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Analysis of Sustainable Lean Manufacturing Implementation in Pune Region Manufacturing Industries

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In business and industry, lean manufacturing techniques are employed to enhance sustainability. Through continuous improvement, lean culture influences the performance of our processes and fortifies our systems. The facility's culture is fostered and delivery success rates are increased by connecting customers and suppliers. The ultimate aim of this research is to draft a methodology to implement sustainable lean in the manufacturing sector of India. The proposed research would address management-related issues and critical success factors (CSFs). For the functioning of sustainable lean manufacturing (SLM). The questionnaires were distributed to managers of manufacturing companies in the Pune region, directors of management, managers of manufacturing, and executives of quality. The returned surveys were legitimate and may be utilized for data analysis after a visual inspection for faults. By calculating Cronbach's alpha, the research tool's reliability was examined. The information was analyzed using a statistical package for the social sciences (SPSS) to get descriptive analysis which demonstrates how factors within each category impacted lean manufacturing using Structural Equation Modeling (SEM) analysis for a better understanding of the lean process. The study revealed success factors like continuous flow, leadership commitment, supplier partnership, and customer engagement impacting sustainable lean manufacturing implementation (SLMI) in manufacturing industries. Additionally, it indicates that barriers like lack of resources, and technological changes, have an impact on SLMI.

Keywords: Lean manufacturing; raw materials; lean management practices; lean manufacturing implementation; sustainability performance.

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1. Introduction

Lean manufacturing practices (LMPs) are used to promote sustainability in business and industry. LMPs are a collection of approaches used to lower production costs, improve productivity, lessen environmental effects, and promote social sustainability. Because LMPs are linked to process improvement, they make it easier to achieve long-term supply chain and organizational success.[1,2] Although lean is a quick and appealing method to decrease waste, businesses struggle to maintain a lean environment over the long term. Lean culture influences process performance and strengthens our systems through continual improvement. Linking customers and suppliers fosters a culture at the facility and improves delivery success rates.[3,4] Customers may adopt various supply chain activities, such as a focused factory, a consistent workload, and group technology, with reliable delivery. In a journey toward lean production, flexible manufacturing is demand-driven by customer orders, achieving market demand and increasing production.[5,6] The best illustration of flexible manufacturing is increased output using the same resources, which has a 100% customer delivery rating.[7] Lean manufacturing uses flexible production as a powerful tool to minimize market selling prices and overall manufacturing costs. The lean workplace offers employees the chance to be creative and to develop their ability, skill, and experience in process control and the production of high-quality goods.

The manufacturing industry is the primary focus, although other industries are working hard to share the burden of tackling sustainability.[8] Over the next fifty years, it is anticipated that the gross domestic product (GDP) per capita will increase by 2.5 times, which corresponds to a tenfold increase in energy consumption, material resource utilization, and production waste.[9] The foundation of a country's and a society's prosperity is the manufacturing sector.[10] Sustainable Manufacturing (SM) is "the making of that process which manufactures product by reducing the negative impact on the environment, saving the natural resources and energy, and making a safer environment for the employees, communities, and consumers", according to the US (United State) department of commerce (US department of commerce).[11]

Lean is described as "a collection of managerial methods and concepts geared toward minimizing wastage in the process of manufacturing and boosting the flow of operations that, from the customers' perspective, add value to the product". LMPs are a collection of strategies used to boost productivity, lower manufacturing costs, have a smaller negative impact on the environment, and have a higher level of social sustainability.[12] Because LMPs are linked to process improvement, they help organizations and their supplier chains achieve sustainable success. One approach to overcoming the various challenges the manufacturing sector faces is the adoption of LMPs.[13] Because LMPs are designed to continuously improve business processes, they will help organizations become more competitive.

The ability to endure in a time of competition is what sustainability is all about.[14] Depending on how it affects the economy, the environment, and society, sustainability has different levels of relevance. Any industry's success is heavily influenced by manufacturing performance. The erosion of human rights and the environment are two factors that affect sustainability.[15] Sustainable development[16] is defined as growth that satisfies present customer demand without compromising the capacity of future customers. In this case, lean manufacturing makes the most of all resources available to provide a high-quality product for the cheapest price.[17] Lean tools and approaches also help to maintain a competitive edge in business. The manufacturing sectors will benefit from the application of LMPs.

The study highlights key success factors such as continuous flow, leadership commitment, supplier partnerships, and customer engagement, which positively influence sustainable lean manufacturing implementation (SLMI). Conversely, barriers like resource constraints, cultural disparities, technological advancements, and weak enforcement mechanisms hinder the adoption of sustainable lean manufacturing (SLM) practices. By identifying these success variables and barriers, the study provides valuable insights into the challenges and opportunities for implementing SLM in the Pune region's manufacturing sector.

The effective implementation of SLM in manufacturing businesses is a complex process that involves addressing major management concerns and utilizing success factors. Challenges include resistance to change, a lack of management support, insufficient training, ineffective communication, and insufficient data for performance measurements. A lack of resources and a focus on the immediate future may delay the implementation process. To address these difficulties, strong leadership, a clear strategic vision, extensive personnel training, good communication, accurate measurements, and stakeholder engagement are required. These elements serve to align the organization's activities, develop a culture of continuous improvement, and maintain operational efficiency.

However, the main focus of the investigation is to discuss the barriers and success factors impacting SLMI in Pune region manufacturing industries.

The configuration of this work is as follows. The study first presents the research backdrop before addressing the notions of continuous flow, commitment from leadership, supplier collaboration, customer involvement, lack of materials, cultural variations, technological advances, low enforcement, and related literary-based topics. Next, the research strategy, theories, and procedures are then discussed. The results, their ramifications, the study's restrictions, and potential future research areas are all examined in the paper's concluding section.

1.1. *Research contribution*

In this era, a greater number of manufacturing industries struggle for competitive prices and the best quality with on-time delivery customer needs. There are several challenges organizations face as loss of business due to process breakdowns, government regulations, management approach, lack of training, defects in the product, and process failures. Organizations in manufacturing industries have started exploring SLM implementation. This study motivates researchers to understand

SLM in the selected Pune manufacturing industry. A literature review study is discussed with an expert to understand the theoretical and practical research level of SLM. With the help of critical success factors (CSFs), the research may take reference in this actual implementation work in manufacturing industries. The practical implementation approach will also help the researcher to define a roadmap for problem-solving through SLM implementation.

1.2. *Research objectives*

The ultimate aim of this research is to draft a methodology to implement sustainable lean in the Indian manufacturing sector. The proposed research would address management-related issues and CSFs for the implementation of SLM. To meet this, the research study aims to focus on the following objectives:

- To identify the influential CSFs for SLMI.
- To analyze the barriers to the implementation of lean in manufacturing industries.

1.3. *Research questions*

The research questions given below were taken from the research objective:

RQ_1. What are the key success factors for implementing sustainable lean practices in the manufacturing industry in the Pune region?

RQ_2. How are the barriers influencing lean implementation in manufacturing industries?

The arrangement of the paper is as follows. Following this introduction, Sec. 2 reviews the literature on the four variables under study and explains how they relate to one another. Section 3 outlines the methodology taken to achieve the goal; and Sec. 4 gives the findings. Section 5 offers the findings, conclusions, and implications of the research.

2. Literature Review

2.1. *Hypothetical framework*

Lean manufacturing is a philosophy that integrates a set of ideas, instruments, and methods into business operations to maximize assets, time, labor, and productivity while raising the caliber of goods and services provided to clients.[18] Using the lean manufacturing mindset is one of the key ideas that helps businesses stand out in the global marketplace.[19] A production technique known as "lean manufacturing" or "lean production" views the use of resources for any task other than producing value for the final consumer as waste. Just-in-time, quality control, work teams, cellular manufacturing, supplier management, and other multifaceted management practices are all included in lean manufacturing as an integrated system.[20]

According to resource dependence theory (RDT), using suppliers in procurement can increase a company's core competitiveness, make it possible to adopt effective procurement policies, and ultimately improve performance.[21] RDT contends, however, that organizations are dependent on outside resources and are not self-sufficient. To obtain essential resources based on their internal resources and organizational plans, organizations depend on their interactions with external entities. Unbalances and possible crises may result from this reliance on outside resources.[22] RDT has a great deal of application in supply chain research because it can reduce or even eliminate uncertainty caused by interruptions in the flow of resources from suppliers. Research on sustainable supply chain management can benefit from Salam *et al.*'s[23] use of RDT to examine how supply chain strategy and supply chain uncertainty relate to organizational performance. Based on RDT, Gebhardt *et al.*[24] investigated the impact of a circular economy and discovered that it can successfully lessen reliance on the supply chain. To investigate the effectiveness of sustainable supply networks, Esfahbodi *et al.*[25] created a framework based on RDT and established a connection between organizational performance and sustainable supply chain practice. RDT is a good tool to use when talking about supply networks' sustainability.

2.2. *Research hypothesis*

The focus of the literature review was on describing the state of lean, its numerous tools, and practices. Therefore, great deals of investigations have focused on the lean manufacturing factors and finally, the barriers depicted in Fig. 1.

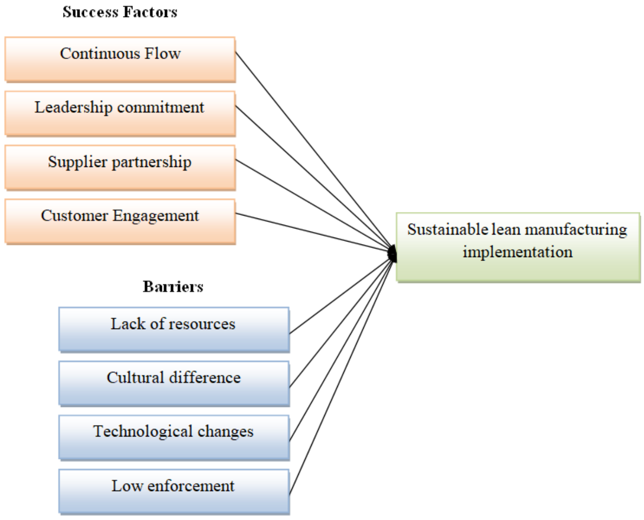

Fig. 1. Hypothesis framework.

Sharma *et al.*[26] analyzed barriers to implementing LMPs in the machine tool industry aiming to improve competitive potential. Similarly, Mishra[27] explored green and lean Six Sigma's (LSS) application through a literature review, identifying five success factors and demonstrating how their integration maximizes resource efficiency. Knol *et al.*[28] examined lean practice implementation dependence on various success variables, highlighting progression-dependent criticality. Blijleven *et al.*[29] identified 16 CSFs enabling lean adoption in IT outsourcing through qualitative assessment. Chiarini and Federico[30] established a framework for lean adoption, emphasizing setting up lean methods, personnel training, teamwork, performance evaluation, and financial monitoring. Continuing in 2021, Swarnakar *et al.*[31] analyzed 17 key factors for sustained LSS adoption in healthcare using a hierarchical model validated through structural equation modeling. Pozzi *et al.*[32] in the same year utilized industry 4.0 technology installations in Italy, highlighting top management guidance, cross-functional teams, pre-project planning, training, and continuous improvement as essential elements. Finally, Barclay *et al.*[33] presented findings from an international study, identifying 13 variables directly associated with ingrained lean culture, explaining over 90% of the variability in survey data.

In its optimal state, continuous flow (COF) entails processing and transporting products directly from one production stage to the next, one piece at a time, ensuring the ideal order size. This approach ensures that each production step works on the specific part needed by the next step just before it's required, effectively eliminating excess inventories, and delivery delays, and facilitating customization for broader market coverage.[34] Leadership commitment and effective communication skills have been identified as crucial managerial attributes for successful lean manufacturing (LM) implementation. Leaders play a pivotal role in guiding organizational alignment and fostering a culture of continuous improvement necessary for LM success.[35] Supplier relationship management refers to a firm's ability to establish, manage, and sustain long-term, dependable partnerships with its suppliers. This entails the mutual sharing and application of operational, financial, and strategic knowledge between the buying firm and its suppliers to generate mutual benefits, ensuring supply chain efficiency and resilience.[36] Customer engagement (CE) is measured by the extent of a customer's physical, cognitive, and emotional involvement in their relationship with an organization. Several studies have linked customer engagement with concepts such as customer co-creation value and customer experience, emphasizing the importance of actively involving customers in product development and service delivery processes.[37]

Organizations must have a deep understanding of the crucial elements that direct and facilitate the efficiency process of production processes to successfully manage the lean adoption process. Organizations starting their lean journeys will benefit from being aware of these characteristics in organizations in emerging and developing nations. Employees have the opportunity to use their creativity while honing their aptitude, expertise, and experience in managing processes and the manufacture of high-quality goods in a lean workplace. Lean manufacturing utilizes every resource at its disposal to produce a product of the highest caliber at the lowest cost. Therefore, success factors like continuous flow, leadership commitment, supplier partnership, and customer engagement impact SLMI in manufacturing industries. As a result, the following hypotheses were formulated:

H_{1a-0}. Continuous flow has no favorable impact on SLMI.

H_{1a}. Continuous flow has a favorable impact on SLMI.

H_{1b-0}. Leadership commitment has no favorable impact on SLMI.

H_{1b}. Leadership commitment has a favorable impact on SLMI.

H_{1c-0}. Supplier partnership has no favorable impact on SLMI.

H_{1c}. Supplier partnership has a favorable impact on SLMI.

H_{1d-0}. Customer engagement has no favorable impact on SLMI.

H_{1d}. Customer engagement has a favorable impact on SLMI.

Ramadas and Satish[38] examined process hurdles impeding small and medium-sized businesses (SMEs) from adopting lean manufacturing, highlighting the need to overcome bottlenecks for successful implementation. Similarly, Shamsi and Alam[39] investigated impediments faced by the information technology sector in implementing LSS, identifying barriers such as part-time commitment, staff turnover, and data collection difficulties. Abu *et al.*[40] discussed the drawbacks of lean manufacturing methods and conducted a survey of Malaysian enterprises to identify obstacles and goals, emphasizing productivity improvement and workplace organization. Vinodh[41] focused on small family-run businesses in northern Italy, emphasizing the role of social networks, consultant support, and leadership in overcoming lean implementation obstacles. Signoretti[42] analyzed barriers to lean implementation in the manufacturing of electrical and electronic components, using interpretative structural modeling to prioritize obstacles including governmental policies and lack of management dedication. Chaple *et al.*[43] utilized total interpretative structural modeling to identify management time, supervision abilities, and senior management expertise as key obstacles to lean implementation success. Jaiswal *et al.*[44] examined the relationship between lean manufacturing, digitalization, and operational success, finding both independently contribute to improved performance. Finally, Buer *et al.*[45] explored the interdependencies of adoption hurdles for lean manufacturing in Indian SMEs, identifying top-level commitment, financial resources, technology apprehension, and leadership as major obstacles.

These studies collectively contribute to a comprehensive understanding of the challenges facing lean manufacturing implementation across different industries and regions.

The implementation of lean and SM techniques in Pune faces various challenges, including a lack of resources such as finance, skilled labor, and access to sustainable technologies.[46] Cultural differences at workplaces serve as significant barriers, impacting both lean and nonlean mines, with disparities in perception regarding lean understanding, resistance to change, and availability of consultants and trainers.[47] Moreover, technological advancements in manufacturing require investments in research and development, skill training, and the adoption of Industry 4.0 technologies to enhance competitiveness and sustainability.[48] However, weak organizational controls and regulatory monitoring, characterized by low enforcement of sustainable lean techniques, hinder the application and adherence to SLM principles.[49] This deficiency in regulatory frameworks and enforcement procedures in Pune may diminish companies' motivation to embrace sustainable practices, emphasizing the need for stronger regulatory oversight and enforcement mechanisms.

In many various industries across the industrial sector in developed nations, lean practices have been widely implemented. There is a ton of evidence that successful lean implementation has given Western companies a competitive edge by increasing efficiency and output. Flexible production is a key component of lean manufacturing, which employs it to reduce both overall manufacturing costs and market selling prices. Lean methods and tools aid in preserving an advantage over others in the business world. Lean manufacturing techniques will be beneficial for industries. Therefore, barriers like lack of resources, cultural differences, technological changes, and low enforcement have an impact on SLMI. As a result, the following hypotheses were formulated:

$H_{2a\text{-}0}$. Lack of resources has no impact on SLMI.

H_{2a}. Lack of resources has an impact on SLMI.

$H_{2b\text{-}0}$. Cultural difference has no impact on SLMI.

H_{2b}. Cultural difference has an impact on SLMI.

$H_{2c\text{-}0}$. Technological changes have no impact on SLMI.

H_{2c}. Technological changes have an impact on SLMI.

$H_{2d\text{-}0}$. Low enforcement has no impact on SLMI.

H_{2d}. Low enforcement has an impact on SLMI.

3. Research Methodology

The research methodology employed in this study revolves around assessing the implementation of SLM in manufacturing industries within the Pune region.

3.1. *Variable description*

SLM is the dependent variable and success and Barriers are Independent variables.

Sustainable Lean Manufacturing: The purpose of SLM is to minimize waste, optimize processes, and lessen environmental impact while preserving profitability. It does this by integrating lean concepts with environmental sustainability goals. SLM implementation in the Pune Region entails implementing resource-efficient manufacturing techniques, adopting eco-friendly manufacturing practices, and emphasizing long-term sustainability in manufacturing operations.[18]

Success Factors: The application of SLM success factors includes essential components that are necessary to attain long-term operational excellence. While supplier alliances promote collaboration and supply chain efficiency, leadership commitment encourages organizational alignment and support, and consumer engagement guarantees that products satisfy market expectations and sustainability preferences, continuous flow assures smooth and efficient production processes. For SLM to be implemented successfully in the Pune area, it is essential to recognize and take advantage of these success characteristics.

Continuous Flow: A key component of lean manufacturing, continuous flow minimizes disruptions and delays in production processes to facilitate a constant and effective flow of information and materials from raw materials to final goods. Pune's manufacturing facilities may become more productive, cut lead times, and minimize waste by implementing continuous flow techniques, which will increase the manufacturing sector's competitiveness and sustainability.[34]

Leadership Commitment: To drive SLM programs, set the example for cultural change, allocate resources, and prioritize sustainable goals, organizational leaders must actively support and participate in these activities. This is known as leadership commitment. In Pune's manufacturing companies, a strong commitment from the leadership is necessary to support a culture of continuous improvement, match business plans with sustainability goals, and get beyond obstacles to SLM implementation.[35]

Supplier Partnership: Supplier partnerships are cooperative relationships with suppliers built on openness, trust, and common objectives. They are intended to maximize supply chain efficiency and advance sustainability through the value

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chain. In Pune's manufacturing ecosystem, forming solid supplier relationships can improve responsiveness, creativity, and resource efficiency. This can facilitate long-term lean techniques and lessen environmental impact throughout the supply chain.[36]

Customer Engagement: Actively including customers in the design, development, and feedback processes is what is meant by customer engagement; it aims to fulfill customers' changing wants, preferences, and sustainability expectations. Providing sustainable solutions that are in line with client values and environmental concerns can stimulate product innovation, market distinction, and brand loyalty in Pune's manufacturing industry.[37]

Barriers: Challenges and impediments that impede the adoption and efficacy of lean and sustainable techniques in manufacturing processes are known as barriers to SLM implementation. These obstacles include a lack of funding, cultural disparities, advancements in technology, and lax enforcement of environmental policies. Overcoming reluctance to change and guaranteeing the effective adoption of sustainable lean concepts in the manufacturing environment of the Pune region depend on addressing these obstacles.

Lack of Resources: The term "lack of resources" describes the absence of the technological, human, or financial resources needed to develop and maintain SLM activities. The implementation of lean and SM techniques in Pune may be hampered by a lack of finance, a paucity of skilled labor, and restricted access to sustainable technologies. These issues will need to be resolved by strategic resource allocation and investment.[46]

Cultural Differences: Cultural differences can cause stakeholder misalignment and complicate SLM implementation efforts because they comprise different corporate values, beliefs, and attitudes about change, sustainability, and collaboration. For enterprises in the culturally varied Pune region to share a commitment to sustainable lean principles, cultural disparities must be addressed through effective communication, training, and cultural integration initiatives.[47]

Technological Changes: Technological improvements in manufacturing, automation, and digitalization have an impact on skill needs, production methods, and sustainability practices. In Pune's manufacturing industry, keeping up with technological advancements means spending on R&D, training skills, and implementing Industry 4.0 technologies to improve competitiveness, sustainability, and operational efficiency.[48]

Low Enforcement: Weak organizational controls, compliance systems, or regulatory monitoring compromise the application and upholding of sustainable lean techniques, which is known as low enforcement. The deficiency in the implementation of environmental legislation, the oversight of sustainability projects, and the lack of accountability in Pune may reduce the motivation of companies to embrace and follow SLM principles, underscoring the necessity of more robust regulatory frameworks and enforcement procedures.[49]

3.2. *Data collection*

Data collection was primarily conducted through the distribution of questionnaires to key personnel within manufacturing companies located in the Pune region. The respondents targeted for this study included managing executives, production supervisors, and quality managers. These individuals were chosen due to their direct involvement in decision-making processes and operations within their respective companies. Five-hundred-forty questionnaires were distributed and only 320 valid responses were received.

3.2.1. *Sampling*

Convenience sampling was utilized for this study due to its practicality and accessibility. Through convenience sampling, 320 respondents were selected for analysis. This sampling technique was chosen for its ease in reaching out to potential participants within the target population. Managers were shortlisted through LinkedIn, a social networking site, and emails were sent to the chief operating officers of the companies to request participation from their managers.

3.2.2. *Demographic profile*

The demographic characteristics, including age, gender, the greatest level of education acquired, department, monthly income, and year of working experience) collected and the responses are tabulated in Table 1. Out of 320 respondents, the number of male respondents is 39% and females are 61% whereas 39% of respondents are grouped into 35–40 years. Most of the respondents are graduates which is responsible for 44% of the total response. Among the participants, all have more or less experience in lean implementation. But 46% of participants have 5–15 years of experience and it is important to note that 45% are production managers and 47% of participants mentioned that their monthly income is below 10,000.

3.2.3. *Questionnaire measures and constructs/items*

The questionnaire comprised two sections. The first section focused on gathering the personal information of the respondents, while the second section aimed to assess the understanding of lean principles among firms, readiness to implement lean practices, and the obstacles faced in the implementation process. Each section contained four questions. The second section of the questionnaire utilized Likert scale questions to gauge respondents' perceptions, ranging from "completely

Table 1. Demographic profile of the respondents.

Demographic profile	Frequency	Percentage
Age		
23–28 years	68	21
29–35 years	110	35
35–40 years	126	39
40 years and more	16	5
Total	320	100.0
Gender		
Male	194	61
Female	126	39
Total	320	100.0
Education		
Diploma	29	9
Graduation	140	44
Post-Graduation	98	31
Others	53	16
Total	320	100.0
Department		
Managing Director	27	9
Production Manager	145	45
Quality Manager	100	31
Others	48	15
Total	320	100.0
Monthly income		
Below 10,000	150	47
11,000–15,000	78	25
15,000–30,000	62	19
Above 30,000	30	9
Total	320	100.0
Experience		
Below 5 years	29	9
5–15 years	148	46
16–20 years	94	30
Above 20 years	49	15
Total	320	100.0

disagree" to "agree". These Likert scale questions enabled a quantitative assessment of the respondents' attitudes and opinions regarding LMPs. Table 2 shows the measurement constructs of the questionnaire.

3.3. *Research design*

Upon collection of responses, a visual inspection of the data was conducted to ensure completeness and accuracy. Subsequently, the data were input into the Statistical Package for the Social Sciences (SPSS) for analysis. Descriptive analysis techniques were employed to examine the impact of various factors on SLM implementation. This analysis facilitated a comprehensive understanding of the relationship between different variables and their influence on lean production practices.

Table 2. Constructs and measurement items.

Measurement constructs	Item	Source
Lean manufacturing implementation (SLMI)		
SLMI1: I Ensure that all product components have been quality tested.	6	Ronald[18]
SLMI2: The workshop is separated into various work areas.		
SLMI3: Each working area is managed and run by skilled and knowledgeable personnel.		
SLMI4: I reduce unnecessary inventory.		
SLMI5: Speed up response time.		
SLMI6: No products are manufactured unless customers place orders for them.		
Continuous flow (CF)		
CF1: I increase productivity due to manufacturing more products in less time.	3	García-Alcaraz *et al.* [34]
CF2: I increase stability.		
CF3: I reduce lead time.		
Leadership commitment (LC)		
LC1: I focus on continuous improvement.	3	Tortorella *et al.*[35]
LC2: Excel at both verbal listening and listening skills.		
LC3: I increase organizational efficiency.		
Supplier partnership (SP)		
SP1: I supply raw materials to the organization.	3	Nimeh *et al.*[36]
SP2: Keep a long-term relationship with the organization.		
SP3: I Product and process improvement.		
Customer engagement (CE)		
CE1: I promote my company through word-of-mouth marketing and loyalty.	3	Almeida and Grilo[37]
CE2: I boost the brand experience.		
CE3: I offer insightful consumer comments and feedback.		
Lack of resources (LR)		
LR1: Overuse of renewable sources of energy.	3	Huang *et al.*[46]
LR2: Maintaining tasks on schedule and under budget.		
LR3: Unsure of which of their resources are accessible.		
Cultural difference (CD)		
CD1: I work to eliminate negative preconceptions and prejudices regarding various communities.	3	Khaba and Bhar[47]
CD2: I facilitate others learning about viewpoints and customs from many cultures.		
CD3: I encourage individuals to advance their abilities.		
Technological changes (TC)		
TC1: Boost the effectiveness of your company's systems.	3	Adjamskyi *et al.*[48]
TC2: I cut down on waste and downtime.		
TC3: Connections with consumers and suppliers are streamlined.		
Low enforcement (LE)		
LE1: I increase my capacity for advancement in other justice-related positions.	3	Sapkal[49]
LE2: I maintain the rule of law in the rural and township portions.		
LE3: I assuring adherence to legal requirements, societal norms, and other guidelines.		

4. Data Analysis

4.1. *Reliability analysis and validity analysis*

The provided data outline the reliability and validity measures for different constructs in the survey, each comprising a set number of questions. The Cronbach's

Table 3. Reliability and validity analysis of each construct.

No.	Construct	α	AVE	No. of items
1	SLMI	0.784	0.5463	6
2	Continuous flow (CF)	0.749	0.7130	3
3	Leadership commitment (LC)	0.821	0.5412	3
4	Supplier partnership (SP)	0.878	0.6490	3
5	Customer engagement (CE)	0.754	0.8864	3
6	Lack of resources (LR)	0.824	0.7164	3
7	Cultural difference (CD)	0.714	0.7411	3
8	Technological changes (TC)	0.920	0.9224	3
9	Low enforcement (LE)	0.801	0.5276	3

alpha coefficient, a measure of internal consistency, was calculated for SLMI, continuous flow (CF), leadership commitment (LC), supplier partnership (SP), customer engagement (CE), lack of resources (LR), cultural difference (CD), technological changes (TC), and low enforcement (LE) constructs were measured using 6, 3, 3, 3, 3, 3, 3, 3, and 3 different questions. The Cronbach's alpha values range from 0.714 to 0.920, all surpassing the widely accepted threshold of 0.70. This indicates that the questions within each construct are highly reliable and internally consistent, demonstrating the robustness of the survey instrument. Additionally, the average variance extracted (AVE) values, representing the amount of variance captured by the construct relative to measurement error, are all above the recommended threshold of 0.5. The AVE values range from 0.5276 to 0.9224, suggesting that each construct adequately explains the variance in its associated items, reinforcing the convergent validity of the survey. In summary, the survey exhibits good internal consistency, as evidenced by the high Cronbach's alpha values, and each construct demonstrates strong convergent validity with AVE values exceeding the recommended threshold. These findings indicate confidence in the reliability and validity of the survey instrument for assessing perceptions and attitudes related to SLMI in the surveyed context. The reliability as well as validity analysis of each construct is represented in Table 3.

4.2. *Evaluation of descriptive test*

Table 4 provides statistical data on SLMI in Pune. It presents an in-depth analysis of the responses provided by the participants to the different questionnaire items. Correlating these statistics with actual manufacturing outcomes helps understand the impact of success factors and barriers. It includes statistical measurements like mean (M) and standard deviation (SD) for each construct. For some constructs and the accompanying survey items for a sample size (N) of 170 respondents. Items like SLMI6 ("No Products Are Manufactured Unless Customers Place Orders for Them") have a high mean of 3.4345, indicating that respondents' perceptions of the SLMI construct are usually positive. The focus of continuous flow (CF) items is on lead time reduction and productivity enhancement; CF2 ("I Increase Stability")

Table 4. Descriptive test.

Construct/Items ($N = 170$)	Mean	S. D.
SLMI		
SLMI1: I ensure that all product components have been quality tested.	3.2995	0.85543
SLMI2: The workshop is separated into various work areas.	3.2419	0.84593
SLMI3: Each working area is managed and run by skilled and knowledgeable personnel.	3.3599	0.88412
SLMI4: I reduce unnecessary inventory.	3.2943	0.92370
SLMI5: Speed up response time.	3.2545	0.94834
SLMI6: No products are manufactured unless customers place orders for them.	3.4345	0.94212
Continuous flow (CF)		
CF1: I increase productivity due to manufacturing more products in less time.	3.2654	0.91201
CF2: I increase stability.	3.3510	0.95822
CF3: I reduce lead time.	3.2845	0.94593
Leadership commitment (LC)		
LC1: I focus on continuous improvement.	3.1644	0.92899
LC2: Excel at both verbal listening and listening skills.	3.0884	0.93737
LC3: I increase organizational efficiency.	3.1356	0.94108
Supplier partnership (SP)		
SP1: I supply raw materials to the organization.	3.1456	0.99662
SP2: Keep a long-term relationship with the organization.	3.0456	0.91057
SP3: I product and process improvement.	3.0567	0.94581
Customer engagement (CE)		
CE1: I promote my company through word-of-mouth marketing and loyalty.	3.0471	0.95772
CE2: I boost the brand experience.	3.1654	0.96626
CE3: I offer insightful consumer comments and feedback.	3.1059	0.96107
Lack of resources (LR)		
LR1: Overuse of renewable sources of energy.	2.8629	0.89877
LR2: Maintaining tasks on schedule and under budget.	3.1000	0.88045
LR3: Unsure of which of their resources are accessible.	2.9554	0.89307
Cultural difference (CD)		
CD1: I work to eliminate negative preconceptions and prejudices regarding various communities.	2.9594	0.87589
CD2: I facilitate others learning about viewpoints and customs from many cultures.	2.9772	0.87588
CD3: I encourage individuals to advance their abilities.	3.2945	0.94235
Technological changes (TC)		
TC1: Boost the effectiveness of your company's systems.	3.0950	1.12295
TC2: I cut down on waste and downtime.	2.8363	1.02490
TC3: Connections with consumers and suppliers are streamlined.	3.1456	1.14184
Low enforcement (LE)		
LE1: I increase my capacity for advancement in other justice-related positions.	3.0566	0.89549
LE2: I maintain the rule of law in the rural and township portions.	3.1257	0.86561
LE3: I assure adherence to legal requirements, societal norms, and other guidelines.	2.8334	0.94288

has a mean of 3.3510. The leadership commitment (LC) questions demonstrate a favorable outlook on organizational efficiency. The mean score for LC1 ("I Focus on Continuous Improvement") is 3.1644. The importance of long-term connections is highlighted by supplier partnership (SP) elements; the mean score for SP1

("I Supply Raw Materials to The Organization") is 3.1456, for example. An emphasis on brand experience is suggested by customer engagement (CE) items, especially by CE2 ("I Boost The Brand Experience"), which has a mean score of 3.1654. The absence of resources (LR) items shows that task management effectiveness is being paid attention to; the mean of LR2 ("Maintaining Tasks on Schedule and Under Budget") is 3.1000. Items in the cultural difference (CD) category show a positive outlook on personal growth, particularly CD3 ("I Encourage Individuals to Advance Their Abilities"), which has a mean score of 3.2945. Effectiveness and streamlined connections are highlighted in technological changes (TC) items; TC3 ("Connections with Consumers And Suppliers Are Streamlined") gets a mean score of 3.1456, for example. The last low enforcement (LE) item, LE2 ("I Maintain the Rule of Law in The Rural and Township Portions"), has a mean of 3.1257, highlighting the significance of upholding the law. The standard deviations give a measure of the variety or consensus in these beliefs throughout the sample, whereas the means give quantitative insight into the respondents' perceptions.

4.3. *Model fitness measures*

The CFI results are depicted in Table 5. A number above 0.9 on the comparative fitting index (CFI) is considered to be a very good fit. However, emphasize that a CFI rating of 0.80 is appropriate and that a CFI level of 0.75 can hint at a model that fits reasonably well. A CFI of 0.906 was obtained from the lean implementation measurement model. This index signifies satisfaction as the index value.

The root mean square error of approximation (RMSEA) results are depicted in Table 6. Fit indices of the model, in particular the RMSEA, show how well the model fits the observed data. The RMSEA value in the default model is 0.58, with a confidence range that spans 0.063–0.091. The observed data and the model's predictions are measured by the RMSEA, and in this instance, the value of 0.58

Table 5. CFI.

Model	NFI Delta 1	RFI Rho1	IFI Delta 2	TLI Rho2	CFI
Default Model	0.982	0.945	0.998	0.975	0.906

Notes: CFI = Comparative Fit Index, NFI = Normed Fit Index, RFI = Relative Fit Index, IFI = Incremental Fit Index.

Table 6. RMSEA.

Model	RMSEA	LO 90	HI 90	PCLOSE
Default Model	0.58	0.063	0.091	0.000

Notes: RMSEA = Root Mean Square Error of Approximation, LO 90 = Lower boundary (RmseaLo) of a 90% confidence interval of the RMSEA, HI 90 = Higher boundary (RmseaHi) of a 90% confidence interval of the RMSEA, PCLOSE = *P*-value of the null hypothesis.

Table 7. Hoelter's index.

Model	HOELTER 0.05	HOELTER 0.01
Default Model	88	96
Independence Model	25	26

indicates a less-than-optimal fit. The confidence interval's lower and upper bounds, which range from 0.063 to 0.091, indicate the likely range in which the genuine RMSEA value will fall. When determining the significance of the RMSEA, the Probability of Close Fit (PCLOSE) is essential. A value of 0.000 suggests that the model does not fit the data well because the p-value is below traditional significance limits. All in all, these findings point to the default model's shortcomings in accurately describing the observed data, highlighting the necessity of model improvement or the use of different requirements to get a better match.

The critical number of samples (N) and, consequently, whether a sample size is sufficient, are determined using the goodness-of-fit of the model as measured by the hoelter index. Hoelter index, the index gives the approximate sample size at which x^2 would no longer be significant, i.e. that is how small one's sample size would have to be for the result to be no longer significant. The index should only be computed if the chi-square is statistically significant. Table 7 shows the Hoelter's index. A model cannot be accepted if Hoelter's N is less than 75. Therefore, Hoelter's N yields two outcomes at the significance levels of 0.05 and 0.01. The lean implementation approach yields acceptable values of 96 at the 0.01 significance level and 88 at the 0.05 significance respectively. A highly high Hoelter's index indicates a good model fit.

4.4. *Hypothesis testing*

The hypothesis test with eight factors is shown in Table 8: Continuous flow has a favorable impact on SLMI with a value of 0.034, which is smaller, than 0.05 (P Value) and it indicates that the null hypothesis (H_{1a}) is rejected. Leadership commitment has no favorable impact on SLMI with a value of 0.002, which is smaller

Table 8. Hypothesis test.

Hypothesis	Path	Significant	Null hypothesis
H_{1a}	CF → SLMI	0.034	Rejected
H_{1b}	LC → SLMI	0.002	Rejected
H_{1c}	SP → SLMI	0.026	Rejected
H_{1d}	CE → SLMI	0.048	Rejected
H_{2a}	LR → SLMI	0.017	Rejected
H_{2b}	CD → SLMI	0.254	Fail to reject
H_{2c}	TC → SLMI	0.043	Rejected
H_{2d}	LE → SLMI	0.345	Fail to reject

than 0.05 (P Value) and it indicates that the null hypothesis (H_{1b}) is rejected. Supplier partnership has a favorable impact on SLMI with a value of 0.026, which is smaller than 0.05 (P Value) and it indicates that the null hypothesis (H_{1c}) is rejected. Customer engagement has a favorable impact on SLMI with a value of 0.048, which is smaller than 0.05 (P Value) and it indicates that the null hypothesis (H_{1d}) is rejected. Lack of resources has an impact on SLMI with a value of 0.017, which is smaller than 0.05 (P Value) and it indicates that the null hypothesis (H_{2a}) is rejected. Cultural difference has no impact on SLMI with a value of 0.254, which is greater than 0.05 (P Value) and it indicates that the null hypothesis (H_{2b}) fails to be rejected. Technological changes have no impact on SLMI with a value of 0.043, which is smaller than 0.05 (P Value) and it indicates that the null hypothesis (H_{2c}) is rejected. Low enforcement has no impact on SLMI with a value of 0.345, which is greater than 0.05 (P Value) and it indicates that the null hypothesis (H_{2d}) fails to reject. They intend to address management-related issues and CSFs for the implementation of SLM to managers of manufacturing industries in the Pune region, directors of management, managers of manufacturing, and managers of quality.

4.5. *Discussion*

The study, "Analysis of SLMI in Pune Region", investigates the application of lean manufacturing techniques to strengthen sustainability in the business and industrial context. By developing a lean culture through continuous improvement, the research explores how such practices influence process performance and strengthen systems. The study aims to draft a methodology for implementing SLM in the Indian manufacturing sector, specifically in the Pune region. The questionnaires distributed to various managerial levels were validated and deemed suitable for data analysis. The reliability of the research tool was confirmed through the calculation of Cronbach's alpha. Utilizing SPSS, the study conducted a descriptive analysis to illustrate the impact of factors within each category on lean manufacturing and employed SEM analysis for a deeper understanding of the lean process. The results of hypothesis testing, presented in Table 8, offer valuable insights into the relationship between different factors and SLMI. Continuous flow (CF), leadership commitment (LC), supplier partnership (SP), and customer engagement (CE) were found to have favorable impacts on SLM implementation, as indicated by the rejection of their respective null hypotheses.[34–37] Conversely, lack of resources (LR), and technological changes (TC), were identified as barriers impacting SLM implementation, leading to the rejection of their null hypotheses.[46,48] Cultural difference (CD) and low enforcement (LE), however, did not show a statistically significant impact on SLM implementation, as evidenced by the failure to reject the null hypothesis.[47,49] These findings provide a nuanced understanding of the CSFs and potential barriers in the SLM context, offering valuable implications for managers and decision-makers in the Pune region's manufacturing industries.

5. Conclusions

Conclusion, implication, limitation and future recommendations: This study focused on the investigation to discuss the barriers and success factors impacting SLMI in Pune region manufacturing industries. To accomplish our objective, research questions were created and then addressed. Lean manufacturing and Manufacturing Industries in the Pune region have been highlighted by the current study. Therefore, the study revealed that continuous flow has a favorable impact on SLMI, which indicates that the null hypothesis (H_{1a}) is rejected. Leadership commitment has a favorable impact on SLMI, which indicates that the null hypothesis (H_{1b}) is rejected. Supplier partnership has a favorable impact on SLMI, which indicates that the null hypothesis (H_{1c}) is rejected. Customer engagement has a favorable impact on SLMI, which indicates that the null hypothesis (H_{1d}) is rejected. Lack of resources has an impact on SLMI, which indicates that the null hypothesis (H_{2a}) is rejected. Cultural difference has no impact on SLMI, which indicates that the null hypothesis (H_{2b}) fails to be rejected. Technological changes have an impact on SLMI, which indicates that the null hypothesis (H_{2c}) is rejected. Low enforcement has no impact on SLMI, which indicates that the null hypothesis (H_{2d}) fails to be rejected.

5.1. *Implication*

The study can be expanded to test more hypotheses with larger sample sizes to obtain more precise results and cover more areas. For the car component sector, specific manufacturing strategies can be developed to obtain improved lean performance. The study revealed success factors like continuous flow, leadership commitment, supplier partnership, and customer engagement impacting SLMI in manufacturing industries. Additionally, it indicates that barriers like lack of resources, and technological changes, have an impact on SLMI.

5.2. *Limitation*

A method of quantitative inquiry has limitations due to the imprecision of the assessment of the empirical data. It is challenging to evaluate the validity of the recommendations, which are judgments of the empirical findings because the data were amassed through evaluations. Furthermore, when conducting surveys, there is always a potential that prejudices will be present. Additionally, it has shown how crucial machine adaptability is to achieving lean performance. Organizations encounter several difficulties, including commercial loss brought on by process breakdowns, regulatory requirements, management style, a lack of training, product flaws, and process failures. Manufacturing companies begin investigating the application of SLM. Researchers are motivated by this study to comprehend SM methods in the chosen industrial sector in Pune.

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