CHAPTER 107

Quality Improvement using Six Sigma Methodology for Pre-Cast Structures

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ABSTRACT

The construction industry, characterized by its complexity and project-specific challenges, often struggles with maintaining consistent quality, adhering to strict deadlines, and controlling costs. Precast concrete production, a crucial aspect of modern construction, frequently encounters issues such as defects**,** material waste**,** and production delays, which can negatively impact overall project efficiency and budget management. Addressing these challenges requires a structured approach to quality improvement, and Six Sigma methodology, particularly the DMAIC (Define, Measure, Analyze, Improve, Control) framework, provides a systematic solution. This study examines the application of Six Sigma in precast concrete production to identify and reduce defects, streamline workflows, minimize resource wastage, and enhance operational efficiency. By integrating data-driven decision-making and a continuous improvement approach, this research highlights how Six Sigma principles can improve the quality and durability of precast structures**.** Through an in-depth analysis of common defects, including dimensional variations, surface imperfections, and reinforcement misplacement**,** the study offers practical recommendations for optimizing production processes. The findings suggest that the implementation of Six Sigma can lead to significant improvements in product quality, process efficiency, and cost-effectiveness, making construction projects more sustainable and reliable. Additionally, by reducing rework and material waste, the adoption of Six Sigma supports environmentally friendly construction practices while enhancing compliance with industry standards. The insights from this study can help construction firms and precast manufacturers achieve higher customer satisfaction, greater competitiveness, and long-term operational excellence**.**

Keywords: Six Sigma; Precast concrete components; DMAIC methodology; Quality improvement; Process optimization; Operational efficiency; Construction management.

1.0 Introduction

To remain competitive in today's construction industry, companies must consistently deliver high-quality work and add value to the clients.

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It is crucial to move beyond the traditional adversarial approach to construction management and instead foster stronger, more direct relationships with clients. Encouraging teamwork on job sites and focusing on producing superior quality work are essential steps in this direction. Achieving these objectives requires the implementation of a continuous improvement (CI) strategy to enhance quality management. One of the effective approach for continues improvement is Six Sigma. Six Sigma provides a structured set of techniques and tools designed to enhance process efficiency and minimize defects.

In this methodology, every task is viewed as a process, and specific steps must be followed to define and refine it. Since a process consists of various actions, changes, and functions, proper planning is crucial to ensure optimal results. This methodology is versatile and can be applied across industries, professions, and even in daily life. Initially, Six Sigma was perceived as a purely statistical method, but over time, it has evolved into a broader discipline aimed at reducing errors and maximizing value. While its adoption may require organizations to navigate the challenges of change, the benefits—such as enhanced performance, reduced costs, increased customer satisfaction, and greater overall success—far outweigh the initial difficulties.

In today's construction industry, precast structures are used for projects completion as it helps in reducing project execution time. Non-adherence of quality norms while creating precast structures may lead to quality issues which ultimately can increase project duration. Quality improvement in precast concrete structures is crucial for ensuring durability, efficiency, and cost-effectiveness in construction projects. The application of Six Sigma methodologies in this area can help reduce defects, minimize waste, and enhance overall structural performance. Precast construction, while offering advantages such as faster project completion and better resource utilization, also faces significant challenges related to material inconsistencies, dimensional inaccuracies, reinforcement misalignment, and surface defects. These quality issues can lead to increased project costs, rework, and delays, ultimately affecting customer satisfaction and safety. The primary objective of any construction project is to ensure that structures are safe and long-lasting.

To enhance structural integrity and safety, precast components are used in today's construction industry. Quality issues in precast components, like improper curing, reinforcement misplacement, or cracks, can significantly impact the structural integrity of buildings. By adopting a systematic quality improvement approach, precast manufacturers can enhance quality of the structures. Ensuring high-quality precast components may result in buildings that are more resilient to environment, load-bearing stresses, and reduce the risk of failures. Defects in precast components often result in excessive material wastage, leading to higher production costs. Manufacturing errors such as dimensional inaccuracies or surface imperfections necessitate rework or replacements, which increase resource consumption and extend project timelines.

Implementing Six Sigma DMAIC methodology may allow companies to identify the root causes of defects, optimize workflows, and minimize material waste. This not only reduces project cost but also promotes sustainability by decreasing the environmental impact of

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construction activities. Arjunbhai (2023) analyzed the role of Six Sigma in enhancing efficiency within construction projects. The research utilized statistical analysis and process optimization techniques to identify primary causes of project delays, defects, and resource wastage. The study highlights the significance of data-driven decision-making and continuous improvement strategies in improving project quality, minimizing costs, and ensuring timely project completion. Efficient production processes are key to the success of precast manufacturing. Variability in concrete composition, improper handling, and inefficient curing processes can slow down production and lead to inconsistent quality. A structured quality improvement approach ensures that production lines operate smoothly, with fewer interruptions due to defective units. Tools such as Statistical Process Control (SPC) and Fishbone Diagrams help analyze production inefficiencies and implement corrective measures, leading to streamlined operations and improved productivity.

Construction projects must adhere to strict regulatory guidelines and quality standards, such as ISO 9001 and ASTM specifications. Poor quality in precast structures can lead to non-compliance issues, resulting in legal penalties, project delays, and reputational damage. By integrating Six Sigma principles, companies can establish a robust quality control system that ensures every precast component meets industry regulations. This proactive approach minimizes the risks associated with non-compliance and strengthens the credibility of construction firms. Also, client expectations for quality and reliability are higher than ever in the construction industry. Defective precast components can lead to customer dissatisfaction, disputes, and loss of business opportunities.

By adopting Six Sigma-driven quality improvement strategies, manufacturers can deliver products that meet or exceed customer expectations. Consistently high-quality precast elements contribute to faster project completion, reduced maintenance costs, and increased client trust, enhancing the overall success of construction projects. Quality improvement initiatives in precast manufacturing help lower emissions by minimizing material waste, reducing energy consumption, and enhancing production efficiency. By incorporating Lean Six Sigma practices, companies can implement eco-friendly processes that align with global sustainability goals while maintaining high-quality output.

1.1 Problem statement

The production of precast concrete elements in the construction industry faces persistent quality challenges, leading to structural defects, increased rework, and cost overruns. Common issues include dimensional inaccuracies, surface defects, reinforcement misalignment, and variations in concrete strength. These defects compromise structural integrity, delay project timelines, and reduce overall efficiency. Addressing these recurring defects requires a systematic approach to quality improvement. Implementing Six Sigma methodologies, particularly the DMAIC framework, can help identify root causes, optimize processes, and enhance the overall quality of precast concrete components.

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1.2 Purpose of study

The primary aim of this study is to explore and apply Six Sigma methodologies, particularly the DMAIC framework, to address inefficiencies and quality challenges in precast concrete production. By systematically identifying and mitigating defects, and enhancing operational efficiency, this study seeks to improve the overall quality and sustainability of precast construction processes.

1.3 Objectives

Considering the above discussion, the primary aim of this study is to explore and apply Six Sigma DMAIC framework to address quality issues in precast concrete production. By systematically identifying and mitigating defects, and enhancing operational efficiency, this study seeks to improve the overall quality and sustainability of precast construction processes. The specific objectives set for this study are given below.

- Use of DMAIC framework to identify recurring defects in precast concrete production process such as dimensional mismatches, surface imperfections, and reinforcement placement errors.
- To systematically investigate and categorize the primary causes of identified defects, focusing on factors such as materials, methods, manpower, and machinery.
- Develop targeted improvement strategies during the Improve phase to address the identified root causes, ensuring practical solutions that are both effective and feasible.

2.0 Literature review

Lean Six Sigma (LSS) is widely regarded as an improvement methodology. Different Parties have Integrated the Lean Six Sigma approaches in their management and production processes in order to improve the product/service characteristics, reduce the costs, improve the capital profitability, and costumer's satisfaction. Alexandra and Luis in year 2013 worked out a model for the improvement of project management within LSS using the method of DMAIC. This model is developed through an instrumental case study in a Portuguese Telecom company with sample of 33 completed projects from 2006 to 2010. The LSS model which integrates the DMAIC cycle, and the statistical tools is capable of diagnosing project management deficiencies, determining their causes, and providing corrective action toward improved project management and the project management processes. In construction of St Pancras raised railway station in London, UK, Stewart and others (2005) applied Six Sigma in the concrete longitudinal beams. The Process Improvement Plan (PIP) of the Six-Sigma process improvement project led to improved productivity, better teamwork, and reduced delays to the project.

LSS is the latest generation of improvement methodologies that came about during the end of 1990's and early 2000's. Burawat (2019) aimed to improve productivity in the highway engineering industry using Lean Six Sigma, Total Productive Maintenance (TPM), Eliminate Combine Rearrange and Simplify (ECRS), and 5S methodologies. The research identified issues

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in the asphalt production process. The issue was solved through Cause-and-Effect Diagram along with the Pareto chart. These methodologies are relevant and can contribute to enhancement in productivity in highway engineering as well as any industry that has a manufacturing and service component. Chiarini & Kumar (2020) synthesized LSS tools and principles with technologies of Industry 4.0 to formulate a new model of Operational Excellence. New technologies or the industry 4.0, as defined by Kolberg *et al.*, (2017), integrate a wide variety of new or emerging technologies for automation and digitization of supply chains and productivity enhancement. For collecting the data, the Italian managers of manufacturing were interviewed at ten case organizations and their procedures associated with Industry 4.0 were directly watched. LSS successful integration required reinvented mapping tools, Horizontal integration ("Autonomous Process Synchronization"), vertical integration ("ERP modules"). Nicoletti (2012) aimed to apply the "Lean and digitize" methodology to procurement processes. The LSS principles, combined with a strategic approach to digitization, can significantly improve procurement processes. By mapping processes, eliminating non- value-added activities, and redesigning processes, organizations can avoid digitizing errors and waste.

Ottou *et al.* (2020) used Six Sigma by DMAIC methodology which gives the primary advantage of time benefit and secondary advantages in customer service, communication, quality, processes, manpower, finance, and decision making. The tendering process for construction company also contributed towards time effectiveness, especially in quantity surveying and procurement. Oguz *et al.* (2012) used LSS methodologies to enhance the production of concrete panels for multi-story housing complex project.

The construction project involved the production of precast concrete panels for 405 villas was running 25 percent behind the schedule. By integrating Lean tools with the DMAIC approach, the project was able to identify and address critical factors affecting production rates, eliminate waste, and achieve in efficiency and schedule adherence. Ke *et al.* (2025) explored the application of LSS as a tool for risk management in engineering projects. It investigates the effectiveness of LSS in identifying, assessing, and mitigating project risks. Statistical analysis (using tools like SPSS or R) is applied to survey data, and thematic analysis (using software like NVivo or MAXQDA) is used for qualitative data.

Morales *et al.*, (2016) described the application of Six Sigma methodologies to improve production operations within a concrete block manufacturing company. The project utilized the DMAIC process and various statistical tools such Pareto graphs, cause-effect diagrams (fishbone diagrams), box plots, scatter diagrams, and response surface methodology (RSM) to identify problems, reduce defects, eliminate downtime and increase overall efficiency and customer service. Husin (2021) Implemented Lean Six Sigma to improve cost and time efficiency in high-rise building projects, specifically focusing on basement construction activities like bored pile, secant pile, and excavation work. This was found that implementing LSS by using DMAIV methodology resulted in a cost efficiency of 6.85% and a time efficiency of 9.60% in the case study project. Panchal *et al.* (2025) investigated the adoption of LSS for remote project

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management during crises, particularly in the Nigeria, adapted LSS framework to improve project outcomes, reduces costs, and enhances team collaboration.

Jowwad *et al.* (2017) used LSS methodology along with DMAIC approach to improve quality and reduce waste in road construction projects. It uses a quantitative approach, employing questionnaire surveys and the Relative Importance Index (RII) method (analyzed with SPSS) to identify critical factors affecting quality and waste in road construction. It Identified root causes using tools like cause-and-effect diagrams and Failure Mode and Effect Analysis (FMEA). Bechtel used Six Sigma methodologies to enhance performance at the Ivanpah Solar Electric Generating System in California. By employing Six Sigma tools, the team optimized material logistics, redesigned the Heliostat Assembly Building for increased efficiency, and streamlined assembly processes. Sakinah and Wahyudi Sutopo (2021) investigated quality improvement in precast concrete production at PT. XYZ, focusing on reducing defects through DMAIC and FMEA.

Primary objective is to identify major defects, analyze their causes, and propose corrective actions. Shuang Wu, Hong Tang (2024) examined the role of Six Sigma in the service industry, analyzed its impact on operational efficiency and customer satisfaction. The study finds that Six Sigma significantly improved service quality, reduces customer wait times, and enhances employee training. However, the methodology relies on structured data, making it less effective for industries with high variability in customer demands. Liang *et al.*, (2005) focused on the structural behavior of steel-concrete composite beams under bending and shear forces. Used Six sigma to improve load-bearing capacity while minimizing material consumption. Lingard *et al.*, (2000) examined the effectiveness of waste management systems in Australian construction companies using Lean Six Sigma (LSS). Love & Li, (2000) quantified the financial and operational impact of rework in construction projects. Using Six Sigma and statistical analysis, the study identifies common causes such as design errors and communication failures. Navon & Goldschmidt, (2010) investigated worker tracking methods to improve labour efficiency in construction. The methodology includes RFID tracking and data analytics.

The objective is to enhance workforce productivity and safety. Pheng & Hui, (2004) implemented Six Sigma in construction project management. It involves statistical defect analysis to enhance quality control and reduce errors. Polat, (2010) compared precast concrete adoption in various economies using Six Sigma. Schroeder *et al.*, (2008) focused on Six Sigma for the development of quality management practices in production operation. Soham *et al.*, (2018) used six sigma in construction industry for improving project quality, reducing defects, and enhancing customer satisfaction. Sarathkumar (2016) used DMAIC methodology and statistical analysis (SPSS software) for a process improvement method in construction, particularly in painting, tile work, and brickwork.

Lade *et al.* (2015) evaluated the performance quality of Ready mix Concrete plants in Mumbai using Six Sigma, which involves collecting information and analyzing data statistically through process sigma levels. Beary *et al.*, (2005) developed a framework based on Lean Six

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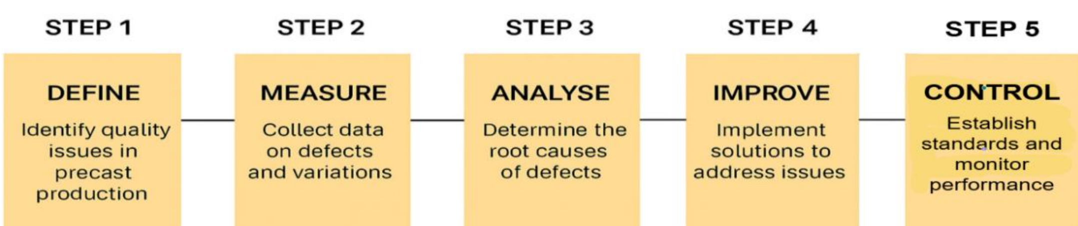
Sigma for enhancing production planning within the homebuilding industry, which integrates the Lean concept of minimizing wastes with Six Sigma's approach of minimizing errors. Zhang *et al.* (2016) applied LSS to logistics to achieve lower costs, reduced inventory, and shorten process cycle time, and improved delivery performance/customer satisfaction, smoother workflow, and higher productivity from employees. Dellifraine *et al.* (2010) made use of the Six Sigma and Lean Systems (SS/L) as quality improvement tools towards providing an opportunity for better health care management from a quality perspective by applying DMAIC & PDCA. Mostafa, (2025) used Six sigma to enhance time efficiency and quality in Nepal construction sector with the implementation of DMAIC approach.

Fashina *et al.* (2020), explores how project management practices influence the performance of small and medium-sized construction firms in Hargeisa. Through a questionnaire-based survey, the study evaluates 16 critical factors, such as market expansion, risk mitigation, project success rates, and quality improvements. The results indicate that integrating Six Sigma and project management methodologies enhances competitiveness, optimizes resource utilization, and boosts customer satisfaction. This research offers valuable guidance for SMEs and policymakers seeking to improve efficiency through structured project management strategies.

3.0 Methodology

The DMAIC methodology, which stands for Define, Measure, Analyze, Improve, and Control, forms the foundation of this study. This systematic and continuous improvement approach is widely used to identify problems, improve product quality, and minimize defects across production systems. Its application in this research focuses on reducing the defects in precast concrete factories to achieve higher levels of quality and align with Six Sigma standards. The methodology is given in Figure 1.

Figure 1: DMAIC Process



3.1 Define

The first stage of the methodology involves identifying key production challenges faced by precast factories, such as mapping production activities to pinpoint defect causes. This

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process includes setting project scope, defining desired outcomes, and ensuring the availability of equipment and resources. Additionally, the Critical to Quality (CTQ) characteristics of the production system are identified to understand internal company requirements and the specific defects impacting the quality of precast concrete.

3.2 Measure

In this stage, data is collected on the number of defects in production, enabling the calculation of Defects Per Million Opportunities (DPMO) to evaluate process performance. The DPMO is calculated using the following formula:

$$DPMO = \frac{Number\ of\ defects}{Total\ Units \times Opportunities\ per\ Unit} \times 10^6 \qquad ....1$$

Using the DPMO value, for calculating the sigma level of process to its benchmark performance. The formula for calculating the sigma level is as follows:

$$Sigma\ (\sigma) = NORMSINV\left[1 - \frac{DPMO}{10^6}\right] + 1.5 \qquad ....2$$

Here, NORMSINV represents the inverse normal distribution function.

3.3 Analyse

In analysis phase, where tools such as cause- and-effect diagram, statistical analysis etc. are used to find the root causes of production defects. The point is to pinpoint what affects defects the most and target it for fixing efforts.

3.4 Improve

Improvement efforts utilize the various quality improvement tools such as FMEA to assess and mitigate risks associated with identified defects. The Risk Priority Number (RPN) is calculated to determine the severity, occurrence, and detection likelihood of potential failures. Actions are then implemented to address high-priority risks, ensuring process stability and quality improvement.

3.5 Control

The final stage involves establishing control measures to sustain improvements. This includes documenting quality standards, implementing best practices, and developing a monitoring system to maintain process performance and prevent future defects.

4.0 Case Analysis

To enhance the quality of precast concrete structures, the DMAIC methodology, was applied at Indo Global Precast System LLP, to identify and address defects and inefficiencies in the manufacturing process of precast structures.

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Figure 2: Pre-Cast component

Source: Author generated

During the assessment, several recurring defects were observed, including surface cracks, honeycombing, dimensional inaccuracies, and curing-related issues. These defects not only contributed to product rejection and material waste but also led to higher production costs and delays in project completion. The company frequently encountered quality-related setbacks, resulting in rework and inefficiencies that affected overall productivity. Some of the pictures of the site are given below as Figure 2, 3 4 and 5.

Figure 3: IN-Site Casting Yard for Precast

Source: Author generated

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Figure 4: Pre-Cast elements

Source: Author generated

Figure 5: Precast Slab from Site Visit

To determine the underlying causes of these defects, an extensive data collection and analysis process was conducted. This involved reviewing past production records, examining defect patterns, and carrying out on-site inspections. The findings revealed that surface cracks and inadequate curing were the most prevalent defects, impacting nearly 55% of all precast

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elements. Additionally, discussions with factory personnel and quality control teams provided further insights into process inconsistencies that contributed to these quality issues. Further investigation pinpointed the primary root causes behind these defects, including inconsistencies in material mixing, improper vibration techniques during casting, and ineffective curing methods. Variations in the water-cement ratio and aggregate blending led to structural weaknesses, while incorrect vibration application resulted in honeycombing and void formations. Additionally, inadequate moisture and temperature control during curing compromised concrete strength and durability. Addressing these challenges required a structured approach to process optimization, quality control, and defect prevention, ensuring a more efficient and reliable precast production system.

The data collection methods included direct observation, interviews with company employees, and a review of relevant literature**.** The data gathered consisted of the monthly production volume, the number of defective units produced each month, and the various types of defects identified. These details are presented in Table 1.

Table 1: Monthly Total Production Defects in Years

Period	Total production (unit)	Total production defect (unit)
Jan-24	60	4
Feb-24	28	5
Mar-24	14	2
Apr-24	39	11
May-24	98	20
Jun-24	90	18
Jul-24	48	11
Aug-24	14	2
Sep-24	10	2
Oct-24	97	19
Nov-24	45	13
Dec-24	47	11
Total	590	118

5.0 Results and Discussion

Through data analysis and statistical tools, the study identified the key factors affecting quality of precast concrete components as:

- *Voids & Honeycombing (49 cases):* Improper concrete compaction led to gaps or air pockets in the structure, reducing strength and durability.
- *Outer Surface Damage (30 cases):* Handling and transportation issues caused chipping, breakage, and uneven surfaces.

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- *Concrete Cracks (26 cases):* Shrinkage, temperature variations, and improper curing resulted in cracks, reducing structural integrity.
- *Broken Concrete (13 cases):* Incorrect demolding or excessive force applied during production caused sections of the concrete to break.

These defects contributed to production inefficiencies, rework, and increased material waste, underscoring the need for process improvements. Using the DMAIC methodology, the research quantified the defect levels and identified their root causes. DPMO and Sigma Levels were calculated for each month as given in Table 2. The average sigma level was found to be 3.10 i.e. below the industry benchmark of 6, indicating room for improvement. The study found that high defect rates were primarily caused by:

- Material-related issues, such as improper concrete mix or contamination.
- Process inefficiencies, including inadequate curing and poor compaction.
- Human factors, such as inconsistent workmanship and inadequate training.

Table 2: DMPO and Six Sigma Level in Each Month

Month	Production Units	Defective Units	DPMO	Sigma Level
January	60	4	16,666.67	3.53
February	28	5	44,642.68	3.08
March	14	2	35,714.29	3.17
April	39	11	70,512.82	2.99
May	98	20	51,020.41	3.06
June	90	18	50,000.00	3.07
July	48	11	57,291.67	3.02
August	14	2	35,714.29	3.17
October	97	19	48,969.07	3.08
November	45	13	72,222.22	2.98
December	47	11	58,510.64	3.02

Cause and Effect diagram for the major causes of defects is given in Figure 6 below. The research confirms that Six Sigma is an effective quality management tool for precast concrete production. By systematically identifying and eliminating defects, companies can enhance operational efficiency, minimize waste, and improve customer satisfaction. However, the findings also highlight challenges in achieving a higher sigma level. While defect rates declined, the process still shows inconsistencies. Factors such as workforce training, real-time monitoring, and advanced statistical analysis are critical for achieving sustained improvements.

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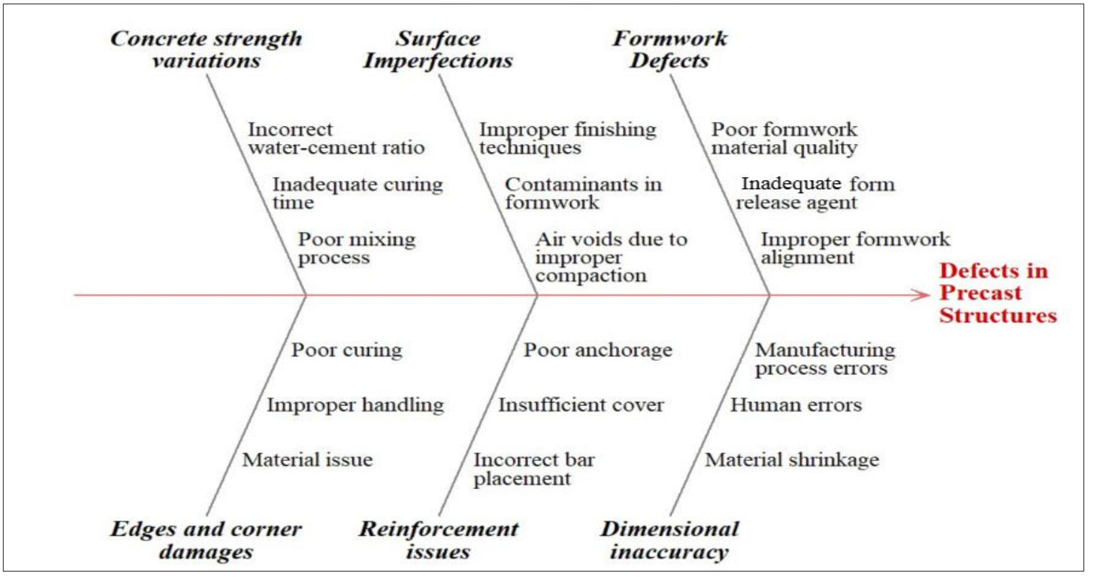
Figure 6: Cause and Effect diagram for Defects and their Causes



6.0 Conclusion and Further Research

This study demonstrates how Six Sigma methodology can effectively improve the quality and efficiency of precast concrete production. By systematically identifying and addressing recurring issues—such as dimensional inaccuracies, surface defects, reinforcement misplacements, and inconsistencies in concrete strength—this research highlights how Six Sigma helps reduce waste, enhance productivity, and optimize construction workflows. The findings confirm that implementing Six Sigma tools results in measurable quality improvements and a reduction in defects. An increase in calculated sigma levels reflects improved control over production processes and emphasizes the significance of continuous improvement. The research also underscores the value of data-driven decision-making in boosting operational efficiency, reducing rework, and improving client satisfaction in the construction industry.

Although Six Sigma offers clear advantages in precast production, broader adoption in the construction sector faces several challenges. Successful implementation requires refining current methodologies, embracing technological advancements, and following a structured process improvement approach. Companies that adopt these strategies are more likely to achieve higher quality, cost-effective, and sustainable outcomes. Six Sigma adoption can lead to increased productivity and long-term industry growth. Despite these benefits, the study does have limitations. Primarily, it focuses only on precast concrete and does not explore Six Sigma's application in other construction methods like cast-in-place concrete, steel framing, or modular

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systems. Each construction technique presents its own unique set of challenges, and further research is needed to evaluate Six Sigma's adaptability to these alternatives.

Another limitation is the lack of financial analysis. While the study discusses defect reduction, it does not assess the cost-effectiveness of implementing Six Sigma. A detailed cost-benefit analysis would help firms evaluate the economic feasibility of investing in quality improvement initiatives. Additionally, the study relies mainly on historical production data and does not incorporate real-time quality monitoring. Integrating real-time systems could improve defect detection and enable timely corrective actions before production completion. This would result in more dynamic and responsive quality control processes. Human factors also present significant challenges. Resistance to change among staff and management can hinder progress. The absence of comprehensive training programs further limits the effective adoption of Six Sigma principles. Overcoming this requires investing in structured training and behavioral strategies to encourage employee involvement in quality improvement efforts.

Moreover, the study does not use advanced analytics like regression models, machine learning, or predictive tools. These techniques could help uncover hidden patterns in defect data and reveal root causes of inefficiencies. Employing such methods would enhance the overall effectiveness of Six Sigma applications in construction. To broaden Six Sigma's scope in construction, future studies should explore its use in various building systems, including cast-in-place concrete, steel structures, and modular buildings. Comparative studies could determine whether similar benefits can be achieved across different materials and production environments. Additionally, the integration of advanced data analytics—such as time-series forecasting, machine learning algorithms, and regression analysis—can provide deeper insights into defect trends and support predictive maintenance strategies. This shift from reactive to proactive quality control would represent a major improvement in construction practices.

Another important direction for future research is the long-term evaluation of Six Sigma's impact. While this study focuses on short-term outcomes, longitudinal research would reveal whether Six Sigma helps sustain high quality over time and across different projects. Since implementing Six Sigma often requires investment in tools, training, and technology, understanding its return on investment (ROI) is crucial. Quantifying savings from defect reduction and process improvements can help companies make better decisions about adopting it as a long-term strategy. The integration of smart technologies such as Internet of Things (IoT) devices, AI-driven analytics, and real-time monitoring systems can significantly strengthen Six Sigma's effectiveness. These technologies allow for instant defect identification and real-time corrections, making quality management more efficient. Future studies should investigate the synergy between Six Sigma and emerging technologies to improve defect detection, process control, and overall construction quality. Finally, overcoming resistance to change is essential for the successful implementation of Six Sigma. Developing behavior-based strategies, offering regular training, and creating incentive systems can help foster employee engagement. Since workforce support is a key factor in quality improvement, understanding and addressing human

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behavior in organizational change is crucial. In summary, this study confirms that Six Sigma has the potential to transform quality management in the construction sector. By refining processes, incorporating technology, considering financial feasibility, and addressing human factors, Six Sigma can lead to more efficient, cost-effective, and high-quality construction outcomes.

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