

Assessing the Importance of Product Quality in Small and Medium Foundries of India

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Abstract: By providing crucial components to sectors like heavy engineering, construction, and automotive, the foundry industry contributes significantly to India's manufacturing economy. Although they make up a sizable share of this industry, small and medium-sized foundries (SMEs) confront formidable obstacles in terms of cost, quality, and worldwide competitiveness. This study evaluates the significance of product quality in Indian SME foundries, concentrating on its effects on sustainability, customer satisfaction, cost effectiveness, and productivity. The study emphasizes the need of systematic quality management methods by highlighting important quality criteria, obstacles, and options for development. The results show that product quality is a strategic component for long-term growth and competitiveness in addition to being a technical necessity. In order to assess overall quality performance, the study takes a quantitative and analytical approach, utilizing statistical quality tools, process capability analysis, and a Composite Quality Performance Index (CQPI) model. The results show that although many SME foundries attain acceptable product quality through rework and inspection, process quality is still relatively low because of excessive variability, insufficient control systems, antiquated machinery, and a lack of adoption of cutting-edge technology.

Keywords: Casting Defects, Foundry Industry, Product Quality, Quality Management, SMEs.

I. INTRODUCTION

The foundry sector, that produces cast components necessary for numerous industries, is a pillar of industrial growth. India is one of the world's top producers of castings, with small and medium-sized businesses (SMEs) accounting for a sizable share of output. These foundries have a significant impact on industrial output, exports, and employment. However, quality is now essential for survival and expansion due to rising customer demands and worldwide competition. The ability of cast components is to satisfy dimensional accuracy, surface finish, mechanical qualities, and dependability is referred to as product quality. Maintaining excellent product quality is crucial in a competitive manufacturing environment in order to lower faults, cut costs, and improve customer satisfaction. In order to be competitive and hold onto market share, manufacturing industries need to constantly enhance the quality of their products. The foundry business provides crucial cast components to the automobile, aerospace, construction, railroad, and heavy engineering industries.

India is one of the world's leading makers of castings, with thousands of foundry units making a substantial contribution to export revenue, industrial output, and job creation. Many of these businesses function as small and medium-sized businesses (SMEs), which are the foundation of the industry. SME foundries have many obstacles despite their economic significance, such as growing international rivalry, volatile raw material prices, strict quality standards, and restricted access to cutting-edge technologies. Production-oriented strategies have given way to quality-driven methods in the manufacturing sector in recent years. Long-term sustainability, customer satisfaction, and competitiveness have all been found to be significantly impacted by product quality. The ability of cast components to satisfy particular standards, like dimensional accuracy, surface finish, mechanical qualities, and functional reliability, defines product quality. Defects including porosity, shrinkage, inclusions, and surface abnormalities are frequently caused by poor product quality and can result in rejection, rework, higher production costs, and unsatisfied customers.

Thus, sustaining market position and attaining operational excellence depend on good product quality. Pattern creation, molding, melting, pouring, solidification, and finishing are some of the interconnected processes involved in casting. The quality of the finished product can be greatly impacted by changes in process variables like temperature, composition, mold properties, and cooling rates. Because of this, maintaining constant product quality calls for strong process control and optimization techniques in addition to efficient inspection systems. For consistent and dependable results, it is crucial to integrate process and product quality. To overcome these issues, the foundry industry has implemented a number of quality improvement techniques over time. To lower errors, increase process capability, and boost productivity, methods including Design of Experiments (DOE), Six Sigma, Lean Manufacturing, Total Quality Management (TQM), and Statistical Quality Control (SQC) have been applied extensively. Modern approaches prioritize defect prevention through systematic analysis and continual improvement, while traditional approaches were mostly concerned with problem discovery and correction. The use of these methods has shown notable gains in quality performance, especially in terms of process parameter optimization and variability reduction.

The foundry industry is changing toward digital and data-driven manufacturing with the introduction of Industry 4.0. Proactive quality control is made possible by these developments, which enable foundries to identify any problems before they arise. However, due to obstacles including high starting costs, a lack of technical know-how, and unwillingness to change, the use of such technologies in SME foundries is still restricted. SME foundries in India confront organizational and operational problems in addition to technological ones, such as poor-quality awareness, a shortage of experienced labor, antiquated machinery, and inadequate data collection systems. These elements impair SMEs' capacity to compete in international markets and impede the efficient application of quality management techniques. To overcome these obstacles, a thorough grasp of the function and significance of product quality is necessary, as is the creation of workable solutions suited to the requirements of SME foundries. In light of this, the current study attempts to evaluate the significance of product quality in India's small and medium-sized foundries.

The study's main objectives are to identify important quality criteria, assess current quality improvement techniques, and examine how product quality affects performance outcomes including cost, productivity, and customer happiness. In order to improve quality performance, it also investigates the integration of contemporary digital technology with conventional quality approaches. By offering a thorough analysis, this study aims to support the creation of efficient quality management plans for SME foundries, enhancing their sustainability and competitiveness in the international market. The foundry industry must shift from traditional trial-and-error methods to data-driven and technologically enabled quality optimization frameworks as global manufacturing evolves toward Industry 4.0 and smart production systems. Six Sigma is one of the new solutions that has become well-known as an organized approach to minimizing process variation and getting rid of flaws. Through the DMAIC (Define–Measure–Analyze–Improve–Control) cycle, Six Sigma places a strong emphasis on statistical decision-making and ongoing improvement. This approach has been effectively used in foundry operations to improve crucial process variables such pouring temperature, mold moisture content, sand composition, gating design, and solidification conditions. Six Sigma deployment has been shown to significantly reduce rejection rates and scrap generation in Indian foundry small and medium enterprises (SMEs), with defect reduction of over 15% and significant cost savings.

Concurrently, additive manufacturing (AM), often known as 3D printing, has become a revolutionary technology in contemporary foundry operations. 3D printing makes it possible to quickly fabricate patterns, molds, and cores straight from CAD models, in contrast to traditional pattern-making techniques that call for specialized tools and longer setup periods. This feature enhances dimensional accuracy, drastically shortens product development periods, and makes it possible to produce extremely complicated interior geometries that are hard or impossible to accomplish with conventional techniques. Technologies including binder jetting, fused deposition modeling (FDM), and selective laser sintering (SLS) are being employed more frequently in foundry applications for sand mold preparation and quick prototyping. According to research, additive manufacturing can significantly shorten lead times and increase mould accuracy, which will improve casting quality and speed up time to market.

In order to stay competitive in the global market, the Indian foundry industry, which is made up of many SMEs, is currently going through a digital revolution. Both Six Sigma and 3D printing have unique but complimentary benefits in this situation. 3D printing addresses design flexibility, quick prototyping, and tooling efficiency, whereas Six Sigma mainly concentrates on process optimization, defect prevention, and statistical control. Comparative studies that particularly look at the relative efficacy of these two strategies in Indian foundry settings are still scarce, nevertheless. Thus, the purpose of this study is to compare Six Sigma with 3D printing in terms of quality optimization for Indian foundry operations. In terms of defect reduction, process efficiency, cost implications, implementation viability, and long-term sustainability, the study assesses both approaches. The possibility of combining these strategies into a hybrid quality optimization framework appropriate for the Indian industrial setting is also examined in this research. The purpose of this paper is to compare the two methods. This research is significant because it offers foundry managers, quality engineers, and researchers' strategic insights to choose the best quality improvement methods based on production volume, operational requirements, and technical maturity.

II. LITERATURE REVIEW

With research concentrating on defect analysis, process optimization, quality improvement techniques, and the integration of cutting-edge digital technology, the study of product and process quality in foundry industries has undergone substantial change. The research emphasizes how important systematic quality management is to enhancing casting performance and lowering faults.

Finding and examining casting flaws and their underlying causes is a major area of study. In an industrial case study on high-pressure die casting, Singh et al. [1] highlighted the significance of process parameter management and identified common faults. Similar analysis of flaws in small-scale foundries was done by Patel et al. [11], who emphasized the effects of inconsistent materials and inadequate process control. In addition to providing insights into defect classification and preventive techniques, Rizvi [14] offered a thorough analysis of casting problems and their fixes.

By connecting casting flaws with supply chain inefficiencies, Narayanaswamy and Natarajan [3] expanded on this approach, showing that quality problems are not just related to production but are also impacted by upstream variables. Predictive modeling and simulation are now crucial techniques for improving product quality. Proactive quality control was made possible by Fu and Yong's [8] demonstration of the application of simulation approaches for casting defect prediction. Predictive modeling was used by Smith et al. [7] to examine quality attributes, demonstrating how data-driven methods can enhance decision-making.

These studies demonstrate how foundries are moving from reactive to predictive quality control. The use of Industry 4.0 and machine learning technologies for quality enhancement is emphasized by recent study. To increase the accuracy of defect detection, Chen and Kaufmann [15] created machine learning algorithms to forecast casting surface flaws. Data-driven models were employed by Dettori et al. [16] to predict the occurrence of defects, allowing for preventive measures. In their investigation of Industry 4.0-based data management systems, Uyan et al. [20], [21] showed how digitalization improves process monitoring and quality control.

Digital twin technology was introduced in centrifugal casting by Anadkat et al. [4], allowing for process optimization and real-time simulation. The choice of materials and process design are also important factors in determining the quality of the final product. The impact of filling system design on casting quality was examined by Campbell et al. [6], with a focus on defect generation. In their study of inorganic binders in foundry sand, Anwar et al. [9], [10] showed improvements in environmental performance and mold quality. By incorporating sensing and monitoring technology throughout the casting process, Kumar et al. [19] created intelligent mold systems for online flaw detection. All of the research points to a close relationship between process and product quality, with changes in one having a direct impact on the other. Modern research emphasizes fault prevention through process control, predictive modeling, and digital technology, whereas older techniques concentrate on problem identification and rectification. Foundries can increase productivity, decrease defects, and boost competitiveness by combining these strategies.

Research Gap Observed

Despite a lot of research, there are still a few gaps:

- Limited research combining Industry 4.0 technologies with conventional high-quality tools
- Inadequate models integrating process and product quality metrics
- Inadequate attention to issues unique to SMEs in Indian foundries

- Quantitative performance indexes, such as the CQPI, are necessary for comprehensive assessment.

The examined literature shows a distinct progression from conventional defect analysis to sophisticated predictive and digital quality management techniques. Even though there has been a lot of development, more study is required to create integrated frameworks specifically for SME foundries, especially in the Indian environment.

III. RESEARCH METHODOLOGY

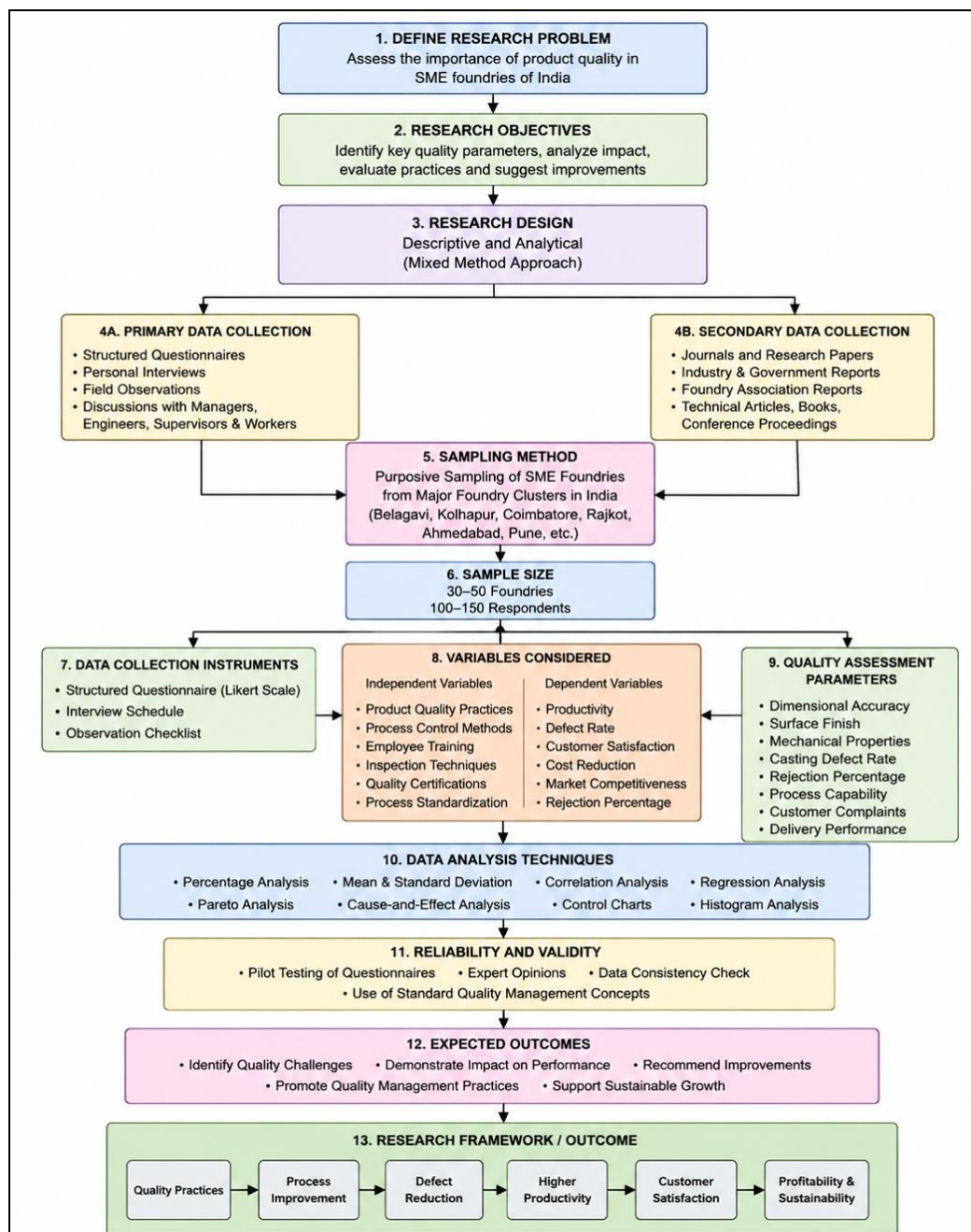


Figure 1. Research Methodology Framework

1. Research Design
2. Research Objectives
3. Research Approach
4. Sampling Method
5. Variables Considered in the Study
6. Data Collection Instruments
7. Data Analysis Techniques
8. Quality Assessment Parameters
9. Reliability and Validity

The flow chart depicts the systematic research approach used to determine the importance of product quality in small and medium foundries in India. The method begins with describing the research problem and determining the primary research objectives for improving quality, increasing productivity, and reducing defects in foundry operations. The study employs a descriptive and analytical research design, using a mixed-method approach that includes both primary and secondary data collection approaches. Primary data is gathered through questionnaires, interviews, field observations, and talks with managers, engineers, supervisors, and employees, while secondary data comes from journals, research papers, industry reports, and technical publications. The technique also includes purposive sampling of SME foundries in significant industrial clusters including Belagavi, Kolhapur, Rajkot, Coimbatore, Ahmedabad, and Pune.

The flow chart also emphasizes the key factors, quality evaluation metrics, and statistical methods utilized in data analysis. Product quality procedures, process control methods, personnel training, and inspection techniques are compared with dependent variables like as productivity, defect rate, customer satisfaction, and cost reduction. To properly evaluate the acquired data, several analytical approaches are used, including percentage analysis, correlation analysis, regression analysis, Pareto analysis, histograms, and control charts. The framework closes by highlighting reliability and validity checks, as well as the study's desired outcomes, which include defect reduction, process improvement, increased productivity, customer happiness, profitability, and sustainability. Overall, the flow chart depicts a clear and structured picture of the entire research process for assessing product quality in Indian SMEs foundries.

1. Research Design

The study uses a descriptive and analytical research design to assess the importance of product quality in India's small and medium foundries (SME foundries). The study aims to determine how product quality affects productivity, defect reduction, customer satisfaction, cost efficiency, and overall organizational success. Both qualitative and quantitative methodologies are employed to gain a thorough understanding of quality management practices in foundries.

2. Research Objectives

- To discover critical product quality criteria in small and medium-sized foundries
- To investigate the effects of product quality on foundry performance
- To investigate the link between quality control procedures and defect reduction
- To assess the effectiveness of quality management approaches for increasing productivity and customer satisfaction
- To offer methods for improving product quality in Indian foundries

3. Research Approach

- i. Primary Data Collection
 - ✓ Primary data is collected directly from SME foundries through:
 - ✓ Structured questionnaires
 - ✓ Personal interviews
 - ✓ Field observations
 - ✓ Discussions with production managers, quality engineers, supervisors, and workers
- ii. b) Secondary Data Collection
 - ✓ Secondary data is collected from:
 - ✓ Research journals
 - ✓ Industry reports
 - ✓ Government publications
 - ✓ Foundry association reports
 - ✓ Technical articles and conference proceedings
 - ✓ Books related to foundry engineering and quality management

4. Sampling Method

The study uses a purposive sample strategy to choose small and medium-sized foundries from

major industrial locations in India. This sampling technique was chosen because it enables the researcher to identify foundries with relevant experience in casting production, quality management procedures, and process control systems. Foundries from major industrial clusters such as Belagavi, Kolhapur, Rajkot, Coimbatore, Ahmedabad, and Pune have been included to ensure diversity in production processes and operational practices. The sample includes both ferrous and non-ferrous foundries, with various output capacity. Respondents include production managers, quality engineers, supervisors, and shop floor workers who have hands-on experience with product quality concerns and process performance. The chosen sample contributes to credible and useful data for assessing the impact of product quality on foundry performance.

Sample Size: The study include:

- 30–50 SME foundries
- 100–150 respondents including managers, engineers, and operators

5. Variables Considered in the Study

i) Independent Variables

- Product quality practices
- Process control methods
- Employee training
- Inspection techniques
- Quality certifications
- Process standardization

ii) Dependent Variables

- Productivity
- Defect rate
- Customer satisfaction
- Cost reduction
- Market competitiveness
- Rejection percentage

6. Data Collection Instruments

i) Questionnaire Design

A structured questionnaire is prepared using Likert-scale questions to measure responses related to:

- Quality Awareness
- Defect Occurrence
- Process Monitoring

- Productivity Improvement
- Customer Complaints
- Quality Certification Practices

ii) Interview Method

Interviews are conducted with:

- Production Managers
- Quality control engineers
- Shop floor supervisors
- Skilled workers

The interviews help in understanding practical challenges in maintaining product quality.

7. Data Analysis Techniques

The collected data is analyzed using statistical and analytical tools such as:

- Percentage analysis
- Mean and standard deviation
- Correlation analysis
- Regression analysis
- Pareto analysis
- Cause-and-effect analysis
- Control charts
- Histogram analysis

These tools help identify relationships between product quality and foundry performance indicators.

8. Quality Assessment Parameters

The following parameters are considered for assessing product quality:

- Dimensional accuracy
- Surface finish
- Mechanical properties
- Casting defect rate
- Rejection percentage
- Process capability
- Customer complaint frequency
- Delivery performance

9. Reliability and Validity

To ensure reliability and validity:

- Pilot testing of questionnaires is conducted.
- Expert opinions from industry professionals and academicians are considered.

- Data consistency and response accuracy are verified.
- Standard quality management concepts are used for analysis.

10. Outcomes of the Study

The research is expected to:

- Identify critical quality-related challenges in SME foundries.
- Demonstrate the impact of product quality on productivity and profitability.
- Provide recommendations for defect reduction and process improvement.
- Encourage adoption of quality management systems such as Six Sigma, SPC, and TQM.
- Support sustainable growth and competitiveness of Indian foundries.

IV. IMPORTANCE OF PRODUCT QUALITY

- o Customer Satisfaction and Market Competitiveness

High product quality ensures that cast components meet customer specifications and performance expectations. In global markets, customers demand consistent and defect-free products, making quality a key determinant of business success. Quality-focused foundries can establish long-term relationships with clients and expand their market reach.

- o Reduction in Defects and Scrap

Casting flaws including inclusions, shrinkage, and porosity cause rejection and rework. Enhancing resource utilization and lowering scrap rates are two benefits of improving product quality. According to research, foundries can greatly increase production and minimize defects by using structured quality improvement methodologies.

- o Cost Efficiency and Profitability

Because of scrap, rework, and warranty claims, poor quality raises production costs. Foundries can lower these expenses and increase profitability by raising the quality of their products. Cost-effective production is made possible by quality improvement programs like Six Sigma and lean manufacturing.

- o Compliance with Standards

Product quality guarantees adherence to global standards like ISO and ASTM. SMEs can compete in international markets and gain credibility through compliance. Additionally, it guarantees the dependability and safety of cast components.

- o Competitive Advantage

In the cutthroat market, superior items serve as a differentiator. Foundries that continuously provide high-quality products build a solid reputation and draw in more clients.

V. CHALLENGES IN MAINTAINING PRODUCT QUALITY IN FOUNDRIES

Because the casting process involves several interrelated variables, including raw material quality, mold preparation, melting temperature, pouring conditions, cooling pace, and finishing operations, maintaining product quality at small and medium-sized foundries in India is a significant issue. Defects like porosity, blowholes, shrinkage cavities, sand inclusions, cold shuts, and dimensional errors can result from even a little change in any of these characteristics. According to studies, one of the main reasons for rejection in the sand casting industry is uneven control over process parameters.

1. Lack of Skilled Manpower

The lack of skilled and technically trained labor is one of the biggest problems SME foundries face. Workers with experience in mold preparation, metal composition control, melting processes, gating and risering design, and defect identification are needed for foundry operations. However, due to a lack of resources and training facilities, many SMEs rely on untrained or semi-skilled labor.

Inadequate technical expertise among employees frequently results in poor finishing operations, uneven mold quality, inaccurate pouring temperatures, and inadequate process control. Casting flaws such as blowholes, shrinkage voids, porosity, sand inclusions, and dimensional errors consequently become more common. Operators could also be ignorant of statistical process control tools, preventive maintenance procedures, and contemporary quality control methods.

Frequent labour turnover in small foundries further affects process stability and organizational learning. Newly recruited workers may require considerable

time to understand operational standards, thereby reducing productivity and increasing rejection rates. Therefore, continuous employee training and skill development programs are essential for improving product quality and process reliability in SME foundries.

2. Outdated Technology

In India, a large number of small and medium-sized foundries continue to use labor-intensive, traditional manufacturing techniques. Due to their lower initial investment costs, traditional sand casting methods, hand mold preparation, and outdated melting furnaces are frequently utilized. However, antiquated equipment frequently leads to greater rejection rates, uneven process parameters, poor dimensional control, and decreased productivity.

Older machinery might not offer effective metal handling methods, reliable temperature management, or appropriate sand testing. Conventional molding techniques and manual pouring procedures raise the risk of process variability and human error. As a result, the market reputation and customer trust are negatively impacted by the uneven quality of cast items.

3. Inadequate Quality Management Systems

The lack of organized quality management systems in many SME foundries is another significant issue. Instead of ongoing monitoring throughout the production cycle, quality control operations are frequently restricted to final product inspection. It becomes challenging to find the underlying causes of flaws and successfully carry out corrective measures in the absence of systematic quality planning and documentation.

Standard operating procedures, process documentation, and quality records are often lacking in small foundries. Poor production parameter monitoring results from a lack of process control methods like Total Quality Management (TQM), Failure Mode and Effects Analysis (FMEA), and Statistical Process Control (SPC). As a result, changes in the characteristics of the sand, the temperature of the molten metal, the pouring speed, and the cooling conditions are all uncontrollable.

4. Financial Constraints

It is challenging to invest in cutting-edge machinery, automation systems, testing facilities, and staff

training initiatives because the majority of small foundries have tight profit margins and little funding.

Automated molding equipment, robotic pouring systems, real-time monitoring devices, and casting simulation software are examples of modern quality enhancement technologies that need significant investment. However, because of market competitiveness and economic demands, many SMEs put short-term operational survival ahead of long-term quality improvement.

The financial resources of foundries are further strained by high energy costs, volatile raw material prices, and rising environmental compliance costs. As a result, quality improvement projects, process improvements, and maintenance tasks are frequently put off. Research and development efforts are also hampered by limited funding, which makes it harder for SMEs to use cutting-edge manufacturing techniques.

5. Resistance to Change

Another significant barrier to improving product quality in SME foundries is resistance to organizational and technological change. Many foundry owners and staff may be reluctant to embrace new technology or quality control procedures since they are used to conventional production techniques. This reluctance stems from a lack of technical knowledge, a fear of financial risks, and an uncertainty about the advantages of modernization.

Training, process redesign, and management commitment are necessary for the implementation of contemporary quality methodologies like Six Sigma, Lean Manufacturing, Total Productive Maintenance (TPM), and automation. However, SMEs frequently struggle to alter their current operating practices and work culture. Workers may fear losing their jobs owing to automation or view new technologies as complex.

6. Poor Raw Material Quality

The final casting quality is greatly influenced by the quality of the raw materials used in foundry operations. Due to financial constraints, many SME foundries rely on locally sourced sand and recovered scrap metal. However, variances in sand characteristics and inconsistent scrap metal chemical composition frequently result in casting flaws and decreased product dependability.

Defects including blowholes, rough surfaces, sand inclusions, and insufficient mold strength can be caused by improper sand grain size, inadequate permeability, excessive moisture content, and contamination. In a similar vein, impurities in molten metal can have an adverse effect on dimensional accuracy and mechanical qualities. SMEs find it challenging to guarantee consistent raw material quality due to limited access to sophisticated material testing equipment.

7. High Defect and Rejection Rates

Inadequate process control and quality monitoring lead to significant rejection and rework rates in many small foundries. Shrinkage, porosity, cold shuts, hot tears, misruns, and dimensional variations are typical casting flaws. Delivery delays, production expenses, and material waste are all increased by these flaws. Regular rejection hurts foundries' reputations in cutthroat marketplaces in addition to having an impact on profitability. Rework procedures lower overall productivity because they need more labor, energy, and machine time. The same quality problems frequently resurface in the absence of systematic defect analysis and preventive measures.

8. Inadequate Process Standardization

For foundry production to remain consistent, process standardization is crucial. For mold preparation, melting, pouring, cooling, and inspection operations, many SMEs do not have well-defined operating processes. Instead than adhering to set rules, operators may use diverse approaches based on their own experiences. This discrepancy increases reliance on individual worker skills and causes differences in production quality. Additionally, the lack of standard operating procedures (SOPs) diminishes process repeatability and makes training challenging. This makes it difficult to maintain consistent product quality across several production batches.

9. Environmental and Regulatory Challenges

Air pollution, trash production, dust emissions, and high energy usage are all linked to foundry businesses. SME foundries face additional difficulties as a result of growing environmental laws pertaining to emissions, waste management, and workplace safety. Investing in waste treatment facilities, dust collecting systems, and cleaner industrial technologies is frequently necessary to comply with pollution control regulations. Many SMEs find it

difficult to adopt environmentally sustainable methods while still maintaining product quality due to a lack of funding. Penalties, operating limitations, and a decline in customer trust are possible outcomes of breaking environmental regulations.

10. Supply Chain and Delivery Issues

Quality performance in SME foundries is also impacted by irregular raw material availability, transportation delays, and material price variations. Production schedules may be disrupted by inconsistent supply chains, and foundries may be forced to employ inferior replacement materials. Production continuity and maintenance operations may be impacted by delayed supply of molding materials, alloys, or spare parts. Furthermore, hurried production procedures and shorter inspection times might result from pressure to fulfill strict customer deadlines, which raises the possibility of flaws. Thus, sustaining both production efficiency and product quality requires effective supply chain management.

VI. IMPACT OF PRODUCT QUALITY ON FOUNDRY PERFORMANCE

Product quality is critical in defining the overall performance and competitiveness of the foundry industry. High-quality castings boost customer satisfaction, lower rejection rates, and increase operational efficiency at small and medium-sized foundries. Product quality has a direct impact on the dimensional correctness, surface finish, mechanical qualities, and reliability of cast components used in automotive, aerospace, agricultural, and engineering applications. Foundries that manufacture defect-free castings are more likely to acquire long-term client loyalty and repeat business prospects.

Improved product quality leads to:

1. Higher productivity due to reduced rework
2. Lower production costs
3. Improved customer satisfaction
4. Enhanced export potential
5. Better sustainability through reduced waste

1. Higher Productivity

One of the biggest advantages of better product quality in foundries is increased productivity. Rework, repair, and rejection are significantly reduced when casting flaws are reduced. This makes it possible for production operations to continue without being disrupted by repeated manufacturing procedures or

problem rectification. Faster production cycles and increased operational efficiency follow from the more effective use of machinery, labor, and raw resources.

2. Lower Production Costs

One of the key benefits of maintaining good product quality in foundries is lower manufacturing costs. The costs of scrap, rework, and material waste are greatly reduced when flaws like porosity, shrinkage, cracks, and sand inclusions are eliminated. Effective quality control procedures reduce wasteful operating expenses by optimizing the utilization of personnel, energy, raw materials, and machine time.

3. Improved Customer Satisfaction

One of the main results of foundries maintaining excellent product quality is increased customer satisfaction. Consumers anticipate cast goods with precise measurements, a smooth surface, dependable mechanical qualities, and flawless operation. Customers become more confident in a supplier's ability and dependability when foundries continuously provide high-quality castings. This improves commercial ties and raises the possibility of recurring business and long-term collaborations.

4. Enhanced export potential

Maintaining excellent product quality in foundries has several advantages, one of which is increased export potential. Cast items must adhere to stringent quality standards, dimensional accuracy, and performance requirements in order to be sold internationally. Foundries that regularly create dependable and flawless castings are more likely to meet customer requirements and international certifications, allowing them to successfully compete in international markets.

5. Better sustainability through reduced waste

One of the main benefits of better product quality in foundries is increased sustainability through decreased waste. High-quality production methods reduce material losses, scrap output, and casting flaws, resulting in more effective use of energy and raw materials. In addition to lowering manufacturing costs, reduced waste also lessens the environmental impact of excessive resource use and the disposal of defective castings.

6. Reduced Casting Defects

Product quality is critical in defining the overall performance and competitiveness of the foundry industry. High-quality castings boost customer satisfaction, lower rejection rates, and increase operational efficiency at small and medium-sized foundries. Product quality has a direct impact on the dimensional correctness, surface finish, mechanical qualities, and reliability of cast components used in automotive, aerospace, agricultural, and engineering applications. Foundries that manufacture defect-free castings are more likely to acquire long-term client loyalty and repeat business prospects.

7. Enhanced Market Reputation

The market reputation of foundries is greatly improved by high-quality products. Consumers like vendors who deliver dependable goods and continuously uphold quality standards. Strong quality management systems enable foundries to win bigger contracts, enter foreign markets, and increase their profitability. SME foundries' credibility is increased and customer confidence is reinforced by quality certifications like ISO 9001.

8. Improved Process Stability

The enhancement of operational control and process stability is another significant effect. Foundries benefit from improved process consistency and decreased production variability when quality parameters are consistently monitored and maintained. Process capability is maintained and flaws are reduced with the aid of methods like Total Quality Management (TQM), Six Sigma, and Statistical Process Control (SPC). Additionally, better process management lowers maintenance expenses and machine downtime.

9. Boost Organisational Culture

Organizational culture and staff morale are also impacted by product quality. Workers in foundries that prioritize quality become more aware of workmanship, process discipline, and methods for continual improvement. Employee productivity and involvement in quality initiatives are further enhanced by training and skill development programs. As a result, the company develops an operational excellence and accountability culture.

10. Better Financial Performance

Maintaining superior product quality is not only a technical necessity but also a strategic factor for the growth and survival of SME foundries in competitive

industrial markets because high-quality products lower warranty claims, customer complaints, and inspection costs. Increased customer satisfaction and decreased operational losses ultimately improve profitability and long-term sustainability.

VII. SUMMARY AND DISCUSSIONS

The study's conclusions highlight how important product quality is as a primary performance factor in small and medium-sized foundries. Although many SME foundries reach acceptable levels of output quality, there is still a great deal of variability in their processes, according to the analysis based on quantitative indicators like defect rate, yield, and process capability indices (Cp and Cpk). For example, a relatively high yield and a moderate defect rate indicate that inspection and rework, rather than intrinsically capable processes, are frequently used to attain acceptable performance. This finding is consistent with research that highlights the shortcomings of conventional quality control methods, which prioritize fault discovery above prevention.

1. Histogram Interpretation

The frequency distribution of casting dimensions in respect to the designated tolerance limits (USL and LSL) is depicted in the histogram. The data's roughly normal distribution suggests that typical causes rather than sporadic anomalies account for the majority of process variance. The comparatively high yield (95%) seen in the data is supported by the fact that the majority of the observations fall inside the specification limits. Nonetheless, the distribution's spread is comparatively large in relation to the tolerance range, indicating a high degree of process variability.

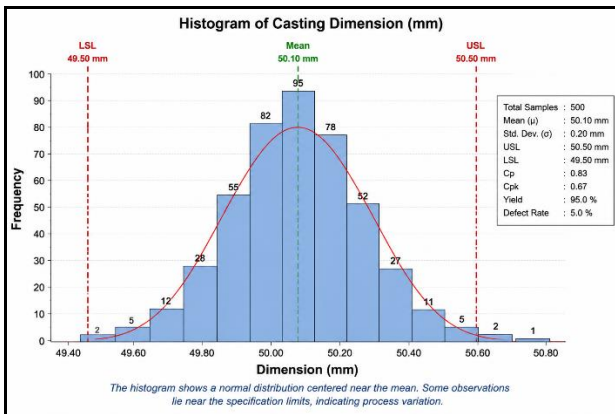


Figure 1. Casting Dimensions Vs Frequency

From a quality perspective, the histogram shows that while the procedure generates satisfactory results, it is insufficiently capable. Defect risk is increased when data points are close to specification limitations. The computed Cp (0.83) and Cpk (0.67) values, which are below the permissible threshold, are in line with this observation. Therefore, to increase process capability and guarantee consistent product quality, it is crucial to reduce process variance and tighten the distribution.

2. Control Chart Interpretation

The control chart, often known as the X-chart, offers information on how stable the casting process is over time. The process is statistically under control and unaffected by major particular causes of variation, as indicated by the plotted data points falling inside the upper and lower control limits. Process stability is further confirmed by the lack of anomalous patterns such abrupt spikes, trends, or cycles.

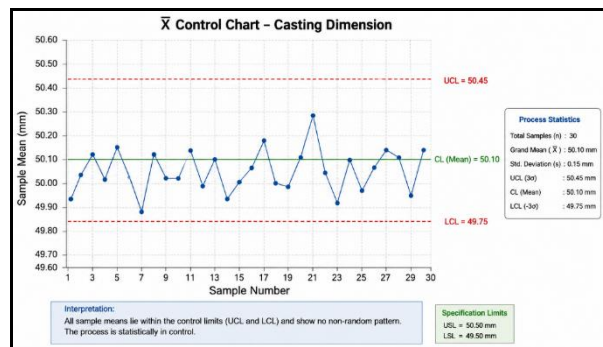


Figure 2.

But a capable process is not always implied by a stable process. The process nevertheless generates variability that is comparatively high in relation to specified limits even though it is under statistical control. This draws attention to a crucial problem in SME foundries: reliable but unoptimized processes. The control chart highlights the necessity of changing the emphasis from just preserving stability to enhancing capability through improved material control, process standardization, and parameter optimization.

3. Radar (Spider) Chart Interpretation

Key quality indicators, such as yield, defect rate, Cp, and Cpk, are comparatively visualized in the radar chart. Strong performance in product-related metrics (yield and low defect rate) is displayed in the chart; these metrics are at the outside boundary, suggesting high scores. On the other hand, the

shape is skewed and irregular since process-related metrics (Cp and Cpk) are much lower. The disparity between process and product quality is amply demonstrated by this imbalance. Although the foundry produces satisfactory results, it mostly depends on inspection and remedial measures rather than strong process control. The radar graphic does a good job of illustrating how process capability needs to be improved. A more consistent and optimal quality performance profile will result from improving Cp and Cpk values, which will assist balance the chart.

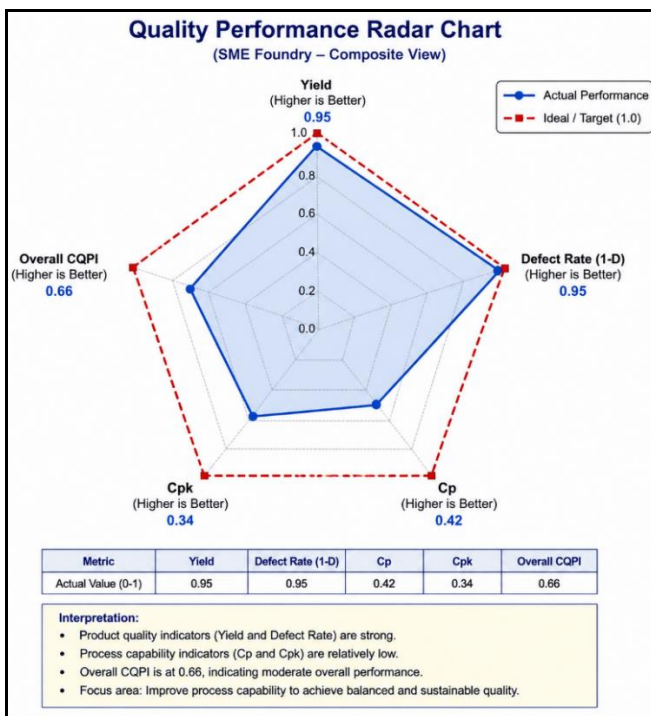


Figure 3.

A recurring pattern can be seen when the control chart, radar chart, and histogram are all interpreted together:

- Although stable, the process is unable
- Although adequate, the product quality is not sustainable
- The main area of concern is still process variability.

In order to ensure long-term consistency, efficiency, and competitiveness in SME foundries, these graphical studies highlight the significance of switching from reactive quality control to proactive process optimization.

VIII. CONCLUSION

This study emphasizes how crucial product quality is to India's small and medium-sized foundries,

highlighting how it directly affects operational effectiveness, cost reduction, customer satisfaction, and overall competitiveness. The analysis shows that well-controlled and optimized procedures lead to product quality rather than only the results of inspection. Important quality measures including yield, defect rate, and process capability indices (Cp and Cpk) offer insightful information about performance levels and point out areas that need development. The results show that even while many SME foundries produce goods of acceptable quality, consistency and long-term performance are nevertheless impacted by process capabilities and control constraints.

The study also shows that a thorough examination of both process and product quality is made possible by incorporating quantitative evaluation techniques like the Composite Quality Performance Index (CQPI). Quality performance can be greatly improved by implementing upcoming technologies like Industry 4.0 and machine learning, as well as organized quality improvement approaches like Six Sigma, Statistical Quality Control, and Lean procedures. To achieve successful implementation, however, issues including scarce resources, a shortage of competent labor, and resistance to change must be resolved. All things considered, increasing the sustainability and international competitiveness of SME foundries in India requires improving product quality through methodical process control and continual improvement.

The process capacity evaluation shows that Cp and Cpk values frequently fall below the suggested threshold of 1.33, indicating that processes are insufficiently capable of reliably satisfying specification constraints. Process centering problems are further highlighted by a significant difference between Cp and Cpk values, where the process mean differs from the goal value. Even with moderate control over process variation, this mismatch raises the risk of problems. These results are in line with earlier studies that found that casting faults are mostly caused by process variability and poor parameter control. Therefore, it is crucial to improve process capability by tightly controlling crucial parameters including pouring temperature, mold composition, and cooling rates.

By combining process and product quality into a single quantifiable score, the Composite Quality Performance Index (CQPI) offers a comprehensive viewpoint. The findings show that whereas process

quality ratings are typically lower, product quality scores are generally higher, resulting in a moderate overall performance index. This disparity implies that SME foundries frequently depend more on remedial actions than on preventative ones. This gap is successfully identified by the CQPI model, which is also a helpful tool for benchmarking and ongoing development. It makes it possible for decision-makers to give top priority to process enhancements that will most significantly affect overall quality performance.

The study also emphasizes how crucial cutting-edge technologies are becoming to raising quality performance. Real-time monitoring and proactive fault avoidance are made possible by the integration of Industry 4.0, predictive modeling, and machine learning technologies. When it comes to detecting process abnormalities and improving production parameters, these technologies are more accurate and efficient than traditional methods. However, because to technical and budgetary limitations, the application of such technologies in SME foundries is still restricted. This suggests that scalable and affordable solutions that are adapted to the capabilities of SMEs are required.

Quality performance is largely determined by organizational and human variables in addition to technology ones. Effective implementation is hampered by a lack of qualified personnel, poor training, and a lack of knowledge of quality management techniques. The implementation of contemporary quality practices is further slowed by resistance to change. In order to improve quality outcomes, capacity building through training programs, knowledge sharing, and managerial commitment is crucial.

From a strategic standpoint, the findings highlight the importance of considering product quality as a component of an integrated system that includes resource management, process quality, and ongoing improvement. Improvements in process control will directly improve product outcomes, lower faults, and increase efficiency because product and process quality are interdependent. For SME foundries, where resource limitations require the best possible use of given capabilities, this integrated approach is especially crucial.

Overall, the conversation shows that although SME foundries in India have made strides toward attaining acceptable quality levels, process competence,

technology adoption, and quality management techniques still have a lot of room for improvement. Achieving sustainable growth and worldwide competitiveness requires the shift from reactive to proactive quality control, which is backed by quantitative indicators and integrated models like CQPI.

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