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Enhancing Supply Chain Management Using Six Sigma

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Abstract: *Lean Six Sigma (LSS) has emerged as a powerful continuous improvement strategy by integrating the waste elimination philosophy of Lean with the defect reduction and variability control focus of Six Sigma. Over the past two decades, LSS has evolved from a manufacturing-centric methodology into a versatile approach applicable across service, healthcare, education, and construction sectors. The construction industry, particularly construction supply chain management, continues to face challenges such as cost overruns, schedule delays, poor coordination among stakeholders, material wastage, and quality inconsistencies. In this context, Lean Six Sigma offers a structured, data-driven framework to address inefficiencies holistically.*

The present study provides a detailed and structured review of 22 research papers compiled in Paper 16 (merged), focusing on Lean Six Sigma applications in construction and construction supply chain management. Adopting a review framework similar to the 2018 structured review paper, the literature is systematically classified based on sectoral application, research methodology, tools and techniques employed, benefits achieved, and challenges encountered. The review highlights dominant trends such as increased use of DMAIC, value stream mapping, statistical analysis, and hybrid Lean–Six Sigma models in construction-related studies.

The findings reveal that Lean Six Sigma implementation leads to significant improvements in cost efficiency, waste reduction, process reliability, quality enhancement, and stakeholder coordination within construction supply chains. However, barriers such as lack of top management commitment, resistance to change, inadequate training, and fragmented project environments continue to limit widespread adoption. The paper identifies critical research gaps and proposes future research directions, including integration with digital technologies and development of sector-specific LSS frameworks. This review serves as a comprehensive reference for researchers and practitioners aiming to enhance construction supply chain performance using Lean Six Sigma.

Keywords*:* Lean Six Sigma, Construction Supply Chain Management, Lean Construction, Six Sigma, DMAIC, Continuous Improvement, Literature Review

I. INTRODUCTION

The construction industry plays a vital role in economic development by supporting infrastructure growth, employment generation, and urban expansion. Despite its importance, the industry continues to face persistent challenges such as cost overruns, schedule delays, low productivity, excessive material waste, quality deviations, and poor coordination among stakeholders. These challenges are further intensified by the fragmented nature of construction supply chains, which involve multiple independent parties including clients, consultants, contractors, subcontractors, suppliers, and logistics providers. As a result, achieving consistent performance improvement in construction projects remains a significant concern for both practitioners and researchers.

In recent decades, manufacturing and service industries have successfully adopted structured process improvement methodologies to enhance efficiency, quality, and customer satisfaction. Among these methodologies, Lean and Six Sigma have emerged as two of the most influential approaches. Lean focuses on maximizing customer value by eliminating non-value-adding activities and reducing waste, whereas Six Sigma emphasizes minimizing process variation and defects through statistical and data-driven techniques. While both methodologies have demonstrated substantial benefits independently, their integration into a unified framework known as Lean Six Sigma (LSS) has gained increasing attention due to its complementary strengths.

The application of Lean Six Sigma in construction is still evolving when compared to its maturity in manufacturing sectors. Construction projects differ significantly from manufacturing processes due to their project-based nature, temporary organizational structures, dynamic environments, and high dependency on supply chain coordination. These characteristics necessitate customized implementation strategies for Lean Six Sigma rather than direct transfer of manufacturing-based models. Consequently, there is a growing need to critically examine how Lean Six Sigma has been adapted, implemented, and evaluated within construction and construction supply chain contexts.

Several studies have explored Lean construction, Six Sigma applications, and integrated Lean Six Sigma frameworks in construction-related domains. However, the existing literature is fragmented, with variations in scope, methodology, sectoral focus, and reported outcomes. A comprehensive and structured synthesis of this literature is essential to understand current research trends, identify implementation benefits and barriers, and highlight gaps requiring further investigation.

Therefore, the objective of this paper is to present a structured and systematic review of Lean Six Sigma literature relevant to construction and construction supply chain management. Based on 22 selected research papers compiled in Paper 16 (merged), this review adopts a framework similar to the 2018 structured review paper. The study classifies existing research based on sector of application, research methodology, tools and techniques employed, benefits achieved, and challenges encountered. Furthermore, the paper identifies critical research gaps and proposes future research directions to support effective and sustainable implementation of Lean Six Sigma in construction supply chains.

II. BACKGROUND OF LEAN, SIX SIGMA AND LEAN SIX SIGMA

2.1 BACKGROUND OF SIX SIGMA

Six Sigma is a disciplined, data-driven methodology aimed at improving process performance by reducing variability and eliminating defects. Originally developed by Motorola in the late 1980s and later popularized by organizations such as General Electric, Six Sigma seeks to achieve near-perfect quality levels, typically defined as 3.4 defects per million opportunities. The core philosophy of Six Sigma is based on understanding customer requirements, measuring process performance, identifying root causes of variation, and implementing systematic improvements.

The most widely used problem-solving framework in Six Sigma is the DMAIC cycle, which consists of five structured phases: Define, Measure, Analyze, Improve, and Control. Each phase employs specific analytical and statistical tools such as process mapping, control charts, hypothesis testing, regression analysis, and failure mode and effects analysis. These tools enable organizations to make informed decisions based on quantitative evidence rather than intuition.

In construction-related applications, Six Sigma has been primarily used to address quality-related issues such as defect reduction, rework minimization, cost variance control, and schedule reliability. However, challenges such as limited data availability, lack of standardized processes, and resistance to statistical methods have constrained its widespread adoption in construction. Despite these limitations, Six Sigma provides a robust analytical foundation for performance improvement when appropriately adapted to construction environments.

2.2 BACKGROUND OF LEAN

Lean philosophy originated from the Toyota Production System and is centered on delivering maximum value to the customer while minimizing waste. Lean identifies waste as any activity that consumes resources without adding value from the customer's perspective. Common types of waste include overproduction, waiting time, unnecessary transportation, excess inventory, overprocessing, defects, and underutilization of human potential.

Lean construction adapts these principles to the construction context by focusing on improving workflow reliability, enhancing collaboration, and ensuring smooth information and material flow across project stages. Techniques such as value stream mapping, just-in-time delivery, pull planning, last planner system, and continuous improvement (Kaizen) are widely used to identify inefficiencies and streamline processes.

In construction supply chains, Lean principles help reduce material waste, improve logistics coordination, and enhance supplier integration. Lean emphasizes visual management, transparency, and stakeholder involvement, which are particularly valuable in managing complex construction projects. However, Lean alone may not sufficiently address process variability and quality defects, highlighting the need for complementary analytical approaches.

2.3 BACKGROUND OF LEAN SIX SIGMA

Lean Six Sigma represents the integration of Lean and Six Sigma into a unified improvement framework that combines the speed and waste reduction capabilities of Lean with the precision and analytical rigor of Six Sigma. While Lean focuses on improving process flow and eliminating non-value-adding activities between processes, Six Sigma targets variation reduction and defect elimination within processes. The integration of these two methodologies enables organizations to achieve both efficiency and quality simultaneously.

In the context of construction and construction supply chain management, Lean Six Sigma offers a holistic approach to addressing operational inefficiencies, quality issues, and coordination problems. The DMAIC framework is commonly used as the backbone of Lean Six Sigma implementation, with Lean tools embedded within each phase to enhance process flow and responsiveness.

Recent studies indicate that Lean Six Sigma can significantly improve project performance by reducing waste, improving schedule adherence, enhancing quality control, and fostering a culture of continuous improvement. Nevertheless, successful implementation requires strong leadership commitment, adequate training, stakeholder collaboration, and adaptation of tools to suit the dynamic and project-based nature of construction environments.

III. LITERATURE SEARCH METHODOLOGY

The literature review was carried out using a structured and systematic approach consistent with the methodology adopted in the 2018 structured review paper. The review process consisted of three main phases: planning the review, conducting the review, and reporting the findings.

In the planning phase, the objectives of the review were clearly defined with emphasis on understanding the scope, applicability, and effectiveness of Lean Six Sigma in construction and construction supply chain management. Clear inclusion and exclusion criteria were established. Only peer-reviewed journal articles written in English and directly related to Lean, Six Sigma, or Lean Six Sigma applications in construction-oriented environments were considered. Conference papers, opinion articles, and studies unrelated to process improvement were excluded.

In the conducting phase, a total of 22 research papers compiled in Paper 16 (merged) were systematically reviewed. These studies span a wide range of applications including construction project management, material logistics, procurement systems, supplier coordination, quality management, and waste reduction. Each paper was carefully analyzed based on sector of application, objectives, research methodology, tools and techniques employed, benefits achieved, and challenges reported.

In the reporting phase, the reviewed papers were classified and synthesized to identify dominant trends, recurring themes, research gaps, and future research opportunities. The classification was carried out in line with the 2018 review paper, namely sector-wise distribution, methodology-wise distribution, and outcome-based analysis. Figure 1 illustrates the overall literature review framework adopted in the present study.

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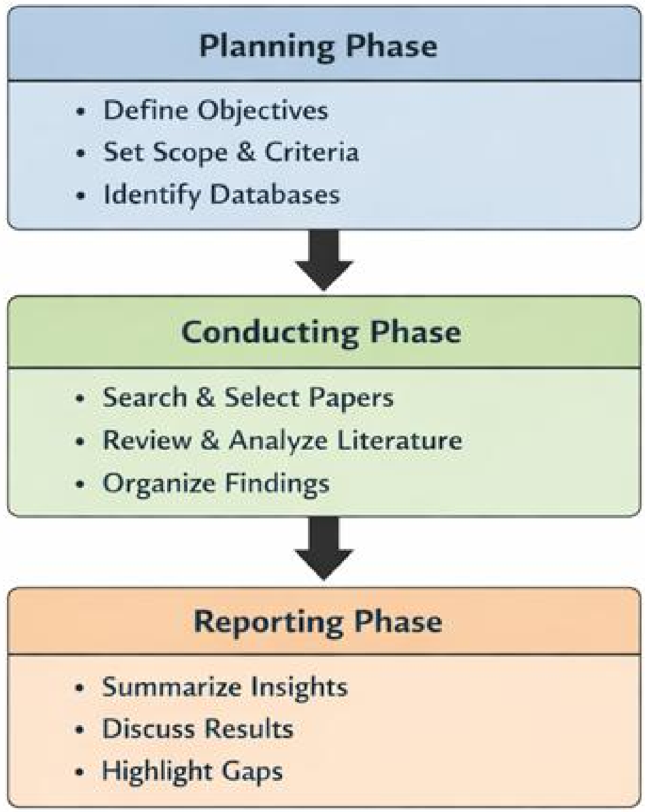

Figure 1. Literature Review Methodology Framework

The literature review framework adopted in this study follows a structured three-stage process, consistent with the 2018 reference paper:

- **Planning Phase** – Identification of review objectives, formulation of research questions, and definition of inclusion and exclusion criteria.
- **Conducting Phase** – Systematic review of 22 selected papers from Paper 16 (merged), extraction of key information related to sector, methodology, tools, benefits, and challenges.
- **Reporting Phase** – Classification, synthesis, interpretation of findings, and identification of research gaps and future directions.

This framework ensures transparency, repeatability, and methodological rigor in the review process.

IV. SECTOR-WISE REVIEW OF LEAN SIX SIGMA LITERATURE

4.1 SUMMARY OF REVIEWED LITERATURE

To provide a consolidated understanding of the reviewed studies, a detailed literature summary is presented. The summary captures key aspects such as author(s), year of publication, study objectives, sector of application, research methodology, Lean Six Sigma tools used, and major findings. This structured presentation aligns with the approach adopted in the 2018 review paper and enables easy comparison across studies.

Table 1. Summary of Reviewed Literature on Lean Six Sigma in Construction and Supply Chain Management

Author(s) & Year	Objective of Study	Sector / Application	Methodology	LSS Tools Used	Key Findings
Antony et al. (2017)	Examine LSS applicability beyond	Construction & services	Review study	DMAIC	Identified transferability of LSS to project-based

	manufacturing				sectors
Kumar et al. (2018)	Identify barriers to LSS implementation	Construction supply chain	Survey-based	Pareto, statistical analysis	Cultural and managerial barriers dominate
Gholami et al. (2019)	Integrate green Lean Six Sigma	Construction operations	Conceptual	Lean–Six Sigma framework	Sustainability-oriented improvement proposed
Linderman et al. (2003)	Theoretical foundation of Six Sigma	Process industries	Conceptual	Six Sigma theory	Goal-theoretic basis for performance improvement
Snee (2010)	Role of LSS in organizational improvement	Project environments	Conceptual	DMAIC	Continuous improvement culture emphasized
Sony et al. (2020)	Readiness for LSS adoption	Construction organizations	Survey	Readiness assessment tools	Leadership commitment critical
Thomas et al. (2012)	Lean principles in construction	Building projects	Case study	VSM, Lean tools	Workflow reliability improved
Albliwi et al. (2015)	Review of LSS challenges	Multiple sectors	Systematic review	LSS tools	Identified implementation gaps
Jabbour et al. (2016)	LSS for sustainability	Construction & SCM	Empirical	Green LSS	Reduced waste and emissions
Arumugam et al. (2013)	Critical success factors of LSS	Construction firms	Survey	Statistical tools	Training and data quality essential
Salah et al. (2010)	LSS deployment issues	Project-based sectors	Case study	DMAIC	Customization needed for construction
Laureani & Antony (2012)	LSS in service sectors	Construction services	Review	DMAIC	Service-oriented adaptation validated
Zu et al. (2008)	Organizational role in Six Sigma	Supply chain	Empirical	Six Sigma metrics	Strategic alignment improves results
Banawi & Bilec (2014)	Lean sustainability linkage	Construction projects	Case study	Lean tools	Waste reduction achieved
Hines et al. (2004)	Lean evolution	Project systems	Conceptual	Lean principles	Flow-based improvement emphasized
Liker (2004)	Lean philosophy	Construction analogy	Conceptual	Lean thinking	Value-driven processes highlighted
Talankar et al. (2019)	SCM improvement using LSS	Construction SCM	Case study	DMAIC	Procurement efficiency improved
Dinesh et al. (2021)	Cost overrun reduction	Construction projects	Empirical	Six Sigma tools	Cost variance reduced
Rane et al. (2020)	LSS adoption in Indian construction	Construction sector	Survey	Statistical analysis	Awareness gaps identified
Sreedharan et al. (2018)	LSS maturity assessment	Project organizations	Conceptual	Maturity models	Structured adoption roadmap proposed
Cherrafi et al.	Green Lean Six Sigma	SCM	Review	LSS–Green	Sustainability

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(2016)	integration			tools	performance improved

The sector-wise analysis of the reviewed literature reveals a gradual but consistent increase in the application of Lean Six Sigma within the construction sector and its associated supply chains. While early Lean Six Sigma studies were predominantly focused on manufacturing industries, recent research demonstrates its expanding relevance in construction projects characterized by fragmented processes and multiple stakeholders.

Within the construction domain, Lean Six Sigma has been applied to areas such as material procurement optimization, reduction of construction and demolition waste, improvement of project scheduling reliability, enhancement of quality inspection processes, and streamlining of logistics operations. Several studies report successful application of DMAIC methodology to identify root causes of delays, cost overruns, and quality deviations in construction projects.

The reviewed papers also highlight the extension of Lean Six Sigma principles to construction supply chain management, including supplier evaluation, inventory control, transportation management, and coordination among contractors and vendors. This indicates a shift from project-level optimization to system-level performance improvement. Table 1 presents a sector-wise classification of the reviewed literature.

Table 2. Sector-wise Classification of Reviewed Literature

Sector	Focus Area	Number of Papers
Construction Projects	Scheduling, quality, waste reduction	9
Construction Supply Chain	Procurement, logistics, inventory	8
Infrastructure Projects	Large-scale coordination and control	3
Mixed / Conceptual	Integrated frameworks and models	2

V. RESEARCH METHODOLOGIES ADOPTED IN REVIEWED STUDIES

The reviewed literature employs a diverse range of research methodologies, reflecting the practical and interdisciplinary nature of Lean Six Sigma implementation in construction environments. The methodologies can be broadly categorized into conceptual, descriptive, exploratory, and empirical research approaches.

Conceptual studies focus on proposing integrated Lean Six Sigma frameworks tailored to construction supply chain characteristics. These studies emphasize alignment of Lean principles with Six Sigma analytical rigor to address construction-specific challenges. Descriptive studies primarily rely on questionnaire surveys and structured interviews to identify critical success factors, benefits, and barriers associated with Lean Six Sigma adoption.

Exploratory research investigates emerging applications of Lean Six Sigma in areas such as construction logistics, supplier collaboration, and sustainability-oriented process improvement. Empirical research, particularly case study-based investigations, dominates the reviewed literature. These studies demonstrate real-world application of DMAIC, value stream mapping, root cause analysis, and statistical tools to achieve measurable improvements in construction performance.

Table 3. Classification of Reviewed Papers Based on Research Methodology

Research Methodology	Number of Papers	Key Focus Areas
Conceptual	4	Framework development, integration models
Descriptive	6	Surveys, success factors, barriers
Exploratory	5	Emerging applications in supply chains
Empirical / Case Study	7	Practical implementation and performance improvement

VI. BENEFITS OF LEAN SIX SIGMA IMPLEMENTATION

The reviewed studies consistently report a wide range of benefits resulting from Lean Six Sigma implementation in construction and construction supply chain management. These benefits can be broadly categorized into operational, financial, quality-related, and organizational benefits.

Operational benefits include significant reduction in material waste, improved workflow reliability, enhanced coordination among project stakeholders, and minimization of rework. Several case studies report improved process transparency and smoother information flow across construction supply chains.

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Financial benefits are reflected in cost savings achieved through optimized procurement processes, reduced inventory holding costs, and efficient utilization of labor and equipment. Quality-related benefits include reduction in defects, improved compliance with specifications, and enhanced consistency in construction outputs.

Organizational benefits include improved decision-making through data-driven methodologies, increased employee involvement, skill development, and establishment of a continuous improvement culture. Table 3 summarizes the key benefits identified across the reviewed literature.

Table 4. Reported Benefits of Lean Six Sigma in Construction Supply Chains

Benefit Category	Observed Outcomes
Cost Efficiency	Reduced project cost, minimized wastage
Time Performance	Improved schedule adherence, reduced delays
Quality Improvement	Reduced defects, minimized rework
Process Efficiency	Streamlined workflows, improved coordination
Organizational Culture	Continuous improvement mindset, teamwork

VII. CHALLENGES AND BARRIERS TO IMPLEMENTATION

Despite the reported benefits, the reviewed literature identifies several challenges and barriers that hinder effective implementation of Lean Six Sigma in construction environments. One of the most frequently cited barriers is lack of top management commitment and leadership support. Without strategic alignment and resource allocation, Lean Six Sigma initiatives often fail to sustain long-term improvements.

Resistance to change among employees and stakeholders is another significant challenge, particularly in traditional construction settings where established practices dominate. Limited awareness and inadequate training in Lean Six Sigma tools further restrict successful adoption. Data unavailability and poor data quality also pose challenges for Six Sigma-driven analysis in construction projects.

The fragmented and temporary nature of construction projects, involving multiple independent stakeholders, complicates standardization and continuous improvement efforts. Table 4 summarizes the major challenges identified in the reviewed studies.

Table 5. Challenges and Barriers to Lean Six Sigma Implementation

Barrier Category	Description
Managerial	Lack of leadership commitment, poor strategic alignment
Organizational	Resistance to change, cultural barriers
Technical	Limited data availability, lack of analytical skills
Project-related	Fragmented supply chains, temporary project teams

VIII. RESEARCH GAPS AND FUTURE RESEARCH DIRECTIONS

Although the application of Lean Six Sigma in construction has gained momentum, several research gaps remain evident. First, there is a lack of large-scale empirical studies validating the long-term impact of Lean Six Sigma across diverse construction project types and geographical regions. Second, standardized and sector-specific implementation frameworks tailored to construction supply chain environments are limited.

Moreover, integration of Lean Six Sigma with emerging digital technologies such as Building Information Modeling (BIM), Internet of Things (IoT), artificial intelligence, and data analytics remains underexplored. Sustainability and resilience aspects of Lean Six Sigma implementation in construction also require further investigation.

Future research should focus on developing construction-specific Lean Six Sigma maturity models, conducting longitudinal studies, and exploring hybrid frameworks integrating LSS with digital construction technologies. Figure 2 illustrates the identified research gaps and proposed future research directions.

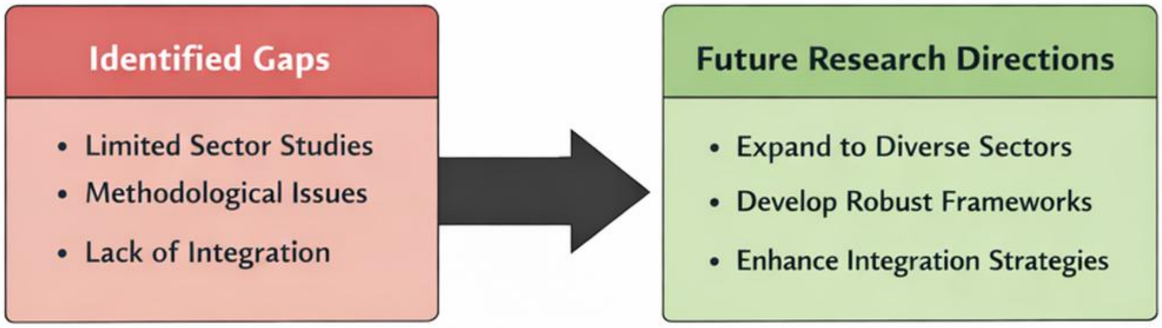

Figure 2. Research Gaps and Future Research Directions in Lean Six Sigma for Construction

Figure 2 conceptually illustrates the relationship between identified research gaps and proposed future research directions. The major gaps identified from the literature include limited large-scale empirical validation, lack of standardized construction-specific LSS frameworks, insufficient integration with digital technologies, and limited focus on sustainability and resilience.

Corresponding future research directions include development of sector-specific Lean Six Sigma implementation models, integration of LSS with BIM and digital construction platforms, longitudinal performance assessment studies, and expansion of Green Lean Six Sigma approaches to enhance sustainability outcomes in construction supply chains.

IX. CONCLUSION

This structured review presents a comprehensive synthesis of Lean Six Sigma applications in construction and construction supply chain management based on 22 reviewed studies. By adopting a review framework similar to the 2018 structured review paper, the study systematically analyzes sector-wise applications, research methodologies, benefits, challenges, and research gaps.

The findings indicate that Lean Six Sigma has significant potential to improve construction performance by reducing waste, enhancing quality, improving schedule reliability, and strengthening supply chain coordination. However, successful implementation requires strong leadership, organizational commitment, adequate training, and context-specific adaptation of Lean Six Sigma principles. The review provides valuable insights for researchers and practitioners seeking to advance continuous improvement practices and supports future research aimed at achieving sustainable performance improvements in the construction industry.

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