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ORIGINAL ARTICLE

Implementation barriers to lean-agile manufacturing systems for original equipment manufacturers: an integrated decision-making approach

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Abstract

The purpose of this research is to determine barriers to the implementation of lean-agile manufacturing systems in the context of Original Equipment Manufacturers (OEMs). Through literature review and expert opinions, 12 critical barriers were identified. Then, a decision-making tool, namely "Interpretive Structural Modeling (ISM)," was used for modeling barriers and identifying the critical barriers through their driving power. Further, the "Decision Making Trial and Evaluation Laboratory (DEMATEL)" was applied to explore the cause-effect relationship between the barriers. Two barriers, namely "Ineffective organizational management" and "Lack of experience with technology adoption," were identified as having significant, influential power. Organizations should focus on these barriers and need to develop strategies to overcome them for the successful implementation of lean-agile manufacturing systems.

Keywords Sustainability · Waste minimization · Flexibility · Implementation barriers · OEMs · Decision support systems

1 Introduction

Many companies intend to implement lean manufacturing systems into their manufacturing processes to eliminate waste, reduce customer lead times, increase product variety, and meet the customization demands. In addition, companies aim to keep the system more agile so that their manufacturing process can be flexible enough to meet highly volatile market demand. Even though there are many theoretical benefits for organizations by implementing lean concepts into their business models, actual implementation levels can be low. For example, in India, only 30% of companies have sustained lean processes. Hence, issues related to implementation analysis are a priority [1, 23].

The Original Equipment Manufacturer (OEM) products are mostly produced by discrete manufacturing processes that generate more waste and raise concerns about environmental sustainability [60]. It may be noted that the contribution of domestic supplies is 56% of the industry turnover, followed by exports of 26% and domestic aftermarket 18% [17]. Even though OEMs have begun to adopt advanced manufacturing technologies like additive manufacturing, IOT, and data

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analytics, they are unable to balance the sustainable dimensions of the firm. This forms the biggest motivation for this study.

There is a significant need to analyze the barriers to lean-agile implementation in Indian OEMs with a focus on sustainability. The present study aims to answer the following research questions:

1. RQ1: What are the barriers to lean-agile manufacturing system implementation?
2. RQ2: Which are the most influential barriers?
3. RQ3: What is the cause-effect relationship between barriers?

This manuscript is arranged as follows: Section 2 presents an in-depth literature review of lean-agile implementation across the different industries and various countries. Section 3 focuses on the methodology and the hierarchical model development. Section 4 is a discussion of results. Finally, Section 5 details the conclusions, limitations, and directions for future research.

2 Literature review

This section outlines the literature related to lean-agile manufacturing system implementation and focuses on the identification of the key challenges/barriers to the same in the Indian OEMs context. Our focus is to highlight the most critical research articles.

Nordin et al. [35] studied barriers that influence lean manufacturing implementation in the Malaysian automotive sector. It was found that lack of training and understanding of different lean tools and employee attitudes were the significant barriers. Singh and Singh [49] identified barriers related to the implementation of lean manufacturing among Indian firms. It was found that market volatility, industry layout, resistance to change, cost factor, product variety, and sustainability were the key barriers. Gandhi et al. [19] carried out research in the context of Indian SMEs and identified drivers related to the implementation of lean and green manufacturing practices and ranked them using the multiple-criteria decision-making (MCDM) methods (TOPSIS and SAW). They found that top management commitment, technology adaptation, and green brand image were the most critical factors. Leon and Calvo-Amodio [26] identified a set of characteristics for implementing lean manufacturing system to achieve sustainability and focused upon the companies that are adopting sustainability into their operations by using an integrated framework.

Bortolotti et al. [8] examined firms that have successfully implemented lean manufacturing systems and analyzed the influence of the organizational culture on its adoption. Results of the confirmatory factor analysis revealed that there exists a positive relationship between the two. Jadhav et al. [22] explored 24 different barriers to lean and agile implementation in manufacturing firms and suggested that its implementation depends on the application of tools/methods, support from management, employee attitudes, and culture and availability of resources. Kumar and Kumar [25] identified the challenges to lean tool implementation in Indian industries. The most significant barriers identified were a lack of management support and no long-term plan for implementing lean manufacturing practices. Cherrafi et al. [12] reviewed research articles on the integration of lean, six sigma, and sustainability and determined the drivers, critical success factors, and barriers to the same.

The details about agile manufacturing could be seen in the literary work of Dubey and Gunasekaran [15] and Potdar et al. [39]. Further, Dubey and Gunasekaran [15] proposed a framework for agile manufacturing, which has six constructs, namely "customer focus, technologies, flexible manufacturing systems, empowerment of workforce, supplier relationship management and organizational culture." The authors used multivariate statistical analysis to check the validity of their proposed framework. Pereira et al. [38] investigated the problems faced by Brazilian firms implementing lean/agile manufacturing systems. The critical issues found were employee resistance, cultural issues, and lack of resources. Engert and Baumgartner [16] focused on the connection between lean practices and sustainability from a systems point of view for firms implementing lean/agile processes. Das [13] studied how the companies are incorporating lean practices in the planning stage of the supply chain for achieving sustainability targets. Tiwari and Tiwari [55] investigated the critical challenges in implementing lean manufacturing systems in the Indian Automobile industry. Different barriers were identified in the Brazilian and Malaysian automobile industries. Jadhav et al. [23] studied barriers which obstructed the implementation of JIT production in Indian firms and analyzed their interrelationship.

Vázquez-Bustelo et al. [56] identified and analyzed different critical factors of agile manufacturing implementation in Spain. Sharma et al. [52] identified "Vertical organizational structure, Lack of reconfigurable layout, and Lack of effective virtual partnerships" as primary barriers for agile manufacturing implementation in Indian enterprises. Vinodh et al. [58] identified 30 criteria for the assessment of agility assessment in Indian pump organizations. Caldera et al. [10] studied how Indian companies can meet sustainability targets by implementing lean and green manufacturing initiatives. They also proved that management systems like policies, auditing, and reporting support lean and sustainable practice adoption. Zahraee [63] found that resources and customer relationships are essential for the successful implementation of lean systems in Iranian firms. Hasan et al. [21] identified the implementation barriers to agile manufacturing among Indian manufacturing firms and studied the relationship between them. Abolhassani et al. [2] studied different manufacturing facilities throughout Pennsylvania and West Virginia and summarized different strategies for implementing lean manufacturing. They conclude that employee commitment and contribution is the most critical factor for successful implementation.

Long ago, Achanga et al. [3] identified critical factors in 6 different management contexts such as management, leadership, finance, organizational culture, skills, and expertise that influence effective implementation of lean manufacturing in the Indian SME context. More recently, Pearce et al. [37] identified critical success factors for implementing lean systems successfully among the Indian SMEs and found that lack of awareness by top management about lean technologies is a significant indicator. Kumar [24] focused on lean implementation barriers in India (Delhi NCR Region) and found that poor planning, no commitment from top management, poor methodology, and lack of employee motivation were the key barriers. Brun [9] found that a lack of understanding and knowledge of lean tools is the most significant concern for implementing lean practices among Italian companies.

Martinez-Jurado and Moyano-Fuentes [31] found that organizational culture, management support, and motivation for quality are the key factors to initiate the lean systems. Salem et al. [46] determined that awareness and positive perceptions of lean systems were necessary for success. It was highlighted that there should be more focus on strategy development and implementation. Antony and Banuelas [5] explored and studied the critical challenges of six sigma implementation in UK manufacturing and service firms. The results showed that top management commitment was a crucial factor for successful implementation. Moori et al. [33] highlighted that employee skills and expertise are the linking parameters between lean system implementation and business performance.

2.1 Research gaps

Most of the prior researches have focused on the identification of barriers and implementation challenges related to financial resources and environmental concerns. However, limited investigations have been found which focus on aspects of employee involvement and human resources management. Significant elements such as employee incentive programs, performance measurement systems, and employee retention rates have not been analyzed. To the best of the authors' knowledge, the present research is a pioneering study designed to address issues of implementation of lean-agile manufacturing systems in Indian OEMs using an integrated Interpretive Structural Modeling (ISM) and Decision Making Trial and Evaluation Laboratory (DEMATEL) approach. The ISM methodology has been employed to explore the driving potential of the shortlisted barriers and to explore the interrelationships between them, whereas the DEMATEL approach helps in analyzing the cause-effect relationships between the barriers.

3 Research methodology and model development

The objective of the current study is to recommend a new theoretical hierarchical ISM-DEMATEL based on an integrated structural model of barriers to the implementation of a lean-agile manufacturing system in the automotive components OEMs. The ISM methodology was applied to develop the mutual relationship and ranking of the barriers. The literature review and an expert panel helped to identify 12 critical variables. The expert team consisted of four senior-level professors (minimum 8 years of experience in the field of OEMs and Sustainability), eight industry managers (minimum 10 years of experience in the field), and six consultants (minimum 7 years of experience). All the above industrial experts were from automotive components of Indian origin organizations.

3.1 Interpretive structural modeling (ISM) approach

The ISM methodology is used to identify the relationship between factors systematically. It helps to interpret ideas in a straight forward simple manner. Academicians use this approach extensively for identifying direct and indirect relationships between the identified factors across various industries [43]. The ISM tool, as compared to other methods (ANP and AHP), is more adept at capturing high-level dynamic complexity [23]. Also, it comprehends the complexities of real-life problems. It may be noted that ranking the different factors can be achieved through various multi-criteria decision-making methods like AHP, ANP, TOPSIS, and DEMATEL. Still, these methods lack in providing the hierarchical structure of the variables for quality decision-making purposes [62]. Hence, in the present study, ISM is used for developing a hierarchical structure with a set of barriers.

The steps involved in the ISM approach are explained below [6, 42].

1. Different barriers to the implementation of lean-agile manufacturing system were identified and are explained below in Table 1:

2. The experts helped us identify the relationship between variables. The contextual relationship was recognized for the 12 barriers. For identifying the direction of the relationship between the barriers, symbols i and j were used.

Table 1 Implementation barriers and their explanation

Sr. no.	Barriers	Explanation	References
1.	*Ineffective organizational management (IB1)*	This includes a lack of long-term vision, organizational culture, commitment, implementation strategies, and inefficient policy framing for personnel (human resources) from the management team. Management without proper long-term vision will fail to leverage the opportunities and lose a competitive advantage. Many issues can arise in an organization like insufficient training, resistance to change, and procrastination because of the lack of top management support and commitment. Employee involvement and commitment is critical for the organization to implement any upgradation program or a new process. It may be noted that it is not easy to change the culture of an organization as it demands considerable time and effort. It includes changing the thoughts, outlook, and habits of employees to the betterment of the organization and molding their mentality to trust the organization. Further, the lack of implementation strategies is a key barrier in implementing improvements in the organizations. The key role of implementation strategies is to make the organization better in terms of a new process or technology adoption. Lastly, the top management team should develop proper implementation policies to achieve success.	Warwood and Knowles [59]; Ravi and Shankar [44]; Scherrer-Rathje et al. [47]; Raj and Attri [41]; Talib et al. [54]; Albliwi et al. [4]; Attri et al. [6]
2.	*Resistance to change offered by the workers and supervisors (IB2)*	It may be noted that it is challenging to change the mindset of workers from their basic principles and traditional way of working. Hence, there is a need to identify any employees who are not comfortable embracing the use of new technologies and offer training to them, highlighting the implementation goals and benefits.	Mudgal et al. [34]; Kumar [24]; Sindhwani et al. [48]
3.	*Lack of communication, cooperation and mutual trust between various levels of management and workers (IB3)*	The success of any new and/or improvement system implementation is fully dependent on the effective communication and cooperation between employees and managers. Hence, trust between managers and employees plays a key role. Team building and bonding between team members positively influence the implementation process of any improvement program.	Sureshchandar et al. [53]; Sindhwani et al. [48]
4.	*Lack of incentive schemes and complex organizational pay and wage structure (IB4)*	Companies should have clear incentive schemes for the successful implementation of improvement programs. One of the critical factors resulting in resistance to change is poorly structured pay packages. Therefore, companies need to carefully design incentives into these programs—including recognition and reward system in their implementation strategy for motivating the workforce.	Mangla et al. [30]; Wong et al. [61]
5.	*Lack of technology upgradation and innovation (IB5)*	While costly, companies should focus on updating their technology continuously for competing in competitive and volatile markets. Technological upgrades not only help utilize resources efficiently but also improve methods and processes. Further, technology is a critical factor in achieving sustainable outcomes.	Balachandra et al. [7]; Long et al. [27]
6.			Expert opinion

Table 1 (continued)

Sr. no.	Barriers	Explanation	References
	Cross-functional conflicts (ERP implementation, TQM, TPM, JIT) (IB6)	The ability to manage cross-functional conflicts with minimal friction is significant to the success of implementing sustainable lean-agile manufacturing systems. Poor interdepartmental relationships brought on by a lack of communication is often responsible for cross-functional conflicts. To avoid these types of conflicts, top management, and the leadership team should clearly define the role and responsibility of each department in implementing the change.	
7.	*Lack of experience with technology adoption (IB7)*	Organizations having the right level of expertise in technology adoption and innovation helps to implant the latest or new technology for maximizing profits, gaining competitiveness, and improving brand image.	Grant [20]; Sindhwani et al. [48]
8.	*Initial capital/budgetary/financial constraints (IB8)*	Finance is essential for firms to support infrastructure, technology upgradation, offering incentives to the workforce, and hiring and training the workforce to implement a lean-agile system successfully. Hence, financial constraints could act as a significant barrier to lean-agile system implementation.	Achanga et al. [3]; Luthra et al. [28]; Sindhwani et al. [48]
9.	*Lack of understanding and promotion of sustainable products and their benefits (IB9)*	In the current scenario, industries are mainly customer-driven. Hence, firms should be able to provide products needed and demanded by customers with a focus on sustainability. Most recently, sustainable products provide a competitive edge and improve market share. Hence, there is a strong need to provide proper training to employees and clients alike about sustainable practices and their benefits.	Mathiyazhagan et al. [32]
10.	*Lack of cooperation from suppliers and consumers (IB10)*	Better collaboration is needed from the customer to understand their needs and to address their issues on time in an effective way. A productive relationship between the company, suppliers, and consumers is essential to achieve sustainable growth.	Potdar et al. [40]; Raut et al. [42]
11.	*Lack of Flexibility in the supply chain network (IB11)*	Companies must improve their capabilities to make their supply chains flexible and agile in a highly dynamic and competitive market.	Sabri and Shaikh [45]; Farahani et al. [18]
12.	*Absence of a valid lean performance measurement system (IB12)*	One of the significant barriers to successful lean system implementation is the lack of a proper performance measurement framework. There is a considerable need to deploy a lean performance measurement system for employees, and incentives may be offered to them accordingly. Further, training sessions should be organized for low-performing employees.	[44]

V: Barrier i will lead to barrier j
A: Barrier j will lead to barrier i
X: Barriers i and j will lead to each other
O: Barriers i and j have no relationship

Based on these interpretations, a pairwise relationship matrix of barriers, namely structural self-interaction matrix (SSIM) was developed (Table 2).

3. The initial reachability matrix (IRM), which is a binary matrix (Table 3) was formulated from the SSIM matrix by employing the following rules:

- If (i, j) entry in SSIM is V, then (i, j) entry in the reachability matrix becomes 1 and (j, i) entry becomes 0.

Table 2 The SSIM

S. no.	Implementation barriers	12	11	10	9	8	7	6	5	4	3	2
1	Ineffective organizational management (IB 1)	V	V	V	V	O	O	V	V	V	V	V
2	Resistance to change offered by the workers/supervisors (IB 2)	A	O	A	A	A	A	X	X	A	A	
3	Lack of communication, cooperation and mutual trust between the various levels of management and workers (IB 3)	V	V	A	A	A	O	V	V	X		
4	Lack of incentive schemes and complex organizational pay and wage structure (IB 4)	V	V	A	O	A	A	V	V			
5	Lack of technology upgradation and innovation (IB 5)	V	V	X	A	A	A	A				
6	Cross-functional conflicts (ERP implementation, TQM, TPM, JIT) (IB 6)	V	O	O	A	A	A					
7	Lack of experience about technology adoption (IB 7)	V	V	O	A	O						
8	Initial capital/budgetary/financial constraints (IB 8)	V	V	O	V							
9	Lack of understanding and promotion of sustainable products and their benefits (IB 9)	V	V	V								
10	Lack of cooperation from supplier and consumer (IB 10)	V	V									
11	Lack of flexibility in supply chain network design (IB 11)	O										
12	Absence of a valid lean performance measurement system (IB 12)	–										

- If (i, j) entry in SSIM is A, then (i, j) entry becomes 0 and (j, i) entry becomes 1.
- If (i, j) entry in SSIM is X, then (i, j) and (j, i) entry becomes 1.
- If (i, j) entry in SSIM is O, then (i, j) and (j, i) entry becomes 0.

Then, the developed binary matrix was checked for transitivity (if factor A is associated to B and B is associated to C, then A is undoubtedly associated to C), and taking into account its effect, the final reachability matrix (FRM) was formulated (Table 4).

4. The reachability matrix is subdivided into different levels to identify the position of each barrier in the hierarchy. The reachability (1's of the row) and antecedent (1's of column) sets for each barrier were identified. Then, the intersection of both sets was found for all barriers. A barrier having the same reachability and antecedent set values gets eliminated from the matrix and is placed at the top position in the hierarchical level. This step is repeated for all other barriers [50]. Table 5 explains the partitioning of the reachability matrix, considering five levels of the evaluation process.
5. With the help of a final reachability matrix (Table 4) and partitioning matrix (Table 5), the ISM model was developed (Fig. 1). For indicating the relationship between two barriers, i and j, an arrow is drawn from i to j and vice versa.

3.2 MICMAC analysis

In this study, MICMAC analysis was used to categorize the critical barriers to the successful implementation of a lean-agile manufacturing system into 4 clusters by considering

Table 3 The IRM

S. no.	IB 1	IB 2	IB 3	IB 4	IB 5	IB 6	IB 7	IB 8	IB 9	IB 10	IB 11	IB 12
IB 1	1	1	1	1	1	1	0	0	1	1	1	1
IB 2	0	1	0	0	1	1	0	0	0	0	0	0
IB 3	0	1	1	1	1	1	0	0	0	0	1	1
IB 4	0	1	1	1	1	1	0	0	0	0	1	1
IB 5	0	1	0	0	1	0	0	0	0	1	1	1
IB 6	0	1	0	0	1	1	0	0	0	0	0	1
IB 7	0	1	0	1	1	1	1	0	0	0	1	1
IB 8	0	1	1	1	1	1	0	1	1	0	1	1
IB 9	0	1	1	0	1	1	1	0	1	1	1	1
IB 10	0	1	1	1	1	0	0	0	0	1	1	1
IB 11	0	0	0	0	0	0	0	0	0	0	1	0
IB 12	0	1	0	0	0	0	0	0	0	0	0	1

Table 4 The FRM

S. no.	IB 1	IB 2	IB 3	IB 4	IB 5	IB 6	IB 7	IB 8	IB 9	IB 10	IB 11	IB 12	Driving power
IB 1	1	1	1	1	1	1	1*	0	1	1	1	1	*11*
IB 2	0	1	0	0	1	1	0	0	0	1*	1*	1*	*6*
IB 3	0	1	1	1	1	1	0	0	0	1*	1	1	*8*
IB 4	0	1	1	1	1	1	1*	0	0	1*	1	1	*9*
IB 5	0	1	1*	1*	1	1*	0	0	0	1	1	1	*8*
IB 6	0	1	0	0	1	1	0	0	0	0	0	1	*4*
IB 7	0	1	0	1	1	1	1	0	0	1*	1	1	*8*
IB 8	0	1	1	1	1	1	1*	1	1	1*	1	1	*11*
IB 9	0	1	1	1*	1	1	1	0	1	1	1	1	*10*
IB 10	0	1	1	1	1	1*	1*	0	0	1	1	1	*9*
IB 11	0	1*	0	0	0	0	0	0	0	0	1	0	*2*
IB 12	0	1	0	0	1*	1*	0	0	0	0	0	1	*4*
Dependency	*1*	*12*	*7*	*8*	*11*	*11*	*6*	*1*	*3*	*9*	*10*	*11*	*90/90*

*Transitive links

the driving power and dependency of each barrier. The 4 clusters are given below:

1. Autonomous—Low driving power and low dependency
2. Dependent—Low driving power and high dependency
3. Linkage—High driving power and high dependency
4. Driving—High driving power and low dependency

The power matrix of MICMAC analysis indicating the 4 clusters was formulated from the FRM and is shown in Fig. 2.

3.3 DEMATEL approach

In this phase of the investigation, the shortlisted 12 barriers were analyzed using DEMATEL methodology for establishing the cause-effect relationship between them [29]. The steps involved in the development of the DEMATEL model are listed below:

1. The experts from the case sector were asked to fill the initial relation matrix by using the following system of grading for establishing the strength of the relationship.

   0- No influence
   1- Little influence
   2- High influence
   3- Very high influence

   Tables from all the experts were collected, and by taking an average of all the entries, the final average initial relation matrix (A) was formulated (Table 6).

2. All the row sums and column sums were calculated for each barrier. After calculating the row and column sums in the matrix "A," the maximum value from both the row and column elements were selected. Then, a normalized initial direct relation matrix (D) was developed using the equation:

Table 5 Level partitions of the final reachability matrix iteration I to iteration V

S. no.	Reachability set	Antecedent set	Intersection	Level
IB 1	1,2,3,4,5,6,7,9,10,11,12	1	1	1 (V)
IB 2	2,5,6,10,11,12	1,2,3,4,5,6,7,8,9,10,11,12	2,5,6,10,11,12	2,5,6,10,11,12 (I)
IB 3	2,3,4,5,6,10,11,12	1,3,4,5,8,9,10	3,4,5,10	3,4 (II)
IB 4	2,3,4,5,6,7,10,11,12	1,3,4,5,7,8,9,10	3,4,7,5,10	3,4,7 (II)
IB 5	2,3,4,5,6,10,11,12	1,2,3,4,5,6,7,8,9,10,12	2,3,4,5,6,10,12	3,4 (II)
IB 6	2,5,6,12	1,2,3,4,5,6,7,8,9,10,12	2,5,6,12	2,5,6,12 (I)
IB 7	2,3,4,5,6,7,10,11,12	1,4,7,8,9,10	4,7,10	4,7 (II)
IB 8	2,3,4,5,6,7,8,9,10,11,12	8	8	8 (IV)
IB 9	2,3,4,5,6,7,9,10,11,12	1,8,9	9	9 (III)
IB 10	2,3,4,5,6,7,10,11,12	1,2,3,4,5,7,8,9,10	2,3,4,5,7,10	3,4,7 (II)
IB 11	2,11	1,2,3,4,5,7,8,9,10,11	2,11	2,11 (I)
IB 12	2,5,6,12	1,2,3,4,5,6,7,8,9,10,12	2,5,6,12	2,5,6,12 (I)

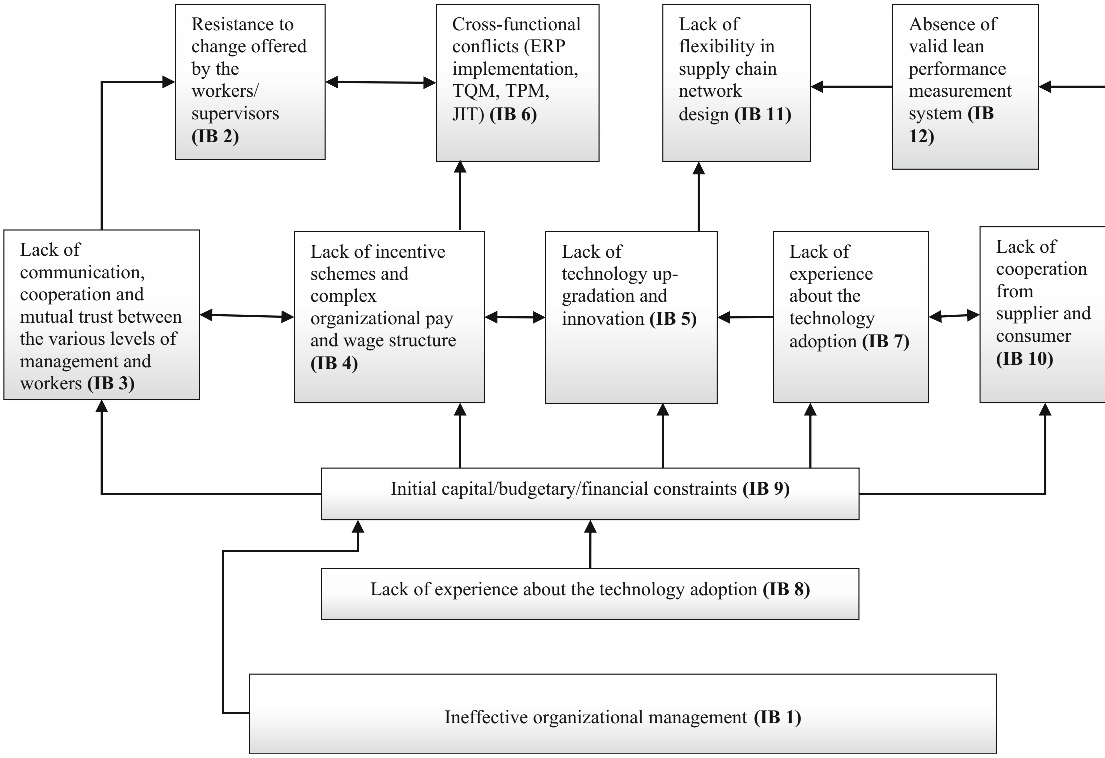

Fig. 1 Structural model of the implementation barriers

$$\mathbf{D} = \mathbf{A} \times \mathbf{S}$$

where S = min [1/(max value of column sum), 1/(max value of row sum)].

3. From the matrix “D” the total relation matrix (T) was developed by using the following relation:

$$\mathbf{T} = \mathbf{D}\,(\mathbf{I}\text{–}\mathbf{D})^{-1},$$

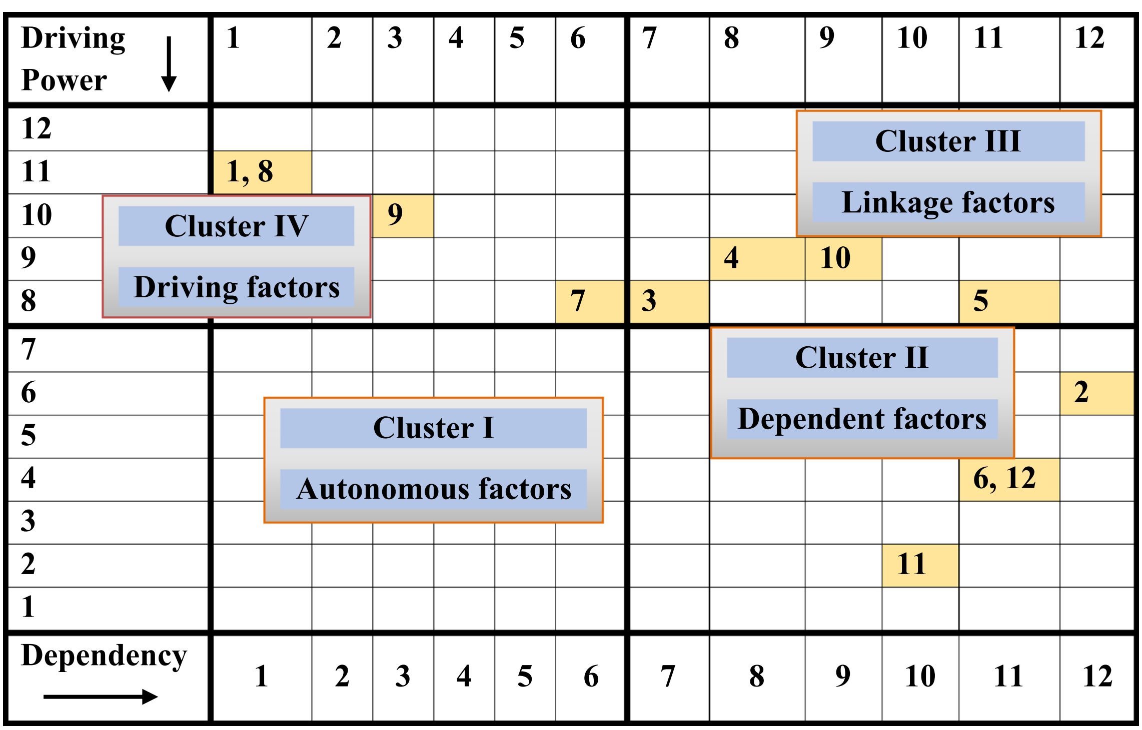

Fig. 2 MICMAC analysis

Table 6 Average initial relation matrix

	B 1	B 2	B 3	B 4	B 5	B 6	B 7	B 8	B 9	B 10	B 11	B 12
B 1	0	3	3	3	3	3	3	2	3	2	3	3
B 2	0	0	3	0	2	3	3	0	1	0	1	1
B 3	3	3	0	3	3	3	3	2	3	2	3	3
B 4	1	3	2	0	1	1	0	0	1	1	1	1
B 5	2	0	3	0	0	2	2	0	1	3	3	3
B 6	0	2	3	0	2	0	0	0	1	2	3	3
B 7	3	3	1	0	2	2	0	0	3	2	1	1
B 8	3	3	3	3	3	3	2	0	1	1	1	3
B 9	1	2	1	0	1	0	0	0	0	1	1	2
B 10	1	0	0	0	1	0	1	1	2	0	1	2
B 11	0	0	0	0	0	1	1	0	0	0	0	1
B 12	0	0	2	0	0	2	0	0	2	0	0	0

where I = identity matrix.

The "T" matrix (Table 7) also shows the sum of each row (ri) and the sum of each column (cj). Further, it indicates the magnitudes of "ri + cj" and "ri − cj." Finally, it highlights the clusters of "cause" and "effect" groups based on the positive or negative sign of the barrier values.

4. From the matrix "T," the value of threshold value (α) was calculated by using the following equation:

$$\alpha = \text{sum of the``T''matrix/number of entries in the matrix}$$
$$= 12.3615/144 = 0.0858$$

5. After calculating the threshold value, the inner dependency matrix (Table 8) was formulated by considering the values $\alpha \geq 0.0858$.
6. From the values of the "ri + cj" and "ri − cj" (Table 7) and the magnitudes of the inner dependency matrix (Table 8), the cause-effect relationship diagram (Fig. 3) was drawn.

Finally, both the ISM and DEMATEL models were integrated as shown in Fig. 4. The values obtained from the inner dependency matrix were used to indicate the strength of the relationship.

4 Results and discussion

An integrated ISM-DEMATEL hierarchical structural model (Fig. 4) of barriers to the implementation of a lean-agile system was developed from the FRM (Table 4), level partitioning matrix (Table 5), and inner dependency matrix (Table 8). The model has five levels, and according to the model, the first level has four barriers (less significant) namely "Resistance to change offered by the workers/ supervisors (IB2)," "Cross-functional conflicts (ERP implementation, TQM, TPM, JIT) (IB 6)," 'Lack of flexibility in supply chain network design (IB 11)," and "Absence of a valid lean performance

Table 7 Total relationship matrix

	B 1	B 2	B 3	B 4	B 5	B 6	B 7	B 8	B 9	B 10	B 11	B 12	ri	ri + cj	ri - cj	Nature
B 1	0.069	0.189	0.1975	0.1298	0.179	0.1934	0.167	0.0853	0.184	0.134	0.1858	0.207	*1.92*	2.77	1.07	Cause
B 2	0.0392	0.052	0.1442	0.0189	0.108	0.1444	0.131	0.0131	0.082	0.043	0.0847	0.092	*0.95*	2.17	− 0.27	Effect
B 3	0.1566	0.189	0.1099	0.1298	0.179	0.1934	0.167	0.0853	0.184	0.134	0.1858	0.207	*1.92*	3.25	0.59	Cause
B 4	0.0561	0.13	0.1065	0.0168	0.069	0.076	0.037	0.0123	0.07	0.059	0.072	0.079	*0.78*	1.31	0.25	Cause
B 5	0.1021	0.057	0.1486	0.026	0.053	0.1219	0.107	0.0204	0.094	0.136	0.1509	0.164	*1.18*	2.3	0.06	Cause
B 6	0.0321	0.13	0.1429	0.0182	0.103	0.0549	0.044	0.0142	0.079	0.095	0.1402	0.151	*1*	2.28	− 0.28	Effect
B 7	0.1285	0.148	0.0979	0.0235	0.117	0.1229	0.051	0.0179	0.15	0.107	0.0927	0.105	*1.16*	2.13	0.19	Cause
B 8	0.1527	0.183	0.1952	0.1318	0.176	0.1903	0.135	0.0255	0.12	0.101	0.1228	0.199	*1.73*	2.06	1.4	Cause
B 9	0.0478	0.084	0.0625	0.0114	0.055	0.033	0.026	0.0086	0.029	0.05	0.0577	0.095	*0.56*	1.73	− 0.61	Effect
B 10	0.0507	0.026	0.0302	0.0114	0.054	0.0288	0.051	0.0378	0.089	0.02	0.0552	0.095	*0.55*	1.45	− 0.35	Effect
B 11	0.0056	0.01	0.0104	0.0017	0.008	0.0403	0.036	0.0013	0.01	0.007	0.0082	0.041	*0.18*	1.36	− 1	Effect
B 12	0.0151	0.026	0.0842	0.0102	0.022	0.082	0.015	0.0069	0.083	0.018	0.0246	0.029	*0.42*	1.88	− 1.04	Effect
cj	*0.85*	*1.22*	*1.33*	*0.53*	*1.12*	*1.28*	*0.97*	*0.33*	*1.17*	*0.9*	*1.18*	*1.46*				

Table 8 Inner dependency matrix ($\alpha = 0.0858$)

	B 1	B 2	B 3	B 4	B 5	B 6	B 7	B 8	B 9	B 10	B 11	B 12
B 1		0.189	0.1975	0.1298	0.179	0.1934	0.167		0.184	0.134	0.1858	0.207
B 2			0.1442		0.108	0.1444	0.131					0.092
B 3	0.1566	0.189	0.1099	0.1298	0.179	0.1934	0.167		0.184	0.134	0.1858	0.207
B 4		0.13	0.1065									
B 5	0.1021		0.1486			0.1219	0.107		0.094	0.136	0.1509	0.164
B 6		0.13	0.1429		0.103					0.095	0.1402	0.151
B 7	0.1285	0.148	0.0979		0.117	0.1229			0.15	0.107	0.0927	0.105
B 8	0.1527	0.183	0.1952	0.1318	0.176	0.1903	0.135		0.12	0.101	0.1228	0.199
B 9												0.095
B 10									0.089			0.095
B 11									0.01			
B 12												

measurement system (IB 12).” These four barriers are less critical for decision-makers as they have a high dependency. In the second level, five barriers are more critical than level one. They are “Lack of communication, cooperation and mutual trust between the management and workers (IB 3),” “Lack of incentive schemes and complex organizational pay/wage structure (IB 4),” “Lack of technology upgradation and innovation (IB 5),” “Lack of experience with technology adoption (IB 7),” and “Lack of cooperation from suppliers and consumers (IB 10).” These barriers have the capability to drive the barriers positioned above them in the hierarchy and are influenced by the barriers below them.

There is a single barrier at each level from 3 to 5 namely “Initial capital/budgetary/financial constraints (IB 9)” (Level 3), “Lack of experience with technology adoption (IB 8)” (Level 4), and “Ineffective organizational management (IB 1)” (Level 5). These three barriers are most important as they act as driving forces for the rest of the barriers above them in the hierarchy. They help to drive the adoption of a lean performance measurement system, influence the network design and flexibility in a supply chain, help to control cross-functional conflicts, reduce the worker's resistance to change by offering incentives, improve communication across various departments, upgrade technology, and improve

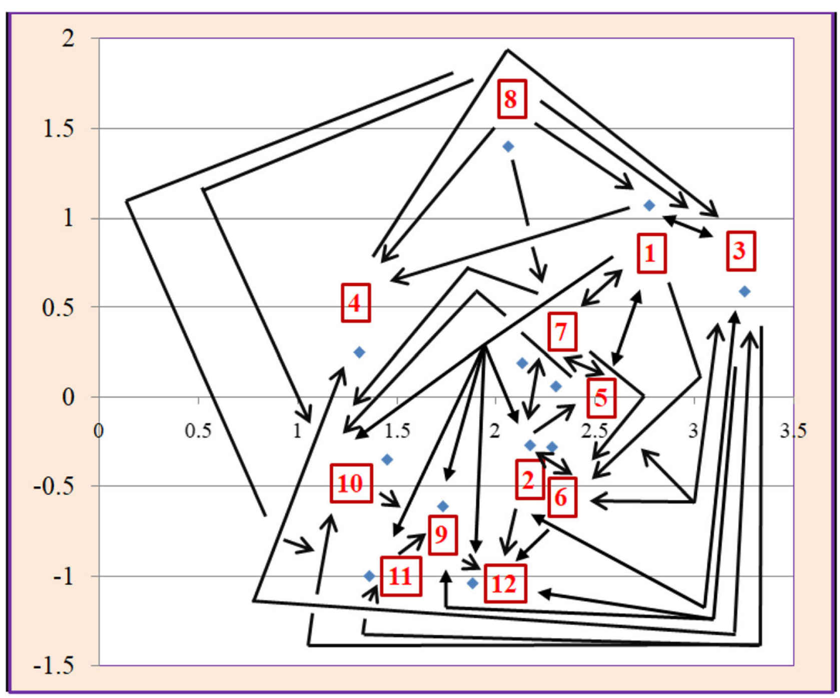

Fig. 3 The cause-effect relationship diagram

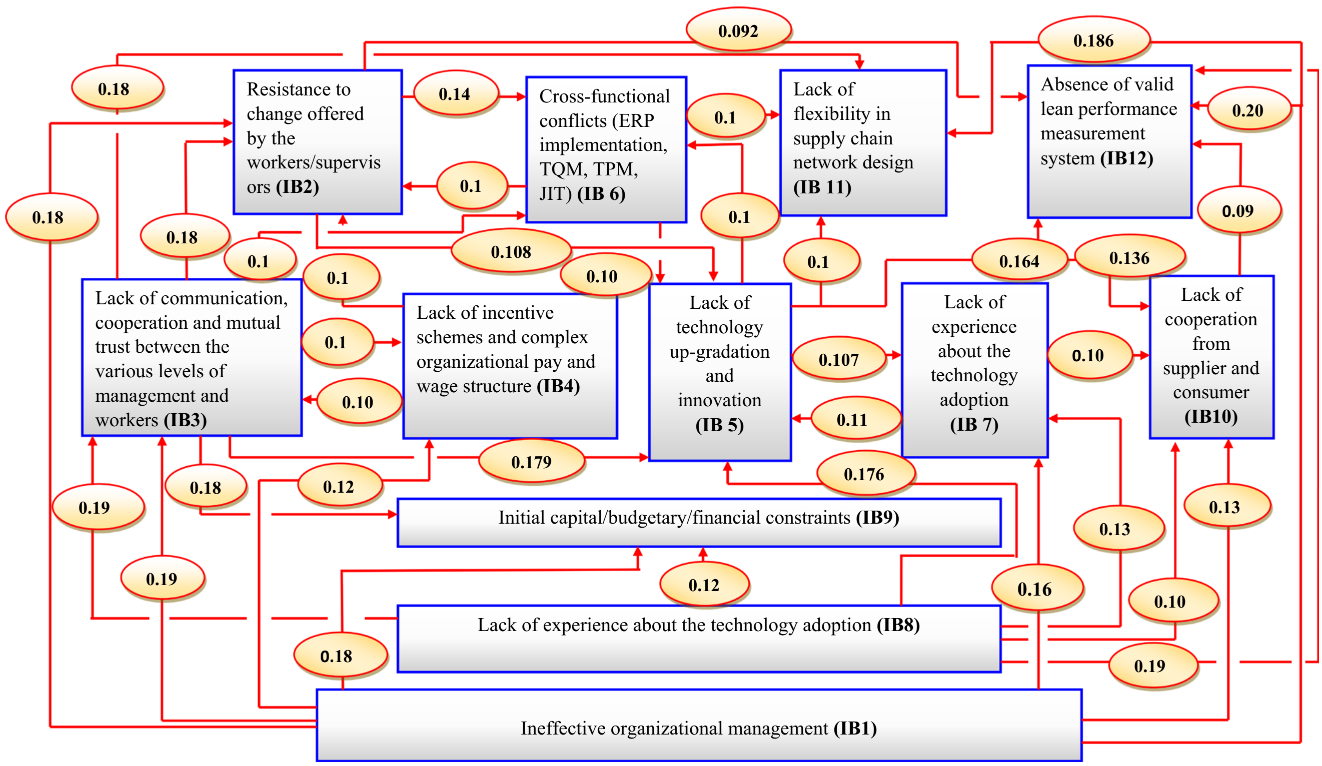

Fig. 4 ISM-DEMATEL integrated structural model of the implementation barriers

cooperation from suppliers and consumers. These barriers need immediate attention from top management for the successful implementation of the lean-agile system in OEMs.

The power matrix of MICMAC analysis is shown in Fig. 2. It may be noted that none of the barriers fell in the first cluster (Autonomous), whereas, in the second cluster (Dependent), the barriers with low driving power and high dependency are shown. These variables are “Resistance to change offered by the workers/supervisors (IB 2)” having a driving power of 6, “Cross-functional conflicts (ERP implementation, TQM, TPM, JIT) (IB 6)” and “Absence of a valid lean performance measurement system (IB 12)” both having an influential intensity of 4, and “Lack of flexibility in supply chain network design (IB 11)” having the driving intensity of 2.

The third cluster (Linkage) comprises of the barriers possessing high driving power and high dependency. There are four barriers in this segment namely “Lack of incentive schemes and complex organizational pay/wage structure (IB 4)” and “Lack of cooperation from suppliers and consumers (IB 10)” both were found to have a driving power of 9, whereas two barriers namely “Lack of communication, cooperation and mutual trust between management and workers (IB3)” and “Lack of technology upgradation and innovation (IB 5)” have influential power of 8. The fourth and the most important cluster (Driving) comprises four barriers namely “Ineffective organizational management (IB 1)” and “Lack of experience with technology adoption (IB 8)” both have the highest driving power of 11, “Initial capital/budgetary/financial constraints (IB 9)” was found to have an intensity of 10, and “Lack of experience with technology adoption (IB 7)” has a magnitude of 8. It becomes clear that barriers IB1 and IB8 need significant attention from top management as these two hindrances possess considerable potential to influence the rest of the barriers and their elimination will lead to a smooth implementation process of the lean-agile system.

The results of this paper and the DEMATEL approach have helped to categorize the 12 barriers into a cause-effect group (Table 7 and Fig. 3). The arrangement of causative factors as per their level of significance are as follows: “Initial capital/budgetary/financial constraints (IB 8),” “Ineffective organizational management (IB1),” “Lack of communication, cooperation and mutual trust between management and workers (IB3),” “Lack of incentive schemes and complex organizational pay/wage structure (IB4),” “Lack of experience with technology adoption (IB 7),” and “Lack of technology upgradation and innovation (IB 5),” whereas the effect group comprised of the following: “Resistance to change offered by the workers/supervisors (IB2),” “Cross-functional conflicts (ERP implementation, TQM, TPM, JIT) (IB 6),” “Lack of cooperation from suppliers and consumers (IB10),” “Lack of understanding and promotion of sustainable products and their benefits (IB 9),” “Lack of flexibility in supply chain network design (IB 11),” and “Absence of a valid lean performance measurement system (IB12).” It may be noted that top management should address the causative factors first as they are acting as healthy and vigorous barriers and elimination of these automatically removes the effect group elements from the shortlisted barriers.

Careful review shows that the significant barriers identified by both methodologies are the same, i.e., IB 1 and IB 8. Also, the ISM approach revealed that IB 2, IB 6, IB 11, and IB 12 are the least significant barriers; these findings are by the findings of the DEMATEL methodology. This leads to the validation of the results of the ISM tool and enhances the accuracy and reliability of the developed integrated model. Further, in the ISM hierarchical model, the intensities of relationships were added for better understanding of the structure of the model (Fig. 4). It may be noted that a strategy needs to be planned to overcome these barriers and a dedicated commitment from top-level management and all employees is necessary for implementing a successful lean-agile manufacturing system. The lean system cannot be implemented in isolation or independently. Hence, everyone must participate proactively in the implementation process. It is the responsibility of top management that every element of the organization receives sufficient training on lean-agile systems. Also, there is a significant need to formulate strategies for offering incentives to the workforce in the context of the lean system implementation for motivating all employees. Further, proper organizational management could aid in achieving an agile system.

Moreover, technology plays a major role in making a system more responsive. Hence technology upgradation is the need of the hour for making the system more agile. This could be at some extra cost, too, as adherence to agility provides more competitive advantage than being leanness [57]. Further, the relationship between different barriers must be clearly explained to all decision-makers to develop policies to overcome the same.

Digalwar et al. [14] have evaluated the critical constructs for measuring sustainable SC practices in the case of Indian lean-agile firms. The authors found that technology-related constructs like “Information technologyenabled system support (ITS)” is the most significant construct which is in line with the present study too. Here in our case, the lack of technology upgradation has emerged as a critical construct too. Similar instances have been observed in the work of Change et al. [11] about modern information technology. Kumar et al. [24] found that poor planning is a major hurdle for implementation of lean system implementation in India, which is also evident from this study too. The present study is also in line with Pereira et al. [38], which suggest employee resistance, cultural issues, and lack of resources are key challenges faced by Brazilian firms implementing lean/agile manufacturing systems. Sindhwani et al. [48] findings of financial challenges as a significant barrier also coincided with the finding of the present study. Further lean-agile manufacturing system also forms the basis of the integrated manufacturing excellence model Paranitharan and Jeyathilagar [36]. However, our findings are in contrast with Singh et al. [51], which depict a lack of training as the most significant barrier.

5 Conclusions

Given the competitive nature of most industries, many companies are adopting sustainable practices to improve brand image, increase customer loyalty, increase market share, and therefore maximize profit potential. To achieve these goals, organizational managers need to plan and adopt lean-agile practices effectively. In this investigation, the three research questions discussed in the introduction were addressed by identifying the barriers to the implementation of the lean-agile manufacturing system. This was accomplished by seeking expert input and exploring the barriers having high influential power using the integrated ISM-DEMATEL approach. Lastly, the shortlisted barriers were clustered into cause-effect groups, and their relationship strength was also analyzed. Both the employed methodologies (ISM-DEMATEL) revealed that the most significant barriers/roadblocks in the adoption of lean-agile systems are “Ineffective organizational management (IB 1),” and “Lack of experience with technology adoption (IB 8).”

This research is designed to assists organizational managers in understanding the most significant barriers to successful lean/agile implementation based on their influential power and the cause-effect relationship between them. Also, this study helps decision-makers to understand the interrelationship between the barriers and strengths of their relationship. Further, it guides them in developing new policies/strategies for effective implementation of lean-agile systems. Additionally, the present study guides organizational managers to tackle the most significant barriers. Also, this investigation guides the researchers and academicians to analyze lean-agile implementation barriers using the MCDM framework. Further, it offers future research directions to them to analyze similar research problems by employing other MCDM and statistical tools to validate the results of the present investigation.

Field validation of the integrated model was done by two managers of OEMs who were not involved in the formulation of the SSIM of the ISM methodology. These managers had previous experience in implementing lean-agile systems. It may be noted that they have very well received the integrated ISM-DEMATEL structural model, and they have expressed a desire to consider the findings of the present study in the implementation process of their lean-agile systems. In this context, the authors visited them after 6 months, and the issues faced by them in the implementation process were discussed. They elaborated that this study was critical in identifying the hurdles which they could come across. Hence, they were ready with mitigating strategies to overcome the barriers.

Their preparedness helped them to save considerable time and money, and they could execute the process of implementation with minimal resistance from the workforce and effective support from the top management. The integrated model was utilized as a handbook in the development of incentives. Strategies were formulated for improving organizational culture and competitiveness in global markets. Training sessions were scheduled to boost employee confidence levels with the use of new technologies. Also, intra and interdepartmental team-building training was offered to improve communication and collaboration. Further, top management got involved early in identifying and eliminating possible financial constraints to achieve long-term organizational goals. Hence, there is clear evidence that the integrated model has helped the OEMs in successfully understanding and analyzing key barriers based on their influential power and the cause-effect nature for the effective implementation of the lean-agile system.

There are limitations in this research too. For example, the expert opinions which were considered for the development of the SSIM of the ISM approach and initial relation matrix of DEMATEL methodology could be biased, which would influence the reliability of the model. However, since two powerful tools were employed for the analysis, the accuracy and reliability of the model are significantly better than individual approaches alone. Generalizability may also be limited as the integrated model was developed by taking expert input from a developing country's setting. The same results may not apply directly to other economies as the relationship between the barriers, and the types of barriers varies from place to place and sector to sector. However, minor modifications to the model may make it applicable to various other settings. In future studies, authors should deploy other MCDM tools such as AHP, ANP, IRP, and TISM, to help validate this model. Also, a statistical tool, namely PLS-SEM, may be employed. Further, a comparative analysis may be carried out across different sectors and various economies, and the reasons for the variations in results may be analyzed.

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