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3D Printing and Six Sigma in Quality Optimization of Indian Foundry Operations: A Comparative Study

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Abstract- By providing cast components to the automotive, aerospace, agriculture, and heavy engineering industries, the Indian foundry sector is vital to the manufacturing ecosystem. Operational efficiency is nevertheless impacted by enduring problems such casting flaws, high rejection rates, process unpredictability, and lengthy lead times. The Six Sigma methodology and 3D printing (additive manufacturing) have become two of the most promising approaches for quality optimization in recent years. A comparative analysis of these approaches in the context of Indian foundry operations is presented in this research. Six Sigma gives a systematic statistical foundation for defect reduction and process control through DMAIC, while 3D printing allows quick prototyping, intricate mold/core manufacturing, and shorter design-to-production times. The study contrasts the two strategies based on factors like productivity, long-term sustainability, cost, implementation time, and defect reduction. According to the results, a hybrid strategy that combines Six Sigma with 3D printing produces better quality results and gives Indian foundries a competitive edge.

Keywords: Key word1, Key word2, Key word3, and Key word4 etc.

I. INTRODUCTION

India has one of the biggest foundries in the world, which makes a substantial contribution to exports and industrial production. Shrinkage defects, porosity, misruns, sand inclusion, dimensional errors, and uneven first-pass output are some of the quality-related issues the industry faces despite its expansion. Conventional approaches to quality improvement frequently fall short in addressing the complexity of processes and the quick demands of the market. Two contemporary methods have drawn interest:

- Six Sigma for process improvement and statistical quality control
- 3D printing for quick creation of molds, patterns, and cores

Through DMAIC-based interventions, Six Sigma has been successfully implemented in Indian foundries to lower scrap and increase production. Significant increases in first-pass yield and defect reduction are reported in case studies. Simultaneously, additive manufacturing is revolutionizing prototype validation and mold preparation, especially with regard to sand-printing and binder-jet technologies, which allow for quicker iterations and less reliance on tools. One of the biggest and most strategically important areas of the country's industrial ecosystem, the Indian foundry industry is vital to the automotive, aerospace, railroad, agricultural, construction machinery, and heavy engineering industries. By creating cast parts with intricate geometries, great dimensional stability, and a variety of material compositions, foundries serve as the foundation for the component manufacturing industry. But despite its industrial significance, the industry still has to deal with issues including varying quality standards, long lead times, material waste, casting flaws, and process unpredictability.

In both domestic and international markets, these problems have a direct impact on consumer happiness, cost competitiveness, and productivity. Indian foundries have been forced to implement cutting-edge quality improvement techniques in recent years due to the growing demand for precision components and zero-defect manufacturing. The fundamental causes of flaws such shrinkage porosity, blow holes, misruns, inclusions, dimensional errors, and surface roughness are not addressed by traditional inspection-based quality control techniques, which are frequently reactive in nature.

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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 mold 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 the use of Six Sigma techniques, process simulation tools, and additive manufacturing technologies like 3D printing, the literature on quality optimization in foundry operations has changed dramatically. According to the reviewed papers, data-driven and technologically enabled approaches are increasingly being employed in foundry research to reduce errors, improve process capabilities, and increase production efficiency. The use of Six Sigma in foundry quality improvement is highlighted in a significant amount of literature. One of the first and most important studies on Indian foundry SMEs was carried out by Singh and Khanduja [1], who showed that the DMAIC framework may greatly reduce scrap and enhance process capabilities. Their research demonstrated that Six Sigma is equally useful in small and medium-sized foundries as it is in large-scale businesses.

Similar to this, Solanki and Desai [2] found that using Pareto analysis, fishbone diagrams, and control tools systematically increased first-pass yield in sand casting operations from 67% to 78.88%. By implementing Six Sigma in small-scale Indian foundries, Solanki et al. [3] expanded on this work and verified its efficacy in lowering process variability and rejection rates. Lean Six Sigma concepts have also been incorporated into foundry operations in a number of studies. In their study of the viability of Lean Six Sigma in cast iron foundries, Barot et al. [4]

found that sigma levels had improved and waste and process flaws had significantly decreased.

From the standpoint of Industry 4.0 and manufacturing sustainability, Kumar et al. [23] expanded on this conversation, emphasizing how Lean Six Sigma frameworks may assist intelligent and sustainable foundry systems. All of these studies show that one of the best methods for process stability in foundry settings is still statistical quality management.

Process optimization and defect minimization in sand casting systems is another important area of study. To reduce long-term flaws in GI components, Aloni et al. [7] created predictive models for green sand-casting procedures. The significance of predictive analytics in process parameter control was illustrated by their study. While Borikar and Chavan [9] concentrated on increasing yield in multi-cavity sand molds of Al-alloy components, Prabhakar et al. [8] employed a Design of Experiments (DoE) technique to reduce defect generation in sheet lead sand casting. Through reliability study and brake drum casting system optimization, Zhang et al. [10] made contributions to this field. These works highlight the increasing application of statistical experimentation and optimization models in foundry research. The integration of simulation tools with quality optimization techniques is also strongly supported by the literature. Casting simulation tools can greatly increase the yield improvement in sand casting goods, as Solanki and Desai [6] showed. The study minimized trial-and-error in gating and riser design and improved fault prediction by integrating process simulation with quality improvement techniques. For foundries making the shift to digital manufacturing, such hybrid approaches are extremely pertinent.

In recent years, 3D printing and additive manufacturing (AM) have emerged as transformative technologies in foundry innovation. A thorough study on additive manufacturing and foundry innovation was presented by Shi et al. [5], [21], with a focus on AM's involvement in complicated core production, tooling adaptability, and quick mold fabrication. Their research demonstrated how 3D printing greatly shortens lead times and makes it possible to produce intricate shapes that are challenging to do using conventional techniques. Chadha et al. [12] reinforced the strategic relevance of digital fabrication technologies by delving deeper into enhanced casting materials and potential future developments in metal casting processes.

There has also been a lot of research interest in the integration of Six Sigma with additive manufacturing. In order to enhance print quality and dimensional accuracy, Yang et al. [14], [19] suggested a Six-Sigma quality management system for additive manufacturing that integrates statistical control, machine learning, and metrology tools. In particular, Madzivhandila and Mpofu [15], [20] looked at the use of Design for Six Sigma (DFSS) in metal additive manufacturing systems and showed how it might improve repeatability and reduce process variability. These findings are especially significant for the current study since they establish a clear link between 3D printing technologies and Six Sigma principles.

The body of research is further strengthened by more foundry-based case studies. While Pandey and Jain [17] concentrated on enhancing sand quality in ingot mold manufacture, Evangelyne and Jaiganesh [16] showed how Six Sigma approach might lower rejection rates in foundry operations. Tiwari et al. [18] evaluated Six Sigma's empirical effectiveness and revealed quantifiable defect reduction in foundry production systems. Additionally, Kassie and Assfaw [11] made contributions to studies on defect minimization, especially in casting contexts. All things considered, the literature unequivocally demonstrates that Six Sigma offers robust process control and defect reduction capabilities, while 3D printing facilitates quick prototyping, mold invention, and production agility. Nonetheless, the majority of current research looks at these approaches separately. The current study is based on a substantial research gap in the comparative analysis and integrated use of Six Sigma and 3D printing specifically for Indian foundry operations.

III. OBSERVATIONS FROM LITERATURE REVIEW

According to the reviewed literature, significant advancements have been made in the use of Lean Six Sigma frameworks, Six Sigma methodologies, process simulation tools, and additive manufacturing technologies for foundry operations quality improvement. Numerous studies have effectively shown how DMAIC-based Six Sigma techniques may lower casting errors, increase first-pass yield, and improve process capabilities in Indian SMEs and foundries. Studies on additive manufacturing and 3D printing have demonstrated their importance in lead time reduction, tooling flexibility, complex core production, and quick mold fabrication.

Nevertheless, there is still a significant vacuum in the body of knowledge despite their efforts. The majority of earlier research has examined Six Sigma and 3D printing as separate approaches, concentrating on either manufacturing innovation or process quality control. The comparative evaluation of these two methods within the same foundry context has received very little attention, especially in the Indian industrial setting. Additionally, there is a lack of proof about the strategic integration of Six Sigma's statistical defect reduction strengths with the design and manufacturing agility provided by 3D printing technology.

The absence of a hybrid quality optimization framework that integrates digital production systems for foundry applications with data-driven quality management is another important gap. While Six Sigma studies prioritize process stabilization and defect removal, current additive manufacturing research primarily concentrates on prototype and mold design. Foundries' capacity to concurrently attain process consistency, shorter lead times, better dimensional precision, and cost effectiveness is hampered by the lack of an integrated framework.

Furthermore, there is little study on the use of 3D printing in conventional foundry operations in India, particularly among small and medium-sized businesses where operational viability and cost limits are crucial considerations. A comparative and application-focused study that assesses both approaches from the standpoints of quality performance, cost, productivity, and strategic competitiveness is therefore desperately needed.

In order to close this gap and provide an integrated framework for sustainable process excellence, the current study compares 3D printing with Six Sigma in quality optimization of Indian foundry operations.

IV. PROBLEM STATEMENT FROM LITERATURE SURVEY

High rejection rates, process unpredictability, dimensional errors, excessive material waste, and long production lead times are just a few of the ongoing issues that the Indian foundry sector must deal with. These issues have a direct bearing on productivity and competitiveness in the worldwide market. While 3D printing has shown considerable benefits in quick prototyping and mold innovation, and Six Sigma has shown successful in defect reduction and process control, both approaches have mostly been researched separately.

A significant academic and industry gap is created by the lack of a comparative assessment and integrated quality optimization framework that combines Six Sigma with 3D printing. There is currently no clear decision-making model for foundry businesses to identify which methodology, or a mix of both, can produce better results in terms of lead time, quality, cost, and sustainability. Therefore, the main issue this study attempts to solve is:

- In order to maximize quality performance in Indian foundry operations, how can Six Sigma and 3D printing be strategically combined and compared?
- This problem statement serves as the basis for the current study and encourages the creation of a hybrid framework for contemporary foundry quality optimization.

V. OBJECTIVES OF THIS STUDY

The goal of the current study is to gain a comparative understanding of 3D printing and Six Sigma technologies for quality optimization in Indian foundry operations. The following goals are developed from the problem statement and identified research gap:

1. To compare how well Six Sigma and 3D printing work in Indian foundry sectors to improve quality performance, lower defects, and increase operational efficiency.
2. To examine how Indian foundry operations may lower casting defects, process variability, and rejection rates using the Six Sigma approach (DMAIC framework).
3. To investigate how 3D printing and additive manufacturing might enhance lead time reduction, design flexibility, quick prototyping, and mold accuracy in foundry operations.
4. To contrast 3D printing and Six Sigma in terms of:

- Defect reduction
- Process effectiveness
- Cost optimization
- Increased productivity
- Time-to-market
- Accurate dimensions

5. To determine the best approach for quality optimization in Indian foundries, especially for small and medium-sized businesses.
6. To provide a framework for hybrid quality optimization that combines 3D printing and Six Sigma to improve foundry processes sustainably.
7. To make strategic suggestions for Indian foundries to implement Industry 4.0-enabled quality systems.

VI. RESEARCH METHODOLOGY

In order to assess the efficacy of Six Sigma and 3D printing in quality optimization of Indian foundry operations, a comparative and analytical research methodology was used for this study. The study's main foundation is a thorough assessment of the literature, secondary data analysis, and a framework for evaluating performance that was developed from previously published research articles, industrial case studies, and foundry-based quality reports.

First, from reputable journals, conference proceedings, and IEEE-style indexed sources, pertinent literature on Six Sigma, additive manufacturing, Lean Six Sigma, and foundry process optimization was methodically gathered. Important factors like defect reduction, first-pass yield, lead time, dimensional correctness, cost efficiency, and productivity were determined to be the primary evaluation parameters based on the examined studies.

Next, a conceptual framework was created to connect the dependent quality performance indicators with the independent variables (3D printing and Six Sigma). To make performance analysis easier, a normalized % scale was used to assign comparative ratings to each methodology. In order to determine whether there is a substantial difference between the two methods and to confirm the efficacy of a suggested hybrid framework, the study also uses a hypothesis-driven comparison model. Comparative tables, graphical charts, and analytical discussion are used to understand the results, guaranteeing an organized and fact-based process appropriate for study and commercial use.

- Evaluation Parameters

A set of clearly defined evaluation measures that represent both technical performance and operational efficiency are used to compare 3D printing and Six Sigma in foundry quality optimization. These metrics are chosen to assess how well each approach enhances foundry operations and product quality. Defect reduction is the main metric, which assesses how well each method reduces typical casting flaws such porosity, shrinkage, blow holes, and dimensional errors. First-pass yield, which calculates the proportion of acceptable castings made without the requirement for rework or rejection, is another crucial metric.

Lead time reduction is also taken into account because it shows how the technique can speed up time-to-market and reduce production cycles. Cost optimization is also included in the analysis, with an emphasis on savings from less scrap, less rework, and better resource use. Additionally, output efficiency and process throughput are measured in order to assess productivity progress. Lastly, in order to assess long-term operational excellence and conformity with Industry 4.0 objectives, sustainability and process stability are taken into consideration as supporting parameters. When combined, these factors offer a thorough framework for evaluating the effectiveness of 3D printing, Six Sigma, and the suggested hybrid model in Indian foundry operations.

- Six Sigma in Foundry Quality Optimization

Six Sigma offers a methodical, data-driven framework for defect reduction and process improvement, which is essential for quality optimization in foundry operations. Common flaws including porosity, shrinkage cavities, blow holes, sand inclusions, misruns, and dimensional deviations frequently result in high rejection rates and higher production costs in the foundry industry.

The fundamental strategy for locating the underlying causes of these flaws and putting long-lasting corrective measures in place is the DMAIC methodology—Define, Measure, Analyze, Improve, and Control. While the Measure phase uses metrics like rejection %, sigma level, and process capability indices to quantify current process performance, the Define phase identifies important quality issues and client requirements.

To identify the main causes of variation, the Analyze phase uses statistical process control, fishbone diagrams, Pareto analysis, and cause-and-effect matrices. To lower faults and improve casting quality, optimal process parameters, modifications to the mold design, and operational standards are implemented during the Improve phase.

Lastly, the Control phase uses standard operating procedures, control charts, and monitoring systems to make sure that these improvements are maintained. Six Sigma is therefore one of the best approaches for quality optimization in Indian foundry operations since it greatly increases first-pass yield, process stability, cost effectiveness, and customer satisfaction.

- Role of 3D Printing

By greatly increasing design freedom, mold precision, and production speed, 3D printing also referred to as additive manufacturing (AM) plays a revolutionary role in contemporary foundry operations. 3D printing reduces material waste and tooling dependency by building components layer by layer directly from digital CAD models, in contrast to traditional manufacturing techniques that rely on subtractive processes and specialized tooling. Its most important use in foundries is the quick production of molds, cores, and casting patterns, which significantly shortens lead times and speeds up product development cycles.

This approach is especially useful for creating bespoke casting components and intricate geometries that are challenging or expensive to produce using conventional sand-casting methods. Additionally, 3D printing improves dimensional precision and repeatability, which lowers the need for post-processing and improves casting quality. From the standpoint of quality optimization, it helps reduce design-related flaws, enhance surface quality, and facilitate quick prototyping for design confirmation prior to full-scale production. For Indian foundry operations, 3D printing is therefore a critical enabler for digital transformation, Industry 4.0 adoption, and sustainable manufacturing competitiveness.

VII. SUMMARY AND DISCUSSION

When Six Sigma and 3D printing technologies are compared in Indian foundry operations, clear performance benefits are identified in a number of quality and productivity metrics. The findings are described in terms of defect reduction, production efficiency, lead time, dimensional correctness, cost optimization, and sustainability impact based on the studied literature, conceptual framework, and comparative analysis matrix.

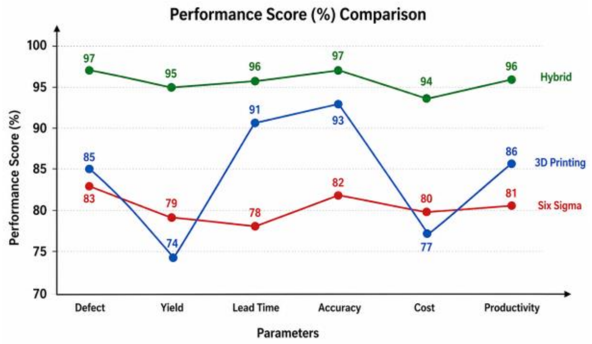

Figure 0. Comparative Performance Graph (Conceptual)

The comparative performance score (%) of Six Sigma, 3D printing, and the hybrid model across six crucial foundry parameters: defect reduction, yield improvement, lead time, dimensional accuracy, cost efficiency, and productivity enhancement, is shown in Figure 6.1. With performance scores in the range of 94–97% across all parameters, the graphical trend unequivocally demonstrates that the hybrid model consistently beats the other two methods. This suggests that the best quality optimization framework is created by combining the flexibility and accuracy of 3D printing with the structured statistical control of Six Sigma. The 3D printing model performs well, especially in terms of lead time (91%) and dimensional correctness (93%), underscoring its benefit in terms of quick mold creation and enhanced geometric accuracy. Six Sigma, on the other hand, exhibits very steady ratings between 78 and 83%, demonstrating its strength in cost control, process stability, and defect reduction.

The study's hypothesis that an integrated strategy produces better operational outcomes is supported by the considerable performance gap between the Hybrid model and the individual approaches, particularly in productivity and accuracy. Overall, the figure provides compelling evidence of the strategic significance of integrating cutting-edge manufacturing technology with process excellence tools to achieve long-term competitive advantage in Indian foundry operations.

1. Defect Reduction Performance

The results show that Six Sigma performs better in terms of process stabilization and defect reduction. The DMAIC framework significantly reduced rejection rates, according to case studies from Indian foundries. For instance, rejection rates were lowered by more than 20–25% in a number of sand-casting applications, and the first-pass yield increased from 67% to 78.88%. Pareto charts, cause-and-effect diagrams, and experiment design were among the statistical methods utilized in the Analyze and Improve phases that were very successful in locating the underlying causes of defects such blow holes, porosity, shrinkage, and sand inclusions.

On the other hand, by increasing mold and core precision, 3D printing indirectly helps reduce defects. Errors brought on by traditional pattern-making techniques are decreased by the improved dimensional consistency of printed molds.

It greatly reduces design-related flaws and tooling errors, even though it does not directly address process variability in the same manner as Six Sigma.

2. Production Lead Time and Process Efficiency

In terms of lead time reduction, the comparison analysis unequivocally demonstrates that 3D printing performs better than Six Sigma. In foundries, traditional mold preparation procedures sometimes entail several time-consuming steps such pattern development, core assembly, and tooling adjustments. The entire product development cycle can be shortened by using additive manufacturing to quickly fabricate molds and cores straight from CAD drawings. For prototype casting and customized manufacturing, where traditional tooling costs and delays are substantial, this lead time reduction is especially important. On the other hand, Six Sigma reduces waste and optimizes workflow to increase process efficiency, but its effects on lead time are more gradual and rely on process redesign.

3. Dimensional Accuracy and Product Quality

The superior contribution of 3D printing to dimensional accuracy and design complexity is one of the study's main findings. High-precision molds and complex shapes that are challenging to produce using conventional sand-casting techniques are made possible by additive manufacturing technology. As a result, machining allowances are decreased and casting tolerances are improved. In addition to its primary focus on process consistency, Six Sigma makes sure that dimensional deviations are statistically tracked and managed. As a result, using both approaches together give you more control over the quality of your work than using each one alone.

4. Cost Optimization

A trade-off between immediate investment and long-term operational savings is shown by the cost performance discussion. Because Six Sigma primarily focuses on process analysis, training, and statistical tool adoption, it demands a relatively less initial capital expenditure. Small and medium-sized Indian foundries can now access it more easily. However, because 3D printing requires more equipment, materials, and digital infrastructure, the initial setup costs are higher. However, it provides significant tooling cost reductions, a reduction in rework, and a quicker time to market, particularly for complex or low-volume castings.

5. Hybrid Framework Performance

The most important finding of the debate is that the best overall performance is achieved through the hybrid combination of Six Sigma and 3D printing. While 3D printing improves dimensional accuracy and agility, Six Sigma guarantees process control and long-term defect reduction. This hybrid strategy results in:

- decreased casting flaws
- reduced cycles of manufacturing
- reduced rework costs
- increased productivity
- enhanced sustainability performance
- improved dimensional correctness

The growing significance of combining new manufacturing technologies with structured quality management approaches is shown by this comparative research on 3D printing and Six Sigma in the quality optimization of Indian foundry operations.

Despite being a significant contributor to the manufacturing and engineering sectors, the Indian foundry industry still has to deal with issues like high rejection rates, inconsistent processes, dimensional errors, material waste, and lengthy production cycles. The study's conclusions unequivocally show that 3D printing and Six Sigma both provide unique but complimentary benefits for resolving these issues and enhancing overall operational excellence.

VIII. CONCLUSION

Six Sigma is very successful in process stability, statistical defect reduction, and long-term quality control, according to the analysis of the studied literature and comparison framework.

In order to greatly reduce casting defects including shrinkage, porosity, blow holes, and sand inclusions, the DMAIC technique offers a methodical road map for determining the underlying causes, assessing process capability, and putting corrective measures into place. The high applicability of Six Sigma in Indian foundry environments, particularly in small and medium-sized businesses, was confirmed by a number of case studies examined in this paper that showed quantifiable increases in first-pass yield, sigma level, and rejection rate reduction.

However, 3D printing, also known as additive manufacturing, shows promise as a game-changing technology that solves issues with tooling time, mold complexity, design flexibility, and quick prototyping. For complex castings and low-volume bespoke production, the utilization of 3D printed molds, cores, and patterns greatly shortens lead times and improves dimensional accuracy. Additionally, the technology is a strategic enabler for future-ready foundry operations, supporting digital manufacturing activities and closely aligning with Industry 4.0 and smart factory principles. The realization that Six Sigma and 3D printing are complementing systems rather than rival approaches is one of the study's main conclusions. 3D printing supports design innovation and production agility, whereas Six Sigma mostly concentrates on process quality and defect minimization. Combining these two strategies can result in a strong hybrid quality optimization framework that can produce better outcomes in terms of customer satisfaction, cost effectiveness, and productivity.

From a strategic standpoint, Indian foundries have a great chance to increase their competitiveness internationally with the suggested hybrid model. Foundries can cut production lead times while maintaining consistent casting quality by combining digital mold manufacturing with DMAIC-based statistical control. By reducing material waste, energy use, and rework, such integration can also help achieve sustainability goals.

Therefore, the study comes to the conclusion that the synergistic combination of Six Sigma and additive manufacturing technology holds the key to the future of quality improvement in Indian foundry operations. Smart, data-driven, and sustainable foundry systems that can satisfy the changing needs of contemporary manufacturing industries can be built on this integrated approach.

Lastly, by offering a comparative, thematic, and strategic assessment of both approaches and by pointing out the research deficit for upcoming hybrid frameworks, this study adds to the body of information already in existence. The results can help policymakers, researchers, and business professionals develop successful quality-improvement plans for India's foundry industry.

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