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Unpacking Lean Six Sigma Practice: A Systematic Literature Review of Performance Outcomes and Implementation Challenges (2020–2025)

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ABSTRAK

Penelitian ini menyajikan Systematic Literature Review terhadap implementasi Lean Six Sigma (LSS) pada periode 2020–2025 dengan fokus pada performance outcomes, tantangan implementasi, serta tren dan novelty yang berkembang. Hasil kajian menunjukkan bahwa LSS secara konsisten memberikan peningkatan pada kualitas, produktivitas, pengurangan defect, efisiensi biaya, serta penurunan lead time di berbagai sektor. Novelty utama terletak pada munculnya Digital Lean Six Sigma (DLSS), integrasi LSS dengan keberlanjutan, dan berkembangnya kerangka kerja hybrid yang memadukan metodologi lain. Meskipun demikian, beberapa kelemahan teridentifikasi, termasuk keterbatasan data, resistensi sumber daya manusia, misalignment alat Lean–Six Sigma, serta kurangnya penelitian longitudinal yang menilai ketahanan dampak jangka panjang. Temuan ini menegaskan pentingnya kesiapan organisasi, dukungan teknologi, dan penguatan budaya perbaikan dalam menjamin keberhasilan LSS. Penelitian di masa depan perlu memperluas studi empiris pada sektor layanan publik, mengeksplorasi integrasi LSS dengan teknologi digital tingkat lanjut, serta mengembangkan model evaluasi jangka panjang untuk menilai keberlanjutan hasil perbaikan.

Kata Kunci: Lean Six Sigma, performance outcomes, implementation challenges, digitalization, sustainability, hybrid LSS.

ABSTRACT

This study presents a Systematic Literature Review of Lean Six Sigma (LSS) implementation from 2020 to 2025, focusing on performance outcomes, implementation challenges, and emerging trends shaping LSS's evolution in modern industries. The findings reveal that LSS consistently improves product quality, productivity, defect reduction, cost efficiency, and lead-time performance across multiple sectors. Key novelty elements include the rise of Digital Lean Six Sigma (DLSS), the integration of LSS with sustainability objectives, and the development of hybrid frameworks combining LSS with complementary improvement methodologies. However, several limitations persist, including data availability issues, human resource resistance, misalignment between Lean and Six Sigma tools, and the scarcity of longitudinal studies evaluating long-term improvement retention. These insights underscore the need for stronger organizational readiness, digital capability, and a continuous improvement in culture to ensure successful LSS deployment. Future research should expand empirical investigations within public service sectors, explore deeper integration between LSS and advanced digital technologies, and develop long-term assessment models to measure the sustainability of improvement outcomes.

Keywords: *Lean Six Sigma, performance outcomes, implementation challenges, digital transformation, sustainability, hybrid frameworks.*

1. Introduction

Lean Six Sigma (LSS) has evolved as a comprehensive process improvement methodology by integrating Lean principles, which focus on waste elimination, with Six Sigma, which emphasizes variation reduction through a data-driven approach. (Kusumawardani & Singgih, 2025). The synergy of these two concepts enables organizations not only to improve product and service quality but also to improve process flow efficiency, minimize non-value-added activities, and ensure long-term stability and consistency of operational performance (Maryadi, Tamalika, et al., 2024). Recent studies in various metadata fields indicate that LSS is increasingly being implemented in both the manufacturing and service sectors as a key strategy for achieving operational excellence and enhancing organizational competitiveness (Maryadi, 2021;Rathi et al., 2021). In practice, frameworks such as DMAIC (Define–Measure–Analyze–Improve–Control), Value Stream Mapping to map process flows and identify sources of waste, and Failure Mode and Effects Analysis (FMEA) to assess potential risks and prioritize improvements, are crucial pillars in systematic efforts to identify root causes, optimize processes, and ensure measurable, continuous improvement across various industrial contexts (Araman & Saleh, 2023).

The integration of Lean and Six Sigma is becoming increasingly important in the context of process improvement because they offer complementary strengths: Lean focuses on accelerating process flow by reducing waste and non-value-added activities, while Six Sigma delivers increased process precision, stability, and capability through systematic variation control (Nedra et al., 2022). This combination creates a more effective approach than either method alone, resulting in faster, more consistent, and higher-quality processes. Recent research shows that organizations implementing Lean and Six Sigma integration experience significant improvements in product quality, reduced cycle times, increased productivity, and greater cost efficiencies (Abbes et al., 2022). In an increasingly competitive and dynamic industrial environment, this integration offers a holistic framework that not only optimizes internal operations but also enhances customer value by enabling more responsive, stable, and adaptable processes that adapt to changing market needs.

Although Lean Six Sigma (LSS) has been widely used across various sectors, its implementation patterns show significant heterogeneity, primarily because the implementation of this methodology is heavily influenced by the organizational context, work culture, management commitment, and the competency of the human resources involved (Kumar Mishra et al., 2025). Studies on metadata reveal that many organizations do not implement LSS comprehensively across the complete DMAIC structure, instead adopting only specific tools or stages, resulting in suboptimal process improvement effectiveness and difficulty in consistent measurement (Sreedharan & Sunder,, 2018). This fragmented approach results in variations in output across organizations, making generalization of empirical findings challenging and making it difficult for researchers and practitioners to assess the actual impact of LSS on operational performance improvement. Consequently, understanding the success of LSS implementation requires considering contextual factors and organizational readiness to achieve more accurate, sustainable, and replicable results across different industry environments (Kaswan et al., 2023).

Another gap identified in Lean Six Sigma (LSS) studies is the lack of a comprehensive synthesis of performance outcomes resulting from its implementation. Although metadata reports various achievements, such as reduced lead times, improved quality, fewer defects, increased Overall Equipment Effectiveness (OEE), and enhanced cost efficiency, these findings are generally presented separately within each study, without integration or cross-industry comparisons that could illustrate common patterns (Persis et al., 2020). This lack of a consistent evaluation framework makes it difficult to determine which outcomes are most dominant, most significant, or most frequently achieved in LSS implementations over a given period. Consequently, there is ample scope for research to develop a systematic mapping of key performance outcomes achieved by organizations in LSS implementation, particularly over the 2020–2025 period. This would provide a clearer, more standardized understanding and serve as a reference for

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researchers and practitioners in designing more effective process improvement strategies (Nedra et al., 2022).

In addition to outcome-related gaps, metadata also reveals significant gaps in understanding the challenges of Lean Six Sigma (LSS) implementation. Various cross-sector studies indicate that organizations frequently face barriers, including employee resistance to change, insufficient training and technical competency, limited data availability and quality, and weak management support in providing adequate resources and commitment to program sustainability (Gupta et al., 2020;Hia et al., 2024). However, these challenges are generally presented separately and not comprehensively analyzed in relation to the success or failure of LSS projects across various operational settings. This fragmentation makes it challenging to understand how these inhibiting factors interact and affect the effectiveness of LSS implementation in modern organizations. Therefore, a systematic synthesis is needed to identify, categorize, and evaluate key inhibiting factors, providing a stronger foundation for developing mitigation strategies and improving the success of LSS programs across. This review differs from prior Lean Six Sigma literature reviews by explicitly integrating performance outcomes and implementation challenges across the 2020–2025 period. While earlier reviews tend to focus on specific sectors (e.g., healthcare or manufacturing), digital transformation, or methodological evolution, they do not systematically map which performance outcomes are most prevalent, how frequently they occur across sectors, or how they relate to recurring implementation barriers. This study addresses that gap by formulating explicit research questions and providing a structured cross-study synthesis that links outcomes, challenges, and emerging trends, thereby offering clearer theoretical consolidation and practical guidance. (Gupta et al., 2020). By combining analyses of outcomes such as lead time reduction, quality improvement, defect reduction, and cost efficiency with an in-depth evaluation of barriers such as employee resistance, data limitations, and inadequate management support, this review aims to provide a more holistic picture of how LSS works across different industry contexts. Furthermore, this approach is expected to yield a more structured understanding of the factors that support and hinder successful LSS implementation, thereby enriching theory and providing practical guidance for organizations to optimize LSS implementation globally.

An evaluation of previous studies reveals a clear prioritization of some of the most frequently reported performance outcomes in Lean Six Sigma (LSS) implementation. Numerous studies confirm that improved product quality and reduced defects are the dominant outcomes consistently emerging as key impacts of LSS implementation across sectors (Aytekin et al., 2023). Furthermore, cost efficiency and increased productivity are key findings, particularly in the manufacturing and healthcare industries, which demand high operational effectiveness and optimal resource management (Skalli et al., 2024). The performance outcomes reported in Lean Six Sigma studies are not incidental results but are directly linked to the methodological mechanisms embedded within LSS. Lean practices such as Value Stream Mapping, 5S, and Kaizen primarily contribute to lead-time reduction, waste elimination, and productivity improvement, whereas Six Sigma tools such as Statistical Process Control, root cause analysis, and capability analysis drive defect reduction, quality enhancement, and process stability.

When integrated through the DMAIC framework, these mechanisms create a structured cause–and–effect relationship between LSS interventions and operational performance. This explains why quality improvement and defect reduction emerge as dominant outcomes, followed by productivity, cost efficiency, and lead time reduction across multiple sectors. It helps guide further analysis of the methodology's contribution to improving overall organizational performance (Maryadi, Moulita, et al., 2024).

An analysis of Lean Six Sigma (LSS) implementation challenges indicates that human and organizational factors exert the most significant influence on the success of process improvement projects. Previous studies, such as those reported by Kumar and Singh (2021), confirm that lack of training, limited technical competency, and resistance to change are the most frequently encountered barriers that directly impact the effectiveness of LSS implementation. Furthermore, constraints related to restricted data, inadequate digital infrastructure, and misalignment between Lean and Six Sigma principles in operational practices also hamper optimal (Hernandez, 2025). This synthesis confirms that challenges in LSS implementation are not only technical but also encompass structural and cultural factors that require a change-management approach, leadership support, and organizational readiness to ensure the success and sustainability of the LSS program.

Although several systematic literature reviews on Lean Six Sigma (LSS) have been published in recent years, most focus on specific dimensions, such as sectoral applications (e.g., healthcare or manufacturing), LSS 4.0 (digital transformation), or methodological evolution. These reviews provide valuable insights; however, they tend to analyze performance outcomes and implementation challenges separately, without offering an integrated synthesis that explains which performance outcomes dominate across sectors, how consistently they appear, and what recurring barriers inhibit their realization. Moreover, prior reviews rarely provide a structured comparison of LSS outcomes across industries or a consolidated mapping of persistent challenges despite methodological maturity. As a result, practitioners still lack a clear, evidence-based reference for prioritizing improvement objectives and anticipating implementation risks when adopting LSS in contemporary organizational contexts. Therefore, this study addresses the following research questions:

- RQ1: What performance outcomes are most frequently reported in Lean Six Sigma implementations between 2020 and 2025?
- RQ2: What key challenges consistently hinder the successful implementation of Lean Six Sigma across industries?
- RQ3: What emerging trends and novel directions are shaping the evolution of Lean Six Sigma in recent literature?

The motivation for this review is to consolidate fragmented empirical evidence into a coherent structure that links outcomes, challenges, and trends. The implications of this study are twofold: theoretically, it strengthens conceptual clarity regarding LSS effectiveness; practically, it provides managers and practitioners with evidence-based guidance to design more focused and sustainable LSS initiatives.

2. Research Metodology

This study used a Systematic Literature Review (SLR) approach to identify, evaluate, and synthesize research on Lean Six Sigma (LSS) implementation in the 2020–2025 period. The search was conducted across several international databases, including Scopus, Web of Science, ScienceDirect, and IEEE Xplore, using keywords such as "Lean Six Sigma," "LSS implementation," "DMAIC," "process improvement," and "performance outcomes." Inclusion criteria included articles published in English in indexed journals and containing empirical data relevant to LSS implementation. Exclusion criteria included conceptual articles, reviews, and publications that did not provide methodological data or analytical implementation results. All articles meeting the requirements were recorded in an extraction sheet for systematic analysis.

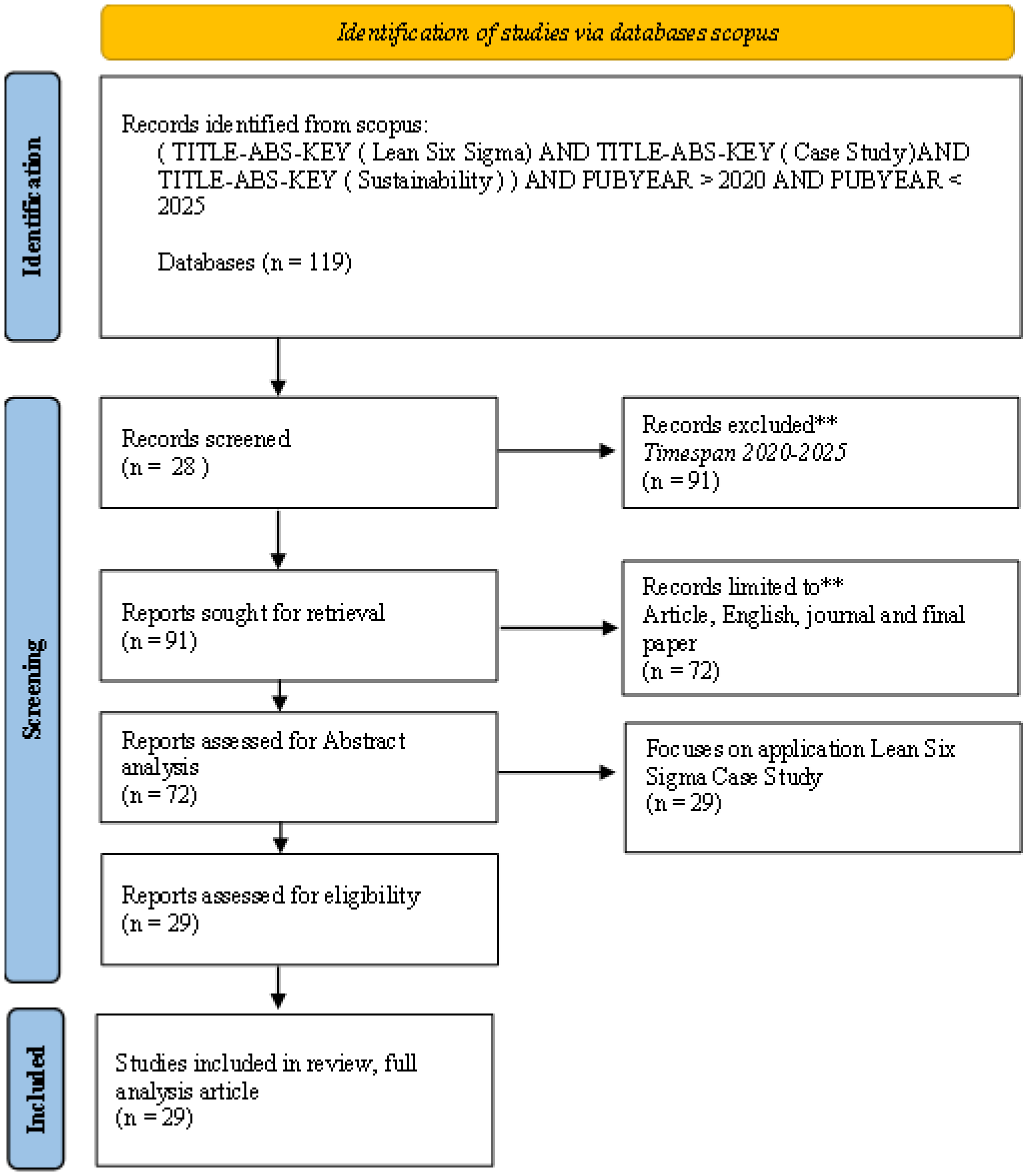

Figure 1. Prisma Diagram for this study

The categorization of performance outcomes and implementation challenges was constructed using an inductive thematic synthesis approach. Initially, all reported outcomes and challenges were extracted verbatim from the selected studies. These items were then grouped based on conceptual similarity, frequency of occurrence, and consistency across sectors. Categories were refined iteratively to ensure mutual exclusivity and theoretical coherence, resulting in outcome and challenge dimensions that reflect dominant patterns in recent LSS literature. The data extraction process included several key components: year of publication, journal name, and quartile ranking, industry sector, methodological approach, LSS tools and techniques used, reported performance outcomes, and identified implementation challenges. The analysis used a combination of descriptive methods to examine publication patterns and research distribution, and thematic analysis to group implementation outcomes and barriers into thematic categories. This approach enables a more comprehensive understanding of the focus of LSS research during the 2020–2025 period and how variations in industry context, methods, and organizational characteristics contribute to the success or failure of LSS implementation.

This study used the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol, an international standard for ensuring transparent, systematic, and replicable literature review processes. PRISMA helps organize the process of identification, screening, eligibility, and final selection of studies for inclusion in the review. Using this protocol makes the article selection process more structured and reduces bias in selecting relevant studies. Therefore, PRISMA was used in this study to guide the step-by-step search process for Lean Six Sigma publications, from initial database identification to article selection for in-depth analysis. The systematic approach through PRISMA also enables links between stages, making the overall selection process more coherent and logical.

The initial identification process yielded 119 articles from the Scopus database using the keyword combination Lean Six Sigma, case study, and sustainability, with a publication year limit of 2020–2025. Based on these results, an initial screening yielded only 28 articles. Ninety-one articles were excluded for failing to meet the time frame constraints. The next stage was screening based on publication type, which limited the sample to journal articles in English, final papers, and journal articles in English, leaving 72 articles for abstract analysis. After abstract review, only 29 articles met the study's focus, namely, case study-based Lean Six Sigma research in the context of sustainability. These articles then proceeded to the eligibility stage, and all were deemed eligible, making them the final sample for analysis in this SLR. Thus, the PRISMA flow illustrates a step-by-step reduction process that systematically connects each selection stage to yield the most relevant studies.

3. Result and Discussion

3.1 Performance Outcomes of LSS

Lean Six Sigma (LSS) studies from 2020 to 2025 show a strong trend toward improved operational performance across various indicators such as quality, productivity, and efficiency. Most studies in the field confirm that LSS implementation results in significant improvements in process stability, particularly when the DMAIC approach is consistently applied (Gupta et al., 2024). Because LSS combines waste reduction from Lean with variation control from Six Sigma, numerous studies position this methodology as a highly effective strategy for achieving more adaptive performance in increasingly complex industrial environments.

The final dataset consists of 28 peer-reviewed journal articles published between 2020 and 2025. The annual distribution shows a noticeable increase after 2021, indicating growing research interest in Lean Six Sigma, particularly in relation to digitalization and sustainability. Most articles were published in journals focused on operations management, industrial engineering, and quality management, including the International Journal of Lean Six Sigma, Production Planning & Control, and Benchmarking.

By sector, manufacturing and healthcare dominate the sample, followed by logistics and public services. This distribution reflects the continued relevance of LSS in process-intensive environments and indicates its expanding application beyond traditional manufacturing contexts.

Quality improvement and defect reduction emerged as the most prominent outcomes across studies. Persis et al. (2022) reported that a structured DMAIC approach significantly reduced defect rates through root-cause identification and data-driven process control. Similar results were also seen in studies of manufacturing and healthcare, which reported quality improvements after implementing techniques such as Value Stream Mapping and Statistical Process Control (Citybabu & Yamini, 2023). The relationship between tight process control and increased output is a consistent pattern across almost all sectors.

In addition to quality, increased productivity is a central outcome of LSS implementation. The studies analyzed show that LSS reduces production times, increases equipment utilization, and lowers operational costs (Gupta et al., 2024). This occurs because various non-value-added activities are successfully identified and eliminated. Kumar and Singh (2021) note that combining Lean tools—such as 5S, Kaizen, and Standard Workwith quantitative Six Sigma analysis can accelerate processes and increase throughput. Overall, productivity and cost efficiency are linearly related outcomes in the context of LSS. Lead time reduction is a key finding in metadata, particularly in the service and logistics sectors. By mapping process flows and eliminating bottlenecks, organizations can significantly reduce cycle times, thereby increasing customer satisfaction (Persis et al., 2022). Another study reports that reduced lead times typically improve on-time delivery and service reliability, which are essential indicators in service-based industries (Rahman et al., 2023). Thus, strengthening customer focus is a central contribution of LSS practices. Several recent studies have documented a growing trend in sustainability-related outcomes, including material efficiency, waste reduction, and reduced energy consumption. Gupta et al. (2024) suggest that integrating LSS with a sustainability perspective yields a dual impact: increased profitability and reduced environmental footprint. Several studies have noted that reducing defects and improving resource utilization accelerate the achievement of operational sustainability targets. Thus, LSS outcomes extend beyond improving internal efficiency to strengthening long-term, sustainability-based organizational performance.

Table 1. Summary of Performance Outcomes Reported in LSS Studies (2020–2025)

No	Outcome Category of Study	Description of Main Findings	Author
1	Quality Enhancement & Defect Reduction	Defect reduction, process stability improvement, product/service quality improvement	Persis et al. (2022)
2	Productivity Improvement	Increased throughput, equipment efficiency, and reduction of non-value-added activities	Gupta et al. (2024); Kumar & Singh (2021)
3	Cost Reduction	Operational cost savings through waste elimination and process efficiency	Gupta et al. (2024)
4	Lead Time Reduction	Reduced cycle time, bottleneck reduction, and increased service speed	Persis et al. (2022)
5	Customer Satisfaction Improvement	Improved timeliness, service quality, and reliability	Nedra et al., (2022)
6	Waste Elimination	Identification and elimination of waste in the process flow	Sreedharan & Sunder (2018)
7	Sigma Level Improvement	Improved process capability and long-term stability	Gupta et al. (2024)

8	Sustainability Outcomes	Material efficiency, waste reduction, increased energy, and lower environmental impact	Gupta et al. (2024)

3.2 Implementation Challenges

Lean Six Sigma (LSS) studies from 2020 to 2025 show a strong trend toward improved operational performance across various indicators such as quality, productivity, and efficiency. Most studies in the field confirm that LSS implementation results in significant improvements in process stability, particularly when the DMAIC approach is consistently applied (Gupta et al., 2024). Because LSS combines waste reduction from Lean with variation control from Six Sigma, numerous studies position this methodology as a highly effective strategy for achieving more adaptive performance in increasingly complex industrial environments.

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Table 2. Key Implementation Challenges in LSS (2020–2025)

No	**Challenges Outcome**	**Problem Description**	**Author**

1	**Human Resource Barriers**	Resistance to change, limited competency, and poor understanding of LSS tools	Kumar & Singh (2021); Gupta et al. (2024)
2	**Organizational & Cultural Barriers**	Lack of leadership support, an unadaptive culture, and misaligned organizational strategies	Kaswan et al., (2023)
3	**Technical Challenges**	Poor data quality, limited data, and complex measurement systems	Persis et al. (2022)
4	**Financial & Resource Limitations**	Budget constraints for training, technology, and process development	Gupta et al. (2024)
5	**Misalignment of Lean & Six Sigma Tools**	Implementation of tools in isolation results in a lack of synergistic results	Sreedharan & Sunder (2018)

3.3 Emerging Trends & Novel Insights

Recent developments indicate that Digital Lean Six Sigma (DLSS) will be the most prominent trend in the 2020–2025 period, particularly through the integration of technologies such as the Internet of Things, machine learning, process automation (RPA), and advanced data analytics. In the metadata literature, Gupta et al. (2024) emphasize that digitalization is not merely a supporting element but has become a critical catalyst, accelerating organizations' ability to identify defects, monitor variation, and automate process control. This integration creates synergies not available with traditional LSS methods, making DLSS the foundation for future data-driven quality and efficiency.

Another growing trend is the adoption of Lean Six Sigma to support sustainability goals. Studies in metadata, such as those by Persis et al. (2022), demonstrate that LSS implementation can reduce material waste, reduce energy consumption, and increase resource efficiency. In addition to providing economic benefits, this approach directly contributes to achieving operational sustainability targets. With increasingly stringent global environmental standards, LSS is positioned not only as a process improvement tool but also as a strategy with the potential to unlock competitive advantages through green performance.

As operational complexity increases, there is a need to develop hybrid frameworks that integrate LSS with other approaches, such as the Theory of Constraints, Total Quality Management, and risk-based design. Gupta et al. (2024) demonstrated that this cross-methodological integration can overcome the limitations of traditional LSS, particularly in process contexts that require high flexibility. Metadata also identified cases of combining LSS with digital and ergonomic approaches to improve work comfort and process stability. However, these findings remain limited and open up new research opportunities. This hybridization points to the evolution of LSS toward a more adaptive and holistic model. Recent research trends also highlight significant gaps, particularly the lack of longitudinal studies evaluating the long-term sustainability of LSS impacts. Rahman et al. (2023) noted that most studies only assess short-term outcomes without observing the retention of process improvements. Furthermore, LSS integration in the public service and healthcare sectors still faces methodological challenges, requiring more empirical analysis. Another gap is the limited discussion of the role of ergonomics in enhancing LSS effectiveness (Sreedharan & Sunder, 2018). Thus, this trend opens up ample scope for the development of more in-depth, multisystem-oriented future research. Table 3 below highlights several developments from Lean Six Sigma studies.

Table 3. Emerging Trends and Novelty Insights in Lean Six Sigma

No	Trend / Novel Insight	Description
1	**Digital Lean Six Sigma (DLSS)**	Integration of digital technologies such as IoT, machine learning, robotic process automation, and advanced analytics to enhance real-time defect detection, process monitoring, and automated control.
2	**Sustainability-Driven LSS**	Use of LSS to reduce material waste, optimize energy consumption, and support environmentally responsible operations through waste elimination and improved resource efficiency.
3	**Hybrid Lean Six Sigma Frameworks**	Combining LSS with complementary methodologies (e.g., Theory of Constraints, Total Quality Management, risk-based approaches) to increase flexibility and meet the needs of complex operational environments.
4	**Customer-Centric LSS**	Shifting emphasis toward improving customer experience by reducing lead time, increasing service reliability, and strengthening service performance stability.
5	**Advanced Statistical & Data-Driven Tools**	Utilization of multivariate analysis, big data analytics, and AI-enabled decision tools to strengthen the analytical precision of LSS projects.
6	**Sectoral Expansion Beyond Manufacturing**	Growing adoption of LSS in public services, healthcare, logistics, and social services, reflecting broader applicability beyond traditional manufacturing.
7	**Longitudinal Performance Gap**	Recognition of the lack of long-term evaluation studies, highlighting the need for longitudinal research to assess sustained impact of LSS implementations.

4. Conclusion

This systematic review reveals that Lean Six Sigma (LSS) continues to deliver substantial performance improvements across diverse industrial settings between 2020 and 2025. The most prominent outcomes include enhanced product and service quality, reduced defects, improved productivity, lower operational costs, and shortened lead times. The findings demonstrate that LSS remains highly relevant, especially when applied through structured frameworks such as DMAIC and supported by data-driven decision-making. Additionally, the review highlights a noticeable shift toward customer-oriented, sustainability-driven performance indicators, demonstrating that LSS is evolving beyond its traditional efficiency-focused boundaries.

A key novelty identified in this review is the emergence of Digital Lean Six Sigma (DLSS), which integrates LSS principles with advanced technologies such as IoT, machine learning, and automation. This digital evolution enhances real-time monitoring, accelerates defect detection, and strengthens analytical precision, positioning DLSS as a critical pathway for future operational excellence. Furthermore, the rise of a hybrid LSS framework combining LSS with methodologies such as Theory of Constraints, ergonomics, and data analytics offers a more adaptive and holistic system capable of addressing increasingly complex operational environments. These findings collectively extend the theoretical and practical boundaries of LSS, providing insight into its expanding applicability and strategic relevance.

Despite these contributions, the review reveals several limitations in existing literature. Most studies focus on short-term project outcomes, leaving little longitudinal evidence to assess the long-term sustainability of LSS improvements. Additionally, many sectors, particularly healthcare, public services, and logistics, show inconsistent methodological rigor and underexplored integration with human-factor considerations. Future research should therefore prioritize longitudinal studies, more profound exploration of digital–LSS synergies, and expanded investigation into ergonomics-based LSS frameworks. Further examination of LSS in emerging sectors and its role in sustainability transformation will also be essential to strengthening the evidence base and advancing the next generation of LSS research.

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