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A fuzzy DEMATEL-based framework for prioritizing waste reduction tools in factories

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Abstract DEMATEL is a multicriteria decision-making method used to analyse interrelationships and identify the cause–and–effect structure between different factors in a system. This method calculates the intensity of the factors' influence on each other, divides them into two categories, "influencing" and "affected", and displays the relationships between them in the form of a directed graph. DEMATEL can help decision-makers identify key factors and set priorities for improving system performance or solving complex problems. Lean manufacturing is an approach to production management designed to eliminate waste in processes, reduce costs, and increase value for customers. DEMATEL is used in lean manufacturing to identify cause–and–effect relationships between factors affecting production. This method can identify key factors in eliminating waste, evaluate the impact of changes, and prioritize improvement actions. As a result, it helps optimize lean processes and achieves continuous improvement. In this study, 14 lean production tools were first identified by reviewing the literature. Then, 10 more comprehensive tools were selected on the basis of expert opinion. Finally, these 10 tools were prioritized via the fuzzy DEMATEL technique. The prioritization results show that effective tools, including the plan, do, check, act (PDCA) thinking method along with Kaizen, ABC analysis for inventory control, and visual inventory control at workstations, play a key role in improving lean production processes. On the other hand, effective tools, such as the use of failure mode and effects analysis to reduce equipment failure and the use of reliability based maintenance, have been more effective in optimizing production systems.

Keyword: Waste, Factories, Fuzzy DEMATEL, Prioritization.

1 Introduction

The DEMATEL technique, proposed by the Genoa Research Center [1], is used to identify patterns of causal relationships between variables [2]. This technique is a method for displaying the complex structure of causal relationships by means of a diagram or matrix, where the matrices or diagrams show relationships on the basis of the elements of the system, and the numbers on the diagrams indicate the intensity of the effect of each element [3; 4]. The use of fuzzy sets is more compatible with verbal and sometimes ambiguous human expressions; therefore, it is better to use fuzzy sets to apply fuzzy numbers to long-term forecasting and decision-making in the real world [5; 38]. Considering that the use of the DEMATELEL method requires expert opinions and that these opinions include verbal and

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ambiguous expressions, to integrate and disambiguate them, it is better to convert these expressions into fuzzy numbers. To solve this problem, Lin and Wu presented a model that uses the DEMATEL method in a fuzzy environment [4; 39]. In the present study, the pattern of causal relationships between the main criteria was identified with the fuzzy DEMET technique in production, and the important issue of creating a lean production system was addressed. The DEMET technique has been used to reflect the internal relationships between the main criteria. Thus, experts are able to express their opinions with greater mastery regarding the effects (direction and intensity of effects) between factors. Notably, the matrix obtained from the DEMET technique (internal communication matrix) shows both the cause–and–effect relationships between factors and the effectiveness and impact of variables. Therefore, the output of the DEMET technique is used as a matrix of the internal relationships of the main criteria.

Lean production is a strategic approach for companies to respond appropriately to challenges, market competition, pressure on inventory and reduction of work in progress. Achieving lean management in organizations requires tools to achieve continuous improvement, reduce waste and increase efficiency in production processes [6]. Lean manufacturing is a management philosophy that seeks to reduce waste, eliminate nonvalue-added activities, and create value through process standardization [7]. Lean manufacturing has become a reference for manufacturing companies, especially those that have emerged from the automotive industry [8; 9].

Various tools and techniques are used to implement lean manufacturing, which is designed to reduce waste (e.g., defects, waiting, movement) and meet different objectives [9; 10]. Tortorella et al. reported that there are more than a thousand tools, although this number is expanding every year [11]; the use of lean manufacturing tools by manufacturing companies is randomly adopted on the basis of the company's conditions and problems, which can contribute to failure [8]. According to the findings of Badhotiya et al. [9], most published case studies on lean manufacturing have a low degree of maturity and only report the application of value stream mapping or describe other basic lean manufacturing tools, such as Kaizen or the tidy system. Negrão et al. [12] reported that successful implementation of lean manufacturing can be achieved by adopting simple lean manufacturing methods and tools that are implemented quickly because they produce tangible results in the short and medium terms and have a positive impact on operational, financial and environmental performance. This helps companies adopt more complex methods and create an efficient cycle for selecting lean tools. However, the dominant approach adopted for implementing lean manufacturing, which relies on traditional lean manufacturing methods and tools, does not benefit from the potential benefits of integrating alternative operational excellence frameworks to strengthen the implementation process [13]. In many manufacturing companies, numerous problems and challenges, especially in the areas of productivity and resource management, lead to waste of time, money and energy. These problems become more prominent, especially when intense competition in the market, rapid changes in demand and the need for greater flexibility put more pressure on companies. The production processes of many of these companies are complicated and, owing to the lack of precise monitoring and optimal systems, easily lead to waste of human resources, raw materials and machinery. This not only increases operating costs but also reduces product quality, prolongs delivery times and ultimately leads to customer dissatisfaction. These problems, especially when they remain chronically in the processes, put companies in a position where they are unable to compete effectively in global markets and respond to customer needs. On the other hand, the existence of financial concerns, economic pressures and the need to reduce costs prompt managers to seek solutions

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for continuous improvement and reduction of waste in production processes. In this context, an in-depth and systematic examination of existing problems and identification of effective solutions for optimizing these processes in manufacturing companies seem to be vital. In this study, a model based on the fuzzy DEMATEL technique is presented for prioritizing lean tools. The fuzzy DEMATEL technique is a decision analysis tool that is used to identify cause–and–effect relationships between different factors and, via fuzzy logic, examines the interrelationships between variables under uncertainty. This method determines the intensity of the effects between different elements and prioritizes them on the basis of their impact on the system.

2 Literature review

Different methods have been used in various studies to address the "prioritization problem"; among these techniques, we can mention the analytic hierarchy process, network analysis, Swara, RAS, etc. One of the efficient methods in prioritization is the DEMATEL method, which identifies the factors that are involved and affected in the work process itself and is therefore superior to other methods. This research addresses prioritizing lean tools via the DEMATEL method under fuzzy data conditions.

Various methods have been proposed in the literature to identify and eliminate waste, but many organizations face numerous problems in implementing lean production systems [14, 36, 34].

The goal of Ravanbakhsh [14] is to present a model and prioritize the key factors of lean production success with interpretive structural modelling approaches and organizational process assets. Using the content validity ratio technique, 11 indicators, "project consultants, lean customers, lean suppliers, support and commitment of senior management, employee participation, Kaizen team, use of lean concepts and techniques, effective communication, alignment with the organization's strategy, reward system, training and evaluation", were identified as the most important indicators affecting the success of lean production. Organizational process asset techniques and interpretive structural modelling were used to test the research questions. In a study, Zabiti Asl et al. [15] used the theory of creative problem solving as a powerful, efficient and structured tool, opening a different perspective in the field of defining and solving problems facing humanity; its aim is to identify the principles and patterns that are used in solving creative problems. To reduce waste in an industrial company, it is used as a driving force, and its problem-solving tools are introduced as effective solutions to realize lean principles in this organization. According to the results of the ranking of the tools of creative problem-solving theory, the trimming tool, which is an analytical tool that plays a fundamental role in problem structuring and situation analysis and directly leads to the elimination of waste and value creation, is the first priority.

The purpose of Bashiri's research [16] is to present a model for evaluating lean production via fuzzy inference systems. The presented model consists of five fuzzy inference systems designed at two levels. The four first-level systems, as tools affecting lean production, produce a score as an output, and these outputs are used as inputs to the final system for evaluating lean production. The results of developing the model and applying it in a machinery and equipment company showed that the presented model, in addition to showing the status of lean production in the organization, is also able to determine the status of the organization in terms of each of the factors and criteria affecting lean production.

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Moghadam Arjomand et al. [17] introduced and reviewed domestic and foreign studies on the practical application of lean tools and methods, reporting their findings, strengths and weaknesses. The result is that the use of lean tools such as value stream mapping, 5S, and continuous improvement can lead to improved performance in various industries and increased customer satisfaction.

Dehghan Nayiri and Bijan [18] used the fuzzy TOPSIS technique with the help of experts in this field to prioritize production boom strategies, and ultimately, the strategy of improving product quality was determined as the first production boom strategy by the experts.

Emamzadeh et al. [19] identified and ranked the most important factors affecting the implementation of lean production by the Chashgar Company via network process analysis. The network analysis process was used to analyse the data. In the network analysis process technique, compliance with process management criteria is the first priority. The communication management criteria are the second priority, the support and support criteria are the third priority, and finally, the change management criteria are the last priority.

Jalalion and Farsijan [20] examined the interaction between the issues of lean manufacturing systems and world-class manufacturing in two stages. The statistical population of the study included 5 companies in the food industry that had started measures towards world-class manufacturing. The results revealed that lean manufacturing tools, flow mapping, Kaizen, total production maintenance, Six Sigma, standard work and 5S are considered for use and implementation in the organizational environment. According to the gray relational coefficient, the most important drivers are "reducing operating costs (marketing and production)" and "global issues (environment-market)", and poor planning and a lack of knowledge are the most important barriers to implementing world-class manufacturing in the manufacturing sector.

Solanki et al. [21] analysed the value stream mapping program to achieve overall superiority in small-scale companies. The results of this analysis revealed that the waiting time was reduced by 90 minutes, and the mold rework was reduced by 31.72%. Dresch et al. [22] presented a method to help SMEs in the industrial sector use the overall effectiveness of equipment as a tool for prioritizing improvement actions. This method provides a basis for continuous improvement and increased productivity in these companies by identifying and analysing the factors affecting equipment performance. Gülyaz et al. [23] developed a product called the “Customer Value Matrix” on the basis of five design principles extracted from the literature. This matrix is designed to facilitate organizations in identifying and capturing customer value and helps them better understand the needs and expectations of customers and take action to create value for them.

Schimanski et al. [24] presented the first software example of building information modelling with the lean construction approach, called “BM”. This product was designed using application requirements and was reviewed by experts in the field of construction management. Liutkevicien et al. [25] presented a general framework for implementing enterprise resource planning and lean management to develop digital business process improvement capabilities. Lean manufacturing aims to reduce operating costs and eliminate waste through two fundamental pillars:

1. A technique that uses stretch manufacturing to produce the required quantity at the required time and with the required quality.

2. Jidoka, an approach that promotes the joint use of machines and human labor to ensure production quality through tools such as visual controls and 100% automated inspection.

By using these methods, lean manufacturing achieves simplification of production processes, a reduction in inventory, and increased efficiency throughout the entire production process [26]. Many lean manufacturing tools are dedicated to achieving faster production flows and eliminating waste to achieve higher profits for owners and better quality for customers [27].

Several lean manufacturing tools have been reported by electronics industry experts to improve manufacturing processes. For example, material and information flow maps and value stream maps can be used to identify time-wasting, nonvalue-added activities, such as unnecessary movements and waste of resources, space, and production equipment [28]. On the other hand, continuous flow is the most efficient way to produce one part at a time, with each part moving immediately from one process step to the next without waste [29]. Lean manufacturing methods that are most commonly used to eliminate waste include just-in-time systems, value stream mapping, on-site warehousing techniques, cellular manufacturing, reduced setup times, pull manufacturing systems, statistical quality control, total maintenance, total quality management, and continuous improvement [30]. The foundry industry is also considered a critical layer in supply chain management because any delay in the delivery of goods or services leads to a chain of delays at each node, resulting in lost sales and customer dissatisfaction [21]. The implementation of lean manufacturing approaches in foundry processes has been reviewed in the literature. A survey conducted by Prasad et al. [31] with 71 lean management professionals on the application of lean manufacturing methods in a foundry in India revealed that lean manufacturing methods are applied moderately in the Indian foundry industry. Władysiak et al. [32] analysed the current state of the foundry process via computer systems and lean manufacturing tools, including layout plans, flow charts and value stream maps. The analysis revealed that the execution of many operations was associated with waiting time because of the time required to prepare the casting molds and organize the required materials or tools. Dhiravidamani et al. [33] examined a case study in the foundry sector of the automotive parts manufacturing industry. In this study, the manufacturing process focused on integrating the Kaizen technique and value stream mapping with a computer-based lean system for value addition. Lyu et al. [28] combined the current state map with system simulation to determine potential waste and inefficient flows. The experimental results revealed that the average cycle time was reduced by 53.33%. Chang et al. [34] used the fuzzy DEMATEL method to define the causal relationships among the factors of supplier selection. Wu and Lee [35] stated that the fuzzy DEMATEL method can solve the problems of complex and dependent factors with uncertainty. Fuzzy DEMATEL has also been validated in the research of Tseng [36].

3 Methodology

The present study is a descriptive survey in terms of purpose, application, and data collection. Sampling was nonprobable and purpose-based. The interviews lasted an average of 20--30 minutes. The research group in this study consisted of 5 academic members and 10 company members who identified and evaluated lean improvement tools. The company experts included 10 senior and middle-level managers of Shiraz Industrial Park who had experience in the fields of production and research and development (at least 3 years), at least a bachelor's degree, and relatively complete familiarity with the fields of supply, distribution, knowledge management, and interest in collaborating in this research. Additionally, during the research, the opinions of researchers and academics in this field were used as needed. In this context, the opinions of 5 university members who were expert professors in the fields of supply chain management and production management were used. In the qualitative part, the

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standardized open interview method was used. The interview protocol included stating the purpose of the research and emphasizing the confidentiality of the information. Additionally, permission to record the interviewees was obtained, and at the end of each session, the interviewees were asked to state if they had anything else to say. To analyse the data obtained from the interviews, phenomenological analysis, which focuses on the participants' perspectives, was used. This method is very useful in analysing qualitative data for investigations in specific situations, such as interviews and conversations. In this method, the focus is on what the lean improvement tools are, what their challenges and effective factors are, and what experiences they have in this regard. In this research, according to the solutions proposed in scientific articles [37, 38], steps were taken to establish 4 criteria for validity, reliability, confirmability, and transferability. For example, to confirm the reliability of the research, 2 people who had no conflicts of interest related to the subject in question were interviewed in parallel. Additionally, to achieve transferability, the data collected in the research process were collected in full detail and in a transparent and unambiguous manner. To achieve the verifiability feature, all the data, notes and documents related to the interviews were saved for subsequent reviews. To confirm the validity of the work, first, in all stages of data collection, the subject of the work was explained clearly to the interviewees, the interviewers' attention (self-review) was carried out during the work process, and the answers of different interviewees were also matched with each other.

$$Z = \left(l_{ij}, m_{ij}, u_{ij}\right) \quad z = \begin{bmatrix} 0 & z_{12} & \cdots & z_{1n} \\ z_{21} & 0 & \cdots & z_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ z_{n1} & z_{n2} & \cdots & 0 \end{bmatrix} \tag{1}$$

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

$$a_{ij} = \sum_{j=1}^{n} z_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij}\right) \tag{3}$$

$$x = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \& \; x_{ij} = \frac{z_{ij}}{r} = \left(\frac{l_{ij}}{r}, \frac{m_{ij}}{r}, \frac{u_{ij}}{r}\right) \tag{4}$$

$$T = \begin{bmatrix} t_{11} & t_{12} & \cdots & t_{1n} \\ t_{21} & t_{22} & \cdots & t_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ t_{m1} & t_{m2} & \cdots & t_{mn} \end{bmatrix} \& \; t_{ij} = \left(l_{ij}{}'', m_{ij}{}'', u_{ij}{}''\right) \tag{5}$$

$$\left[m_{i}''\right] =* (j - x)^{-1}, \quad \left[u_{ij}''\right] = x_u * (I - x_u)^{-1} \tag{6}$$

$$\left[l_{ij}''\right] = x_l * (I - x_l)^{-1} \tag{7}$$

$$R = (R_i)_{n*1} = \left[\sum_{i=1}^{n} T_{ij}\right]_{n*1} \tag{8}$$

$$c = (c_i)_{1*n} = \left[\sum_{i=1}^{n} t_{ij}\right]_{1*n} \tag{9}$$

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On the basis of the literature and the expert interviews conducted, a total of 14 tools were identified (Table 1). Determining the improvement tools depends on operational experts. First, group meetings were held to evaluate and analyse the tools and their impact on the organization's performance. Ten of the tools were selected on the basis of the experts' opinions and their own experience (Table 3). In the next step, these tools are prioritized via the fuzzy DEMATELEL approach.

Table 1 Lean improvement tools

Icon	Factors Effective in Lean Improvement
1	Use the Plan, Do, Check, Act Thinking Method with Kaizen
2	Reduce both safety stock and inventory in production
3	Reduce redelivery time (from supplier to factory warehouse)
4	Use ABC analysis for inventory control
5	Use the reliability based maintenance principle
6	Use failure mode and effect analysis to reduce equipment failure
7	Improve shipping and packaging conditions of supplied materials
8	Reduce waste due to transportation, excessive movement, and waiting
9	Implement visual inventory control at workstations
10	Use the 5S system in inventories and workstations
11	Improve the quality of supplied materials
12	Use the Kanban system
13	Standardize inventory and operations
14	Provide 5S, Lean principles, Kaizen, and total production maintenance training modules for direct labor, maintenance, and warehouse

4 Findings

The fuzzy DEMATELL method was adopted to prioritize the proposed lean tools. This method has been chosen for two reasons: first, the ability of the DEMATELL method to transform the interrelationship between the characteristics of the problem into a structured model [39]. Second, fuzzy logic can be used to overcome the uncertainty judgment of experts [40]. Methods such as the analytic hierarchy process, TOPSIS and Vycover cannot establish causal links between variables; however, the DEMATELL method has succeeded in doing this [41-43].

The first step is to form a group of experts with sufficient knowledge and experience on the subject to collect data to solve the problem. In this step, while standard criteria are specified to compare the criteria with each other, 5 qualitative expressions are used, and the names of these expressions and their equivalent fuzzy values are shown in Table 2. After the opinions of the experts are collected, the fuzzy equivalent of each answer is replaced according to Table 2. Thus, the initial fuzzy direct correlation matrix is formed. This matrix is

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shown in Equation 1. The following equation represents factors i and j, where i=1, 2, 3, …, n and j=1, 2, 3, …, n.

Table 2 Qualitative expressions and equivalent values

No effect	(0.25, 0, 0)
Very little effect	(0.5, 0.25, 0)
Little effect	(0.75, 0.5, 0.25)
High effect	(1, 0.75, 0.5)
Very high effect	(1, 1, 0.75)

The improvement tools obtained and their associated impacts on different key performance indicators are listed in Table 3. The table shows the impact of the tools on the key performance indicators in descending order.

Table 3 10 Selected Effective Tools for Lean Improvement

Icon	Effective Factors for Lean Improvement
1	Using the Plan, Do, Check, Act Thinking Method with Kaizen
2	Reducing Redelivery Time (from Supplier to Factory Warehouse)
3	Using ABC Analysis for Inventory Control
4	Using Reliability-Based Maintenance
5	Using Failure Mode and Effect Analysis to Reduce Equipment Failure
6	Reducing Waste from Transportation, Excessive Movement, and Waiting
7	Improving the Transportation and Packaging Conditions of Supplied Materials
8	Implementing Visual Control of Inventory and Workstations
9	Using the 5S System in Inventories and Workstations Lean Principles, Kanban, Kaizen, and Productive Maintenance Training Modules for Direct Labor, Maintenance, and Warehouse
10	Improving the Quality of Supplied Materials

Out of a total of 15 distributed questionnaires, all were completed and returned by experts. To rank the factors via the fuzzy DEMATEL technique, the following steps were performed:

Formation of the average matrix: After receiving the experts' opinions, these opinions were combined via the arithmetic mean method, and the average matrix was obtained. Table 4

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shows the average of the experts' opinions based on the matrix of fuzzy direct relationships in the form of (L, M, U).

Table 4 Average expert opinions

	1	2	3	4	5	6	7	8	9	10
1	0,0,0	0,0.25,0.5	0,0.25,0.5	0.25,0.5,0.75	0.5,0.75,1	0,0,0.5	0,0.25,0.5	0,0,0	0.25,0.25,0.75	0,0.25,0.5
2	0,0,0.25	0,0,0	0,0,0.25	0.25,0,0.75	0,0,0	0.25,0,0	0,0,0.25	0,0,0.5	0.25,0.25,0.75	0,0,0
3	0,0,0	0,0,0.5	0,0,0	0,0.75,1	0,0,0	0,0.25,0.5	0.25,0,0	0,0,0.5	0,0.75,1	0,0.25,0.5
4	0,0,0.25	0,0,0.25	0,0,0.25	0,0,0	0.5,0.75,1	0,0,0.25	0,0,0.5	0,0,0.25	0,0,0	0,0,0.25
5	0.25,0,0	0,0,0.25	0,0,0.5	0,0,0	0,0,0	0.5,0.75,1	0,0,0	0,0,0	0,0,0.25	0,0,0.25
6	0,0,0	0,0.5,0.5	0,0.5,0	0,0,1	0.25,0.75,1	0,0,0	0.25,0.5,0.75	0,0,0	0.25,0.75,1	0,0.25,0.5
7	0,0,0.5	0,0,0.5	0,0.25,0.5	0.5,0.75,0	0.5,0,0.75	0.5,0.75,1	0,0,0	0,0,0.25	0.5,0,0.5	0,0.5,0.5
8	0,0,0.25	0,0,0.25	0,0.25,0.5	0,0,0.25	0,0,0.75	0,0.5,0.25	0,0.25,0.5	0,0,0	0,0,0.25	0.25,0.5,0.75
9	0,0,0.75	0,0.25,0.25	0,0.5,0.25	0.25,0.25,0.75	0.5,0.75,1	0,0,0	0.25,0.5,0.75	25,0.5,0.75	0,0,0	0.25,0.5,0.75
10	0,0.25,0.25	0,0,0.25	0,0,0	0.25,0.5,0.75	0.5,0.75,1	0,0,0	0,0,0	0,0,0	0,0.25,0.5	0,0,0

Table 5 shows the normalized direct relationship matrix.

Table 5 Normalized direct relationship matrix

	1	2	3	4	5	6	7	8	9	10
1	0،0،0	0،0.125،0.25	0،0.125،0.25	0.125،0.25،0.375	0.25،0.375،0.5	0،0،0.25	0،0.125،0.25	0،0،0	0.125،0.125،0.375	0،0.125،0.25
2	0،0،0.125	0،0،0	0،0،0.125	0.125،0،0.375	0،0،0	0.125،0،0	0،0،0.125	0،0،0.25	0.125،0.125،0.375	0،0،0
3	0،0،0	0،0،0.25	0،0،0	0،0.375،0.5	0،0،0	0،0.125،0.25	0.125،0،0	0،0،0.25	0،0.375،0.5	0،0.125،0.25
4	0،0،0.125	0،0،0.125	0،0،0.125	0،0،0	0.25،0.375،0.5	0،0،0.125	0،0،0.25	0،0،0.125	0،0،0	0،0،0.125
5	0.125،0،0	0،0،0.125	0،0،0.25	0،0،0	0،0،0	0.25،0.375،0.5	0،0،0	0،0،0	0،0،0.125	0،0،0.125
6	0،0،0	0،0.25،0.25	0،0.25،0	0،0،0.5	0.125،0.375،0.5	0،0،0	0.125،0.25،0.375	0،0،0	0.125،0.375،0.5	0،0.125،0.25
7	0،0،0.25	0،0،0.25	0،0.125،0.25	0.25،0.375،0	0.25،0،0.375	0.25،0.375،0.5	0،0،0	0،0،0.125	0.25،0،0.25	0،0.25،0.25
8	0،0،0.125	0،0،0.125	0،0.125،0.25	0،0،0.125	0،0،0.375	0،0.25،0.125	0،0.125،0.25	0،0،0	0،0،0.125	0.125،0.25،0.375
9	0،0،0.375	0،0.125،0.125	0،0.25،0.125	0.125،0.125،0.375	0.25،0.375،0.5	0،0،0	0.125،0.25،0.375	12.5،0.25،0.375	0،0،0	0.125،0.25،0.375
10	0،0.125،0.125	0،0،0.125	0،0،0	0.125،0.25،0.375	0.25،0.375،0.5	0،0،0	0،0،0	0،0،0	0،0.125،0.25	0،0،0

Table 6 shows the overall relationship matrix.

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Table 6 Overall Matrix

	1	2	3	4	5	6	7	8	9	10
1	0.05،0.12،-0.31	0،0.61،-0.22	0،0.9،-0.18	0.19،1.31،-0.33	0.44،2.21،-0.47	0.12،1.31،-0.3	0.03،0.8،-0.23	1.94،0.29،-0.28	0.16،1.17،-0.3	0.26،0.98،-0.32
2	0.02،0.02،-0.04	0،0.1،-0.29	0،0.17،-0.1	0.19،0.21،-0.14	0.2،0.37،-0.51	0.19،0.23،-0.37	0.04،0.15،-0.13	2.03،0.08،0.06	0.16،0.32،-0.15	0.27،0.19،-0.28
3	0.01،0.13،-0.2	0،0.54،-0.17	0،0.85،-0.33	0.05،1.46،-0.11	0.09،2.04،-0.61	0.06،1.37،-0.35	0.14،0.76،-0.29	0.53،0.36،0.01	0.04،1.43،-0.17	0.07،1.06،-0.19
4	0.04،0.03،-0.12	0،0.15،-0.13	0،0.22،-0.1	0.01،0.26،-0.41	0.29،0.84،-0.16	0.07،0.43،-0.12	0.01،0.2،-0.09	0.21،0.07،-0.11	0.02،0.3،-0.31	0.03،0.23،-0.21
5	0.14،0.08،-0.18	0،0.4،-0.11	0،0.59،-0.06	0.05،0.68،-0.24	0.14،1.24،-0.46	0.3،1.16،0.07	0.05،0.52،-0.19	0.83،0.2،-0.15	0.07،0.79،-0.15	0.11،0.6،-0.16
6	0.04،0.2،-0.24	0،1.06،-0.2	0،1.56،-0.33	0.11،1.82،-0.28	0.35،3.31،-0.37	0.13،2.09،-0.44	0.16،1.39،-0.09	2.34،0.53،-0.26	0.19،2.1،-0.23	0.32،1.61،-0.29
7	0.09،0.15،-0.12	0،0.61،-0.2	0،1.04،-0.19	0.4،1.57،-0.53	0.68،2.24،-0.54	0.44،1.73،-0.14	0.1،0.81،-0.4	4.26،0.32،-0.2	0.34،1.29،-0.3	0.58،1.22،-0.29
8	0.01،0.14،-0.14	0،0.5،-0.2	0،0.89،-0.08	0.02،1.07،-0.34	0.04،1.79،-0.34	0.01،1.4،-0.26	0،0.79،-0.17	0.03،0.27،-0.25	0،1.07،-0.3	0.13،1.09،-0.08
9	0.12،0.19،-0.03	0،0.81،-0.31	0،1.35،-0.22	0.42،1.7،-0.4	0.95،2.93،-0.45	0.28،1.88،-0.44	0.17،1.2،-0.19	13.66،0.63،-0.07	0.09،1.53،-0.62	1.84،1.52،-0.21
10	0.04،0.2،-0.06	0،0.36،-0.12	0،0.56،-0.16	0.14،0.95،-0.06	0.32،1.69،-0.02	0.08،0.94،-0.2	0.01،0.49،-0.22	0.23،0.21،-0.16	0.02،0.83،-0.15	0.03،0.6،-0.29

The threshold value of the average score was calculated as 0.342. Table 7 shows the matrix of values of the threshold matrix.

Table 7 Values of the threshold matrix

	1	2	3	4	5	6	7	8	9	10
1	0	0	0	0	0.49	0	0	0.61	0	0
2	0	0	0	0	0	0	0	0.62	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0.4	0	0	0	0
6	0	0	0	0	0.68	0	0	0.8	0.41	0
7	0	0	0	0	0.52	0.49	0	1.42	0	0.37
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0.67	0	0	4.66	0	0.81
10	0	0	0	0	0.44	0	0	0	0	0

Table 8 shows each of the factors and their levels of influence and impact.

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Table 8 Level and rank of influence and impact of factors

	D	R	D-R	D+R	Identity	Rank
1	2.07	-0.3	2.36	1.77	Cause	3
2	0.49	0.05	0.44	0.54	Cause	6
3	1.36	0.44	0.92	1.81	Cause	5
4	0.24	1.62	-1.38	1.86	Effect	8
5	1.27	3.47	-2.2	4.74	Effect	9
6	3.32	1.96	1.35	5.28	Cause	4
7	3.56	0.95	2.62	4.51	Cause	2
8	0.32	8.68	-8.37	9	Effect	10
9	6.91	1.39	5.51	8.3	Cause	1
10	0.94	2.19	-1.25	3.13	Effect	7

Figure 1 shows a cause–and–effect diagram of the influencing factors.

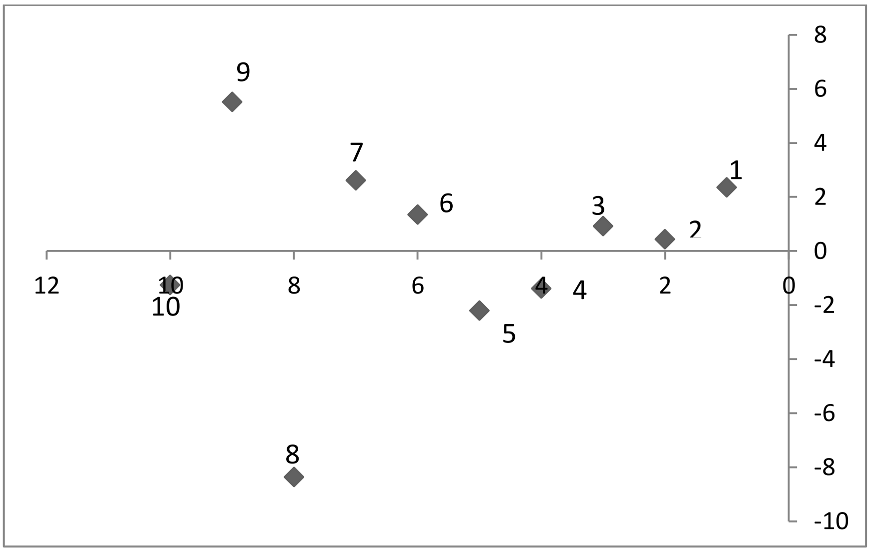

Fig. 1 Cause–and–effect diagram

5 Discussion

The aim of the present study was to evaluate lean tools and design a general framework based on the lean manufacturing approach. The fuzzy-deterministic method, which is used to analyse the interrelationships between lean tools, can be useful in identifying and solving problems in manufacturing systems. This method, which involves evaluating mutual effects and determining priorities, helps managers make more effective management decisions. In addition, identifying success factors before implementing lean tools increases the probability of success in implementing lean projects. Therefore, in the present study, among the influential factors, the use of planning, doing, checking, and acting methods with Kaizen and the use of ABC analysis for inventory control have the highest priority, and among the

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affected factors, the use of failure mode and effect analysis to reduce machine failure and the use of reliability based maintenance have the highest priority.

Palang and Khatrak [44] emphasized that the lean manufacturing approach is a vital tool for increasing productivity in manufacturing processes. The benefits observed after implementing individual or combined lean manufacturing techniques were a reduction in cycle time, elimination of nonvalue-added activities and production costs, and increased productivity. The gains achieved in terms of improving the work environment and ergonomic gains include time reduction, optimizing the production flow, and reducing the number of nonvalue-added activities and the distance travelled in the factory. Dhiravidamani et al. [33] argued that in many industrial processes, nonvalue-added activities can constitute more than 90% of the total activity of a factory. After the reforms were implemented, this percentage was reduced to 67%. Furthermore, Arnheiter and Maleyeff [45] proposed the benefits of the lean manufacturing approach in addition to reducing inventory levels, reducing process variation, demand variability, supplier variation and production variation, which includes changes in product quality characteristics. This finding is consistent with the implementation of Kaizen, which showed a reduction in variation and the absence of outliers after the implementation of improvement measures. According to Liutkevicien et al. [25], a deep understanding of the current situation should be combined with creative thinking to foster innovation and systematic problem solving. The implementation of solutions to reduce lead times via design thinking techniques (i.e., ideation and prototyping) helps in the design of support components. Jafarnejad et al. [46] emphasized that managers and executives should inform their employees about the goals and philosophy of lean and familiarize them with the functions of each lean activity so that they can adopt a clear and explicit direction.

6 Conclusions and suggestions

In today's competitive markets, organizations are seeking to improve their performance through various methods, including lean production. Lean production creates a system in the organization that results in minimal waste in performance. This system has several tools that have been mentioned in various articles and research. Identifying and prioritizing lean tools provides the basis for selecting more appropriate tools and providing more efficient action plans. On the other hand, the lack of resources available to the organization creates conditions that must be used on the basis of prioritization in the use of different tools. In this study, 10 lean tools with higher priority were identified via the fuzzy DEMATEL technique. The results of this study can help organizations that are seeking to implement a lean system take greater steps toward creating a lean system by spending fewer resources.

Appropriate lean production and prioritization are determined via the fuzzy DEMATEL method, which ultimately leads to the establishment of an improvement action plan. This approach helps organizations achieve continuous and sustainable improvement by providing a sequence plan for applying selected tools and their implementation schedule. The proposed model, with the ability to be implemented in most SMEs, offers a broad perspective for improving organizational performance. Finally, to ensure performance improvement, companies should implement a package of management decisions that include forming cross-functional kaizen teams, setting relevant performance goals and indicators, establishing reward and incentive systems, and holding monthly meetings to monitor production system bottlenecks. These management actions, along with appropriate system flexibility, help organizations achieve optimal and sustainable performance.

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