

Analysis of Barriers to Implement Lean Manufacturing Principles and Industry 4.0 Technologies Concurrently in Indian Manufacturing Organizations

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Industries all over the world are practicing Lean Manufacturing (LM) techniques during the last twenty years and have significantly reduced the wastes from the shop floor level to enterprise level activities. On the other hand, the industrial settings are elevated to the next level with the help of Industry 4.0 technologies. Despite this transition, Small and Medium Enterprises (SMEs) face challenges like technological constraints, financial limitations and regulatory complexities. To address this issue, the present study aims to analyse the barriers for implementing LM and Industry 4.0 concurrently in SMEs across process, product and service industries in the southern part of India. In addition, the driving forces and strategies were also analysed to understand the perception towards LM and Industry 4.0. A questionnaire-based survey methodology is adapted to carry out the research. The survey method is intended to highlight the barriers faced by Indian SMEs while implementing LM and Industry 4.0 technologies. Though 43% of the surveyed SMEs already started practicing LM and Industry 4.0 techniques, remaining still requires directions to adapt these techniques. A novel approach adapting hypothesis testing and Principal Component Analysis (PCA) was used to prioritize the identified barriers. Analysis on the survey results show that the majority of the barriers are related to standards, knowledge and awareness on LM and Industry 4.0. The results provide an overview of Indian SMEs' present status on LM and Industry 4.0 adaption, and important aspects to be focused by the organizations' management and academicians for the successful implementation.

Keywords: Implementation barriers, Lean and Industry 4.0, Principal component analysis, Questionnaire based survey, Small and medium enterprise

Introduction

Small and Medium Enterprises (SMEs) are vital for employment and production in the global manufacturing sector. Lean Manufacturing (LM) improves organizational performance by eliminating wastes. Over time, SMEs have been trying to improve flexibility, overall effectiveness and response time to varying customer demands. Globalization and growing technologies substantially impacted SMEs, making it essential to transform into an efficient production model.¹ Despite the efforts to adapt new strategies, a large number of SMEs, particularly in India are yet to practice LM. Indian SMEs must choose appropriate lean tools according to their work culture, work condition and infrastructure. Challenges like lack of human resources, unawareness on new technologies, lack of commitment and other facilities hinder the adoption of LM. Researchers have studied the importance of organization's resources and their

implications on LM practices. LM needs employee involvement and empowerment irrespective of their function and hierarchy. Comparing the present scenario, LM is a low-tech approach, yet outshines effectiveness and simplicity.

The need for product quality and efficient manufacturing systems demands the transformation of industries to Industry 4.0.⁽²⁾ This era enabled by electronics, industrial robots, information technology, and Cyber-Physical Systems (CPSs) results in digitally integrated manufacturing systems. Though complete understanding of employing Industry 4.0 technologies into the present conventional manufacturing systems is under study, researchers acclaim that the Industry 4.0 may shift the competence of human workers rather than replacement.³ Truly, the skill and knowledge requirements of human workers may likely to improve and be more specialized. But the capital investment required may hinder the adoption of Industry 4.0 technologies for economically developing countries.⁴ Hence focused efforts needed to implement Industry 4.0 technologies for industries with higher

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production volume and low-cost work force. Integration of LM and Industry 4.0 could modernize present manufacturing systems especially SMEs. However adapting new technologies comes with challenges and barriers, making it essential to identify and address them for successful transformation.

LM and its Implementation Barriers in Indian Context

Indian SMEs have shown steady growth in areas like production, employment, and global performance. While most Large Manufacturing Enterprises (LMEs) already follow LM practices, SMEs reliant on them contribute to product quality, market response time, and productivity. To align with LME expectations, SMEs must also adopt LM practices. Over the past few decades, SMEs have become one of the most dynamic and rapidly evolving sectors in the Indian economy.⁵ Researchers reported many issues with the LM implementation in Indian SMEs and the main factors include, customers, suppliers, management, organizations and market. Also, researchers reported many barriers that include, Lack of direction and planning (LB1), Lack of project sequencing (LB2), Lack of management commitment (LB3), Lack of exposure on lean construction (LB4), Lack of understanding of lean concepts and their benefits (LB5), Lack of lean implementation skills (LB6), Lack of client and supplier involvement (LB7), Lack of attitude and ability to work in group (LB8), Lack of infrastructural facilities (LB9), Social, cultural factors and human aspects (LB10),

Inadequate training and communication (LB11), Unwillingness to learn and see (LB12), Uncertainty in the supply chain (LB13), Insufficient internal/external funding (LB14), Resistance to change (LB15), Transportation activities (LB16), and Insufficient management time (LB17). The correlation of barriers and tools identified through literature is depicted in Table 1.

Industry 4.0 and its Implementation Barriers in Indian Context

Industry 4.0, introduced in Germany in 2011, aimed to boost the competitiveness of its manufacturing sector through full digitalization. It involves integrating Cyber-Physical Systems (CPS) into manufacturing and logistics using the Internet of Things (IoT) and related services. This shift impacts business models, work structures, value creation, and services.² Industry 4.0 technologies are rapidly evolving, with growing conceptual and theoretical frameworks. Its core principles include connectivity, information transparency, technical assistance, and decentralized decision-making. The transformation is driven by nine key technologies: data analytics, IoT, system integration, autonomous robots, cybersecurity, augmented reality, simulation, cloud computing, and additive manufacturing. Additional emerging technologies include artificial intelligence (AI), mobile tech, Real-Time Location Systems (RTLS), and Radio Frequency Identification (RFID).¹³

Table 1 — Barriers to implementation of LM

LM Barriers	TQM	7-Quality Control	JIT	POKA YOKE	Kaizen	5S	TPM	Kanban	Continuous improvement/ Pull system	Production leveling/ Heijunka	Cycle /lead time reduction	Cellular manufacturing	SMED	Daily hurdle meeting/ democratic culture	Bottle neck removal	Focused factory production
LB1	1	1	1	1	1	1	1	—	—	—	—	—	—	—	—	—
LB2	1	1	1	1	1	1	1	—	—	—	—	—	—	—	—	—
LB3	1,4,7	1	1,4,7	1,6,7	1,6	1,3,6	1,4,6,7	4	4,7	7	4,7	4,7	4	2	4,7	4
LB4	1	1	1	1	1	1	1	—	—	—	—	—	—	2	—	—
LB5	4,7	—	4,7	7	—	3	4,7	4	4,7	7	4,7	4,7	4	2,5	4,7	4
LB6	4,7	—	4,7	7	—	—	4,7	4	4,7	7	4,7	4,7	4	—	4,7	4
LB7	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—
LB8	4,7	—	4,7	7	—	3	4,7	4	4,7	7	4,7	4,7	4	2,5	4,7	4
LB9	1,4	1	1,4	1	1	1	1,4	4	4	—	4	4	4	—	4	4
LB10	1,7	1	1,7	1,6,7	1,6	1, 6	1,6,7	—	7	7	7	7	—	2	7	—
LB11	1	1	1	1	1	1	1	—	—	—	—	—	—	2	—	—
LB12	1	1	1	1	1	1	1	—	—	—	—	—	—	—	—	—
LB13	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—
LB14	4	—	4	6	6	6	4,6	4	4	—	4	4	4	—	4	4
LB15	1,4	1	1,4	1,6	1,6	1, 6	1,4,6	4	4	—	4	4	4	—	4	4
LB16	7	—	7	7	—	—	7	—	7	7	7	7	—	—	7	—
LB17	4	—	4	—	—	—	4	4	4	—	4	4	4	—	4	4

India unfortunately has relied seriously on the service sector that cannot hire bulk semi-literate workforce.³ Inadequate indigenous technologies and over-dependence on the other technologically advanced countries are the major issues for lower level of Industry 4.0 adaption. Consequently, Indian manufacturing enterprises still lack the understanding of Industry 4.0 technologies. There are many barriers to be addressed in order to advance its enterprises to the Industry 4.0 paradigm. Literature showed that most of the research works focused the establishment of CPSs which requires advanced education system, qualified workforce, and common perspectives of LM principles.¹⁴

Link between LM and Industry 4.0

LM has long proven effective in reducing waste through practical methods rather than new technologies. Meanwhile, Industry 4.0 offers benefits like higher productivity, flexibility, cost reduction, faster delivery, and improved quality.¹⁵ Given their individual advantages, a key question arises: how does their combined implementation affect manufacturing performance? Satoglu *et al.*¹⁶ argued that Industry 4.0 alone cannot resolve issues caused by poor organization and recommended adopting LM practices first. Tortorella & Fettermann¹⁷ analyzed data from 147 Brazilian manufacturers using both LM and Industry 4.0, finding moderate but positive impacts on performance. Similarly, Khanchanapong *et al.*¹⁸ using data from 186 Thai manufacturers, found significant improvements in lead time, quality, flexibility, and cost from the joint application of LM tools and Industry 4.0 technologies. Dombrowski *et al.*¹⁹ evaluated 260 German cases and identified strong links between waste reduction and cloud computing. These studies provide useful insights to guide manufacturers in selecting technologies that support better decision-making.

Both PCA and Industry 4.0 promote simplified, decentralized systems with small, low-complexity modules. However, a deeper understanding of their integration is still needed. In developing economies, especially among SMEs, current solutions are often proprietary and tailored to specific needs, which may lead to conflicting interests during implementation.¹⁷ Thus, it is crucial to address the challenges and barriers involved in adopting both approaches simultaneously in SMEs.

Need and Objectives of the Study

This research investigates key barriers to the joint implementation of LM and Industry 4.0. Previous studies highlight a lack of empirical research on identifying these barriers in developing countries like India.¹³ Existing literature on their combined adoption is limited, with few studies addressing implementation challenges through empirical analysis. The novel aspects of the study includes the dual focus on LM and Industry 4.0 integration, context-specific application for Indian manufacturing sector, and the use of Friedman's test to prioritize the implementation barriers which address the concerns of previous studies. In this survey-based study, respondents provided insights on Lean Industry 4.0 and related implementation barriers. Based on prior research, the study's objectives are as follows:

- ✓ To study in detail the driving forces, strategies, and barriers associated with concurrent implementation of LM and Industry 4.0.
- ✓ To conduct a questionnaire-based survey in Indian SMEs.
- ✓ Analyze the responses and report on major driving forces, strategies and most important barriers.

Methodology

The research methodology pursued in the present study is shown in Fig. 1. It starts with a detailed literature review about the present status of LM and Industry 4.0 implementation in India, issues and barriers of implementing LM and Industry 4.0 in Indian SMEs. A questionnaire is prepared to conduct

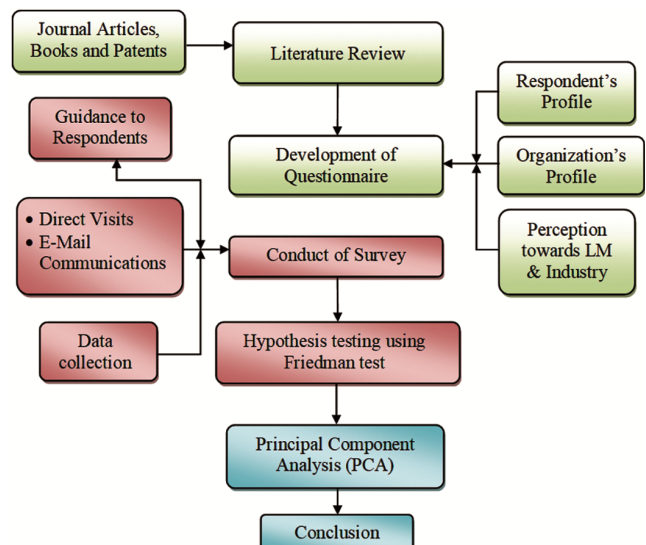


Fig. 1 — Flow chart of the proposed work

the survey-based study to assess the barriers. To confirm the significance/correctness of collected responses, hypothesis testing is carried out using Friedman test. Using mean & Standard Deviation (SD), the collected data are analyzed and reported. The positive correlation among the barriers are further analysed using Principal Component Analysis (PCA) based on which the major barriers are prioritized.

Preparation of Questionnaire

The questionnaire was developed based on insights from the literature, and input from industrial experts and researchers. The questionnaire focused on key areas: awareness, adoption status, driving factors, implementation strategies, and barriers. It was structured in three sections and reviewed for reliability by five experts from Indian industries and academia. Their feedback was incorporated into the final design:

- i. Expert 1: Operations Manager, electronics manufacturing, 14 years' experience.
- ii. Expert 2: Senior Manufacturing Engineer, automobile industry, 15 years' experience.
- iii. Expert 3: Lean Consultant with 18 years of implementation experience.
- iv. Expert 4: Professor with a PhD in industrial engineering, 20 years' research in lean, quality, supply chain, and tech incubation; also heads a tech incubation cell.
- v. Expert 5: Associate Professor at a national institute with 14 years' experience and numerous publications on Lean Six Sigma, TQM, and Industry 4.0.

Based on expert feedback, the questionnaire was refined for clarity, relevance, and alignment with the study objectives, ensuring it could be completed within the given time. The first section gathers details on respondents' qualifications, roles, and expertise in LM and Industry 4.0. The second covers organizational type, size, workforce, and experience with LM and Industry 4.0. The third section, titled 'Perception towards LM and Industry 4.0,' includes questions across major dimensions, each with related sub-questions. The main dimensions are:

1. The driving forces responsible for implementing LM and Industry 4.0 (Q1)
2. Strategies were used to engage staff in LM and Industry 4.0 practices and their success rate (Q2)
3. Barriers related to management while implementing LM and Industry 4.0 practices (Q3)

4. Barriers related to employee while implementing LM and Industry 4.0 practices (Q4)
5. Barriers related to lack of knowledge while implementing LM and Industry 4.0 practices (Q5)
6. Barriers related to lack of resources while implementing LM and Industry 4.0 practices (Q6)
7. Barriers related to finance while implementing LM and Industry 4.0 practices (Q7)
8. Other barriers which prevents the successful implementation of LM and Industry 4.0 practices (Q8)

The driving forces and barriers under these dimensions are adapted from the literature in consultation with the expert members from academia and industry. The five-point Likert scale is utilized to assess the qualitative responses from the respondents of sampled industries. The values in the scale vary from minimum rating of 1 to maximum rating of 5 with equal distribution [Strongly disagree (SD)-1, Disagree (DA)-2, Neither or nor agree (NA)-3, Agree (AG)-4, Strongly agree (SA)-5].²⁰

Target Industries

According to the Ministry of MSME (2006), industries fall under manufacturing or service sectors and are further classified as small, medium, or large based on plant and machinery investment. As this study focuses on LM and Industry 4.0 implementation barriers in SMEs, only SMEs from South India were contacted via electronic communication and direct visits. The survey covered three SME categories: product-based, process-based, and service industries.

Validation through Hypothesis Testing

To validate the initial questionnaire, feedback was obtained from industry experts and academicians. Based on their input, necessary revisions were made before distribution to selected industries. The responses collected serve as the primary data for this study. To assess their significance, the following hypotheses were formulated:

- Ho (null hypothesis) : The industrial responses are not significant
 H1 (alternative hypothesis) : The industrial responses are significant

Principal Component Analysis

This study uses PCA to reduce the number of LM and Industry 4.0 implementation barriers based on their correlation and association. PCA is a widely used and effective method for dimensionality

reduction, often outperforming techniques like ANOVA in categorization.²¹ It extracts hidden patterns from data and converts them into orthogonal variables called principal components (PCs), which capture most of the variance in the original dataset.

Results and Discussion

Industry Statistical Data

A list of 75 companies — 25 each from process, product, and service sectors was compiled using industrial directories to ensure diverse representation across southern India, including districts in Tamil Nadu, Kerala, Karnataka, and Andhra Pradesh. Companies were initially contacted by phone, followed by emails with study details and the questionnaire. Some local firms were approached in person. Industries were categorized by scale, domain, and technological focus. As shown in Fig. 2, thirty five companies responded, but 7 were excluded due to incomplete or invalid responses, leaving 28 valid responses (37.3%), a reasonable rate for supply chain and operations studies. Challenges such as low awareness, time constraints, and limited knowledge of LM and Industry 4.0 affected participation. To ensure data reliability, only responses from qualified individuals with relevant roles and experience in digital initiatives were considered. Assumptions included:

- i. Responses were truthful on the organization's present status and plans
- ii. Industrial category and scale represented were accurate
- iii. Despite of limited sample size, 28 responses offer valuable conclusions about LM and Industry 4.0 integration

Among the responses, 12 are from process industries (43%), 10 are from product industries

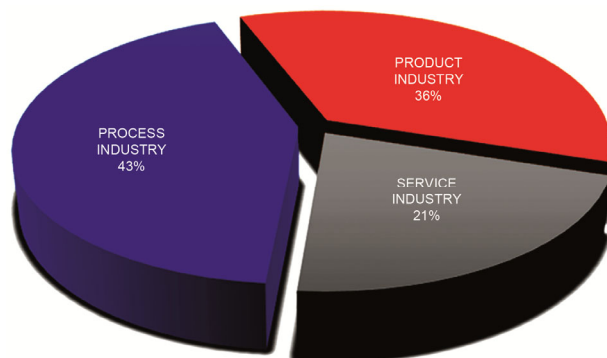


Fig. 2 — Percentages of organization from different categories participated

(36%) and 6 are from service industries (21%). Only 12 industries (42.8%) have begun practicing either LM or Industry 4.0 techniques in pilot area and 7 industries (25%) are planning to implement. Remaining industries do not have any idea of implementation due to various reasons.

Hypothesis Testing

Friedman's test is designed for the projects within-subjects like the participants undergoing several distinguishing conditions. Also Friedman's test does not consider normality of the data such as interval or ratio but ordinal or skewed. Importantly, the test is more suitable for the studies dealing with very small sample sizes. In the present study Friedman's test is a robust choice as limited respondents from different industrial setup were taking up the same questionnaire. In order to establish the arithmetic difference among the respondents, Friedman's non-parametric test was conducted in statistical package for social science (SPSS) using a 0.05 significance level and the results are presented in Table 2. The critical values fetched from statistical table are assessed with test results. The values of test statistics for all the 8 topics are higher than the critical values. Hence, alternative hypothesis (H1) is accepted and null hypothesis (H0) is rejected for all the cases.

Analysis on the Data

Based on literature, perceptions of LM and Industry 4.0 implementation were grouped into eight categories. A questionnaire using a five-point scale was shared with industry professionals, including managing directors, service managers, and operations managers. Response variation or missing data depended on each respondent's experience and familiarity with the topics. To analyze the data, mean and standard deviation (SD) were calculated for each category. The number of responses exceeding the mean in each category is shown in Fig. 3. Reasons for these variations are discussed in the following sections.

The Driving Forces Responsible for Implementing LM and Industry 4.0, and Strategies to Engage Staff

The key driving forces for implementing LM and Industry 4.0 are presented in Table 3. Some organizations scored above the mean for factors like cost reduction, quality improvement, efficient shop floor use, and increased innovation and strategy. Quality enhancement in products and processes is crucial for

Table 2 — Friedman’s non-parametric test results

S. No	Questionnaire dimensions	DOF (n-1)	Critical value $\chi^2\alpha$	Calculated values of test statistics	Test result
1	Q1	27	40.115	42.177189	H0 is rejected
2	Q2	27	40.115	67.347744	H0 is rejected
3	Q3	27	40.115	70.048288	H0 is rejected
4	Q4	27	40.115	48.48843	H0 is rejected
5	Q5	27	40.115	50.461454	H0 is rejected
6	Q6	27	40.115	44.179667	H0 is rejected
7	Q7	27	40.115	44.020772	H0 is rejected
8	Q8	27	40.115	47.294663	H0 is rejected

Table 3 — Driving Forces Responsible for Implementing LM & Industry 4.0, and Strategies to Engage Staff

Driving forces and Strategies		Mean	S. D	% of industry response > mean
Driving forces				
Cost reduction ^{1,24}		4.214	0.876	50
Quality improvement ²⁵		4.5714	0.504	57.14
Reduction in time-to-market ^{1,2}		3.5	0.839	42.85
Work force ^{1,25}		3.5	0.839	42.85
Customer satisfaction improvement ²⁴		4.286	0.713	42.85
Effective utilization of shop floor ^{1,25}		3.429	0.997	50
Eliminate wasteful practices ⁴		4.214	0.787	42.85
Improved competitiveness ²⁴		3.357	0.731	35.71
Increased innovation and strategy ²⁶		2.857	0.848	64.28
Strategies				
Employee engagement in identifying solution ¹⁵		3.071	0.813	21.42
Employee empowerment ³		3.429	0.836	42.85
Standardizing ²⁷		3.786	1.101	57.14
Emphasis on training and skill building ²⁸		3.5	1	50

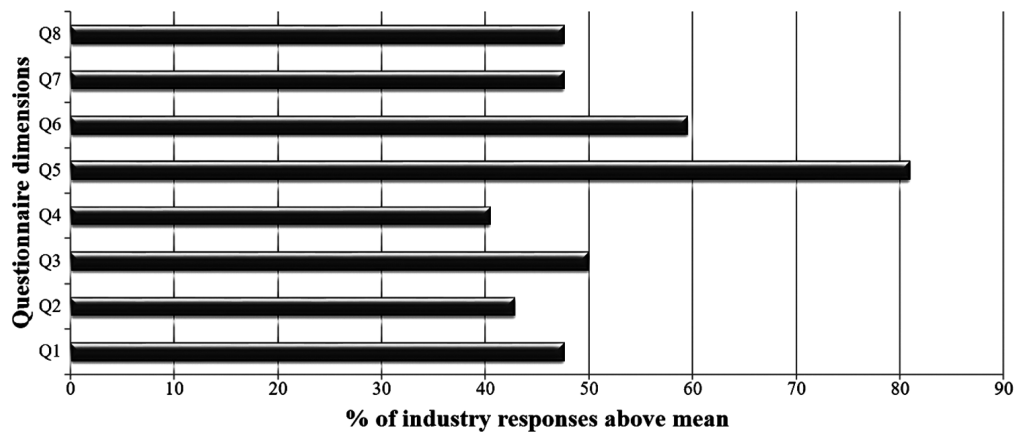


Fig. 3 — Percentages of organization whose responses are greater than mean

customer satisfaction. Although 'increased innovation and strategy' had the lowest mean, it received the most responses above the mean. Innovation in specific industrial activities is essential for long-term competitiveness.²² Other driving forces also showed notable mean values, all aligned with organizational goals. The analysis of strategies for engaging staff in LM and Industry 4.0 implementation is also presented in Table 3. Staff involvement in new initiatives is

challenging, as it requires meeting additional expectations. Ghosh²³ identified standardization as a key factor in adopting new technologies. Similarly, this study found standardization to have the highest mean score. Training and skill development followed as the next most impactful strategy, helping to motivate goal-oriented employees. Identifying and training such individuals can effectively support LM and Industry 4.0 implementation.

Barriers related to Management while Implementing LM and Industry 4.0 Practices

One major barrier identified from the literature is management commitment, with three specific issues: lack of strategic understanding, lack of focus on advancing rather than the operations at the cost of developing the organization, and lack of data control & protection. Among these, the third one received the least concern from respondents. Few industries scored above the mean for these barriers, with 'lack of strategic understanding' receiving the highest mean score (2.929) as shown in Table 4. This likely reflects limited awareness of LM and Industry 4.0 and their benefits. Management support in Indian SMEs remains a challenge, highlighting the need for greater familiarity with LM and Industry 4.0 tools. Executive training, leadership development programmes, and strategic alignment workshops will help the management to understand the importance of strategies on improving operational efficiency, competitiveness.

Barriers related to Employee while Implementing LM and Industry 4.0 Practices

The barriers related to employees in implementing LM and Industry 4.0 are presented in Table 4. As key stakeholders, employee engagement is essential for successful adoption.³⁵ Many industries reported above-average concern for resistance to change, which is closely linked to poor participation. Common causes include fear of increased workload, attachment to traditional methods, reluctance to accept new challenges, fear of job loss due to mistakes, and dissatisfaction with rewards or financial incentives. Focusing on SMEs, few of the solutions identified from literature to overcome this barrier include executive communication, involving employees in the transformation process, proper training and education.³⁶ Employer must address these employee-related issues in order to successfully bring LM and Industry 4.0 culture inside the organization.

Table 4 — Mean and SD values for barriers while implementing LM and Industry 4.0 practices

Barriers	Barrier No	Mean	S. D	% of industry response > mean
Management related barriers				
lack of strategic understanding ²⁴	BA1	2.929	1.052	64.28
Lack of focus on advancing rather than the operations at the expense of developing the organization ²⁹	BA2	2.714	0.81	50
Lack of data control & protection ³⁰	BA3	2.714	1.117	35.71
Employee related barriers				
Employee resistance to change ^{30,31}	BA4	3.357	0.911	50
Employee fear about losing job ³¹	BA5	3.071	1.12	35.71
Poor employee participation ³⁰	BA6	3.357	0.911	35.71
Knowledge related barriers				
Need of continuous training ⁴	BA7	3.786	0.686	78.57
Lack of understanding about interaction between human and technology ³⁰	BA8	3.929	0.716	85.71
Lack of knowledge about lean industry 4.0 implementation ¹⁴	BA9	3.929	0.604	78.57
Resources related barriers				
Lack of resources ^{14,24}	BA10	3.704	0.609	64.28
Lack of capital fund ⁴	BA11	3.296	0.912	42.85
Poor communication system ⁴	BA12	3.444	0.641	35.71
Lack of strategies ¹⁴	BA13	3.37	1.006	50
Lack of time for in-depth understanding ³⁰	BA14	3.333	1.074	57.14
Finance related barriers				
No direct financial advantages ³²	BA15	3.429	0.742	57.14
Financial benefits not recognized ³²	BA16	3.5	0.839	57.14
Very few financial resources ³⁰	BA17	3.5	0.839	64.28
Other implementation barriers				
Inventory management ³³	BA18	3	0.861	35.71
Lack of standards ²⁴	BA19	4.071	0.979	42.85
Not familiar with lean industry 4.0 technologies ^{14,30}	BA20	4.071	0.604	21.42
Difficulty in coordinating different units of organization ³³	BA21	3.714	1.357	64.28
Need for a specialist ⁴	BA22	3.143	0.848	42.85
Change in quality control and improvement ³⁴	BA23	3.857	0.756	78.57

Barriers related to Lack of Knowledge while Implementing LM and Industry 4.0 Practices

Inadequate knowledge is a major barrier to implementing LM and Industry 4.0, encompassing training, tool understanding, and awareness at all organizational levels. From Table 4, over 78% of industries rated knowledge-related barriers above the mean. Key reasons include limited understanding of LM and Industry 4.0 benefits, lack of guidance in selecting suitable tools, and concerns about return on investment. Among all barriers, knowledge-related issues demand the most attention, as they received strong responses from most firms. Lack of understanding about interaction between human and technology scores the highest and can be eliminated by Human-centric design, collaborative workflows, and continuous feedback loops.³⁷ Intuitive and user-friendly technological systems which can integrate technological capabilities and human skills must be designed to allow employees to focus on creativity demanding tasks. It shall also establish continuous feedback systems to ensure the supporting their work processes.

Barriers related to Lack of Resources while Implementing LM and Industry 4.0 Practices

The analysis of barriers related to resource constraints is presented in Table 4. 'Lack of resources' received the highest number of responses above the mean, followed by 'lack of time for in-depth understanding.' Skilled resources are essential for LM and Industry 4.0 projects, but benefits often take time to materialize.³⁸ Implementing these tools requires adequate staffing. Contributing factors include:

- SMEs' limited finances to hire skilled workers
- Lack of employee appraisal systems
- High labor turnover
- Time pressure from market competition limiting focus on implementation

SMEs often suffer from lack of resources due to their limited financial availability. Still there are potential strategies reported in the literature that could overcome the barrier include resource mapping, process optimization, and external partnership. It requires a thorough assessment over underutilized resources, the level of LM implementation and the possibilities of collaborating with external partners to gain additional technical resources.

Barriers related to Finance while Implementing LM and Industry 4.0 Practices

Financial factors and market sales play a critical role in implementing LM and Industry 4.0. Key financial

barriers include no direct financial advantages, financial benefits not recognized, and very few financial resources.^{32,39} Recognizing financial gains is crucial for management due to resource limitations, high implementation costs, and overall financial constraints. From Table 4, equal responses above the mean for 'no direct financial advantage' and 'financial benefits not recognized,' suggesting that LM and Industry 4.0 offer long-term, not immediate, benefits. Most industries rated 'very few financial resources' highest, indicating SMEs are less financially equipped than LMEs for costly transitions. To overcome this barrier, SMEs can seek government grants or incentives as the government schemes support LM initiatives and digital transformation in India. Also, phased implementation that begins with minimal investment based pilot projects before scaling up the transformation would better overcome the finance related barriers. SMEs can conduct Return on Investment (ROI) analysis to identify the cost saving areas by adapting LM and Industry 4.0 practices.⁴⁰

Other Barriers which prevents the Successful Implementation of LM and Industry 4.0 Practices

Among the other barriers identified as shown in Table 4, 'change in quality control and improvement' and 'difficulty in coordinating different units of organization' have been highly reported by respondents. Developing a unified quality framework as a holistic approach, real-time quality monitoring through data analytics and sensors, and promoting a continuous improvement culture within the organization could help in overcoming these barriers. The barrier 'lack of standards', score highest mean (4.071) which influence the performance either independently or in combination with other barriers. It arises when workers are negligent about standard practices and hesitate to excel in their activities. Identification of such activities is important while planning for LM and Industry 4.0 implementation.

Analysis through PCA

Multiple barriers may interact positively or negatively, so it's essential to narrow them down to the most significant ones. This study uses PCA to identify key barriers. Table 5 shows Eigenvalues from factor analysis, indicating the variance explained by each factor, based on SPSS output. A Scree plot generated in MINITAB™ (Fig. 4) reveals seven components with Eigen values ≥ 1 , which are selected as primary factors. The data presented in Table 5 is explained in Eq. 1.

$$\begin{aligned}
 PC - 1 = & 4.9927 \times BA1 + 3.6096 \times BA2 + 2.9005 \times BA3 + 2.0326 \times BA4 + 1.7096 \times BA5 + 1.5628 \times BA6 + 1.1683 \times BA7 \\
 & + 0.9106 \times BA8 + 0.7161 \times BA9 + 0.6528 \times BA10 + 0.461 \times BA11 + 0.3838 \times BA12 + 0.2512 \times BA13 \\
 & + 0.1815 \times BA14 + 0.1388 \times BA15 + 0.0799 \times BA16 + 0.0344 \times BA17 + 0.0138 \times BA18 + 0.0056 \times BA19 \\
 & + 0.0038 \times BA20 + 0.0009 \times BA21 + 0.00 \times BA22 + 0.00 \\
 & \times BA23
 \end{aligned}
 \tag{1}$$

Similarly, other principal components (PCs) can be expressed like PC-1. Over 82% of variability is explained by the top five PCs, with components 8 and 9 showing minimal difference. The first 10 PCs account for over 92% of the variability, and the top 11 cover 95%. Similarly, Table 6 highlights closely related barriers within each PC. For example, in PC-1, BA1, BA3, BA4, BA5, BA6, and BA15 cluster together, while BA2, BA9, and BA19 also show

strong correlation. This emphasizes the importance of identifying positively associated barriers.

A loading plot (Fig. 5), created using MINITAB™, displays the loadings of all 23 barriers on PC-1 (22.9% variability) and PC-2 (16.5%). Eleven barriers, including BA19 (the most influential), showed strong positive loadings on both PCs. Others like BA21, BA20, BA22, BA9, BA2, and BA7 also load positively. These are primarily management and implementation-related barriers, and addressing them together may yield positive outcomes.

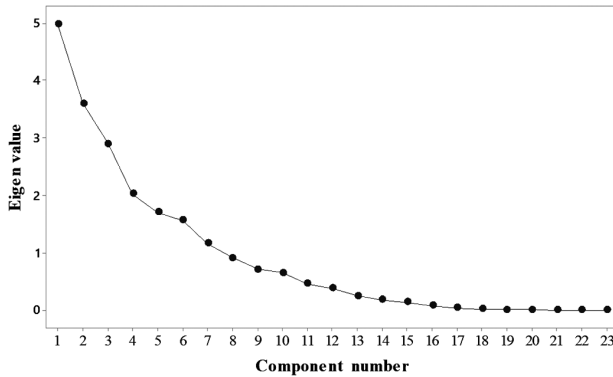


Fig. 4 — Scree plot (BA1 to BA23) of Eigen values vs PCs

Implications

Although the study mainly focused on SMEs in southern India, small enterprises across regions faced greater challenges than medium ones. These included limited technical exposure, low awareness, and financial constraints. Small firms often rely on traditional models and show less adaptability to digitalization, whereas medium enterprises demonstrated higher readiness and better infrastructure. Nonetheless, appropriate strategies can help overcome these barriers. The findings suggest

Table 5 — Eigen values of the PCs

Component	Total	Initial Eigen Values of PCs	
		Percentage of variance	Cumulative percentage
PC1	4.9927	22.90	22.90
PC 2	3.6096	16.50	39.40
PC 3	2.9005	13.30	52.70
PC 4	2.0326	9.30	62.10
PC 5	1.7096	7.80	69.90
PC 6	1.5628	7.20	77.10
PC 7	1.1683	5.40	82.40
PC 8	0.9106	4.20	86.60
PC 9	0.7161	3.30	89.90
PC 10	0.6528	3.00	92.90
PC 11	0.4641	2.10	95.00
PC 12	0.3838	1.80	96.70
PC 13	0.2512	1.20	97.90
PC 14	0.1815	0.80	98.70
PC 15	0.1388	0.60	99.40
PC 16	0.0799	0.40	99.70
PC 17	0.0344	0.20	99.90
PC 18	0.0138	0.10	100.00
PC 19	0.0056	0.00	100.00
PC 20	0.0038	0.00	100.00
PC 21	0.0009	0.00	100.00
PC 22	0	0.00	100.00
PC 23	0	0.00	100.00

Table 6 — Principal component Analysis

Barrier	Principal Components (PCs)						
	PC-1	PC-2	PC-3	PC-4	PC-5	PC-6	PC-7
BA1	0.315	0.001	-0.095	0.060	0.055	-0.058	-0.323
BA2	0.247	0.202	-0.057	-0.107	-0.047	-0.015	0.060
BA3	0.374	0.037	0.014	0.034	0.075	0.163	0.026
BA4	0.300	0.060	0.113	-0.111	0.124	-0.214	-0.394
BA5	0.332	-0.152	0.066	-0.220	0.216	-0.144	0.299
BA6	0.351	-0.023	-0.116	-0.142	0.153	0.459	-0.152
BA7	0.104	0.056	0.075	0.303	0.218	0.253	0.089
BA8	0.076	-0.132	0.285	0.203	0.010	0.266	0.000
BA9	0.211	0.196	0.173	0.076	-0.079	-0.140	0.400
BA10	-0.109	-0.104	0.358	-0.043	0.272	-0.128	0.056
BA11	0.066	-0.315	0.193	-0.064	-0.323	0.008	-0.174
BA12	0.181	-0.257	0.153	0.128	-0.310	-0.266	-0.131
BA13	0.114	0.034	-0.250	0.577	0.126	-0.225	0.085
BA14	0.104	-0.107	-0.426	0.109	-0.235	-0.174	-0.200
BA15	0.371	-0.220	-0.072	-0.178	0.166	-0.123	0.295
BA16	0.136	-0.321	-0.249	-0.104	-0.300	0.248	0.034
BA17	0.034	-0.234	0.117	0.290	-0.229	0.358	0.188
BA18	-0.025	-0.104	0.319	-0.194	-0.147	-0.125	-0.132
BA19	0.203	0.435	0.298	-0.072	-0.170	0.057	-0.195
BA20	0.132	0.170	0.261	0.414	-0.091	0.046	-0.158
BA21	0.035	0.452	-0.113	-0.199	-0.433	0.151	0.246
BA22	0.079	0.198	-0.195	0.089	-0.023	-0.199	-0.051
BA23	0.134	-0.066	0.132	0.096	-0.294	-0.287	0.303

that industrial transformation relies heavily on resource knowledge and organizational structure. Therefore, businesses should raise employee awareness, encourage adoption of new technologies, and support skill development.

Conclusions

The study explores the current adoption of LM and Industry 4.0 among Indian SMEs. Upon the distribution of questionnaires covering major drivers, strategies, and implementation barriers to 75 companies, 28 reliable responses were received. Analysis revealed that 43% companies have started implementation, 25% plan to adapt shortly, and 32% hesitate due to perceived challenges. Key drivers include cost reduction, quality improvement, and increased innovation and strategy. Imperative barriers identified through PCA include lack of standards, difficulty in coordinating different units of organization, not familiar with lean industry 4.0 technologies, need for a specialist, lack of knowledge about lean Industry 4.0 implementation and need of continuous training. The study is reliant on respondent expertise and limited to southern India, offering a foundational understanding of LM and Industry 4.0 awareness on SMEs. It underscores the need for future research focused on tool-specific, industry-specific, and systematic training frameworks to support effective implementation.

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