	0.03	0.13	0.07	0.13
A2	0.13	0.00	0.10	0.10	0.03	0.03	0.03	0.07	0.07	0.03	0.10	0.10
A3	0.10	0.07	0.00	0.03	0.07	0.03	0.03	0.03	0.03	0.10	0.07	0.03
A4	0.03	0.03	0.07	0.00	0.03	0.07	0.07	0.13	0.07	0.13	0.10	0.10
A5	0.03	0.03	0.03	0.03	0.00	0.03	0.03	0.03	0.03	0.03	0.03	0.03
A6	0.10	0.03	0.03	0.03	0.03	0.00	0.03	0.03	0.07	0.03	0.13	0.13
A7	0.13	0.10	0.10	0.03	0.03	0.03	0.00	0.07	0.10	0.10	0.13	0.07
A8	0.10	0.10	0.07	0.10	0.03	0.07	0.10	0.00	0.03	0.07	0.07	0.07
A9	0.07	0.03	0.03	0.10	0.03	0.07	0.10	0.07	0.00	0.03	0.10	0.03
A10	0.10	0.03	0.07	0.07	0.07	0.03	0.07	0.07	0.03	0.00	0.07	0.10
A11	0.03	0.07	0.10	0.07	0.07	0.10	0.10	0.10	0.10	0.07	0.00	0.07
A12	0.13	0.10	0.03	0.07	0.03	0.03	0.13	0.10	0.03	0.10	0.10	0.00

Source(s): Authors' own contributions

Table 8. Generalized direct-relation matrix S

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
A1	0.32	0.36	0.34	0.37	0.31	0.30	0.28	0.28	0.23	0.40	0.37	0.41
A2	0.38	0.22	0.31	0.31	0.20	0.21	0.24	0.27	0.23	0.28	0.35	0.34
A3	0.29	0.22	0.16	0.20	0.19	0.16	0.18	0.19	0.16	0.27	0.25	0.22
A4	0.30	0.25	0.28	0.22	0.20	0.24	0.28	0.33	0.24	0.36	0.36	0.34
A5	0.15	0.13	0.13	0.13	0.08	0.11	0.13	0.13	0.11	0.14	0.15	0.15
A6	0.31	0.22	0.21	0.22	0.18	0.15	0.22	0.21	0.21	0.24	0.34	0.32
A7	0.41	0.33	0.33	0.28	0.22	0.23	0.23	0.29	0.28	0.36	0.41	0.33
A8	0.36	0.31	0.28	0.31	0.20	0.24	0.30	0.21	0.21	0.31	0.33	0.31
A9	0.28	0.21	0.22	0.28	0.17	0.21	0.27	0.24	0.15	0.24	0.32	0.24
A10	0.32	0.22	0.25	0.25	0.21	0.19	0.25	0.25	0.18	0.21	0.29	0.31
A11	0.31	0.28	0.31	0.29	0.23	0.27	0.31	0.31	0.27	0.31	0.28	0.31
A12	0.41	0.33	0.27	0.31	0.13	0.23	0.35	0.32	0.22	0.36	0.38	0.27

Source(s): Authors' own contributions

Table 9. Total-relation matrix M

We also figure out the D, R, D + R, D − R value by using R code. Here D & R show us the relation among them. Table 10 provides the results (Step 7). Here, we rank the obstacles based on the values of (D + R), which represent the degree of centrality from Table 10. The ranking is given in Table 11.

From Table 10 we can see the value of (D − R). There we can find both positive and negative value. We can define these values into effective group and cause group. Effective group refers the values which are (D − R) < 0. The rest of the values mean positive values go under the cause group.

	A1	A2	A3	A4	A5	A6	A8	A9	A10	A11
D	3.984	3.358	2.484	3.403	1.552	2.830	3.380	2.840	2.934	3.479
R	3.853	3.087	3.094	3.180	2.424	2.545	3.047	2.495	3.471	3.843
D + R	7.837	6.444	5.579	6.583	3.375	5.374	6.427	5.335	6.405	7.322
D − R	0.130	0.271	−0.610	0.222	−0.872	0.285	0.333	0.345	−0.537	−0.364

Source(s): Authors' own contributions

Table 10. Relationship between criteria

Barriers	D + R	Ranking
(A1) Size of company	7.837	1
(A11) Adoption of lean practice	7.322	2
(A12) Plant layout and maintenance	7.219	3
(A7) Insufficient expert management	6.737	4
(A4) Technical resources	6.583	5
(A2) Production time	6.444	6
(A8) Employee attitude	6.427	7
(A10) Capital cost	6.405	8
(A3) Manpower	5.579	9
(A6) Environmental aspects	5.374	10
(A9) Unaware about the benefit	5.335	11
(A5) Variety of designs	3.375	12

Source(s): Authors' own contributions

Table 11. Ranking framework of the barriers

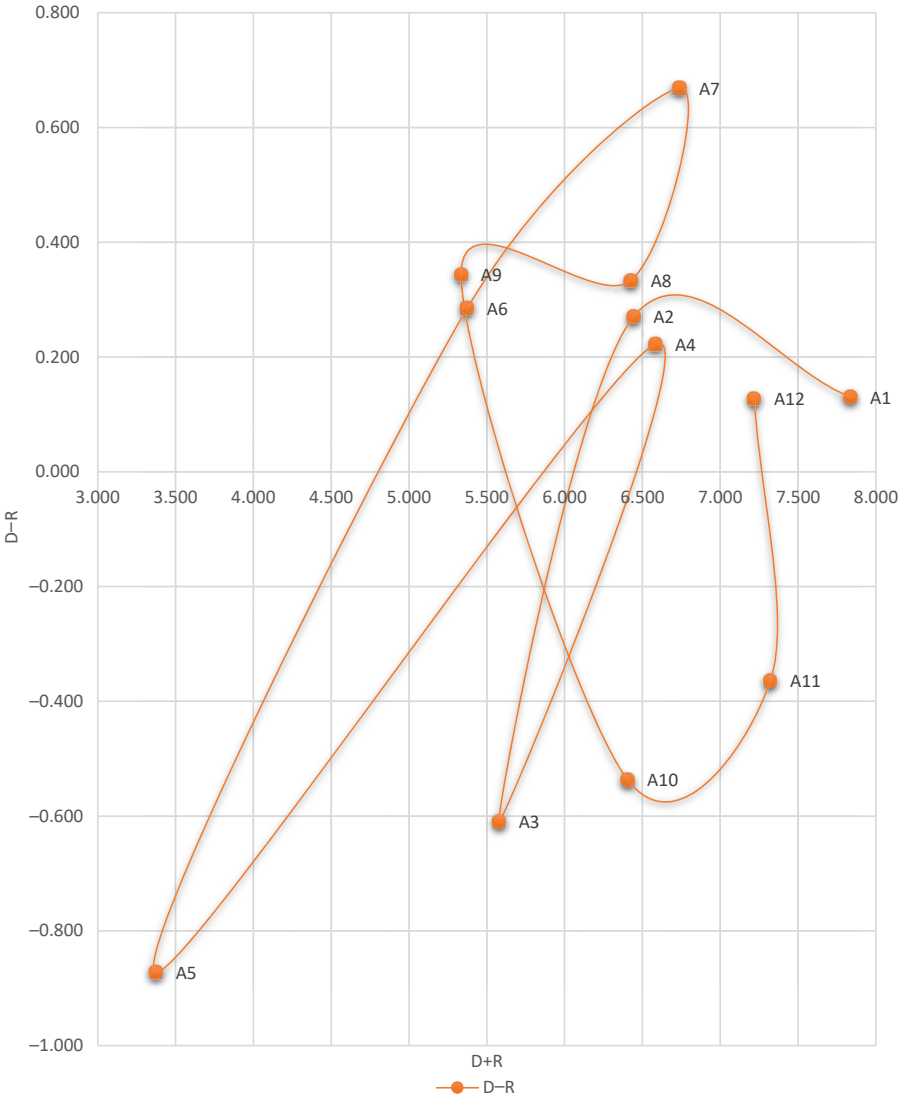
(D + R) degree of central role ranking shows in Table 11. From that table, A (1) Fragmented Industry Structure placed at first with value of 7.837, A (11) Rejection of lean practice placed at 2nd with a value of 7.322. The following A (12) Inadequate Plant layout and maintenance have value of 7.213. These three criteria have close value that refers that these three criteria are the main barriers in term of implement LM in the furniture industry. Then A (4), A (2), A (8), A (10) have the closest value. Mentioned four criteria have also eloquent influence on the furniture industry's adoption of lean manufacturing. A (3), A (6), A (9) have value of 5.579, 5.374 and 5.334, these three criteria impact on the industry ranked third. A (5) has the lowest value of 3.375 which have the lowest influence.

Depend on (D − R) our 12 criteria divided into two groups. (D − R) > 0 values are in cause group. These criteria are straightaway impact on the rest of the criteria. From Figure 3, A (3), A (5), A (10), A (11) criteria have the negative value for that placed in negative side of Y-axis. Where, the cause group appears in the positive side in the graph. Y-axis shows the level of influence. The X-axis of the graph represents the value of (D + R) and the axis shows consequence of criteria.

The pivotal role's degree is shown by the horizontal axis (D + R), on which the causal diagram was built. The vertical axis is (D − R), which represents the strength of the relationship.

In Figure 4 there shows the barrier ranking of the value (D + R) that we found from R code. From R code there a threshold value (α) of 0.2612414. With this threshold value we build up a causal interactions diagram. The diagram is buildup based on Table 9 which is total relation matrix M. Figure 5 uses an arrow to indicate the values greater than 0.2612414. This number was used to assess the important connections between the barriers. By following the row of that matrix, we buildup the threshold diagram which is given in Figure 5. From Figure 5 we can see the influences of the barriers. The most arrows pointed on A (1), A (11), A (12). That means the A (1), A (11), A (12) barriers have the most impact in our furniture industry. A (5) has the lowest number of arrows pointed at. A (6) and A (9) have the second lowest arrows pointed at them. So, A (5) has the lowest influence in the furniture industry in based of our result.

From Figure 5, a causal interactions diagram, serves as a visual representation of the relationships between barriers influencing LM adoption in the furniture industry of Bangladesh. It provides a basis for strategic planning and decision-making aimed at improving the adoption process. Industrial managers can use this diagram to gain insights into critical factors, their interconnections and their relative strengths. By analyzing Figure 5,



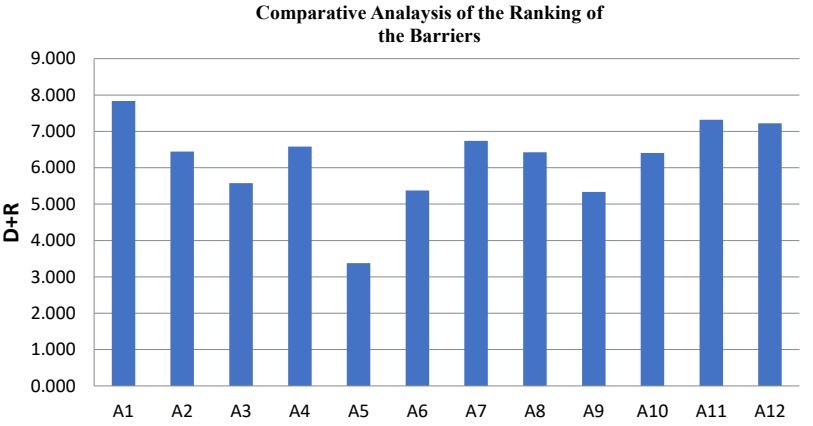
Source(s): Author's own contributions

Figure 3.
Causal diagram of (D − R) vs (D + R)

managers can make informed decisions, allocate resources effectively and prioritize actions to improve LM adoption within their industry.

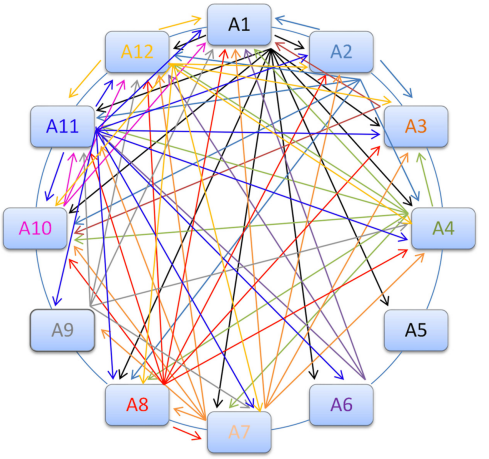
4.2 Validation of results

In this part of the study, the ranking of the barriers, causal diagrams were further validated with the help of industry practitioner. A series of focus group discussions were conducted in three phases, which involved 12 industrial managers to validate the research findings.



Source(s): Author's own contributions

Figure 4.
Bar charts of the ranking



Note(s): Above mentioned A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12 are the barriers
Source(s): Author's own contributions

Figure 5.
Causal interaction diagram of total relation matrix

The selection criteria for the participants included their years of working experience, current organizational affiliation and area of expertise. Specifically, participants were chosen based on having at least 15 years of working experience, currently working in a manufacturing organization, and possessing knowledge of LM principles. In the first phase, the ranking of lean implementation barriers was given to the participants for validation. After the discussion, the participants reached a consensus on the ranking of barriers. During the second phase, the participants were asked to validate the barriers within context of the barriers. This was done to ensure that the barriers identified in the first phase were accurately categorized. Finally, the causal diagram and causal interactions diagram was presented to the participants. The participants were asked for their opinions on the direct and indirect

relationships among the barriers, and whether they were appropriate in the context of furniture industry of Bangladesh. The participants expressed that they found the direct and indirect relationships among the barriers to be appropriate and relevant in the current context. Overall, this phase helped to further validate and refine the identified barriers and provided a deeper understanding of the relationships among them.

5. Discussion and implications of the study

5.1 Discussion of the findings

The findings of our LM study hold substantial significance in the context of the furniture industry in Bangladesh. Just as Industry 4.0 (I4.0) technologies have transformed manufacturing, the adoption of LM practices can revolutionize the furniture industry's operations. However, understanding the barriers to LM adoption and their implications is essential for fostering this transformative change. This study sheds light on the elements obstructing LM implementation and analyzes their impact on the industry's journey towards efficiency and sustainability. Our study contributes to the growing body of research on LM adoption, particularly within the context of the furniture industry in Bangladesh. In comparing our findings with existing studies, we can draw attention to the distinctive aspects and significance of the research. Our study stands out as one of the few initiatives to investigate LM implementation barriers in the Bangladeshi furniture industry. While previous studies have addressed LM adoption in various contexts, such as manufacturing and service sectors (Ponnambalam *et al.*, 2023; Robertsone *et al.*, 2022; Leite *et al.*, 2022; Mathiyazhagan *et al.*, 2022), none have specifically focused on the furniture industry in Bangladesh. This specificity is vital as different industries often face unique challenges in LM implementation. Therefore, our research fills a critical gap in the literature by shedding light on the barriers specific to this industry. Similar to broader studies on LM, we recognize the intricate web of interdependencies among LM adoption criteria in the furniture industry. Our utilization of the fuzzy-DEMATEL method allows us to understand these complexities better. By delving into the causal relationships among various factors, we can pinpoint which criteria exert the most influence and which are most vulnerable to external influences. This sophisticated approach sets our study apart from simpler analyses in the LM literature. In contrast to general LM studies, our research within the furniture industry of Bangladesh reveals that "Fragmented Industry Structure," "Rejection of Lean Practice" and "Inadequate Plant Layout and Maintenance" are the top three barriers. This contrasts with studies in other sectors (Abu *et al.*, 2022; Qureshi *et al.*, 2022), where barriers may differ in significance. These unique findings underline the industry-specific nature of LM challenges, emphasizing the importance of tailoring strategies to address these particular obstacles. Our study offers practical insights into how the furniture industry in Bangladesh can overcome LM adoption barriers. The focus on "Insufficient Expert Management" highlights the need for knowledgeable leadership during the transition phase. Additionally, addressing "Limited Technical Resources" and "Lack of Capital Cost" becomes crucial. These findings guide industry practitioners in crafting targeted strategies, showcasing the real-world relevance of our research. In summary, our study bridges the gap in the literature by addressing LM adoption barriers in the Bangladeshi furniture industry. While drawing on established LM concepts, our research provides industry-specific insights that can guide strategies for successful adoption. The authors have noticed that the outcomes under various circumstances do not significantly change. It demonstrates how reliable our model is. LM adoption of Bangladesh furniture sector is primarily influenced by three barriers. These are the "Fragmented Industry Structure," "Rejection of Lean Practice," and "Inadequate Plant Layout and Maintenance". The rest of the barriers are being influenced by these three barriers. However, the technique used in this study enabled them to be combined, producing a

framework that all the decision-makers involved could utilize to recognize and comprehend cause-and-effect links between groups of decision criteria. By comparing and contrasting our findings with existing studies, we emphasize the uniqueness of our contribution and underscore the need for industry-tailored approaches in LM implementation. This study lays the foundation for further research on LM in emerging markets, where such insights are crucial for industries striving for growth and competitiveness.

5.2 Theorical implications

The results of this study, from the standpoint of a practitioner, aid in comprehending the barriers and their interaction. Using our methodology, it is possible to prioritize the barriers and direct attention toward them in the proper order. Before implementing lean, the company must make sure that the management is dedicated and has the knowledge and abilities to recruit personnel. Another key barrier to lean deployment is Resistance to Changes and absence of awareness of the benefits. The biggest problem with lean implementation is the propensity to fall back into old routines when barriers arise. Therefore, knowledgeable inspiration and leadership are required during the shift phase. Along with fixing these internal issues, lean implementation needs to be broadened. Despite the fact that this study primarily employs case studies from wooden furniture companies, the created technique can be applied to other industries. As a result, overcoming a number of pertinent difficulties can be considerably linked to the offered structural framework of this research. Application of lean practices can directly contribute to the achievement of SDGs 12 (responsible consumption and production), eight (decent work and economic growth), 13 (climate action), 9 (industry innovation and infrastructure) and others, because it improves and augments production processes while taking into account effects on the environment, the workplace and natural resources. The literature already available on the application of lean gains various theoretical insights from this study, including:

(1) Highlighting the main barriers that the emerging market furniture sector will face in implementing LM.

(2) Using the fuzzy-DEMATEL technique to assess and rank the main obstacles.

(3) To have a thorough understanding of how LM deployment might affect productivity and lessen any unfavorable effects on the furniture business

(4) Laying the groundwork for further, in-depth research to give decision-makers a better understanding of the barriers facing the introduction of LM in many other manufacturing sectors.

5.3 Practical implications

The explanation given above exemplifies the observations made from the research, which will aid the furniture industries in understanding the barriers that are most important, least important and how they are related. Administrators will be better able to recognize the barriers in implementing lean as a result of this understanding. The study would be interesting to lean practitioners since it might be applied in organizations to focus on the interaction of obstacles needed for the effective adoption of LM. If manufacturers, researchers and politicians had a better understanding and understanding of these barriers, they could remove important obstacles to the implementation of lean projects. Scholars from different fields of industrial management could also follow the findings and discussions on the results. Managers will utilize the analysis as a starting point to boost their lean initiatives within their manufacturing organizations. By focusing on the largest barriers, the study might help managers in manufacturing organizations use their resources as efficiently as possible. They

can choose which obstacle to concentrate on first by taking into account how this study analyzes the barriers and shows the hierarchical relationships between them. Since lean utilization and resource management are listed first among all the barriers, managers and policymakers should first focus on these issues. This study offers valuable practical insights for stakeholders in the furniture industry. The findings provide actionable guidance for industry practitioners, making our research directly relevant to real-world challenges. The practical implications are highlighted below:

Addressing fragmented industry structure: Given that "Fragmented Industry Structure" is a significant barrier, furniture manufacturers should consider strategies to collaborate and consolidate their operations. This could involve forming alliances, sharing resources or creating industry associations to collectively address common challenges.

Overcoming resistance to lean practice: Since "Rejection of Lean Practice" is a top barrier, it is essential to focus on change management and employee engagement strategies. Implementing lean practices should involve educating and involving the workforce in the process to minimize resistance.

Improving plant layout and maintenance: "Inadequate Plant Layout and Maintenance" is another critical barrier. Manufacturers should prioritize investments in facility upgrades, layout optimization and regular maintenance to create an environment conducive to lean manufacturing.

5.4 Policy implications

Industry consolidation support: Policymakers can encourage furniture manufacturers to collaborate and consolidate their operations by offering incentives, tax breaks or grants for joint ventures or mergers that promote efficiency and competitiveness.

Change management training: Government-backed programs can provide training and resources for change management, emphasizing the importance of employee buy-in and participation when transitioning to lean practices.

Plant infrastructure development: Policies should support infrastructure development in the furniture industry, including incentives for upgrading plant layouts and ensuring regular maintenance to enhance efficiency.

Quality standards and certification: Establish industry-specific quality standards and certification programs that incentivize manufacturers to maintain high standards in plant layout and maintenance, aligning with lean principles.

Knowledge sharing platforms: Create platforms for knowledge sharing and best practice dissemination within the fragmented industry. Government-sponsored initiatives or industry associations can facilitate this exchange.

Research and development grants: Encourage R&D initiatives that focus on innovative solutions for overcoming barriers related to plant layout and maintenance. Grants and funding support can be provided for such projects.

By prioritizing these practical and policy implications based on the top three barriers, the furniture industry in Bangladesh can systematically address the challenges it faces in adopting lean manufacturing practices, leading to enhanced productivity and competitiveness. This study could be helpful to firms by helping them prioritize the lean implementation based on the performance measurements they think are more strategically crucial to improve.

6. Conclusion and future scopes of the study

In conclusion, this research has provided valuable insights into the challenges and opportunities surrounding the adoption of lean manufacturing practices in the Bangladeshi

furniture industry. By employing the DEMATEL technique, we have uncovered a nuanced understanding of the barriers faced by this sector. The study's conclusions indicate that there are numerous managements, technical and financial-related obstacles in the Bangladeshi furniture industry, making the application of lean a difficult procedure. This study has revealed several managerial, technical and financial barriers, rendering the implementation of lean practices a complex endeavor in the Bangladeshi furniture industry. Notably, both lean and non-lean organizations identified financial constraints as the primary obstacle. This underscores the critical role of financial resources in lean adoption. Moreover, a lack of expertise and knowledge emerged as a major impediment, emphasizing the need for training and skill development in lean methodologies. These conclusions enhanced our understanding of the deficiency of lean implementation in the furniture business in Bangladesh. It is shown that because the furniture companies have limited resources and capital, they can't employ all lean tools and methods simultaneously. Additionally, it highlights the significance of addressing management gaps and promoting specialized production processes, design and workmanship. To navigate those barriers and foster the efficient implementation of lean principles, it is imperative for the Bangladeshi furniture industry and relevant stakeholders to take deliberate actions. These actions encompass cultivating expertise among management, enhancing quality control mechanisms, investing in research and development and addressing structural inefficiencies.

While this study provides valuable insights, it acknowledges certain limitations. Authors have derived some barriers from expert opinions, leaving room for additional research to explore a more comprehensive range of barriers. Although authors have applied the fuzzy-DEMATEL approach to enhance result acceptance, other criteria-ranking methods (i.e. fuzzy-AHP, fuzzy-TISM, fuzzy-VIKOR etc.) warrant exploration in future work. The future research landscape in this domain is promising. It could encompass a more comprehensive investigation into barriers affecting the furniture industry's lean implementation. Additionally, exploring alternative fuzzy aggregation methods may offer deeper insights. Future studies should also focus on the broader industry ecosystem and outreach strategies tailored to different sectoral perspectives. This study contributes to the growing body of knowledge on lean adoption in the furniture sector of Bangladesh. It underscores the industry-specific challenges and offers valuable insights for practitioners and policymakers alike. Further research in this sector holds great potential for improving lean implementation and enhancing the competitiveness of the industry on a global scale.

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Appendix

The supplementary material for this article can be found online.

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