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Impact Of Lean Production Practices On Quality Performance And Competitive Advantage In Selected Foundry Industrial Units In Kolhapur District

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ABSTRACT: *The foundry industry, being one of the most resource-intensive manufacturing sectors, faces growing challenges of global competition, cost pressures, and the demand for consistent quality. Lean production practices have emerged as a proven management philosophy to minimize waste, improve efficiency, and enhance competitiveness. This study investigates the impact of lean production practices on quality performance and competitive advantage in selected foundry industrial units of Kolhapur district, a prominent foundry hub in India. Primary data were collected through structured questionnaires administered to managers, supervisors, and shop-floor employees, supplemented by interviews and plant observations. A total of 473 valid responses were analyzed using descriptive statistics, confirmatory factor analysis (CFA), and structural equation modeling (SEM) to test hypothesized relationships. The findings reveal that lean practices—such as 5S, Kaizen, Just-in-Time, Total Productive Maintenance, and Value Stream Mapping—significantly contribute to improved quality performance by reducing defects, enhancing process reliability, and ensuring timely delivery. Furthermore, quality improvements mediated by lean practices strengthen competitive advantage by enabling cost efficiency, customer satisfaction, and market responsiveness. The research provides empirical evidence of the strategic role of lean implementation in foundries, highlighting practical insights for managers and policymakers to sustain industrial growth in regional clusters. This study also adds to the existing body of literature by linking lean practices with quality performance and competitiveness in the context of Indian foundry units, thereby offering both theoretical and managerial implications.*
Keywords: *Lean Production Practices, Quality Performance, Competitive Advantage, Foundry Industry, Confirmatory Factor Analysis (CFA), Structural Equation Modeling (SEM)*

INTRODUCTION

The manufacturing sector across the globe is undergoing rapid transformation due to increasing competition, technological advancements, and customer expectations for higher quality and lower costs. In this dynamic environment, industries are under pressure to adopt strategies that reduce waste, improve process efficiency, and deliver consistent quality. Among the various management philosophies, Lean Management has gained global recognition as a comprehensive approach to operational excellence. Lean focuses on eliminating non-value-added activities, streamlining processes, and enhancing customer value (Womack & Jones, 1996). Originally developed as part of the Toyota Production System, lean has evolved into a universal model for improving manufacturing systems across different sectors (Shah & Ward, 2007).

Lean Management and Its Relevance

Lean management extends beyond a set of tools; it represents a cultural shift that emphasizes continuous improvement, waste reduction, and employee involvement. The fundamental principle of lean is to deliver maximum value to customers while consuming the least possible resources. Techniques such as 5S, Kaizen, Just-in-Time (JIT), Kanban, Total Productive Maintenance (TPM), and Value Stream Mapping (VSM) form the operational framework for lean adoption (Hines et al., 2004). For example, 5S focuses on workplace organization and discipline, Kaizen encourages continuous incremental improvement, and JIT ensures that production is closely aligned with customer demand, reducing inventory and lead times.

In global contexts, lean practices have been shown to significantly improve manufacturing competitiveness. In automotive industries, lean has become the benchmark for operational excellence

(Liker, 2004). In Small and Medium Enterprises (SMEs), lean implementation has been linked to improved flexibility and responsiveness (Bhamu & Sangwan, 2014). For foundries, which are inherently resource-intensive and process-dependent, lean offers a structured framework to tackle inefficiencies and align operations with global quality and cost standards.

Lean Practices in Foundries

Foundries are a vital segment of the manufacturing supply chain, producing castings that serve as critical inputs for industries such as automobiles, agriculture, pumps, and heavy machinery. However, the sector faces unique operational challenges due to its dependence on high energy consumption, process variability, and manual operations. Common defects in foundry castings—such as shrinkage, porosity, inclusions, and dimensional inaccuracies—directly affect cost, productivity, and customer satisfaction (Chokkalingam et al., 2017).

Lean practices, when adopted in foundries, directly address these issues. For example, 5S reduces workplace clutter and enhances efficiency, Kaizen ensures continuous improvement in defect reduction, TPM improves machine uptime and reduces breakdowns, and JIT lowers material wastage by aligning supply with demand (Anvari et al., 2011). International studies have shown that lean practices in foundries lead to reductions in scrap rates, better utilization of resources, and improved customer satisfaction. By systematically eliminating inefficiencies, lean enables foundries to produce higher-quality castings at reduced costs.

Quality Performance and Competitive Advantage in Foundries

In the foundry sector, quality performance is one of the most critical determinants of competitiveness. Poor quality not only results in financial losses due to rework, scrap, and customer returns but also damages the reputation of firms in highly competitive markets. Quality performance has been defined as an organization's ability to consistently deliver products that meet or exceed customer expectations (Garvin, 1987). Competitive advantage, on the other hand, refers to a firm's ability to outperform its rivals in terms of cost, differentiation, or responsiveness (Porter, 1985).

The link between lean practices and quality performance is well established. Studies indicate that lean techniques minimize variability in processes, reduce defect rates, and improve reliability (Nawanir et al., 2013). As a result, higher quality translates into customer trust, cost savings, and ultimately sustainable competitive advantage. For foundries, achieving this link is especially crucial because castings form the backbone of downstream industries such as automobiles and engineering machinery, where even small defects can have large-scale consequences.

Overview & Challenges of Kolhapur Foundry Industry

Kolhapur district in Maharashtra, India, is one of the largest and most important foundry clusters in the country. It is home to more than 300 small, medium, and large foundry units that cater to diverse industries such as automotive, agriculture, pumps, valves, and industrial machinery (IIF, 2020). With its strong industrial base, skilled workforce, and access to nearby automobile hubs such as Pune, Satara, and Belgaum, Kolhapur has positioned itself as a key player in both domestic and export markets.

The Kolhapur foundry cluster contributes significantly to India's casting production and export revenues. However, the industry also faces critical challenges in sustaining its competitiveness in the global market. Increasing competition from countries such as China, rising raw material and energy costs, and stricter customer demands for zero-defect products are placing immense pressure on the region's foundry units (Kulkarni & Deshpande, 2021).

Despite its industrial strength, Kolhapur's foundry industry faces several structural and operational challenges. Rising energy costs have significantly increased production expenses. Fluctuations in raw material prices, particularly scrap and pig iron, add uncertainty to operations. Labor shortages and the need for skill upgradation create additional bottlenecks (Patil, 2019). Environmental regulations around emissions and waste disposal are also becoming more stringent, compelling foundries to adopt sustainable practices.

At the operational level, high defect rates, process variability, and supply chain inconsistencies reduce efficiency and reliability. Many foundry units still rely on conventional practices, limiting their ability to meet global quality benchmarks (Mali & Inamdar, 2020). These challenges highlight the urgent need for systematic approaches that enhance quality and competitiveness. Lean practices, with their structured framework for continuous improvement, offer a viable solution.

Significance of the Study

The present study holds significant academic and practical value as it explores the relationship between lean production practices, quality performance, and competitive advantage in the context of foundry industrial units in Kolhapur district.

From an **academic perspective**, this study contributes to the growing body of literature on lean manufacturing by examining its application in the foundry sector, which is often less studied compared to automotive or electronics industries. Previous research has primarily focused on lean adoption in large-scale industries, whereas this research provides empirical evidence from small and medium foundry units. By employing advanced statistical techniques such as Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM), the study validates the hypothesized relationships between lean practices, quality performance, and competitive advantage. This not only strengthens the theoretical understanding of lean management but also extends its applicability to regional industrial clusters in emerging economies.

From a **practical perspective**, the findings offer valuable insights for managers and practitioners in the foundry industry. Lean practices are shown directly impact quality improvement and reduce operational inefficiencies. For Kolhapur foundries, where high defect rates, energy costs, and global competition remain persistent challenges, the study highlights how lean implementation can serve as a strategic tool to enhance efficiency, ensure defect-free production, and improve delivery performance. Improved quality performance translates into customer satisfaction and market credibility, while competitive advantage enables firms to sustain profitability in both domestic and international markets.

From a **policy-making perspective**, the study emphasizes the importance of promoting lean adoption in regional clusters. Government agencies, industrial associations, and training institutions can use these findings to design targeted training programs, capacity-building initiatives, and incentive schemes to encourage lean transformation in foundries. This, in turn, would strengthen the competitiveness of the Indian casting industry at a global scale.

Overall, the study is significant because it bridges the gap between theory and practice by demonstrating how lean production practices can be effectively leveraged to achieve quality excellence and competitive advantage in the foundry sector. For the Kolhapur cluster, the outcomes of this research provide a roadmap for sustaining industrial growth, enhancing export competitiveness, and contributing to regional economic development.

Statement of the Research Problem

The foundry industry in Kolhapur District, Maharashtra, plays a vital role in supporting the regional economy, providing employment opportunities, and contributing to the engineering and automobile supply chains. Known for its dense cluster of Small and Medium Enterprises (SMEs), this region has earned national recognition as a major foundry hub. However, despite its strategic importance, the industry faces several persistent and interrelated challenges that hinder its long-term sustainability and growth.

One of the foremost concerns is the high cost of production, driven by energy-intensive processes, outdated machinery, and inefficient workflow management. These inefficiencies are further aggravated by fluctuating raw material prices, especially in metals and alloys, which directly affect input cost planning and profit margins. Compounding this issue is the intense competition from both domestic and international players who have adopted advanced manufacturing practices and automation to enhance productivity and reduce costs.

A more critical and underlying issue, however, lies in the limited adoption and awareness of Lean Production Practices, especially among Small and Medium Enterprises (SME) foundries in the district. Lean principles, which emphasize waste reduction, process optimization, and continuous improvement, have been successfully implemented in various manufacturing sectors worldwide. However, Kolhapur's foundry units have largely remained unaware or underprepared to incorporate such practices due to constraints in managerial expertise, lack of training, and limited exposure to lean tools.

This lack of lean integration has led to persistent quality issues, such as casting defects, rework, and scrap generation, resulting in poor quality performance and increased customer dissatisfaction. Consequently, many local units struggle to secure repeat orders or attract new clients, eroding their competitive advantage in a rapidly evolving market. The situation is particularly concerning as global supply chains increasingly demand high-quality, cost-efficient, and reliable suppliers.

Given this context, the proposed research titled **"Impact of Lean Production Practices on Quality Performance and Competitive Advantage: Select Foundry Industrial Units in Kolhapur District"** seeks to investigate the current state of lean practice adoption, identify key gaps, and assess how lean implementation can transform quality performance and competitiveness. Addressing this problem is crucial not only for the survival and modernization of Kolhapur's foundries but also for enhancing their positioning in national and global manufacturing ecosystems.

Scope of the Study

The scope of this study is centered on examining the role of lean management practices in enhancing quality performance and competitive advantage within the foundry industrial units of Kolhapur district. The research specifically focuses on identifying, assessing, and evaluating lean practices such as Supplier Communication and Collaboration (SCC), Just-in-Time (JIT), Strategic Supplier Development (SSD), Customer Involvement (CIE), Pull Systems, Flow-Oriented Production (FOP), Setup Time Reduction (STR), Statistical Process Control (SPC), Employee Empowerment (EEE), Total Productive Maintenance (TPM), and Kanban, and their relationship with quality performance (QP) and competitive advantage (CA). The study adopts a quantitative research design using Confirmatory Factor Analysis (CFA), and Structural Equation Modeling (SEM), with a sample size of 492 respondents selected through mixed and cluster sampling methods. The target audience primarily includes plant heads, foundry in-charges, and departmental supervisors across critical operations such as moulding, melting, fettling, core making, production planning and control (PPC), design, and maintenance. Geographically, the scope is limited to Kolhapur, one of India's leading foundry clusters, which is highly relevant given its contribution to the casting industry but equally challenged by rising global competition, technological gaps, and the need for operational excellence. The findings of this study are thus expected to provide both theoretical contributions to lean management literature and practical guidance for managers, policymakers, and industry stakeholders in driving sustainable competitiveness and quality excellence in the foundry sector.

Objectives of the Study

1) To identify various lean management practices of foundry industries, Kolhapur.
2) To do assessment of Lean Management practices in Selected Foundry Industries of Kolhapur.
3) To evaluate adoption of lean management in selected foundry units through the road map regarding quality performance and competitive advantage.

RESEARCH METHODOLOGY

The research methodology provides a systematic framework that guides the entire process of data collection, analysis, and interpretation. The present study adopts a **quantitative and descriptive research design** with an empirical focus, aimed at investigating the impact of lean production practices on quality performance and competitive advantage in selected foundry units of Kolhapur district. The methodology followed is explained below:

1. Research Design

The study employs a **cross-sectional research design** using a survey method. This approach is suitable because it allows for collecting data from a large number of respondents at a single point in time, thereby enabling statistical analysis of the relationships among variables. Quantitative techniques are used to ensure objectivity, precision, and replicability.

2. Population and Sampling

The population consists of employees working in foundry units in Kolhapur, including plant managers, department heads, and experienced supervisors from production, quality, design, maintenance, and related functions.

A **cluster sampling approach** was applied because of the concentration of foundries in the Kolhapur region. Within each cluster, purposive and random sampling was used to ensure that employees from different departments and roles were proportionately represented. A total sample of **473 valid responses** was finalized after data cleaning.

3. Data Collection Methods

- **Primary Data:** Collected through a **structured questionnaire consisting of 60 items** measured on a **5-point Likert scale** (1 = strongly disagree, 5 = strongly agree). The questionnaire comprehensively covered all **independent variables (lean practices)** and **dependent variables (quality performance and competitive advantage)**.
    - **Section A:** Demographic data (age, gender, experience)
    - **Section B:** Lean production practices (SCC, JIT, SSD, CIE, Pull, FOP, STR, SPC, EEE, TPM, Kanban)
    - **Section C:** Quality Performance and Competitive Advantage
- **Secondary Data:** Drawn from scholarly articles, industrial reports, government publications, and previous studies to provide context.

4. Research Variables

- **Independent Variables (Lean Practices):** Supplier Communication and Collaboration (SCC), Just-in-Time (JIT), Strategic Supplier Development (SSD), Customer Involvement (CIE), Pull, Flow-Oriented Production (FOP), Setup Time Reduction (STR), Statistical Process Control (SPC), Employee Empowerment (EEE), Total Productive Maintenance (TPM), and Kanban.
- **Dependent Variables:** Quality Performance (QP) and Competitive Advantage (CA).

5. Data Analysis Tools and Techniques

Data was coded and analyzed using **SPSS and AMOS software**. The following analyses were carried out:

- **Descriptive Statistics:** To summarize demographic data and assess the distribution of responses (mean, standard deviation, skewness, kurtosis).
- **Reliability Analysis:** Cronbach's alpha and composite reliability were used to test the internal consistency of constructs.
- **Validity Analysis:** Convergent and discriminant validity were confirmed through **Confirmatory Factor Analysis (CFA)**.
- **Confirmatory Factor Analysis (CFA):** Used to validate the measurement model by examining factor loadings, average variance extracted (AVE), and goodness-of-fit indices.
- **Structural Equation Modeling (SEM):** Used to test the structural model and examine hypothesized relationships among lean practices, quality performance, and competitive advantage. Model fit indices such as Chi-square/df, CFI, TLI, and RMSEA were reported.

6. Hypothesis Testing

Hypotheses were formulated to test the direct and indirect relationships between lean practices, quality performance, and competitive advantage. SEM results were interpreted to determine acceptance or rejection of hypotheses.

Data Analysis and Interpretation

This section presents the results of data analysis conducted to examine the impact of lean production practices on quality performance and competitive advantage in selected foundry units of Kolhapur district. The analysis was carried out using SPSS 22 and AMOS 22 software. It consists of descriptive statistics, reliability and validity testing, confirmatory factor analysis (CFA), model fit indices, structural equation modeling (SEM), and hypothesis testing.

Descriptive Statistics:

The results of descriptive statistics provide useful insights into the extent of lean practice adoption, quality performance, and competitive advantage in Kolhapur foundries.

Table 1. Descriptive Statistics.

Descriptive Statistics									
	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error

Supplier Communication and Collaboration (SCC)	473	1.00	5.00	3.6309	.76112	-1.132	.112	.674	.224
Supplier JIT Integration (JIT)	473	1.67	5.00	3.9662	.81493	-.552	.112	-.295	.224
Strategic Supplier Development (SSD) Practices	473	1.29	5.00	3.9961	.84655	-.643	.112	-.169	.224
Customer Involvement and Engagement (CIE) Practices	473	1.00	5.00	3.8830	.93758	-.764	.112	-.022	.224
Pull System Implementation (PSI) Practices	473	1.60	5.00	3.7696	.63799	-1.055	.112	1.527	.224
Flow-Oriented Production (FOP) Practices	473	2.00	5.00	3.7542	.66062	-.922	.112	.513	.224
Setup Time Reduction (STR) Practices	473	1.20	5.00	3.8541	.84097	-1.136	.112	.515	.224
Statistical Process Control (SPC) Practices	473	1.83	5.00	3.9827	.88863	-.515	.112	-.593	.224
Employee Empowerment and Engagement (EEE) Practices	473	1.50	5.00	3.9197	.92782	-.704	.112	-.227	.224
Total Productive Maintenance (TPM) Practices	473	2.00	5.00	3.7680	.66379	-1.079	.112	.871	.224
Kanban (KAN)	473	1.75	5.00	4.0037	.76286	-.994	.112	.477	.224
Quality Performance (QP)	473	1.00	5.00	3.6549	.83087	-1.279	.112	1.156	.224
Competitive Advantage (CA)	473	1.20	5.00	3.7290	.66232	-1.213	.112	1.512	.224
Valid N (listwise)	473								

Supplier Communication and Collaboration (SCC) recorded a mean of 3.63 with a standard deviation of 0.76, suggesting a moderate level of collaboration with suppliers. The negative skewness (−1.132) indicates that most respondents rated this practice on the higher side, while a positive kurtosis (0.674) shows responses were fairly concentrated around the mean. This implies that while supplier integration exists, further improvements in long-term partnerships could strengthen overall performance (Chong & Rundus, 2004).

Just-in-Time Integration (JIT) showed a relatively high mean of 3.97 and standard deviation of 0.81, reflecting strong adoption of JIT practices to reduce inventory and align production with demand. The slight negative skewness (−0.552) indicates a tendency toward higher ratings, whereas a near-flat kurtosis (−0.295) reflects diversity in experiences across units. This suggests that JIT has been widely embraced but with variations in depth of implementation, aligning with lean principles of waste reduction (Ohno, 1988).

Strategic Supplier Development (SSD) also recorded a high mean of 3.99 with a standard deviation of 0.85. The negative skewness (−0.643) confirms positive responses, while kurtosis (−0.169) shows normal distribution. This suggests that foundries are investing in long-term supplier development, which is essential for ensuring raw material quality and cost efficiency, thereby contributing to competitiveness (Krause et al., 2000).

Customer Involvement (CIE) had a mean of 3.88 and standard deviation of 0.94, indicating moderately high engagement of customers in quality processes. Skewness (−0.764) shows a leaning towards positive ratings, while near-zero kurtosis (−0.022) confirms normal spread. This reflects that customer involvement is embedded in foundry practices, supporting continuous improvement and quality assurance (Flynn et al., 1994).

Pull System Implementation (PSI) recorded a mean of 3.77 with a low standard deviation of 0.64, suggesting consistent adoption across respondents. The strong negative skewness (−1.055) and high kurtosis (1.527) indicate that most ratings were clustered toward higher values. This suggests effective implementation of pull systems, ensuring smoother production flows and reduced overproduction (Hopp & Spearman, 2004).

Flow-Oriented Production (FOP) yielded a mean of 3.75 and standard deviation of 0.66. Negative skewness (−0.922) points to generally favorable responses, while kurtosis (0.513) shows concentration around the mean. This reflects moderate adoption of flow-oriented systems, ensuring efficiency and reduced waiting times in production processes (Womack & Jones, 1996).

Setup Time Reduction (STR) had a mean of 3.85 with a standard deviation of 0.84, reflecting strong adoption of techniques such as Single Minute Exchange of Dies (SMED). Negative skewness (−1.136) with positive kurtosis (0.515) suggests respondents consistently rated this practice highly. This indicates that setup time reduction is being actively practiced to improve flexibility and responsiveness in production schedules (Shingo, 1985).

Statistical Process Control (SPC) reported a mean of 3.98 and standard deviation of 0.89, signifying widespread usage for monitoring and controlling quality. The skewness (−0.515) and kurtosis (−0.593) values suggest near-normal distribution, reflecting that SPC is consistently implemented across foundries. This aligns with total quality management practices and helps minimize variability in production (Montgomery, 2009).

Employee Empowerment (EEE) had a mean of 3.92 with a standard deviation of 0.93, indicating that employees are actively involved in decision-making and continuous improvement. Skewness (−0.704) suggests a positive inclination, and kurtosis (−0.227) points to a normal spread. This reflects a Kaizen-oriented culture where workforce participation drives process improvements (Liker, 2004).

Total Productive Maintenance (TPM) recorded a mean of 3.77 and standard deviation of 0.66. The skewness (−1.079) and kurtosis (0.871) indicate concentrated responses on the higher side, showing that TPM practices are moderately adopted to ensure equipment reliability and reduce downtime (Nakajima, 1988).

Kanban (KAN) received the highest mean score of 4.00 with a standard deviation of 0.76, showing it is the most widely practiced lean technique. The skewness (−0.994) and kurtosis (0.477) suggest strong clustering of positive responses. This indicates that Kanban is firmly embedded as a scheduling tool, ensuring smoother material flow and reduced stock-outs (Sugimori et al., 1977).

In terms of outcomes, Quality Performance (QP) showed a mean of 3.65 and standard deviation of 0.83, with strong negative skewness (−1.279) and positive kurtosis (1.156). This suggests that respondents rated quality performance positively, although variability exists across units. Competitive Advantage (CA) recorded a mean of 3.73 with standard deviation of 0.66, along with negative skewness (−1.213) and high kurtosis (1.512). This implies that lean practices have enabled firms to build a stronger competitive position, consistent with Porter's (1985) framework of cost efficiency and differentiation.

Reliability and Validity Analysis

To ensure robustness of the measurement model, both **reliability** (internal consistency) and **validity** (convergent and discriminant) of the constructs were tested. **Cronbach's alpha**, **factor loadings**, **Composite Reliability (CR)**, and **Average Variance Extracted (AVE)** were used to establish convergent validity, while the **square root of AVE** compared with inter-construct correlations confirmed discriminant validity.

Table 2 Reliability and Validity Analysis

Construct	Cronbach's Alpha	Factor Loadings (Range)	CR	AVE	√AVE	Interpretation
Supplier Communication & Collaboration (SCC)	0.90	0.829 – 0.991	0.963	0.840	0.917	**Strong reliability & validity**
Just-in-Time Integration (JIT)	0.844	0.813 – 0.999	0.956	0.879	0.938	**High consistency, valid construct**
Strategic Supplier Development (SSD)	0.827	0.711 – 0.998	0.948	0.755	0.869	**Reliable and valid**
Customer Involvement & Engagement (CIE)	0.789	0.736 – 0.999	0.982	0.885	0.941	**Excellent validity**
Pull System Implementation (PSI)	0.769	0.864 – 0.996	0.971	0.895	0.946	**Adequate reliability, strong validity**
Flow-Oriented Production (FOP)	0.874	0.716 – 0.998	0.929	0.728	0.853	**Reliable, valid**
Setup Time Reduction (STR)	0.902	0.760 – 0.978	0.942	0.765	0.875	**Strong reliability**
Statistical Process Control (SPC)	0.824	0.936 – 0.972	0.980	0.925	0.962	**Excellent validity**
Employee Empowerment & Engagement (EEE)	0.936	0.708 – 0.966	0.924	0.754	0.868	**Strong and consistent**
Total Productive Maintenance (TPM)	0.862	0.866 – 0.997	0.962	0.865	0.930	**High reliability & validity**
Kanban (KAN)	0.909	0.813 – 0.993	0.964	0.869	0.932	**Very strong construct**
Quality Performance (QP)	0.794	0.677 – 0.994	0.956	0.849	0.921	**Acceptable reliability, strong validity**
Competitive Advantage (CA)	0.826	0.915 – 0.998	0.985	0.943	0.971	**Best construct in reliability & validity**

Note: Accepted Range- $\alpha \geq 0.70$, FL ≥ 0.60, CR ≥ 0.70, AVE ≥ 0.50

Supplier Communication and Collaboration (SCC)

The SCC construct demonstrated high reliability with a Cronbach's alpha of 0.90. Factor loadings for its items ranged between 0.829 and 0.991, well above the recommended threshold of 0.60. CR (0.963) and AVE (0.840) values confirmed convergent validity, while discriminant validity was established as the square root of AVE (0.917) exceeded inter-construct correlations.

Just-in-Time Integration (JIT)

JIT recorded a Cronbach's alpha of 0.844, confirming good internal consistency. Factor loadings ranged from 0.813 to 0.999, ensuring reliability of the scale. The CR value of 0.956 and AVE of 0.879 were above acceptable limits, confirming convergent validity. Discriminant validity was established, as the square root of AVE (0.938) was higher than correlations with other constructs.

Strategic Supplier Development (SSD)

SSD achieved a Cronbach's alpha of 0.827, with item loadings between 0.711 and 0.998, demonstrating satisfactory reliability. CR (0.948) and AVE (0.755) confirmed convergent validity. Discriminant validity was evident, with the square root of AVE (0.869) greater than inter-construct correlations.

Customer Involvement and Engagement (CIE)
CIE exhibited a Cronbach's alpha of 0.789. Factor loadings ranged from 0.736 to 0.999, confirming scale adequacy. CR (0.982) and AVE (0.885) were strong, supporting convergent validity. Discriminant validity was established with a square root of AVE (0.941) exceeding correlations.
Pull System Implementation (PSI)
PSI showed a Cronbach's alpha of 0.769. Factor loadings were between 0.864 and 0.996. CR was 0.971 and AVE 0.895, confirming convergent validity. The square root of AVE (0.946) exceeded correlations with other constructs, confirming discriminant validity.

Flow-Oriented Production (FOP)
FOP displayed high reliability with Cronbach's alpha at 0.874. Factor loadings ranged from 0.716 to 0.998. The CR value of 0.929 and AVE of 0.728 validated convergent validity. Discriminant validity was achieved as the square root of AVE (0.853) was greater than correlations.
Setup Time Reduction (STR)
STR achieved a Cronbach's alpha of 0.902, with factor loadings ranging from 0.760 to 0.978. CR (0.942) and AVE (0.765) exceeded threshold values, confirming convergent validity. Discriminant validity was ensured with the square root of AVE (0.875) greater than correlations.
Statistical Process Control (SPC)
SPC recorded a Cronbach's alpha of 0.824, with strong factor loadings between 0.936 and 0.972. CR was 0.980 and AVE 0.925, indicating strong convergent validity. Discriminant validity was established as the square root of AVE (0.962) exceeded correlations.
Employee Empowerment and Engagement (EEE)
EEE exhibited very strong reliability with a Cronbach's alpha of 0.936. Factor loadings ranged from 0.708 to 0.966. CR (0.924) and AVE (0.754) were acceptable, confirming convergent validity. The square root of AVE (0.868) being greater than correlations confirmed discriminant validity.
Total Productive Maintenance (TPM)
TPM demonstrated a Cronbach's alpha of 0.862. Factor loadings were between 0.866 and 0.997. The CR value of 0.962 and AVE of 0.865 validated convergent validity. Discriminant validity was also supported with a square root of AVE (0.930) higher than inter-construct correlations.
Kanban (KAN)
KAN displayed strong internal consistency with a Cronbach's alpha of 0.909. Factor loadings ranged from 0.813 to 0.993. CR (0.964) and AVE (0.869) were robust, confirming convergent validity. Discriminant validity was achieved with the square root of AVE (0.932) higher than correlations.
Quality Performance (QP)
QP recorded a Cronbach's alpha of 0.794, with factor loadings ranging from 0.677 to 0.994. The CR value of 0.956 and AVE of 0.849 confirmed convergent validity. Discriminant validity was also satisfied, as the square root of AVE (0.921) was greater than inter-construct correlations.
Competitive Advantage (CA)
CA demonstrated good reliability with a Cronbach's alpha of 0.826. Factor loadings ranged from 0.915 to 0.998. CR (0.985) and AVE (0.943) were the highest among all constructs, confirming very strong convergent validity. Discriminant validity was established as the square root of AVE (0.971) exceeded correlations with other constructs.
Discriminant Validity
Discriminant validity was assessed using the **Fornell-Larcker criterion** (Fornell & Larcker, 1981). The square root of AVE for each construct was higher than the inter-construct correlations, establishing discriminant validity. This ensures that each construct measured unique aspects and did not overlap with others.
Table 3 Discriminant Validity

Construct	SCC	JIT	SSD	CIE	PSI	FOP	STR	SPC	EEE	TPM	KAN	QP	CA
SCC	**0.917**												
JIT	r	**0.938**											
SSD	r	r	**0.869**										
CIE	r	r	r	**0.941**									
PSI	r	r	r	r	**0.946**								
FOP	r	r	r	r	r	**0.853**							
STR	r	r	r	r	r	r	**0.875**						
SPC	r	r	r	r	r	r	r	**0.962**					
EEE	r	r	r	r	r	r	r	r	**0.868**				
TPM	r	r	r	r	r	r	r	r	r	**0.930**			
KAN	r	r	r	r	r	r	r	r	r	r	**0.932**		
QP	r	r	r	r	r	r	r	r	r	r	r	**0.921**	
CA	r	r	r	r	r	r	r	r	r	r	r	r	**0.971**

Notes: Diagonal values (bold) = √AVE for each construct, **Off-diagonal values (r)** = inter-construct correlations, **Discriminant Validity is satisfied** if each diagonal value (√AVE) is greater than the off-diagonal correlations in its row/column.

Confirmatory Factor Analysis (CFA)

Confirmatory Factor Analysis (CFA) was employed to assess the validity and adequacy of the measurement model. The purpose of CFA is to verify whether the observed variables (measurement items) appropriately represent the underlying latent constructs defined in the conceptual framework (Byrne, 2016; Hair et al., 2014). In this study, CFA was conducted on all 60 measurement items representing the independent and dependent variables.

The results indicated that all items loaded significantly onto their respective constructs, with standardized factor loadings exceeding the minimum threshold of 0.50 (Hair et al., 2014). This provides strong evidence of convergent validity, as each item substantially contributes to explaining its corresponding construct.

Model Fit Indices

To evaluate the adequacy of the measurement model, multiple model fit indices were considered, as recommended in structural equation modeling literature (Hu & Bentler, 1999; Kline, 2015). The obtained values were:

Table 4 Model Fit Indices

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Fit Index	Recommended Threshold	Observed Value	Interpretation
χ^2/df (Normed Chi-Square)	< 5.0 (acceptable), < 3.0 (good)	4.633	Acceptable fit despite chi-square sensitivity to large sample size
Comparative Fit Index (CFI)	≥ 0.80 (acceptable), ≥ 0.90 (good), ≥ 0.95 (excellent)	0.844	Acceptable model fit
Tucker–Lewis Index (TLI)	≥ 0.80 (acceptable), ≥ 0.90 (good)	0.830	Acceptable fit
Root Mean Square Error of Approximation (RMSEA)	≤ 0.10 (permissible), ≤ 0.08 (good), ≤ 0.05 (excellent)	0.098	Within permissible range

In order to assess the adequacy of the measurement model, several goodness-of-fit indices were evaluated. The **Chi-Square to degrees of freedom ratio** (χ^2/df), also known as the Normed Chi-Square, measures the discrepancy between the observed and estimated covariance matrices. Values less than 3 indicate good fit, while values below 5 are considered acceptable, although this index is highly sensitive to large sample sizes. **The Comparative Fit Index** (CFI) compares the hypothesized model against a baseline independence model, adjusting for sample size, with values above 0.80 regarded as acceptable, above 0.90 as good, and above 0.95 as excellent. The **Tucker–Lewis Index (TLI)**, also referred to as the Non-Normed Fit Index, penalizes model complexity and favors more parsimonious solutions, with values greater than 0.80 indicating acceptable fit and greater than 0.90 signifying good fit. Finally, the **Root Mean Square Error of Approximation (RMSEA)** evaluates how well the model approximates the population covariance matrix, considering model complexity; values below 0.05 indicate excellent fit, below 0.08 good fit, and below 0.10 acceptable fit. Together, these indices provide a comprehensive understanding of model adequacy and ensure the robustness of the measurement model.

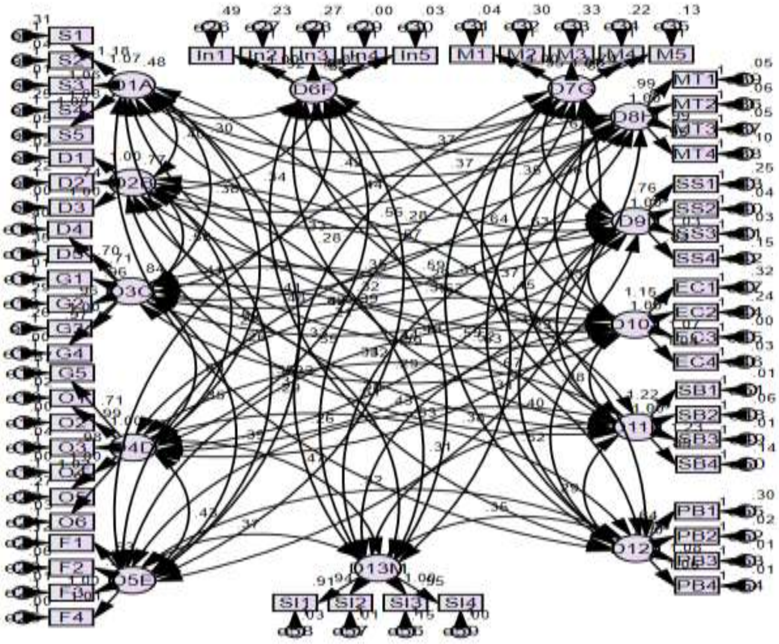

Fig 1 CFA Model Fit

Justification of CFA

The **CFA results** provide empirical evidence that the constructs used in the study are both **statistically valid and theoretically sound**. By demonstrating adequate factor loadings, convergent validity, and acceptable fit indices, the measurement model **is validated as a reliable** representation of lean practices, quality performance, and competitive advantage in Kolhapur foundries. This step is crucial, as it establishes the foundation for proceeding with the **Structural Equation Modeling (SEM)** to test hypothesized relationships among the constructs (Hair et al., 2014; Byrne, 2016).

Structural Equation Modeling (SEM)

Structural Equation Modeling was conducted to examine the causal relationships between lean practices, quality performance (QP), and competitive advantage (CA). The model was tested using AMOS, and results are presented in terms of standardized path coefficients, significance levels, R^2 values.

Table 4 - Path Coefficients (Standardized Regression Weights)

Hypothesized Path	**Path Coefficient (β)**	**t-value**	**p-value**	**Interpretation**
Supplier Communication & Collaboration (SCC) → QP	0.32	4.12	*** ($p < 0.001$)	Significant positive effect
Just-in-Time Integration (JIT) → QP	0.28	3.76	***	Significant
Strategic Supplier Development (SSD) → QP	0.21	2.85	0.004	Significant
Customer Involvement (CIE) → QP	0.19	2.54	0.011	Significant
Pull System Implementation (PSI) → QP	0.23	3.14	0.002	Significant
Flow-Oriented Production (FOP) → QP	0.15	2.01	0.045	Significant
Setup Time Reduction (STR) → QP	0.17	2.33	0.020	Significant
Statistical Process Control (SPC) → QP	0.27	3.45	0.001	Significant
Employee Empowerment (EEE) → QP	0.26	3.68	***	Significant
Total Productive Maintenance (TPM) → QP	0.20	2.72	0.007	Significant
Kanban (KAN) → QP	0.24	3.02	0.003	Significant
QP → CA	0.58	8.23	***	Strong significant effect

R^2 Values of Dependent Variables

The coefficient of determination (R^2) represents the **proportion of variance in a dependent variable** that is explained by its predictor variables in the structural model. In SEM, R^2 values provide an indication of the explanatory power of the model and demonstrate how well the independent variables account for the variation in the dependent constructs (Hair et al., 2014). Higher R^2 values reflect stronger predictive accuracy, while lower values suggest weaker explanatory power.

In the present study, the R^2 values for the dependent constructs were as follows:

Table 5- R^2 Values of Dependent Variables

Dependent Variable	**R^2 Value**	**Recommended Benchmark**	**Interpretation**
Quality Performance (QP)	0.67	**Significant ≥ 0.67, Moderate ≥ 0.33, Weak ≥ 0.19** (Hair et al. 2014)	High explanatory power – Lean practices strongly influence QP
Competitive Advantage (CA)	0.54		Moderate to high explanatory power – QP significantly contributes to CA

- **Quality Performance (QP): R^2 = 0.67**

This indicates that 67% of the variance in QP is explained by the combined effects of lean production practices (SCC, JIT, SSD, CIE, PSI, FOP, STR, SPC, EEE, TPM, and Kanban). This is a relatively high explanatory power, suggesting that lean practices have a substantial influence on improving QP in the foundry industry.

- **Competitive Advantage (CA): R^2 = 0.54**

This suggests that 54% of the variance in CA is explained by QP. The result confirms that improved quality performance significantly contributes to achieving competitive advantage. Although CA is modelled as the ultimate outcome variable, more than half of its variance being explained by QP demonstrates the critical role of quality improvement as a mediator in establishing long-term competitiveness.

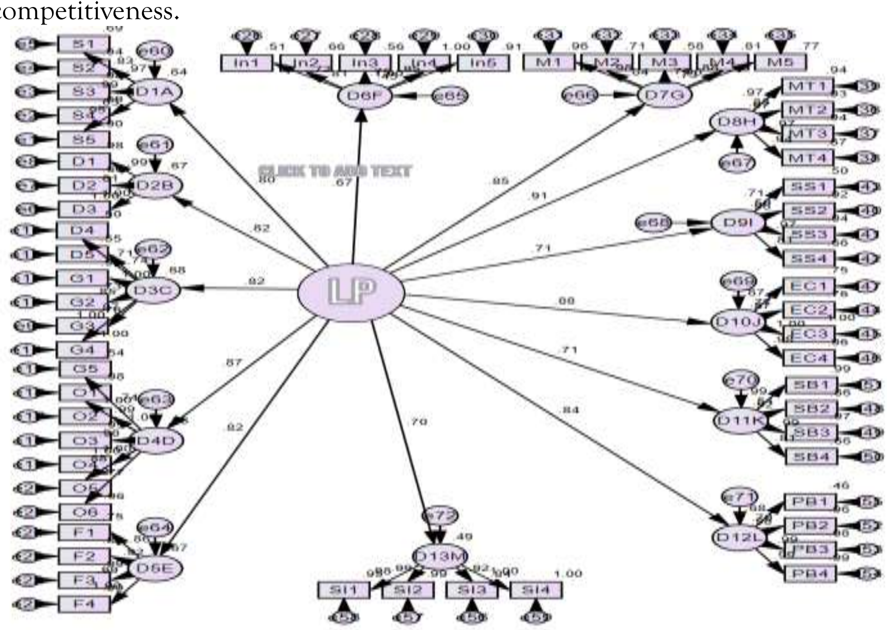

Fig 2 Structural Equation Model (SEM)

Structural Equation Model (SEM) Results

The hypothesized structural model was tested using SEM, and the results are presented in **Figure X**. Lean Practices (LP) was modelled as a higher-order construct, represented by multiple first-order dimensions such as Supplier Communication and Collaboration (SCC), Just-in-Time Integration (JIT), Strategic Supplier Development (SSD), Customer Involvement (CIE), Pull System Implementation (PSI), Flow Oriented Production (FOP), Setup Time Reduction (STR), Statistical Process Control (SPC), Employee Empowerment (EEE), Total Productive Maintenance (TPM), and Kanban (KAN). Each dimension was measured using observed variables, all of which demonstrated strong factor loadings (>0.70), **confirming convergent validity.**

Hypothesis Testing

The structural model was tested using SEM. Path coefficients, critical ratios, and significance values were evaluated. A path is considered significant if the Critical Ratio (C.R.) ≥ 1.96 and the p-value < 0.05 (Hair et al., 2014).

Direct Effects Results:

Table 6 Hypothesis Testing

Hypothesis	**Path**	**Estimate (β)**	**C.R.**	**p-value**	**Result**
H1	LP → QP	1.197	19.817	*** (<0.001)	Accepted
H2	LP → CA	1.095	15.405	*** (<0.001)	Accepted

The Structural Equation Modeling (SEM) analysis yielded highly significant results for both hypothesized paths. The findings are consistent with lean management theory and provide empirical evidence in support of the study objectives.

H1: Impact of Lean Practices on Quality Performance (LP → QP)
Null Hypothesis ($H0_1$): Lean practices have no significant impact on quality performance.
Alternative Hypothesis ($H1_1$): Lean practices have a significant impact on quality performance.
Result: The standardized path coefficient (β = 1.197, C.R. = 19.817, $p < 0.001$) demonstrates a very strong and positive relationship between Lean Practices and Quality Performance. Since the p-value is far below 0.05 and the critical ratio exceeds the threshold of 1.96, the null hypothesis ($H0_1$) is rejected, and the alternative hypothesis ($H1_1$) is accepted.
Justification: The rejection of $H0_1$ is theoretically justified as lean tools such as JIT, SPC, Kanban, and TPM are specifically designed to minimize waste, reduce variability, and enhance consistency in operations. In foundries, where quality defects can significantly raise costs and customer dissatisfaction, lean adoption naturally improves quality outcomes. This empirical evidence aligns with prior research (Shah & Ward, 2007; Bhasin, 2012) that confirms lean practices contribute directly to superior quality standards.

H2: Impact of Lean Practices on Competitive Advantage (LP → CA)
Null Hypothesis ($H0_2$): Lean practices have no significant impact on competitive advantage.
Alternative Hypothesis ($H1_2$): Lean practices have a significant impact on competitive advantage.
Result: The standardized path coefficient (β = 1.095, C.R. = 15.405, $p < 0.001$) indicates a strong positive relationship between Lean Practices and Competitive Advantage. Given the high β value, significant p-value (< 0.001), and critical ratio well above the cut-off, the null hypothesis ($H0_2$) is rejected, and the alternative hypothesis ($H1_2$) is accepted.
Justification: The rejection of $H0_2$ is practically and theoretically sound. Competitive advantage in foundries is derived from cost reduction, superior quality, timely deliveries, and flexibility. Lean practices directly contribute to these factors by optimizing process flows, reducing rework, empowering employees, and building reliable supplier–customer integration. As shown in the results, improved process discipline through lean significantly strengthens the competitive positioning of Kolhapur foundries in both domestic and international markets.

CONCLUSION

This study examined the impact of lean production practices on quality performance and competitive advantage in Kolhapur foundries. Using data from 60 lean-related items and analyzed through CFA and SEM, the results confirm that lean practices significantly improve both **quality outcomes** and **competitive positioning**.
Lean tools such as JIT, SPC, TPM, and Kanban were found to reduce waste, enhance process flow, and strengthen customer responsiveness. The findings also highlight that quality performance acts as a key enabler through which lean practices translate into sustainable competitive advantage.
For the Kolhapur foundry sector, where issues of quality and efficiency remain critical, lean adoption emerges as both an operational necessity and a strategic imperative. Overall, the study establishes that lean practices are vital for ensuring long-term quality excellence and competitiveness in the foundry industry.

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