Review

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Evaluating Lean Six Sigma's Impact on Operational Efficiency in Small and Medium-Sized Manufacturing Enterprises: A Systematic Review

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Systematic Review

Evaluating Lean Six Sigma's Impact on Operational Efficiency in Small and Medium-Sized Manufacturing Enterprises: A Systematic Review

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Abstract: The increasing demand for operational efficiency in small and medium-sized manufacturing enterprises (SMEs) has sparked interest in Lean Six Sigma (LSS) methodologies. LSS integrates Lean's waste elimination focus with Six Sigma's variability reduction, offering a comprehensive framework for process improvement. Despite its potential, SMEs face unique challenges in implementing LSS, such as financial limitations and resistance to change. This systematic review evaluates the application of LSS in SMEs, analyzing its impact on operational, financial, and quality performance across different industries and geographical regions. The study identifies key success factors, barriers, and research gaps while proposing regression models to predict financial gains associated with LSS adoption. The review followed PRISMA guidelines, sourcing literature from SCOPUS, Web of Science, and Google Scholar published between 2014 and 2024. The inclusion criteria targeted studies involving LSS implementation in manufacturing SMEs. Data extraction included study characteristics, methodologies, and outcomes. A risk of bias assessment was conducted using the Newcastle-Ottawa Scale. The synthesis involved descriptive statistics, effect measures, and sensitivity analyses. Out of 150 initially identified studies, 109 met the inclusion criteria. The findings demonstrate that LSS implementation significantly improves operational performance, with 77.98% of studies showing reductions in cycle time and defect rates. Financial outcomes, including cost savings and ROI, showed moderate to large effects, with 63.58% of the reviewed studies reporting cost reductions. Quality improvements were noted across studies, particularly in First Pass Yield, with 67% of studies demonstrating enhanced quality metrics. The geographic distribution indicated strong research activity in India (23.85%), the United States (6.42%), and Europe (5.50%). Both developed (46.79%) and developing (45.87%) economies contributed extensively. Key barriers included resource constraints (reported in 45% of studies) and resistance to change (noted in 31%). LSS offers substantial benefits for SMEs, driving process efficiency, cost reduction, and quality improvements. However, challenges such as limited resources and organizational resistance must be addressed for successful adoption. This review provides insights into best practices, highlights research gaps, and suggests areas for future investigation, emphasizing the need for customized LSS strategies tailored to the unique contexts of SMEs.

Keywords: lean six sigma (LSS); small and medium-sized enterprises (SMEs); manufacturing efficiency; process improvement; DMAIC methodology; operational performance; quality enhancement; cost reduction

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1. Introduction

In today's rapidly evolving business landscape, companies face relentless pressure to enhance performance and achieve sustainable growth. Stagnation is often perceived as a lack of progress, with profit margins that fall short of previous targets considered signs of underperformance [1,2]. Consequently, organizations are increasingly scrutinized by shareholders and financial markets to demonstrate not only operational efficiency but also robust financial outcomes [3]. To navigate this competitive environment effectively, companies must continuously evaluate and refine their

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strategic plans and execution capabilities, ensuring they optimize shareholder value in both the short and long term [3,4].

A variety of business process improvement frameworks are available to help organizations enhance operational efficiency and strategic performance [5,6]. Among these methodologies, LSS has gained widespread adoption globally, utilized by leading corporations to drive continuous improvement [8,12]. LSS is a collaborative and systematic approach that integrates the principles of Lean, which focuses on waste elimination and process flow improvement, and Six Sigma, which aims at reducing variability and minimizing defects [10]. Lean methodology, originating from the Toyota Production System developed by Taiichi Ohno in post-World War II Japan, seeks to distinguish between value-adding (VA) and non-value-adding (NVA) activities within an organization [7,9]. Value-adding activities are those that directly transform products or services in ways that customers are willing to pay for, while non-value-adding activities, termed "Muda" in Lean terminology, represent inefficiencies that should be minimized [11]. The Lean approach aims to reduce cycle times and lead times by eliminating NVA operations, thereby enhancing overall process efficiency [16]. However, implementing Lean practices effectively can be challenging, particularly in fostering an organizational culture that sustains the continuous use of Lean tools and techniques [13]. Conversely, Six Sigma, developed by Bill Smith at Motorola in the mid-1980s and popularized by General Electric's Jack Welch in the 1990s, is a structured framework focused on reducing process variation to improve quality and consistency [14,15]. The methodology follows a five-phase framework known as DMAIC (Define, Measure, Analyze, Improve, Control), guiding organizations in systematically identifying and resolving inefficiencies [19]. Although Six Sigma is data-driven and effective in process optimization, it is limited in addressing waste elimination without the integration of Lean principles [8].

The fusion of Lean and Six Sigma into the LSS framework provides a balanced methodology for enhancing process effectiveness and quality while lowering costs and boosting customer satisfaction [6,18]. Nevertheless, integrating these methodologies presents challenges, particularly regarding organizational culture and leadership commitment. Despite these challenges, LSS has garnered recognition as a powerful continuous improvement strategy, offering significant potential for achieving operational excellence [19]. The increasing importance of LSS in driving performance improvement is especially relevant for small- and medium-sized enterprises (SMEs). A systematic review of its application in SMEs is both timely and necessary [3,14]. SMEs, which play a crucial role in the global economy, face unique challenges when adopting continuous improvement initiatives due to constraints in resources and leadership dynamics [20]. These enterprises significantly contribute to global employment and economic activity but often struggle with issues such as cash flow management, innovation, and strategic planning [17]. This review aims to explore the existing literature on LSS implementation in SMEs, identify key success factors and barriers, and provide insights on leveraging LSS for sustainable growth and competitiveness. The five principles illustrated in Figure 1 form the foundation of Lean Six Sigma, driving organizational success by enhancing efficiency, quality, and customer satisfaction.

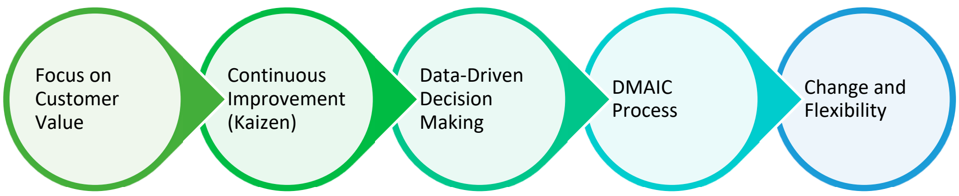

Figure 1. Key principles of Lean Six Sigma.

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The first principle, focusing on customer value, underscores the importance of aligning processes with customer expectations to achieve competitive advantage and market growth [19]. Continuous improvement (Kaizen) fosters a culture of incremental enhancements, involving employees at all levels, which leads to sustained effectiveness and quality improvement. Data-driven decision-making ensures that organizational decisions are based on measurable data, leading to sustainable outcomes [12]. The DMAIC process offers a systematic approach to problem-solving, encompassing goal definition, performance measurement, issue analysis, process improvement, and outcome control to achieve long-term success [13]. Lastly, promoting change and flexibility supports adaptability and transparency, enabling organizations to respond effectively to market dynamics and sustain long-term growth [9]. The systematic review has identified several research gaps in the existing literature concerning the application of Lean Six Sigma in small- and medium-sized manufacturing enterprises (SMEs). These gaps point to areas where current research is lacking, suggesting opportunities for further investigation to better understand and implement LSS in this context, as summarized in Table 1.

First, while substantial research has been conducted on LSS adoption in large organizations, studies focusing on the unique challenges faced by SMEs, especially those in resource-constrained environments, are limited. Existing literature often overlooks specific barriers such as limited financial and human resources, which can hinder effective LSS adoption. Moreover, the literature tends to prioritize operational performance improvements, with insufficient emphasis on the impact of LSS practices on sustainability performance and long-term strategic outcomes. Second, the integration of digital technologies within LSS frameworks in the context of SMEs remains underexplored. The synergistic potential between emerging Industry 4.0 technologies and LSS has not been fully examined, indicating a gap in understanding how these innovations could enhance LSS implementation and outcomes. Lastly, most studies utilize cross-sectional or case study methodologies, limiting insights into the longitudinal impact of LSS on organizational growth and transformation over time. Addressing these gaps will provide a more comprehensive understanding of how SMEs can leverage LSS for sustained competitive advantage and resilience.

Table 1. Comparative Analysis of the Existing Review Works and Proposed Systematic Review on the Application of Lean Six Sigma for SMEs.

Ref.	Cites	Year	Contributions	Pros	Cons
[21]	356	2014	Explores the critical failure factors for Lean Six Sigma in various sectors, based on a systematic literature review of 56 papers published between 1995 and 2013.	Identifies 34 common failure factors; provides insights across different sectors and organizational sizes.	Discusses many gaps and limitations that need further research.
[22]	69	2014	Reviews literature on Total Productive Maintenance (TPM) implementation practices in manufacturing organizations, with a focus on SMEs in India, and identifies gaps in current research and practices.	Highlights the importance of TPM for productivity and competitive advantage; suggests directions for future research.	Focuses primarily on Indian SMEs; may not be generalizable to other contexts.
[23]	136	2016	Explores lean manufacturing in food-processing SMEs, identifying barriers to adoption and challenges specific to the food industry, based on a multiple-case-study research approach.	Offers insights into contextual factors and barriers specific to the food-processing industry; helps practitioners anticipate obstacles.	Focuses exclusively on food-processing SMEs; may not be generalizable to other sectors.
[24]	128	2016	Investigates Lean Manufacturing (LM) practices in Brazilian SMEs, analyzing the implementation and its impact on performance using structural equation modeling (PLS-SEM).	Provides insights into fragmented LM practices and their impact on performance; highlights specific areas for improvement.	Limited to Brazilian SMEs; fragmented approach to LM implementation.
[25]	25	2018	Reviews the implementation of Six Sigma in various manufacturing industries, examining its success using different performance indicators, based on a critical review of 112 research articles.	Offers insight into the implementation and measurement of Six Sigma in manufacturing; identifies gaps in research.	Does not cover service industries; limited to specific performance indicators.

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[26]	40	2018	Examines critical success factors for Lean Six Sigma and Six Sigma implementation in small and medium-sized manufacturing enterprises, comparing them with larger corporations.	Identifies key success factors for both SMEs and large organizations.	Implementation challenges in SMEs due to resource limitations.
[27]	26	2019	Investigates Lean Six Sigma in the Brazilian context, focusing on its characteristics and opportunities for future research, based on a review of 104 scientific publications.	Highlights critical success factors, particularly top management support; provides practical applications in large Brazilian industries.	Limited to Brazilian studies; lacks a standard framework for LSS.
[28]	121	2019	Reviews benefits and challenges of Lean Six Sigma implementation across various sectors from 2000 to 2018, including manufacturing, health care, human resource, financial, and education.	Offers a comprehensive review of LSS implementation across multiple sectors; identifies research gaps.	May not fully capture recent developments beyond 2018.
[29]	55	2019	Explores common themes and research gaps in Lean Six Sigma related to small- and medium-sized enterprises (SMEs) within manufacturing organizations, using a systematic review methodology.	Identifies research gaps and provides insights for improving LSS implementation in SMEs.	Limited to peer-reviewed English papers; excludes conference and white papers.
[30]	11	2019	Examines the impact of Lean Manufacturing (LM) on performance in manufacturing SMEs and introduces a new lean implementation framework for very small businesses (VSBs).	Highlights recent progress in LM among SMEs; proposes a framework for VSBs.	Limited to manufacturing SMEs; may not apply to other sectors.
[31]	92	2019	Reviews Lean implementation (LI) in SMEs, identifying main challenges and critical success factors through a systematic review methodology of 403 papers.	Provides a comprehensive view of Lean implementation challenges and CSFs in SMEs.	Focuses on SMEs only; may not address Lean implementation in large organizations.
[32]	52	2019	Identifies research gaps in Lean manufacturing (LM) literature from a systematic review of 120 articles published between 2005 and 2016, and groups these gaps into meaningful themes.	Provides a detailed analysis of LM research gaps and groups them into logical themes.	May not cover the latest research developments post-2016.
[33]	8	2020	Identifies and explores critical success factors (CSFs) for Six Sigma through an extensive literature review of 64 research articles, proposing a categorized list of vital CSFs.	Provides a categorized list of CSFs; useful for increasing the success rates of Six Sigma programs.	Focuses on SMEs only; does not consider failure experiences of larger industries.
[34]	25	2021	Compares the effect of Lean Manufacturing (LM) implementation in manufacturing sectors of developing and developed countries, based on a review of 63 studies published between 2015 and March 2020.	Provides comparative insights into LM practices across different economies; highlights difficulties faced by SMEs.	Limited to manufacturing sectors; no reported negative impacts of LM.
[35]	12	2022	Reviews Lean Six Sigma literature in the Indian context from 2010 to 2021, focusing on various perspectives such as author profiles, types of firms, methodologies used, and key findings.	Provides a comprehensive classification and framework for future research in LSS within India.	Limited to studies published in the Indian context; may not address global trends.
[36]	3	2023	Identifies enablers and barriers to Lean implementation among first-line employees (FLEs) in SMEs, highlighting future research avenues for improving understanding of lean methodology implementation.	Provides insights into FLEs' roles and factors affecting lean implementation; offers a framework for future research.	Limited citations; focused on FLEs' roles in lean implementation.
[37]	0	2024	Examines human-related lean practices (HRLP) in the context of lean manufacturing (LM) implementation in SMEs, based on a review of 193 publications between 2013 and 2023.	Provides a thorough analysis of HRLPs important for lean success; helps in guiding lean implementation in SMEs.	Limited to publications in English; may not cover all HRLPs or regional variations.
Proposed systematic review			Provides a comprehensive consolidation of existing research on the implementation of Lean Six Sigma in SMEs, identifies configurations, performance metrics, and common challenges. Proposes regression models for financial metrics associated with LSS components.	Offers a holistic analysis of Lean Six Sigma applications, bridging gaps in performance metrics across different industry contexts; highlights research gaps for future exploration.	-

1.1. Research Motivation

The drive to achieve sustainable growth and operational efficiency is more critical than ever for small and medium-sized enterprises (SMEs). Unlike larger corporations, SMEs often struggle with unique constraints, such as limited financial and human resources, which can hinder their ability to implement complex methodologies for continuous improvement. LSS offers a powerful approach for optimizing processes and enhancing productivity, but its practical application in SMEs raises challenges that are distinct from those faced by larger enterprises. The implementation of LSS involves high costs and intricate change management, factors that can be particularly daunting for SMEs. Yet, the existing literature has not sufficiently explored these dynamics. By critically examining the economic and operational aspects of LSS in the context of SMEs, this study aims to shed light on how these enterprises can harness LSS to overcome resource constraints, improve process efficiency, and achieve long-term growth.

1.2. Research Questions

The research questions in Table 2 were formulated to systematically evaluate the application of Lean Six Sigma in SMEs. They aim to explore critical factors influencing its implementation, assess outcomes, and identify gaps in current literature. The questions are designed to provide a robust framework for understanding the key challenges and opportunities within SMEs adopting LSS practices.

Table 2. Proposed Research Questions.

Q	Research Questions
Q1	What are the key success factors and barriers to the implementation of Lean Six Sigma in SMEs across various industries and geographical contexts?
Q2	To what extent does the adoption of Lean Six Sigma influence employee engagement, satisfaction, and skill development in small and medium-sized enterprises?
Q3	What are the most common challenges faced by SMEs in integrating Lean Six Sigma into existing workflows, and how can these be mitigated?
Q4	How do the outcomes of Lean Six Sigma implementation vary between manufacturing SMEs in developed versus developing countries?
Q5	What financial metrics or performance indicators are most influenced by Lean Six Sigma practices in SMEs, and how can regression models predict their impact?

1.3. Research Contribution

This systematic review makes significant contributions to the field of LSS in small and medium-sized manufacturing enterprises (SMEs) by addressing critical research gaps and advancing the existing body of knowledge. The research contributions of this work are as follows:

- This review presents a detailed analysis of the application of Lean Six Sigma within SMEs, emphasizing the unique challenges these enterprises face due to resource constraints and operational complexities. The study aggregates insights from various industries, highlighting how SMEs can adopt LSS methodologies to enhance efficiency, reduce waste, and improve overall performance.
- By systematically analyzing existing literature, the research identifies the primary factors that contribute to the successful implementation of LSS in SMEs, such as leadership commitment, employee engagement, and the alignment of LSS initiatives with strategic business goals. It also discusses common barriers, including limited financial resources, lack of specialized skills, and resistance to change.
- The review identifies gaps in the current literature, particularly in the integration of digital technologies and Industry 4.0 solutions with LSS practices in the SME context. It encourages

future research to explore the synergistic effects of combining LSS with advanced technologies to optimize outcomes in resource-constrained settings.

- The study offers practical guidance for SMEs seeking to implement LSS, providing best practices and strategies to overcome common challenges. It includes recommendations for adapting LSS tools and techniques to the specific needs and limitations of SMEs, ensuring more sustainable and impactful outcomes.

1.4. Research Novelty

The novelty of this study lies in its focus on addressing the practical challenges associated with implementing LSS in SMEs, particularly in environments with limited resources. Unlike existing research, which often focuses on large organizations, this study delves into how LSS can be adapted and sustained in smaller businesses. It highlights key areas that need further investigation, such as overcoming cost constraints and enhancing employee engagement with continuous improvement methodologies. The study also provides a framework for comparative analysis across different economic contexts, emphasizing the specific needs of SMEs in developing regions. This research identifies gaps in the existing literature related to how LSS is integrated into workflows within resource-constrained settings and proposes strategies to optimize production and reduce waste. Moreover, the study suggests pathways for future exploration into combining traditional LSS practices with emerging digital technologies, such as Industry 4.0 innovations, to unlock additional value in process improvements. This approach introduces a new perspective on how technology-driven process optimization can enhance the effectiveness of LSS in various industrial settings, thus broadening the applicability of the methodology beyond traditional manufacturing environments.

2. Materials and Methods

This section outlines the systematic review framework, materials, and methodologies leveraged to develop the proposed survey, grounded in LSS principles specifically adapted for small and medium-sized manufacturing enterprises (SMEs). By defining a rigorous selection roadmap, we ensured a targeted literature foundation, encompassing only relevant studies from highly regarded publication sources. The retrospective decennial review (2014–2024) supports an in-depth analysis of LSS applications over the past decade, shedding light on trends, challenges, and advancements in implementing Lean Six Sigma within the SME sector [1] – [148].

2.1. Eigibility Criteria

To align the literature selection with the objectives of this review, we established stringent inclusion and exclusion criteria. Table 3 presents these criteria, ensuring that only studies directly relevant to LSS applications in SMEs are incorporated [149] – [171]. This process reinforces the review’s focus on empirical rigor and thematic relevance, aligning with the study's aim to contribute high-impact insights into the field.

Table 3. Proposed Inclusion and Exclusion Criteria.

Criteria	Inclusion	Exclusion
Topic	Publications examining the application of Lean Six Sigma in SMEs, with empirical evidence or case studies.	Publications lacking focus on Lean Six Sigma applications in SMEs.
Research Framework	Articles incorporating a research framework where Lean Six Sigma is methodologically applied to SMEs.	Articles without a framework on Lean Six Sigma applications in SMEs.
Language	Papers written in English to ensure accessibility and standardized interpretation.	Papers in languages other than English.

Period	Publications between 2014 and 2024 to capture contemporary and relevant insights.	Publications outside the 2014–2024 timeframe.

These criteria were applied rigorously to filter the most pertinent studies, ensuring a focused analysis that captures the nuances and practical implications of Lean Six Sigma in SMEs. By adopting a systematic approach, the study builds a comprehensive understanding of how Lean Six Sigma enhances operational efficiency and competitive advantage in SMEs, with insights that are directly transferable to practitioners and researchers alike.

2.2. Information Sources

The literature for this systematic review was sourced from three reputable online research repositories accessible via the OpenAthens platform through the University of Johannesburg's online library. A comprehensive search strategy was applied across the selected databases—Google Scholar, Scopus, and Web of Science—to ensure a robust and multidisciplinary foundation. The search utilized targeted keywords aligned with the study's title, and the eligibility criteria were rigorously applied to filter publications, ensuring alignment with the review's objectives. Table 4 provides a summary of the online research databases used, highlighting each source's purpose and alignment with the inclusion/exclusion criteria to support the study's integrity [149] – [171].

Table 4. Summary of Online Research Repositories Used.

Database	**Access Platform**	**Inclusion/Exclusion Criteria Applied**	**Purpose of Use**
Google Scholar	Browser	Yes	Ensures broad coverage across multidisciplinary sources.
Scopus	OpenAthens (UJ Online Library)	Yes	Accesses high-quality, peer-reviewed journal articles.
Web of Science	OpenAthens (UJ Online Library)	Yes	Provides publications with strong research impact and citations.

The use of these databases enables a high level of comprehensiveness and reliability in sourcing peer-reviewed literature, facilitating an analysis that not only captures the breadth of Lean Six Sigma applications in SMEs but also emphasizes quality and impact. By combining resources with different disciplinary strengths, the review establishes a solid basis for identifying the nuanced influences of Lean Six Sigma on SME performance metrics.

2.3. Search Strategy

To ensure a targeted collection of relevant journal articles, conference papers, book chapters, and dissertations, a structured and comprehensive search strategy was implemented across the three online research repositories. Figure 2 illustrates this step-by-step approach, leveraging specific keywords and logic operators ("AND" and "OR") tailored to the systematic literature review (SLR) title. Initially, the SLR title was deconstructed into a logical search equation:

"(lean six sigma" OR "lean manufacturing" OR "six sigma" OR "LSS") AND ("small and medium-sized enterprises" OR SME OR "small and medium businesses" OR "small manufacturing" OR "medium manufacturing" OR SMB OR "small enterprises" OR "medium enterprises" OR "small companies" OR "medium companies") AND (application OR implementation OR adoption OR impact OR effect OR performance)"

This equation, combined with the inclusion and exclusion criteria outlined in Table 3, was used to filter results and isolate publications aligned with the study's focus on Lean Six Sigma applications in SMEs. Finally, a manual review of titles, abstracts, and search tags was conducted to produce a

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refined list of studies, culminating in a primary set of literature for the systematic review. Our search strategy overview if illustrated in Figure 2 [149] – [171].

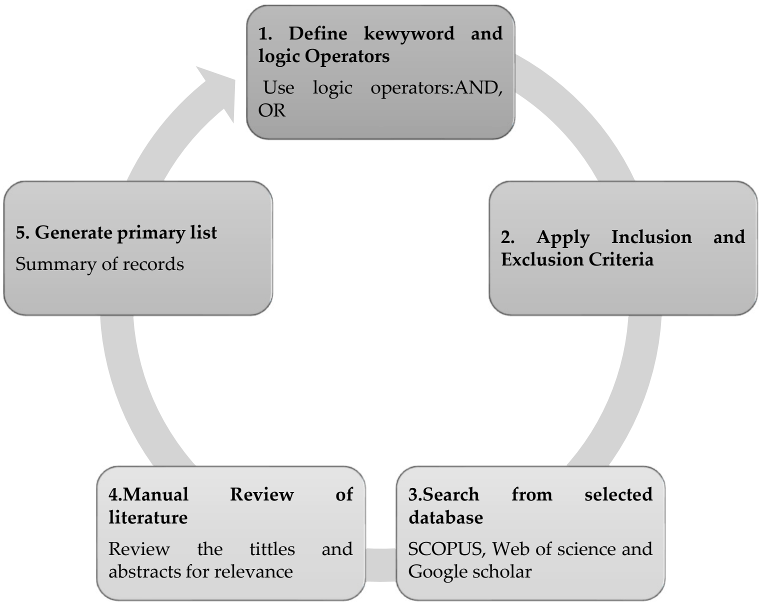

Figure 2. Search Strategy Overview.

This rigorous approach ensures a high-quality, focused selection of publications that address the impact and implementation of Lean Six Sigma methodologies in SMEs, supporting the study's goal of offering comprehensive insights into operational efficiency and performance enhancements within this sector.

2.4. Selection Process

To ensure the integrity and relevance of the studies included in this systematic review, we conducted a thorough selection process using the SCOPUS, Web of Science, and Google Scholar databases, accessed via the University of Johannesburg's online library through the OpenAthens platform. These databases allowed us to apply stringent inclusion and exclusion criteria designed to align with the review's objectives. The inclusion criteria required publications related to Lean Six Sigma applications in small and medium-sized manufacturing enterprises, published between 2014 and 2024, written in English, and containing a clear research framework applying Lean Six Sigma within SMEs. Publications outside of these criteria—those not relevant to Lean Six Sigma in SMEs, without a research framework, published before 2014 or after 2024, or written in languages other than English—were excluded [149] – [171].

To further refine the selection, relevant keywords were applied to the search, ensuring the retrieval of studies directly aligned with Lean Six Sigma implementations in SMEs. The manual screening was performed by two independent reviewers (T.B.C and L.), each conducting initial screenings of titles, publication dates, and abstracts to assess relevance. Following the initial screen, full-text articles were evaluated to confirm the inclusion of key study details, contextual insights, methodologies, and outcomes. Both reviewers worked independently to ensure objectivity and reduce bias in the selection process. After completing individual screenings, they convened to resolve any disagreements. In cases of conflicting opinions, the reviewers deliberated collaboratively to reach a consensus. If consensus was not achieved, the study was excluded from the review. This systematic six-step selection process is illustrated in Figure 3.

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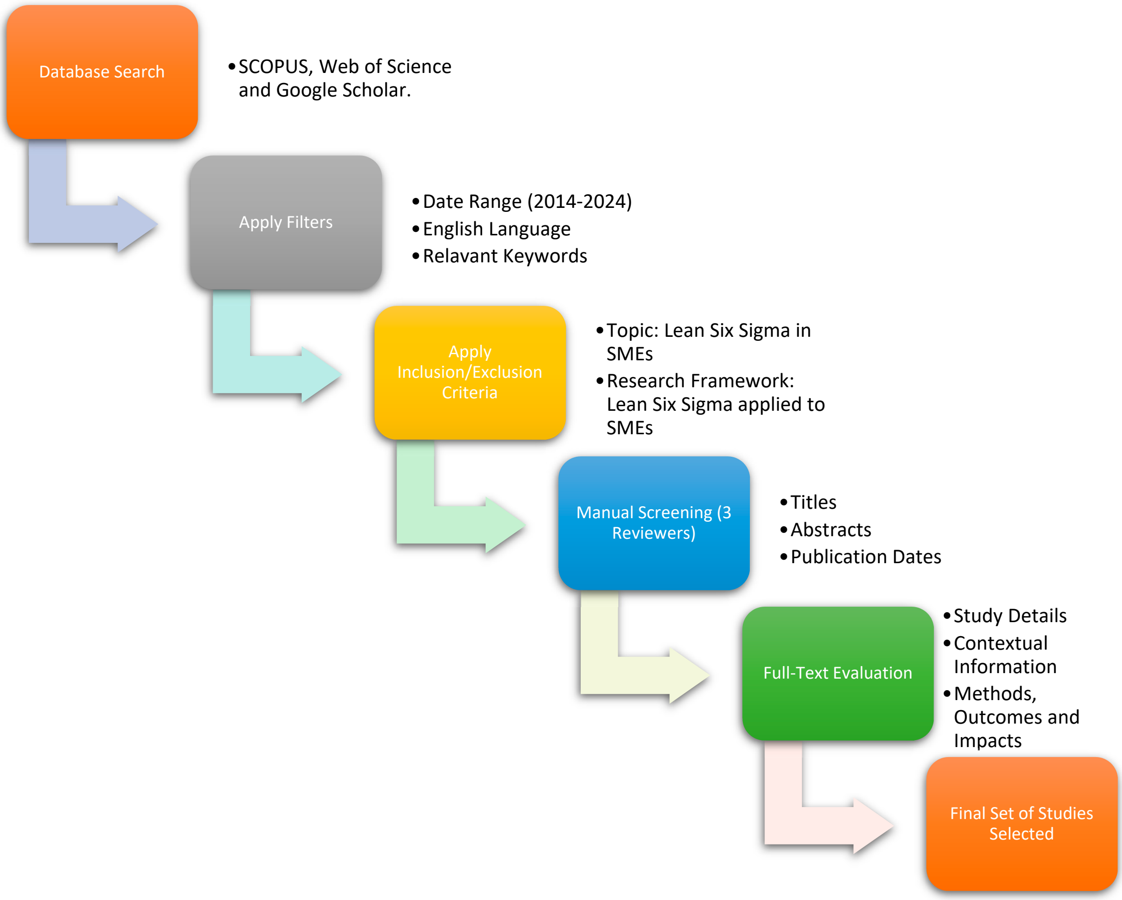

Figure 3. A Six-Step Selection Process used to Gather Relevant Studies.

This structured approach to study selection strengthens the validity of the systematic review, ensuring that the included studies provide robust, high-quality evidence on the application of Lean Six Sigma in SMEs, ultimately enhancing the reliability of the review's insights.

2.5. Data Collection Process

The data collection for this review was conducted using Google Scholar, Web of Science, and Scopus, with three independent reviewers involved to ensure accuracy, reliability, and minimize potential biases. Figure 4 illustrates the data collection workflow, detailing each step to enhance transparency and reproducibility. Initially, each reviewer independently extracted data from the selected studies, focusing on essential elements such as study characteristics, outcomes, and specific Lean Six Sigma metrics relevant to SMEs. This manual extraction process, intentionally devoid of automation tools, allowed for a meticulous and comprehensive approach. Following independent extraction, the reviewers conducted cross-checks to verify consistency and accuracy. Any discrepancies identified during this stage were resolved through direct discussions, ensuring a unified dataset. In instances where multiple reports corresponded to a single study, specific decision rules were applied to select the most comprehensive and up-to-date data. Once accuracy and completeness were confirmed, the collected data was consolidated in an Excel database for final validation and subsequent analysis [149] – [171].

Figure 4. Workflow of Data Selection and Extraction.

This structured approach to data collection reinforces the reliability of the systematic review, supporting the synthesis of robust findings on Lean Six Sigma applications in SMEs.

2.6. Data Items

This section provides a comprehensive overview of the data items sought in this systematic review, focusing on both primary outcomes and additional variables relevant to the impact of Lean Six Sigma on small and medium-sized manufacturing enterprises (SMEs). The primary outcomes include key performance metrics such as operational and financial outcomes, Innovation Performance, Customer Outcomes, and Long-term impacts. In addition to these outcomes, the review considers study and participant characteristics, intervention details, industry-context, and external market influences, ensuring a thorough contextual understanding of the application and effects of Lean Six Sigma methodologies in SMEs.

This approach allows for a nuanced analysis of how Lean Six Sigma contributes to improving production processes, cost-efficiency, and overall competitiveness across diverse manufacturing settings and operational environments within SMEs. The detailed examination of these factors provides a comprehensive understanding of the conditions under which Lean Six Sigma is most effective in driving performance improvements in small and medium-sized manufacturing enterprises [149] – [171].

2.6.1. Data Items Collection Method

In this systematic review on the application of Lean Six Sigma in small and medium-sized manufacturing enterprises (SMEs), a rigorous data collection process was implemented to ensure accuracy and minimize bias, adhering to PRISMA 2020 guidelines. Data was sourced from Google Scholar, Web of Science, and Scopus, with two independent reviewers involved. Each reviewer conducted an independent extraction of data, focusing on key study characteristics, outcomes, and Lean Six Sigma metrics. To ensure reliability, the reviewers cross-checked one another's work, resolving discrepancies through discussion and expert consultation when needed. For studies with multiple reports, decision rules were applied to select the most comprehensive data. The final dataset was consolidated in an Excel database for validation and analysis [149] – [171].

In terms of data items, the review concentrated on both primary outcomes and additional variables that reflect the impact of Lean Six Sigma in SMEs. Primary outcomes included operational and financial performance, innovation, customer satisfaction, and long-term impacts, providing a comprehensive view of how Lean Six Sigma methodologies enhance production efficiency, cost-effectiveness, and overall competitiveness. The review also considered contextual factors like study characteristics, intervention details, industry settings, and external market influences, allowing for a thorough understanding of Lean Six Sigma's effectiveness across various manufacturing environments. to be a flowchart.

2.6.2. Data Items Variables

This section provides an overview of the data items targeted in the review, emphasizing both primary and supplementary variables related to the impact of Lean Six Sigma on SMEs. The primary outcomes focus on key performance indicators, including operational and financial performance, innovation, customer satisfaction, and long-term impacts. These metrics quantify the tangible benefits of Lean Six Sigma in enhancing production processes, cost-efficiency, and competitiveness see Table 5 [149] – [171].

Additionally, the review considers various contextual factors, such as study and participant characteristics, intervention details, industry context, and external market influences. This comprehensive approach facilitates a nuanced analysis of how Lean Six Sigma methodologies drive performance improvements across diverse manufacturing environments.

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Table 5. Data Items Variables.

Fields	Description
Research Title	The title of each study was included in the review
Year of Publication	The year when the study was published
Online database	The database where the study was sourced (Google Scholar, SCOPUS, Web of Science
Journal Name	The Publisher in which the articles was published
Research Type	The type of publication (e.g. Article, Journal, Case study, Applied Research, Empirical study, etc.)
Number of Citations	The number of times the study has been cited by other researchers
Financial Information	Any financial performance information that was mentioned in the study.
Innovation Performance	Innovations or improvements reported as an outcome of the research.
Organizational Outcomes	Impacts on organizational processes, efficiency, teamwork, etc.
Employee Outcome	Effects on employee skills, confidence, or overall performance.
Customer Outcome	Impacts on customer satisfaction, complaints, or behavior
long term Impacts	Long-term effects of the research, such as sustainability or competitive advantage

2.7. Study Risk of Bias Assessment

In this systematic review on the application of Lean Six Sigma in small and medium-sized manufacturing enterprises (SMEs), a rigorous risk of bias assessment was undertaken to ensure the reliability and validity of the synthesized findings. Due to the diverse study designs included—spanning both randomized and non-randomized studies—the Newcastle-Ottawa Scale (NOS) was selected as the most appropriate tool. The NOS evaluates bias across three essential domains: Selection, Comparability, and Outcome/Exposure, offering a structured and consistent approach to assess the quality of observational studies. Each study was independently assessed by two reviewers to minimize the potential for individual bias. Discrepancies between reviewers were addressed through consensus discussions, and if agreement could not be achieved, a third reviewer was consulted to provide an impartial decision. This multi-step process, depicted in Figure 5, supports a robust and transparent assessment framework. For studies with multiple reports, decision rules were implemented to ensure that only the most relevant and up-to-date data were included. This meticulous selection and cross-checking procedure enhances the integrity of the review, allowing for a comprehensive and unbiased synthesis of findings. No automation tools were utilized during this process, ensuring a thorough manual evaluation.

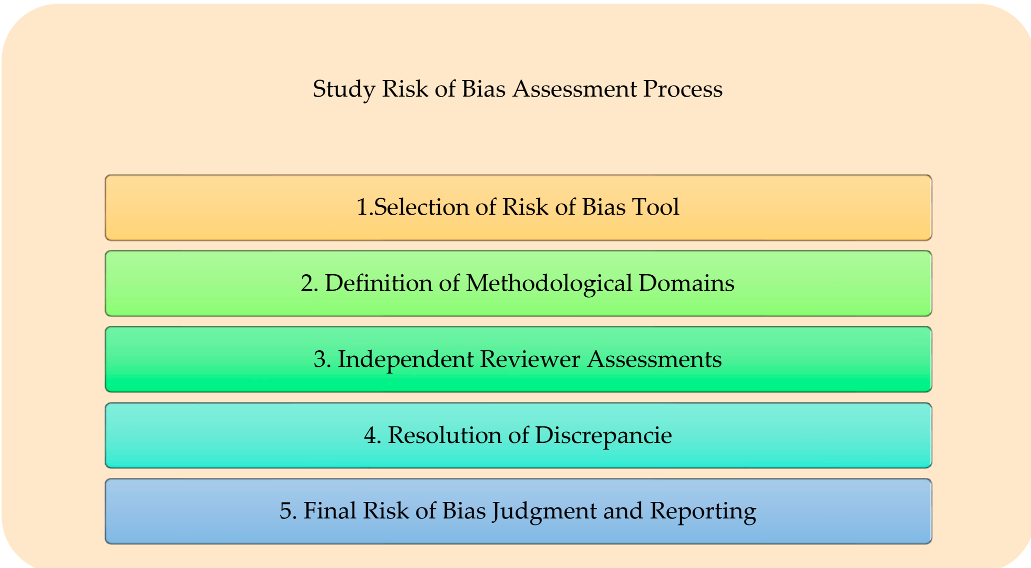

Figure 5. Study Risk of Bias Assessment.

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By implementing this systematic risk of bias assessment, the review provides reliable conclusions on Lean Six Sigma's impact on SME performance, offering insights grounded in rigorously vetted evidence.

2.8. Effect Measures

In this systematic review, effect measures were utilized to comprehensively evaluate Lean Six Sigma's impact within SME manufacturing firms. The approach begins by defining the primary outcomes of interest related to Lean Six Sigma applications, followed by selecting appropriate effect measures that align with these intended outcomes. Each chosen effect measure is transparently reported to ensure clarity and replicability across contexts. After defining and selecting the effect measures, the results were meta-analyzed, with particular consideration given to the heterogeneity of the included studies or contexts, as shown in Figure 6 [149] – [171]. This approach addresses the variation across studies, enhancing the robustness and reliability of the synthesized findings. Lastly, the framework emphasizes the practical linkage between effect measures and decision-making, providing insights to assist SME stakeholders in interpreting the results effectively and making informed, evidence-based decisions.

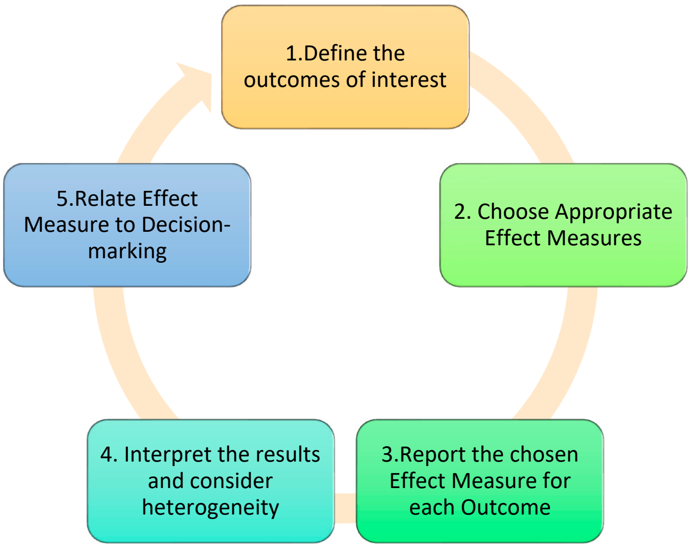

Figure 6. Effect Measures Methodology Outline.

This systematic approach to effect measurement not only strengthens the analytical depth of the review but also ensures that the findings are meaningful and actionable for decision-makers within SMEs, reinforcing the value of Lean Six Sigma applications in this sector.

2.9. Synthesis Method

2.9.1. Eligibility Criteria for Synthesis Grouping

The synthesis process for evaluating the application of Lean Six Sigma within small and medium-sized manufacturing enterprises (SMEs) involved systematically organizing studies into key thematic areas. This was achieved through meticulous screening and data extraction, aligning with the predefined inclusion and exclusion criteria outlined in Table 6. The criteria ensured that each study focused on Lean Six Sigma's relevance to SMEs, included a research framework, was published in English, and fell within the 2014–2024 publication period. Studies meeting these criteria were compiled in an Excel sheet, where data was extracted and organized according to the categories shown in Table 6.

Table 6. Synthesis-Specific Grouping.

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Category	Data Extracted
Study Details	Research Title, Year of Publication, Online Database, Journal Name, Research Type, Number of Citations, Google Scholar Ranking
Contextual Information	Industry or Sector, SME Characteristics, Geographic Location, Economic Context
Methods of Information	Type of Study, Research Design, Sample Size, Sample Characteristics, Data Collection Methods, Data Analysis Techniques, Methodologies, Types of Virtual Collaboration (Synchronous, Asynchronous, Hybrid)
Outcomes and Impacts	Operational Performance, Financial Information, Innovation Performance, Collaboration Outcomes, Employee Outcomes, Customer Outcomes, Long-term Impacts

The synthesis eligibility process involved several structured steps to ensure consistency and transparency. Initially, studies were screened against the inclusion and exclusion criteria to confirm alignment with the review's focus on Lean Six Sigma applications in SMEs. This screening assessed relevance, research framework presence, language, and publication date compliance. Following the initial screening, detailed data extraction was performed, capturing study details, contextual factors, methodologies, and outcomes systematically. Extracted characteristics were then compared against predefined synthesis groups, such as operational performance and financial impact, facilitating accurate categorization. For studies that exhibited significant findings across multiple areas or appeared as borderline cases, subjective judgments were made to classify them under the most relevant synthesis group based on their primary contribution. This structured approach ensured that the grouping for synthesis was transparent, consistent, and reflective of the studies' impact on Lean Six Sigma applications within SMEs.

2.9.2. Data Preparation and Transformation Methods

To ensure consistency and comparability across data extracted from the reviewed studies, specific data preparation and transformation methods were applied. These methods addressed issues related to missing information and data format discrepancies, ensuring that all data was uniformly prepared for presentation and synthesis. The Data Preparation Methods for Review is tabulated in Table 7.

Table 7. Data Preparation Methods for Review.

Criteria	Method Used
Handling Missing Information	Studies lacking essential information were excluded from the review. For studies providing data in ranges (e.g., survey responses between 90–120 participants), midpoint estimates were used to standardize the figures.
Data Conversions	Fractions and percentages were converted to decimals using Microsoft Excel, ensuring uniformity and facilitating direct comparisons across all data points.

These preparation methods contributed to the rigor and reliability of the review, allowing for a consistent synthesis of findings on Lean Six Sigma's application within SME manufacturing firms.

2.9.3. Data Presentation and Visualization Techniques

To effectively communicate the results of this systematic review, we employed a combination of tabular and graphical methods as detailed in Table 8 [149] – [171]. These techniques were selected to ensure a clear, accessible, and comprehensive presentation of the findings related to LSS applications in SMEs. We structured tables to organize and compare key findings across studies systematically.

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These tables included data such as study contributions, benefits, challenges of LSS adaptation, and impacts on SMEs. To prioritize relevance, tables were ordered by factors like the year of publication and citation counts, highlighting the most influential studies within the field. Microsoft Excel and Microsoft Word were used to create visual representations, including pie charts, graphs, and flow charts. Pie charts illustrated the proportion of studies addressing various LSS aspects, such as methodologies or challenges encountered. Graphs displayed trends over time and distributions of study outcomes, aiding in the identification of patterns and correlations. Flow charts outlined the study selection and synthesis process, offering a clear visual summary of the methodological steps undertaken. These visual aids were designed to enhance transparency, allowing readers to quickly understand key insights and patterns. By integrating these graphical tools with detailed tabulation, we aimed to provide a nuanced and easily interpretable overview of the synthesized data.

Table 8. Data Presentation and Synthesis Workflow.

Steps	Description
1. Data Collection	Collect raw data from reviewed studies.
2. Data Preparation	Address missing information and perform data conversions.
3. Tabulation Methods	Structure tables to include study contributions, benefits, challenges, and impacts; order tables by publication year and citation count.
4. Graphical Methods	Create pie charts, graphs, and flow charts to visually represent study selection and outcome distribution.
5. Presentation of Results	Combine tabular and graphical methods to offer a comprehensive and transparent view of findings.
6. Review and Finalize	Review for completeness and accuracy; prepare results for inclusion in the review.

This workflow ensures that the data presentation is both thorough and accessible, providing readers with a clear understanding of the systematic review findings related to Lean Six Sigma in SME manufacturing.

2.9.4. Methods for Data Synthesis and Meta-Analysis

Given the significant heterogeneity among the included studies, a traditional meta-analysis was deemed impractical. Instead, structured summaries and descriptive statistics were used to integrate the findings, as this approach accommodated the variations in study designs and outcome measures. Microsoft Excel and Microsoft Word facilitated the preparation of tables, graphs, pie charts, and flow charts, which effectively organized and displayed the diverse data, allowing for the identification of patterns and trends. The structured summaries offered a comprehensive overview of LSS implementation benefits and challenges, reflecting the range of contexts and outcomes in the studies. This synthesis method ensured a transparent and accessible presentation of findings, accommodating the unique characteristics of each study.

2.9.5. Investigation of Heterogeneity Sources

To explore potential sources of heterogeneity among the study results, we conducted subgroup analyses that examined variations based on factors such as industry sector, enterprise size, and specific LSS techniques. For instance, we grouped studies by manufacturing sector to investigate if the effectiveness of LSS varied across sectors. We also analyzed the impact of SME size on LSS outcomes. These subgroup analyses enabled the comparison of results across different levels of each factor, with statistical tests for interaction used to determine if observed effects differed significantly between subgroups. As meta-analysis was not feasible due to the lack of standardized effect estimates, results were organized in tables to allow for a visual assessment of how these subgroup factors influenced LSS effectiveness and challenges in different contexts. While these analyses

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provided valuable insights, they were exploratory rather than prespecified in our protocol. Therefore, the findings should be interpreted cautiously, considering the limitations of the available data and the methods employed.

2.9.6. Sensitivity Analyses

Sensitivity analyses were conducted to assess the robustness of the synthesis results concerning methodological assumptions and decisions. These analyses examined the impact of excluding studies identified as high risk of bias and tested alternative statistical models to verify that specific studies or analytical techniques did not unduly influence conclusions. This approach reinforced the reliability of our findings by addressing potential biases and confirming consistency across different analytical scenarios, ultimately enhancing the credibility of the conclusions on LSS applications for SMEs.

2.10. Reporting Bias Assessment

Assessing the risk of reporting bias was critical to ensure the validity and reliability of this systematic review on Lean Six Sigma for SMEs. Potential biases, including selective publication, language bias, and selective reporting of outcomes, were methodically addressed. We employed contour-enhanced funnel plots as a visual tool to detect asymmetries in the data, differentiating between missing studies due to bias and those missing by chance. These plots, with statistical significance contours, provided a robust representation of potential biases. This assessment relied on proven techniques documented extensively in the literature, emphasizing methodological rigor. Contour-enhanced funnel plots visually assessed the distribution of studies, allowing us to identify and account for potential biases. Two independent reviewers conducted this evaluation, and discrepancies were resolved through consensus or, when necessary, with input from a methodological expert. No automation tools were employed for bias assessment; instead, a manual approach was chosen to ensure careful data analysis and visualization. Further, we performed comprehensive manual searches across multiple databases, including Google Scholar, Scopus, and Web of Science, to cross-reference data and address discrepancies, reinforcing the robustness of our conclusions. Given the unique context of LSS studies in SMEs, standard methods for assessing reporting bias were adapted to align with the characteristics of these studies, ensuring relevance and accuracy. All methods and approaches used in this assessment are thoroughly documented in the supplementary materials, promoting transparency, and allowing future researchers to replicate or build on our analysis. This commitment to openness enhances the overall rigor and reliability of research in Lean Six Sigma applications for SMEs.

2.11. Certainty of Evidence

To ensure the external validity and credibility of outcomes related to LSS applications in SMEs, a systematic certainty assessment was conducted. This approach helps verify the quality of the presented evidence, allowing readers to gauge the reliability of the conclusions drawn. The assessment followed a structured, four-step method, as illustrated in Figure 7, which facilitated a thorough and transparent evaluation [149] – [171]. The four stages of the certainty assessment included (1) tool selection, where an appropriate tool was chosen to evaluate certainty, tailored to the specific focus of the study on LSS applications in SMEs; (2) evaluating factors that influence certainty, such as study design quality, data consistency, and relevance; (3) defining the overall certainty level by synthesizing insights from these factors to assign a certainty level to each outcome category, providing a nuanced understanding of evidence strength; and (4) engaging multiple reviewers with transparent reporting, where reviewers independently assessed each outcome and resolved discrepancies through consensus discussions, ensuring objectivity and rigor in the certainty evaluation. Figure 7 provides a visual summary of the certainty assessment stages, covering outcome categories, certainty levels, the number of studies included, and justification for each certainty decision. By following this structured process, the certainty assessment offered a clear, accessible evaluation of the evidence quality. This transparency enables readers to appreciate the strength of

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the study's conclusions on LSS applications in SMEs, reinforcing the reliability and relevance of the findings.

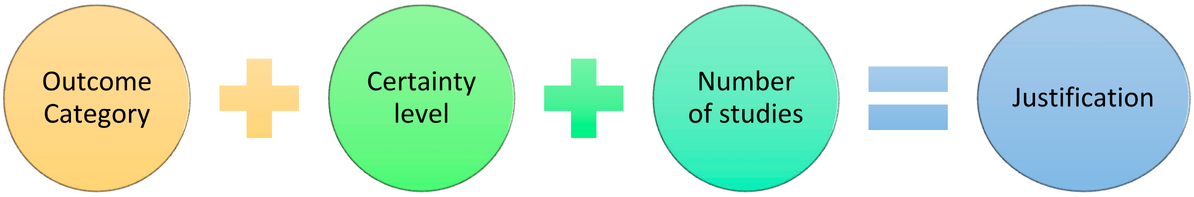

Figure 7. Certainty of Evidence procedure.

By following this structured process, the certainty assessment offered a clear, accessible evaluation of the evidence quality. This transparency enables readers to appreciate the strength of the study's conclusions on LSS applications in SMEs, reinforcing the reliability and relevance of the findings.

3. Results

This section presents the comprehensive findings from the systematic review on the application of LSSin small and medium-sized manufacturing enterprises (SMEs). The goal was to evaluate the extent of LSS implementation, understand the challenges SMEs face, and assess the outcomes achieved. Through synthesizing data from multiple studies across various geographic locations, industry contexts, and research designs, the review provides a well-rounded perspective on LSS adoption, highlighting both operational performance impacts and broader organizational outcomes. Following this introduction, the key phases involved in evaluating systematic review results are illustrated in Figure 8, which provides a visual summary of the processes used to ensure the validity, reliability, and relevance of the included studies.

Figure 8. Key Phases in Evaluating Systematic Review.

The analysis revealed several key trends and patterns: LSS implementation in SMEs often results in improvements in operational efficiency, cost reduction, and quality control, but challenges such as resource limitations and resistance to change are common barriers. The findings underscore the

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benefits of LSS for enhancing productivity and competitiveness in SMEs, while also identifying limitations that need to be addressed for effective application. Furthermore, insights into best practices emerged, suggesting that tailored LSS strategies, appropriate resource allocation, and strong leadership are essential for successful implementation. The review also points out areas for future research, particularly in adapting LSS methodologies to fit SMEs' unique constraints and needs.

3.1. Study Selection

3.1.1. Results of the Search and Selection Process

The search process involved three major databases: SCOPUS, Web of Science, and Google Scholar. Initially, 150 records passed the inclusion criteria based on automated selection tools, as outlined by the established inclusion and exclusion criteria. However, during the screening process, only 109 records were retained for inclusion in the systematic review. The screening identified 32 duplicate records, and the remaining 9 records were excluded due to the absence of a proper structured methodology. Ultimately, 109 studies were successfully included in the review, with all initially selected records verified by human review. As shown in Figure 9, this flow chart outlines the progression of records through each stage of the review process, from identification and screening to eligibility and final inclusion.

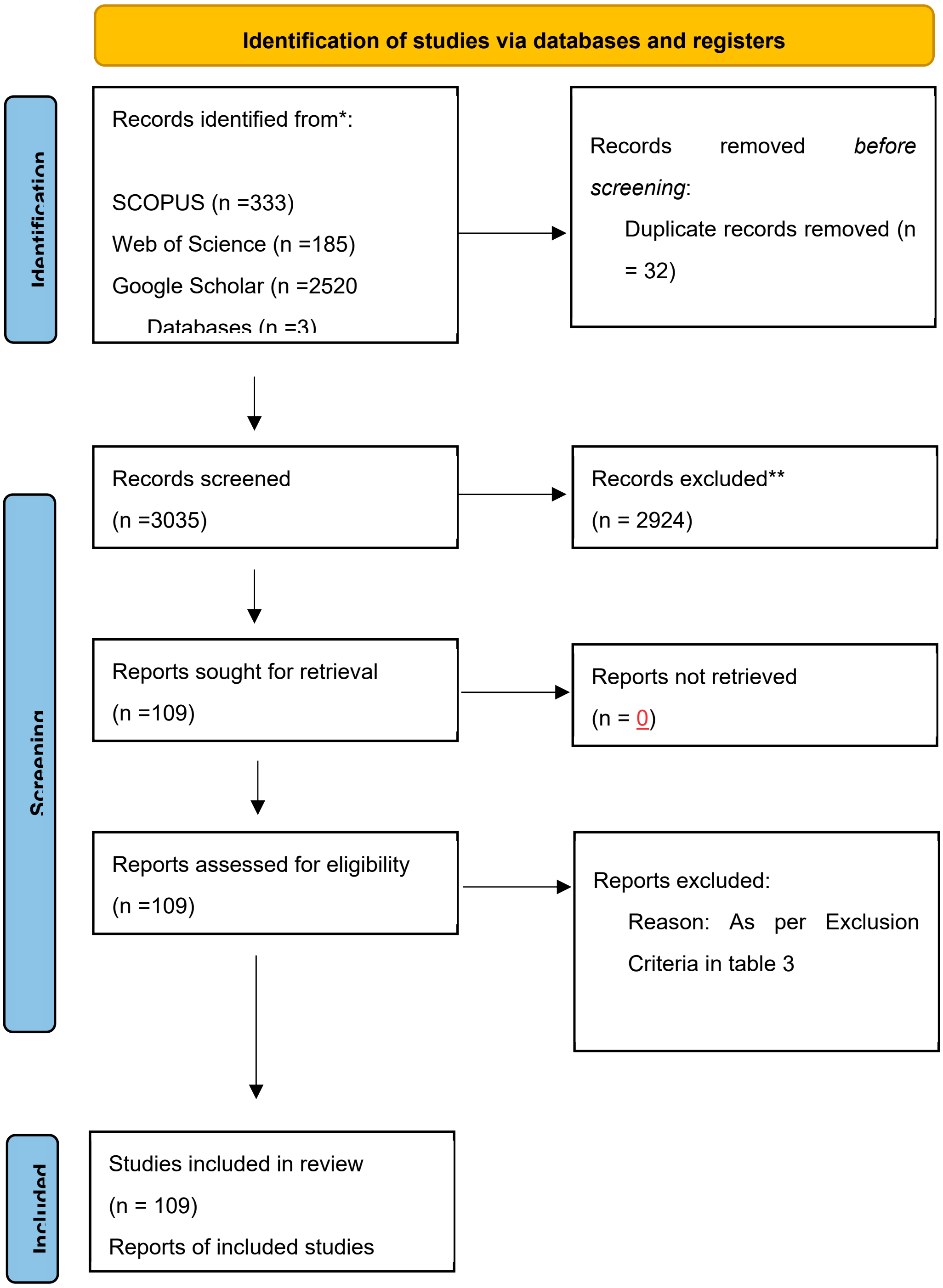

Figure 9. Proposed PRISMA Flowchart.

The search and selection process were comprehensive, reducing the initial 150 records to 109 studies that met the stringent criteria. This rigorous screening highlights the focus on quality and relevance, ensuring that only studies with robust methodologies were included in the systematic review. The process emphasized transparency and adherence to the inclusion and exclusion criteria, forming a solid foundation for the subsequent analysis. The systematic review process resulted in records obtained from three major databases, showcasing a comprehensive search strategy, as illustrated in Figure 10. Google Scholar contributed 29% of the total records, reflecting its extensive coverage and inclusion of diverse publications relevant to Lean Six Sigma in small and medium-sized manufacturing enterprises (SMEs). Scopus provided 32% of the total records, offering a significant portion of high-quality, peer-reviewed sources spanning various disciplines. The largest share, 49%,

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was sourced from Web of Science, indicating its robust collection of high-impact journals and a substantial presence of relevant research.

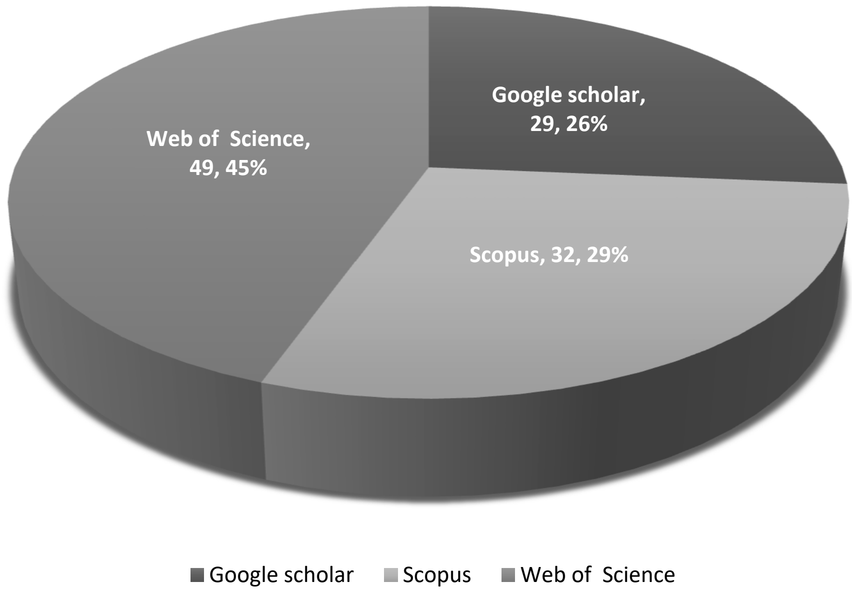

Figure 10. Research distribution by Sources.

This distribution across Google Scholar, Scopus, and Web of Science facilitated a thorough and balanced capture of the literature. This comprehensive approach enhanced the depth and reliability of the review, ensuring a well-rounded perspective on LSS studies in SMEs.

3.1.2. Studies Which Met the Inclusion Criteria But Excluded

During the screening process, 150 studies initially appeared to meet the inclusion criteria. However, after a thorough review, it was discovered that 32 of these studies were duplicates, and 9 studies lacked a well-structured methodology, leading to their exclusion from the review.

3.2. Study Characteristics

The annual publication trend, as depicted in Figure 11, shows an initial downward trajectory, followed by an upward trend beginning in 2017 and peaking in 2024 with 30 studies. This peak reflects a substantial increase in research activity related to Lean Six Sigma implementation in SMEs. The year 2024 marks a notable surge in research outputs, spanning various publication types, including journal articles, applied research, and conference papers. This upward trend highlights the increasing academic and practical interest in Lean Six Sigma methodologies for enhancing operational efficiency, reducing costs, and improving performance in SMEs. The initial decline from 2014, followed by a consistent rise in publications from 2019 to 2024, emphasizes the growing focus on applying Lean Six Sigma to transform manufacturing practices and drive performance improvements.

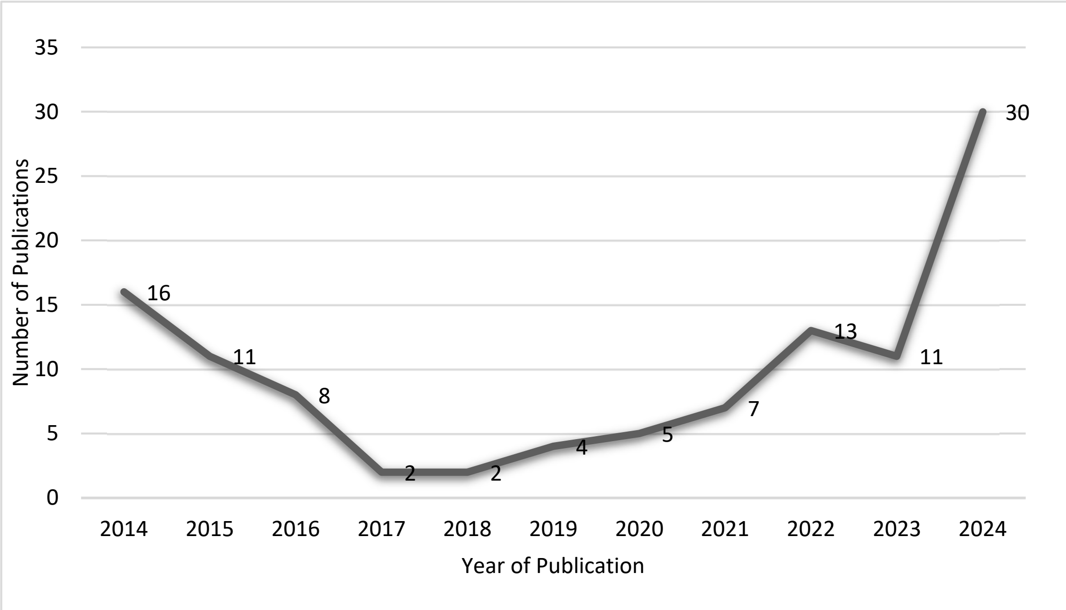

Figure 11. Research distribution by Volume per year.

The upward trajectory in publications from 2017 to 2024 demonstrates an escalating interest in Lean Six Sigma for SMEs, reflecting the methodology's importance in operational transformation and competitive improvement within the manufacturing sector. The distribution of publication types, as illustrated in Figure 12, reveals that journal articles constitute the majority at 63.58%, followed by conference papers (11.10%), applied research (7.6%), and empirical studies (13.12%). This increase in scholarly output aligns with the rising adoption of Lean Six Sigma tools and strategies, which are pivotal for optimizing production processes and enhancing competitiveness in SMEs.

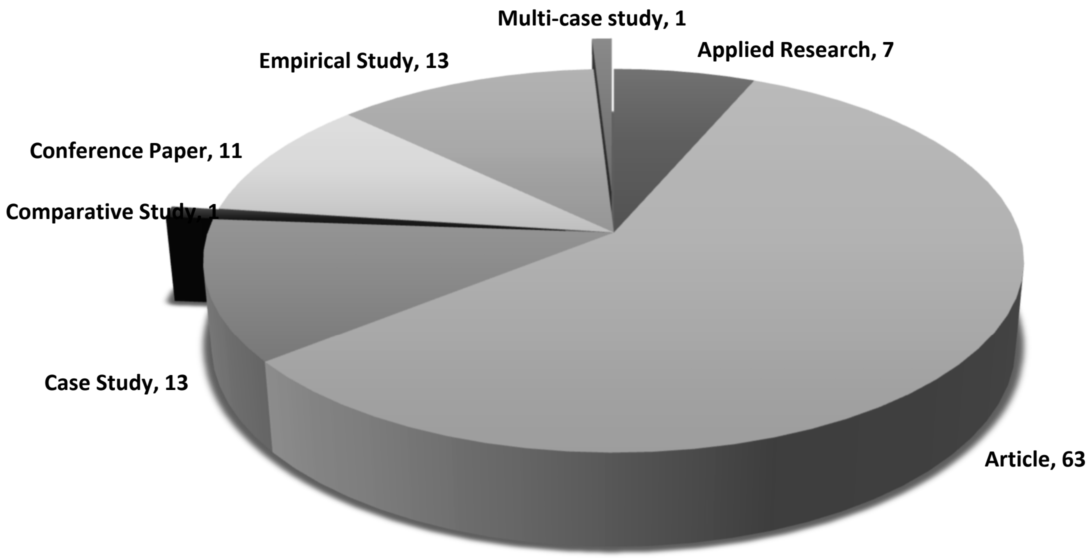

Figure 12. Research distribution by Research Design.

The dominance of journal articles in this review's distribution of publication types underscores the robust academic interest in Lean Six Sigma for SMEs. This trend corresponds with a broader adoption of Lean Six Sigma methodologies aimed at achieving production efficiency and operational excellence in the SME manufacturing sector.

As summarized in Table 9, the effect measures derived from the studies included in this systematic review focus on three primary performance areas: operational performance, financial performance, and quality performance. Each category is assessed using relevant statistical measures, such as Mean Difference (MD) for continuous outcomes and Risk Ratio (RR) for binary outcomes, to provide a detailed understanding of Lean Six Sigma's impact on SMEs. For operational performance, effects are categorized as trivial, small, moderate, or large based on percentage improvements in indicators like cycle time and defect rates. Financial performance metrics are particularly sensitive, with small percentage changes translating to significant monetary impacts, which is critical for SMEs. Quality performance measures include both continuous and binary outcomes, offering a comprehensive view of improvements in quality indicators, such as First Pass Yield (FPY). The rationale for each effect measure is also presented, underscoring the significance of these metrics in evaluating Lean Six Sigma's impact within SMEs.

Table 9. Effect Measures from Studies Conducted.

Outcome	Effect Measure	Thresholds/Ranges	Number of studies	Rationale
Operational Performance	Continuous (Mean Difference, MD)	Trivial Effect: MD < 5% Small Effect: MD = 5%–10% Moderate Effect: MD = 10%–20% Large Effect: MD > 20%	109	Improvements in operational performance indicators such as cycle time, defect rates, and throughput are common. A reduction of less than 5% is considered trivial, while anything over 20% is seen as a major improvement.
Financial Performance	Continuous (Mean Difference, MD)	Trivial Effect: MD < 2% Small Effect: MD = 2%–5% Moderate Effect: MD = 5%–10% Large Effect: MD > 10%	109	Financial metrics are more sensitive, with small percentage changes representing significant monetary impact, particularly for SMEs. Effects are measured by cost savings, ROI, and revenue growth with more conservative thresholds.
Quality Performance	Continuous (Mean Difference, MD) Binary (Risk Ratio, RR)	(Continuous)Trivial Effect: MD < 5% Small Effect: MD = 5%–10% Moderate Effect: MD = 10%–15% Large Effect: MD > 15% RR (Binary): No/Trivial Effect: RR = 1.0 Small Effect: RR = 0.9–0.95 Moderate Effect: RR = 0.8–0.9 Large Effect: RR < 0.8	67	Quality improvements are essential in manufacturing. MD is used for ratios or percentages such as First Pass Yield (FPY), while RR assesses the probability of achieving desired quality levels. Industry-standard thresholds are applied

The categorization of effect measures across operational, financial, and quality performance areas provides a structured framework to assess Lean Six Sigma's impact in SMEs. These measures, with defined thresholds, allow for a nuanced understanding of improvement levels, supporting SMEs in making data-informed decisions to enhance efficiency and competitiveness.

Table 9 below provides a detailed overview of the study characteristics extracted from 109 publications focusing on the applications of Lean Six Sigma in manufacturing SMEs. This table captures essential information that contributes to a deeper understanding of Lean Six Sigma research. Key aspects include the publication year, which reveals trends and shifts in research focus over time, and the research type, distinguishing between empirical studies, case studies, literature reviews, and theoretical frameworks. These distinctions highlight the diversity of research approaches applied in the field. Further details in the table cover the disciplinary focus, which demonstrates the interdisciplinary nature of Lean Six Sigma applications, spanning various fields and industries. The research design outlines frameworks like qualitative, quantitative, or mixed methods, showing the range of approaches utilized. Methodologies highlight specific Lean Six Sigma tools such as DMAIC (Define, Measure, Analyze, Improve, Control), Kaizen, and process mapping. Additionally, data collection techniques, including surveys, interviews, observations, and archival research, ensure the reliability and validity of findings. Data analysis methods like statistical analysis, thematic analysis, and case study analysis further elucidate the outcomes. Finally, Table 9 summarizes the organizational outcomes observed in the studies, including enhancements in efficiency, quality, cost reduction, and customer satisfaction. This synthesis of study characteristics offers valuable insights into the effectiveness of Lean Six Sigma in various manufacturing contexts, enriching the knowledge base surrounding Lean Six Sigma and its transformative potential for SMEs in manufacturing.

Table 9. Comprehensive Overview of the Study Characteristics.

Ref.	Year	Research Type	Discipline	Location	Research Design	Methodology	Data Analysis Techniques	Organizational Outcomes
[40]	2016	Article	Service and Production	Europe	Case studies, observations, interviews	Case studies, observations, interviews	Comparative analysis, trend identification	Cooperation development with networks and large customers
[41]	2016	Article	Manufacturing	Netherlands	Multi-method triangulation approach	Literature study, focus group, retrospective interviews	Confirmatory evidence and proposals for revision	Not specified
[42]	2022	Article	Business & Economics	UK	Not specified	Questionnaire survey, literature review	Not specified	Not specified
[43]	2024	Article	Business & Economics	UK	Not specified	Questionnaire survey, literature review	Not specified	Not specified
[44]	2015	Article	Food Processing	Europe	DMAIC methodology	Shop floor observations, brainstorming sessions, material balance analysis, ANOVA test, DoE, FMEA	Descriptive statistics, ANOVA, Pareto chart, cause-and-effect diagram, DoE	Improved efficiency and teamwork
[45]	2018	Article	Manufacturing	Not specified	Single-case study	Qualitative methods, VOC records, VSM, histogram	SIPOC, C&E diagram, FMEA, process cycle efficiency, takt time, brainstorming	Cross-functional team collaboration, training on basic problem-solving tools
[46]	2020	Article	Business & Economics	UK	Not specified	Questionnaire survey	Not specified	Not specified
[47]	2021	Article	Engineering, Business & Economics	Slovakia	Not specified	Questionnaire survey	Not specified	Not specified
[48]	2022	Article	Business & Economics	Slovakia	Not specified	Questionnaire survey	Not specified	Not specified
[49]	2014	Article	Engineering Business & Economics	Sweden	Not specified	Questionnaire survey	Not specified	Not specified
[50]	2023	Article	Construction & Building Technology	England	Questionnaire and expert opinion survey	Questionnaire survey, expert opinion survey	Fuzzy TOPSIS method	Not specified
[51]	2022	Article	Manufacturing	Greece	DMAIC Methodology	Case study analysis	Evaluation of critical success factors, indirect monetary measurement	Specific critical success factors identified, benefits realized
[52]	2021	Article	LSS Implementation	India	Extensive literature review, questionnaire survey	Questionnaire survey, literature review	Statistical analysis, Interpretive Structural Modeling (ISM), MICMAC analysis,	Identified barriers affecting LSS implementation in SMEs

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							Structural Equation Modeling (SEM)	
[53]	2023	Article	LSS Implementation	Saudi Arabia	Principal Components Analysis (PCA)	Literature review, factor analysis	PCA to identify critical success factors (CSFs)	Not specified
[54]	2022	Article	Manufacturing	USA	DMAIC Methodology	Literature review, expert opinions	Comparative analysis of existing frameworks, development of new framework	Provides a guide for LSS implementation tailored to SMEs
[55]	2022	Article	Clothing Manufacturing	Tunisia	Experimental	Discrete-event simulation, statistical distribution analysis	Bizagi Process Modeler, Stat fit Student Version	Increased production efficiency, reduced lead time, and waiting time
[56]	2023	Article	Tire Manufacturing	India	Mixed Methods	Data collection via quality tools, measurements, and control charts	Statistical analysis, process capability analysis, control charts	Improved process management, reduced wastage
[57]	2022	Article	Manufacturing SMEs	India	Graph theoretic approach for evaluating critical success factors (CSFs)	Conceptual analysis and index development	Graph theoretic model	
[58]	2023	Article	Manufacturing/Industrial	India	Quantitative	Questionnaire-based survey	TOPSIS, Grey Relational Analysis (GRA)	Improved understanding of LSS barriers; not quantified
[59]	2023	Article	Clothing SMEs	Tunisia	Case Study	Survey, Process Capability Measurement	Root Cause Analysis, Process Modeling and Simulation	Improved process efficiency, better performance in certified SMEs, customer satisfaction
[60]	2023	Article	SMEs	Pakistan	Survey	Survey, Spearman's correlation test	Cronbach's alpha, Spearman's correlation test, Factor analysis	Positive impact on environmental performance; no significant impact on operational and business performance
[61]	2024	Article	Small Manufacturing Enterprises	India	Case Study	Literature review, Expert surveys	CIMTC, Importance-Index Analysis, ISM-MICMAC Analysis	Identification of 13 key strategies; high internal consistency; modelled strategies for LSS implementation
[62]	2024	Article	Small Manufacturing Enterprises	India	Quantitative	Fuzzy TOPSIS, Literature review	Barriers to LSS implementation, Prioritized strategies	Improved implementation of LSS; enhanced performance through prioritization of strategies
[63]	2024	Article	Small Manufacturing Enterprises	Northern Ireland	Qualitative	Thematic analysis, Coding, Repeat interviews	Absorptive capacity routines, Implementation strategies	Framework for wider application in SMEs
[64]	2021	Article	Small Manufacturing Enterprises	Not specified	Quantitative	Not specified	Crisis management strategies, Decision-	Not specified

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							making frameworks	
[65]	2024	Article	Printing Industry	India	Qualitative	DMAIC approach, Statistical process control, Capability analysis	Top Management Leadership, Data-Based Validation, Technical Know-how, Industrial Engineering Knowledge Base	Not specified
[66]	2016	Empirical Study	Manufacturing	Germany	Qualitative	Survey questionnaire, pre-tested for clarity	Correlation and regression analysis	Identifies the importance of core competence and organizational culture in LSS readiness, suggests training and development for enhancing LSS readiness
[67]	2022	Article	Machinery and Equipment SMEs	Malaysia	Qualitative	Descriptive analysis using Microsoft Excel	Lean understanding, implementation, and success	Provides a model for assessing and enhancing LM maturity in M&E SMEs
[68]	2023	Article	Manufacturing	USA	Qualitative	Descriptive analysis, value stream mapping, SMED	Inventory management, production flow, changeover times	Digital inventory management and automated systems, reduced changeover times
[69]	2024	Case Study	Timber Component Manufacturing	UK	Quantitative	Manual trimming efficiency, downtime, OEE (Overall Equipment Effectiveness)	Reduction in downtime, increase in OEE	Not specified
[70]	2021	Article	Medical Equipment Manufacturing	India	Quantitative	Best Worst Method (BWM), Analytic Hierarchy Process (AHP), Analytic Network Process (ANP)	Environmental LSS enablers, strategic and environmental-based enablers	Improved sustainability practices, reduced environmental impact, enhanced operational efficiency
[71]	2022	Article	Micro-Small and Medium Enterprises	India	Quantitative	AHP, Fuzzy-DEMATEL	Management-based factors, training- and education-based factors, technology-based factors, barriers to LSS adoption	Enhanced productivity, improved quality, increased profitability, and better social sustainability
[72]	2017	Comparative Study	Electronics, Automotive, Health, Transportation, Services, Aerospace, Oil	France	Survey	Online survey, pilot study	Wilcoxon signed-rank test, Cronbach's alpha	Rapid process improvement, customer satisfaction, sustainability
[73]	2021	Case Study	SMEs, Higher Education	UK	semi-structured interviews	Interviews, curriculum review	Comparative analysis	Improved graduate employability and productivity for SMEs
[74]	2022	Article	Furniture Production	Europe	Statistical analysis	Chi-square test, Cramer's contingency coefficient	Process capability, Return on Equity (ROE)	Improved ROE, reduced waste, and cost of non-conforming products, increased process capability

[75]	2024	Article	Manufacturing	Malaysia	Quantitative	Six-point Likert scale questionnaire	SEM, Reliability and validity analysis, Chi-square test	Positive influence of lean and Six Sigma on sustainable performance; Limited implementation of IR 4.0 technologies
[76]	2020	Article	Machinery and Equipment	Malaysia	Qualitative	Semi-structured Interviews	Content Analysis	Improvement in Organizational Performance
[77]	2023	Multi-case study	Manufacturing SMEs in India	India	Case study	Direct observation, structured questionnaire interviews, archival data	Cross-case comparison	Improved operational efficiency, reduced emissions, better labor relationships, increased profitability
[78]	2024	Case Study	Plumbing Industry	USA	Quantitative	Data collection via Six Sigma tools	Statistical analysis	Increased customer satisfaction, annual savings of $248,034
[79]	2019	Empirical Study	Optical Lens Assembly	China	Empirical Case Study	Process analysis, Value Stream Mapping, Statistical analysis	Statistical testing, Value Stream Mapping	Reduction in working hours from 132 hrs to 110.741 hrs, reduction in inventory carry rate from 41.6% to 20.8%, financial gain of NT$15.57 million
[80]	2024	Case Study	South African Service Industry	South Africa	DMAIC Methodology	Pareto chart analysis, cause-effect diagram, PDCA approach	Process Cycle Efficiency (PCE), Value-Added Time (VDT), Non-Value-Added Time (NVDT), Uptime, Downtime	Improved process efficiency and reduced waste, enhanced customer satisfaction, increased profitability
[81]	2024	Case Study	Injection Moulding, SMEs	Netherlands	DMAIC Methodology	Experimental Testing, Statistical Analysis	ANOVA, Paired t-test, Taguchi S/N Analysis	Improved Process Settings, Enhanced Product Consistency, Optimized Mould Design
[82]	2024	Case Study	Commerce and Services	Portugal	Empirical	Statistical Analysis	Six Sigma Knowledge Levels, Adoption Barriers	Not specified
[83]	2024	Article	Automotive	Czech Republic	Survey Study	Online Questionnaire	Statistical Analysis, Fisher's Exact Test	Variation in Six Sigma performance perceptions
[84]	2024	Empirical Study	Large Firms	Indonesia	Quantitative	Statistical Analysis	Business Performance	Holistic implementation improves performance
[85]	2017	Empirical Study	SMEs	India	Quantitative	Structural Equation Modeling	Economic, Environmental, Social Sustainability	Enhanced perspective on LMPs' role in sustainability; Practical insights for SME managers
[86]	2014	Empirical Study	SMEs	India	Quantitative	Statistical Analysis	Overall Equipment Effectiveness (OEE), Rework, Maintenance vs. Operation Cost, Defect Rate, Sigma Level	
[87]	2020	Article			Not Specified	Statistical Analysis	Not specified	Not specified
[88]	2014	Article	Manfacturing	Indonesia	Not Specified	Statistical Analysis	Not specified	Not specified
[89]	2024	Conference Paper	Professional Services	Peru	Not Specified	Statistical Analysis	Not specified	Improved delivery times and customer satisfaction

[90]	2024	Case Study	Transformer Manufacturing	USA	Longitudinal	Data collection, Surveys	Statistical Analysis, Minitab	Achieved a 50% reduction in equipment failures, improved process efficiency
[91]	2023	Empirical Study	IT	Europe	Survey	Online surveys	Regression analysis	Improved team coordination
[92]	2022	Case Study	Manufacturing	USA	Case study	Interviews, document review	Thematic analysis	Strengthened partnerships
[93]	2021	Article	Finance	Asia	Longitudinal	Surveys, interviews	Structural equation modeling	Higher collaboration quality
[94]	2015	Article	Manfacturing		Not Specified	Surveys, interviews		Not specified
[95]	2023	Article	Construction SMEs	UK	Quantitative	Fuzzy TOPSIS method	Barriers and strategies for LSS implementation	Not specified
[96]	2014	Conference paper	Manufacturing	Brazil	Case Study	Review, DMAIC Application	Feasibility Study	Not specified
[97]	2014	Conference paper	Manufacturing	Malaysia	Literature Review	Literature Review	Comparative Analysis	Challenges and cultural gaps
[98]	2015	Article	Manufacturing	Poland	Observations, Interviews	Case Studies, Observations	Qualitative Analysis	Benefits and barriers of LSS implementation
[99]	2024	Article	Manufacturing	Iraq	EFA, FAHP, FTOPSIS	Questionnaire, EFA, FAHP, FTOPSIS	Multi-Criteria Decision Analysis	Continuous improvement strategy
[100]	2014	Conference paper	Manufacturing	Italy	Survey	Survey	Descriptive Analysis	Relationship among lean and agile manufacturing
[101]	2014	Article	Manufacturing	Colombia	Four Phases	Case Studies, Implementation	Evaluation, Impact Assessment	Best practices in process management
[101]	2015	Conference paper	Manufacturing	Romania	Email Survey	Email Survey	Statistical Analysis	Critical success factors identified
[102]	2024	Article	Food Industry	Jordan	Case Study	Motion and Time Study	Value Stream Mapping	Improved efficiency in packing and labelling operations
[103]	2024	Article	Manufacturing	India	Framework Validation	Structural Instruments	Statistical Validation	Benefits of LGSS practices in operational processes
[104]	2024	Article	Medical Equipment	India	Case Study	DMAIC, Sustainability Tools	Descriptive and Quantitative Analysis	Operational and environmental sustainability
[105]	2014	Conference paper	Manufacturing	China	Framework development	Email Survey	-	Not specified
[106]	2014	Article	Manufacturing organisations	Not specified	Linear regression and SEM	Email Survey	-	Not specified
[107]	2014	Article	Manufacturing	USA	Case study	Observations	Not specified	Potential barriers to lean adoption
[108]	2014	Article	Manufacturing	India	Empirical study	Various tools (brainstorming, pareto analysis, etc.)	Statistical analysis	Not specified
[109]	2024	Article	Manufacturing	India	Empirical study	Survey	Structural equation modeling	Not specified
[110]	2014	Article	Steel industry	Sweden	Case study	Case study	Not specified	Not specified
[111]	2014	Article	Manufacturing	India	Empirical study	Not specified	Not specified	Not specified
[112]	2014	Conference paper	Manufacturing	Singapore	Empirical study	Case study	Not specified	Not specified
[113]	2016	Conference paper	Manufacturing	Thailand	Design of Experiment	Value Stream Mapping; Design of Experiment	Statistical analysis	Increased production and met customer demand

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[114]	2024	Article	Various sectors	Saudi Arabia	Grey-DEMATEL analysis	Grey-DEMATEL analysis	Grey-DEMATEL analysis	Not specified
[115]	2016	Article	Automotive	India	LSS framework development	DMAIC; Lean tools	Statistical analysis	Not specified
[116]	2015	Article	Food and beverage	Portugal	Not specified	Not specified	Not specified	Not specified
[117]	2024	Article	Medical device manufacturing	Malaysia	Partial least square-based SEM	Survey	Structural equation modeling	Not specified
[118]	2024	Conference paper	Manufacturing	Morocco	Questionnaire survey	Questionnaire survey	Not specified	Not specified
[119]	2015	Article	Manufacturing	Italy	DMAIC Methodology	Case study	ANOVA, Chi-square test	Not specified
[120]	2015	Conference paper	Food-processing	Belgium	DMAIC Methodology	Case study	Not specified	Not specified
[121]	2014	Article	Food Processing	Europe	Quantitative	Questionnaire	Statistical analysis	Not specified
[122]	2024	Article	Manufacturing	Poland	Quantitative	Statistical analysis	Statistical analysis	Not specified
[123]	2024	Conference Paper	Services	Morocco	Quantitative	Questionnaire	Statistical analysis	Not specified
[124]	2014	Article	Manufacturing	India	Quantitative	Data analysis	Statistical analysis	Not specified
[125]	2016	Article	Manufacturing	Netherlands	Mixed methods	Surveys; Interviews	Mixed methods	Not specified
[126]	2024	Article	Manufacturing	Italy	Qualitative	Case studies	Data analysis	Not specified
[127]	2015	Applied Research	Cement Bags Manufacturing	Not specified	Experimental Design	Survey, Observation, Data Analysis using MINITAB	Statistical Analysis, Process Capability Analysis	Improved operational efficiency and cost savings
[128]	2021	Applied Research	Fruit Juice Manufacturing	India	Experimental Design	Survey, Observation, Data Analysis using VSM, Cause and Effect Diagram	Statistical Analysis, DMAIC methodology	Improved operational efficiency and cost savings
[129]	2015	Applied Research	Automotive Spare Parts Manufacturing	India	Case Study	Statistical analysis, DMAIC framework	Defect rate reduction, process improvement	Improved process efficiency, long-term quality improvements
[130]	2024	Empirical Study	Manufacturing and Services	USA	Survey-based	Online surveys, Interviews	Statistical analysis, Regression models	Better cross-functional team collaboration
[131]	2024	Empirical Study	Manufacturing, Construction, Distribution, Service	Africa	Survey-based	Surveys, Interviews	Descriptive statistics, Ranking analysis	Mixed perceptions of benefits and challenges
[132]	2024	Empirical Study	Professional Services	Peru	Cross-sectional	Survey, Pilot Test	Statistical Analysis, ANOVA	Improvement in delivery times, increased productivity, higher on-time order percentage, increased income
[133]	2015	Empirical Study	Cement Manufacturing	Not specified	Cross-sectional	Survey, Pilot Test	Statistical Analysis, ANOVA	Increased annual production by 335,700 bags, reduced waste,

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								improved revenue by $21,682.61 per year
[134]	2020	Applied Research	Large manufacturing company	Zimbabwe	Case Study	Statistical analysis, Lean Six Sigma metrics	Manufacturing performance, process improvement	Enhanced manufacturing performance, cost reduction
[135]	2015	Applied Research	Construction industry	Not specified	Case Study	Statistical analysis, Lean Six Sigma tools	Construction project performance, process improvement	Sustainable improvements in construction processes
[136]	2019	Article	Manufacturing	France	Case study	Multi-criteria model, AHP method	Critical success factors for LSS implementation	Not specified
[137]	2016	Empirical Study	German Manufacturing SMEs	Germany	Empirical Analysis	Systematic Empirical Data Collection	Analysis of Critical Success Factors (CSFs)	Need for enhancement of core competencies and organizational culture; preparation work for LSS readiness
[138]	2022	Case Study	Manufacturing	Greece	DMAIC Methodology	Interviews, Observations	Qualitative analysis	Significant improvements using only employee working hours
[139]	2024	Case Study	Manufacturing	Not specified	DMAIC Methodology	Observations, Data Logs, Production Records	Statistical Analysis, Comparative Metrics	Increased production by 335,700 bags annually, Improved OEE from 0.454 to 0.543, Sigma level increased from 3.91 to 4.00
[140]	2019	Case Study	Manufacturing SMEs	Malaysia	Survey	Email Survey	SPSS 22.0	Significant relationship between LSS factors and operational performance; Management engagement and leadership perceived as most important
[141]	2020	Article	Manufacturing	India	DMAIC Methodology	Email Survey	[Data Analysis Techniques]	Improved efficiency, Reduced waste
[142]	2016	Applied Research	Automotive, Electronics	UK	Single Case Study	First Run Yield (FRY), Sigma Score	FRY Improvement from 98.4% to 99.03%, Sigma Score Improvement from 3.65 to 3.85	Achieved a significant reduction in scrap rate and financial savings, enhancing manufacturing efficiency and process capability.
[143]	2018	Applied Research	Plastic Manufacturing	India	Case Study	Surveys, Inspection	Statistical Analysis	Reduced defect rate of Floor Trap 6x4x2 fittings from 18% to 7%, leading to cost savings and improved product quality.
[144]	2022	Case Study	Bookkeeping and Tax Consulting	South Africa	DMAIC Methodology	Surveys, interviews	Statistical analysis	Process efficiency improvements, cost savings, enhanced service quality
[145]	2023	Case Study	Tyre Manufacturing SMEs	India	DMAIC Methodology	Schematic analysis, Measurement with Scaler and Scale	$\bar{X}$ and R charts, Pareto analysis, Capability histograms	Reduced material wastage, Increased production efficiency
[146]	2019	Empirical Study	Manufacturing SMEs	India	Case Study	Statistical analysis, process mapping	Scrap rate, rework rate, process efficiency	Improved waste management and cost reduction in manufacturing SMEs
[147]	2022	Empirical Study	Small and Medium Enterprises	India	Qualitative, Case Study	Interviews, Literature Review	Thematic Analysis	Improved Process Efficiency, Better Organizational Culture, Skill Development

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The structured data in Table 9 showcases the adaptability and positive impact of Lean Six Sigma practices in SMEs, underlining the significance of diverse research approaches and interdisciplinary applications. This systematic review contributes to understanding best practices in Lean Six Sigma and highlights areas for future research, strengthening SMEs' operational efficiency and competitiveness.

As illustrated in Figure 13, the geographic distribution of publications on LSS in SMEs highlights how different countries contribute to the research landscape in this field. The bar chart shows each country or region's publication count, offering insights into where LSS practices are most studied within the SME sector. India leads with 23.85% of the total publications, reflecting a strong emphasis on Lean Six Sigma in its SME sector. This prominent position suggests a significant research and practical interest in process improvement methodologies. The United States (6.42%) and the United Kingdom (5.50%) follow, indicating their established research infrastructures and industrial focus on efficiency methodologies. Malaysia and Europe each account for 5.50% of publications, showing a growing regional interest in LSS. Notably, 8.29% of publications lack specified geographic information, which may indicate studies with a global or nonspecific focus.

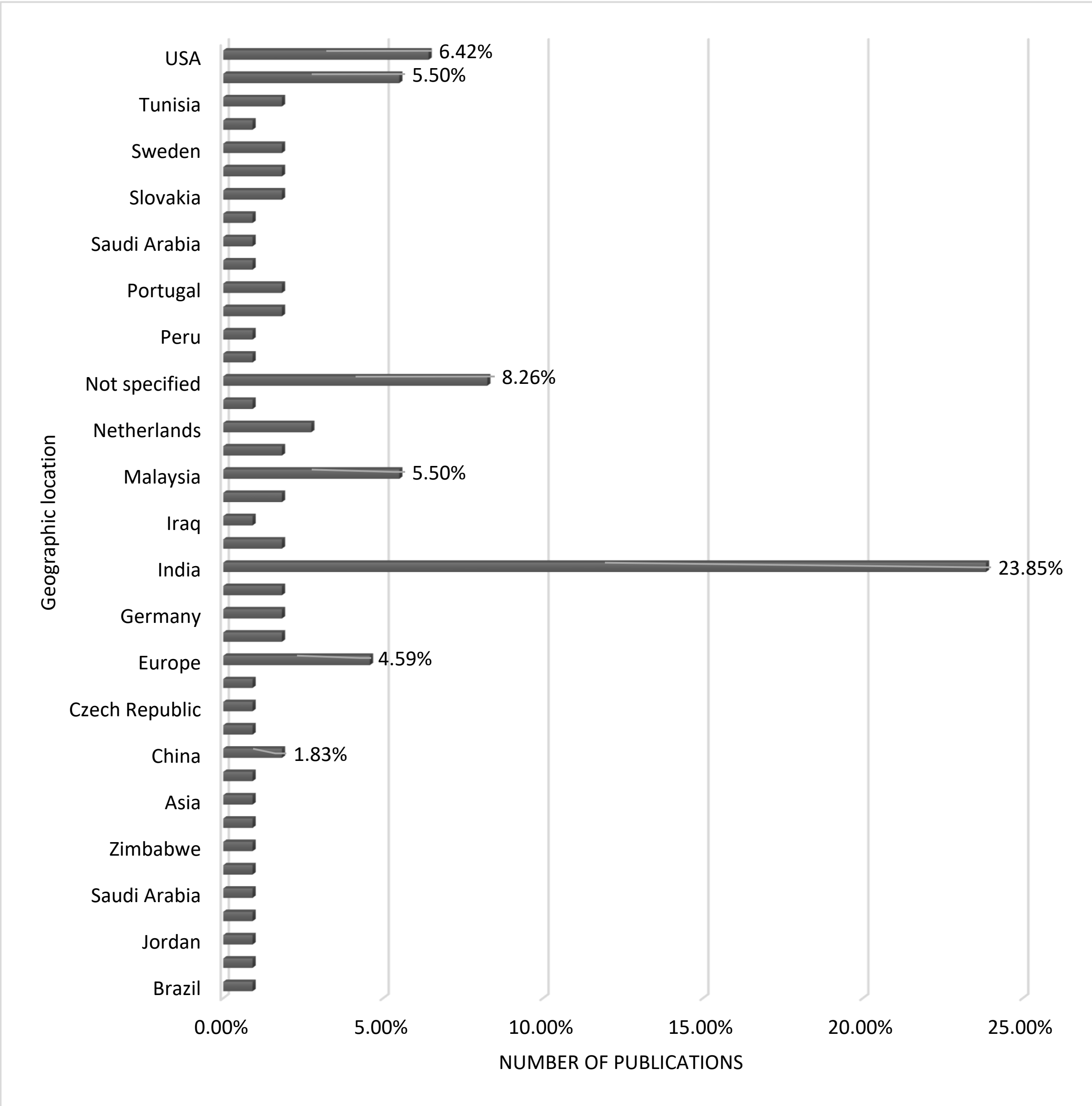

Figure 13. Research distribution by Geographic Location.

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As depicted in Figure 14, the distribution of research publications based on economic context reveals significant interest in the application of LSS in SMEs across diverse economic landscapes. The studies are categorized into three segments: Developed, Developing, and Not Specified. Notably, a substantial portion of publications comes from both developed (46.79%) and developing (45.87%) economies, underscoring the relevance of LSS in enhancing operational efficiency across different economic settings. The high volume of studies from these contexts suggests the widespread applicability of LSS practices, particularly in waste reduction and quality improvement, independent of economic conditions. The smaller percentage of publications (7.34%) categorized as "Not Specified" raises questions about the inclusion of mixed or undefined economic contexts in current research, highlighting an area for further exploration.

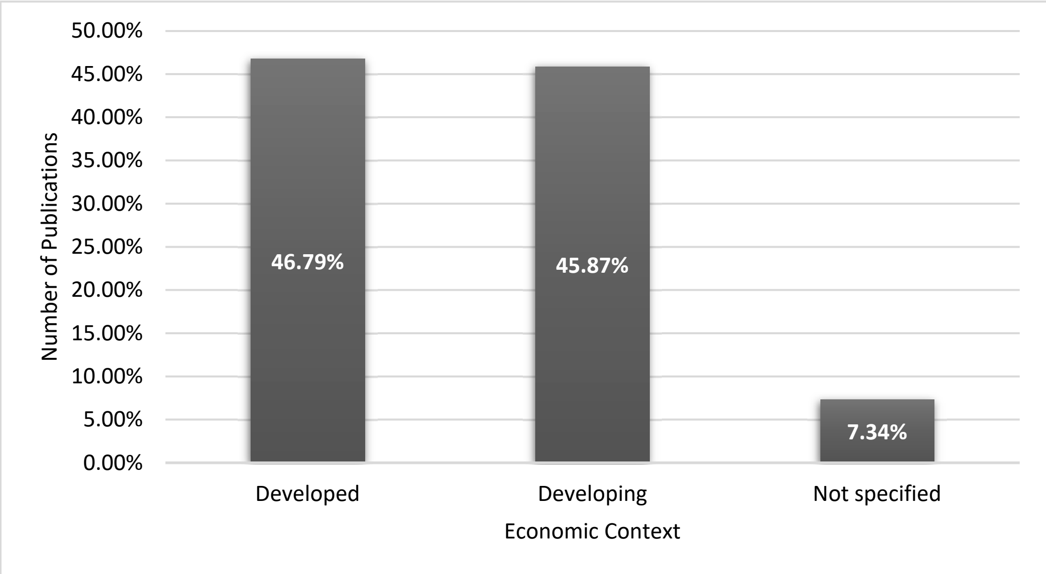

Figure 14. Research distribution by Economic Context.

The distribution shown in Figure 14 underscores the adaptability and importance of LSS across varied economic environments, with nearly equal representation in both developed and developing economies. This distribution serves as a foundation for examining how LSS methodologies are tailored to specific economic contexts, and it suggests potential opportunities for future research in less defined economic settings.

3.3. Risk of bias in Studies

The Newcastle-Ottawa Scale (NOS) was utilized to assess the quality and risk of bias within the included studies, focusing on three primary domains: selection, comparability, and outcomes, as shown in Table 9. Each study was rated on a star-based system, with a maximum score of nine stars indicating the highest quality. Studies were categorized as high (7–9 stars), moderate (5–6 stars), or low quality (0–4 stars) based on their total star ratings. This section presents the results of the NOS analysis, highlighting the quality of evidence and identifying potential biases that may influence the findings of this systematic review.

Table 9. Study Quality Assessment using Newcastle-Ottawa Scale.

Ref.	Selection (0-4 stars)	Comparability (0-2 stars)	Outcomes (0-3 stars)	Total Stars	Quality rating
[148,147,143, 149 45, 67,79,101]	☆☆☆☆	☆☆	☆☆☆	9	High Quality
[40,41,48,70,77]	☆☆☆☆	☆☆	☆☆☆	9	High Quality.
[105,126,44,60]	☆☆☆☆	☆☆	☆☆	8	High Quality

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[101,131,46,78,90]	☆☆☆☆	☆☆	☆☆	8	High Quality
[116,119,120,121,122]	☆☆☆	☆☆	☆☆☆	8	High Quality
[42,80,81,93, 105]	☆☆☆☆	☆	☆☆☆	8	High Quality
[104,95,77,118,106]	☆☆☆	☆	☆	5	Moderate Quality
[10,12,13,43,47,65,66,110]	☆☆	☆	☆☆	5	Moderate Quality
[130,132,50,51,52,53,54,55,87,88,89]	☆☆☆	☆	☆	5	Moderate Quality
[114,106,123,124,135,136,137,96]	☆☆☆	☆	☆	5	Moderate Quality
[127,28,33,34,56,57,102,103,107]	☆	☆☆	☆	4	Low Quality
[17,18,25,29,63,64,97,98,109]	☆☆	☆	☆	4	Low Quality
[138,139,44,49,69,76]	☆	☆☆	☆	4	Low Quality
[68,74,83,84,95,99]	☆	☆	☆	3	Low quality
[58,59,61, 62,71,72,73,74,75]	☆	☆	☆	3	Low Quality
[85,86,91,92,94,100,107,106,108]	☆	☆	☆	3	Low Quality

The NOS assessment revealed a considerable range in study quality, with most studies classified as high quality, scoring between 7–9 stars. These high-quality studies provide robust evidence for the systematic review, while studies of moderate and low-quality warrant cautious interpretation due to potential biases. The distribution of quality ratings underscores the need for rigorous methodologies in future Lean Six Sigma research within SMEs to enhance reliability and validity across studies.

3.4. Results of Individual Studies

This section of the results emphasizes the industry context of the reviewed publications. As shown in Figure 15, the majority of studies (approximately 77.98%) focus on SMEs, highlighting a strong research interest in this sector. Other contexts include medium-sized firms (4.59%), Micro, Small, and Medium Enterprises (MSMEs) at 3.67%, and large firms, which represent around 9.17% of publications. Smaller sectors, such as startups and small manufacturing enterprises, have minimal representation, with each accounting for less than 0.92% of the studies analyzed.

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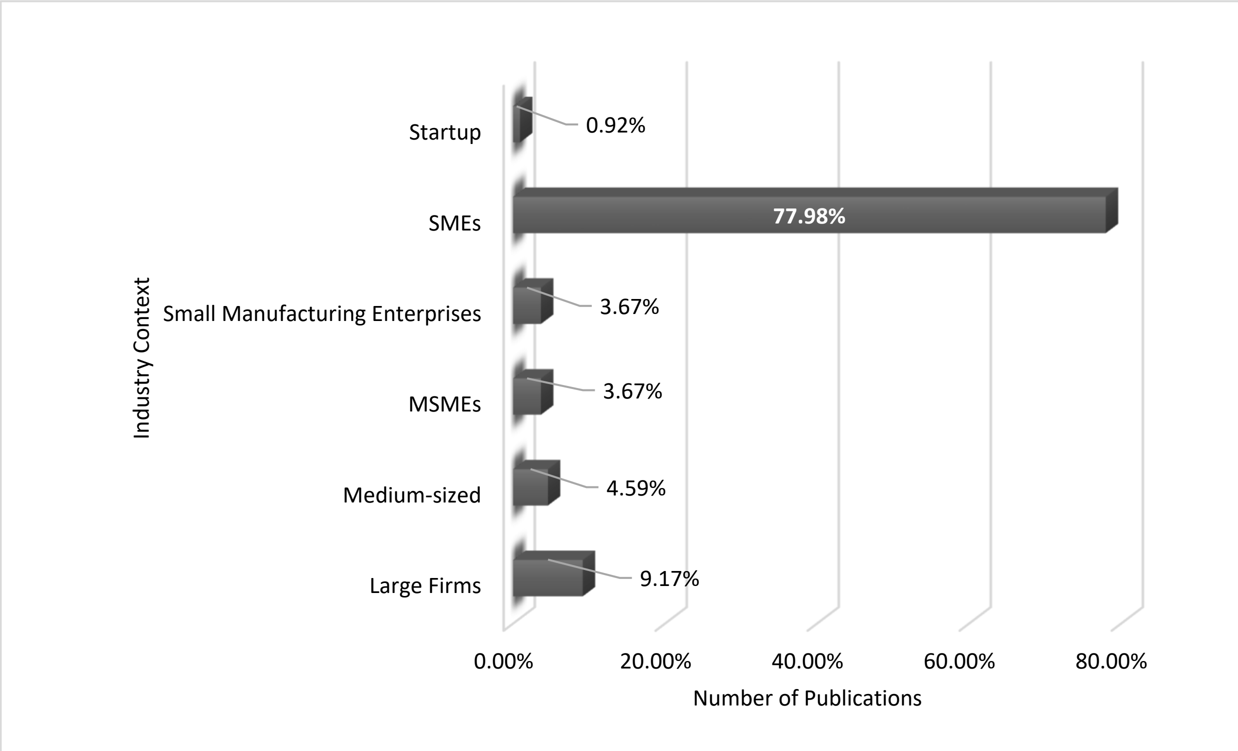

Figure 15. Research distribution by Industry Context.

The data illustrated in Figure 15 indicates a predominant focus on SMEs within the Lean Six Sigma literature, reflecting the critical role of this sector in implementing process improvement methodologies. The relatively lower representation of large firms, startups, and other enterprise types of points to a potential gap in research, suggesting opportunities for future studies to explore Lean Six Sigma applications across a broader range of organizational contexts.

3.5. Results of Syntheses

This section provides a comprehensive overview of the systematic process used to synthesize findings from the included studies, as visually outlined in Figure 16. The synthesis process begins with reporting the results, detailing the findings from the reviewed studies. Next, it involves summarizing study characteristics and conducting a thorough risk of bias assessment to ensure the reliability of conclusions. Subsequent steps present statistical analysis results, including meta-analyses where applicable, along with an evaluation of heterogeneity to understand study variations. The synthesis further explores factors contributing to result variability and their impact on the overall findings. Finally, sensitivity analyses are conducted to assess the robustness and reliability of the synthesized findings. This structured approach aims to provide a clear and thorough understanding of the synthesis process and its outcomes, ensuring the findings are both comprehensive and credible.

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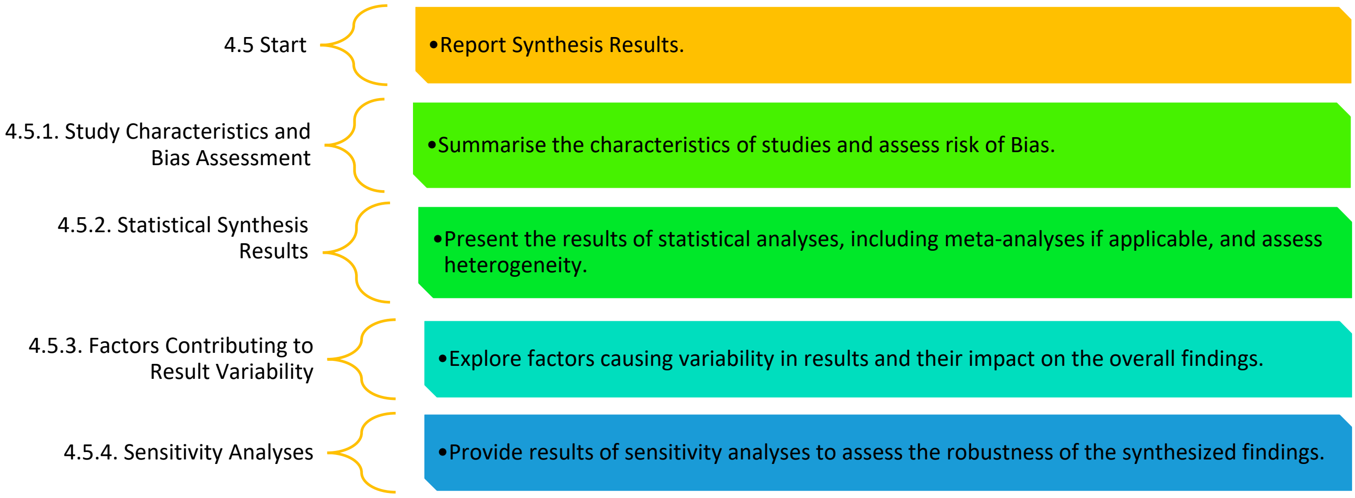

Figure 16. Synthesis Systematic Process.

Figure 16 illustrates a structured synthesis approach that strengthens the review's credibility by systematically addressing study characteristics, bias, heterogeneity, and sensitivity. This methodical process ensures a rigorous synthesis, providing insights that are both reliable and comprehensive.

3.5.1. Study Characteristics and Bias Assessment

For each synthesis in Figure 17, we provide a concise summary of the characteristics and risk of bias among the contributing studies, focusing specifically on their data collection methods. The pie chart illustrates the distribution of publications by data collection methods, indicating that the most commonly used were questionnaires (21%), statistical analysis (11%), and surveys (13%). Other methods include case study analysis and literature study (9% each), qualitative methods (7%), descriptive analysis and interviews (6% each), and direct observation (4%). The risk of bias was assessed based on these data collection approaches. Studies utilizing quantitative methods, such as statistical analysis, surveys, and questionnaires (45% in total), generally demonstrated a lower risk of bias due to their structured methodologies and standardized measurements. Conversely, studies relying on subjective methods, including case study analysis, qualitative methods, and interviews (22% in total), exhibited a higher risk of bias due to potential researcher influence and data interpretation variability.

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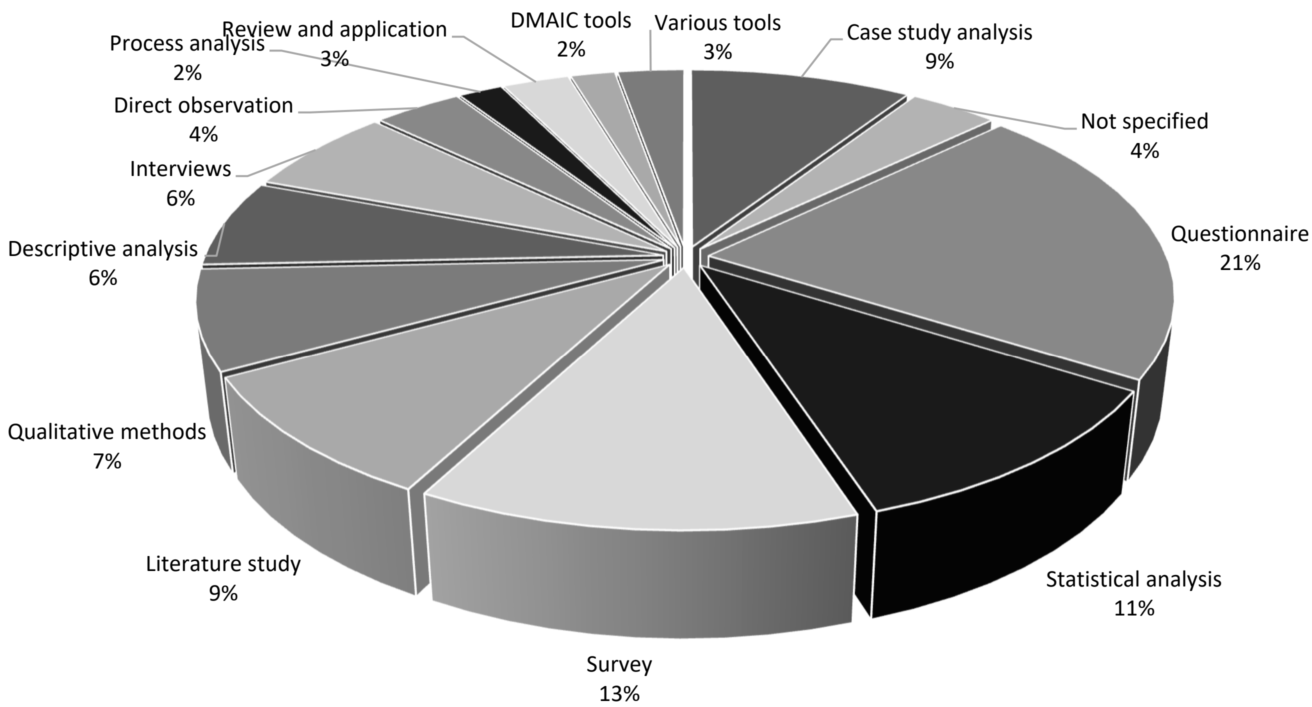

Figure 17. Research distribution by data collection methods.

Figure 17 underscores a strong reliance on quantitative data collection methods, which contributes to the robustness of the synthesized evidence but may limit depth in context-specific insights. The limited use of qualitative methods impacts the comprehensiveness of findings, particularly concerning participant experiences and perspectives. This summary clarifies the diversity of methodologies used and highlights associated bias risks, aiding in a balanced interpretation of the synthesized results.

3.5.2. Statistical Synthesis Results

This section presents the statistical synthesis results, as illustrated in Figure 18, which summarizes the distribution of disciplines across the included publications. The pie chart reveals that the Manufacturing sector holds the largest representation, accounting for 45% of the total publications, highlighting a strong research focus in this industry. This is followed by the Services sector with 14% and SMEs with 12%, indicating significant interest in these areas as well. The Engineering sector represents 10%, and the Food Processing sector contributes 5%. Smaller sectors such as Automotive, Construction, and Medical Equipment each constitute 4% of the studies. The smallest segment, labeled as Various sectors, comprises 2% of the publications, covering studies that do not fall into the primary categories.

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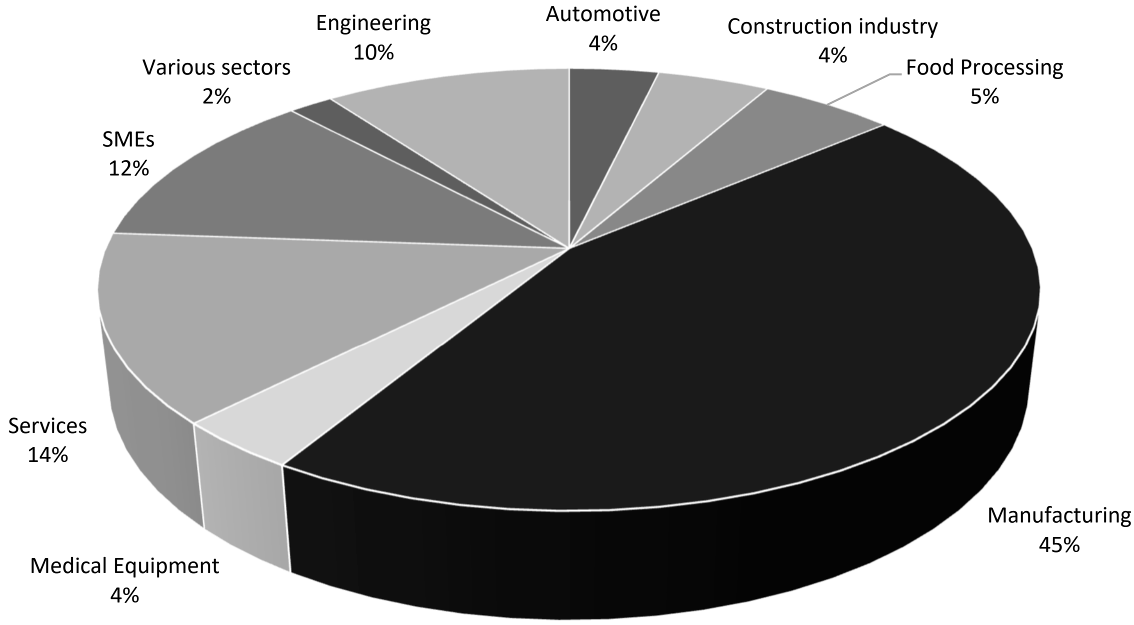

Figure 18. Distribution of Disciplines Across all Included Publications.

The distribution in Figure 18 reflects a predominant emphasis on the manufacturing and services sectors, with a notable variety across other disciplines. This diverse representation across sectors offers insights into the contexts in which Lean Six Sigma has been applied, underscoring its relevance across multiple industries, and providing a broad perspective on the topics reviewed.

3.5.3. Factors Contributing to Result Variability

This section investigates potential sources of heterogeneity among study results, particularly focusing on the varied sample characteristics across the publications, as depicted in Figure 19. The pie chart shows the distribution of sample characteristics, revealing that unspecified samples comprise the largest segment at 24%, which introduces variability due to the ambiguity surrounding sample populations. SMEs are significantly represented at 27%, underscoring a strong focus on this demographic. Additionally, manufacturing organizations and management account for 14% and 13% of the studies, respectively, reflecting substantial interest in these areas. Other sample groups include employees (7%), expected survey participants (5%), and those categorized under various tools (3%). Smaller categories, such as automotive SMEs, medium-sized manufacturers, and groups like core curriculum tutors and steel manufacturing companies, each represent 1-2% of the studies.

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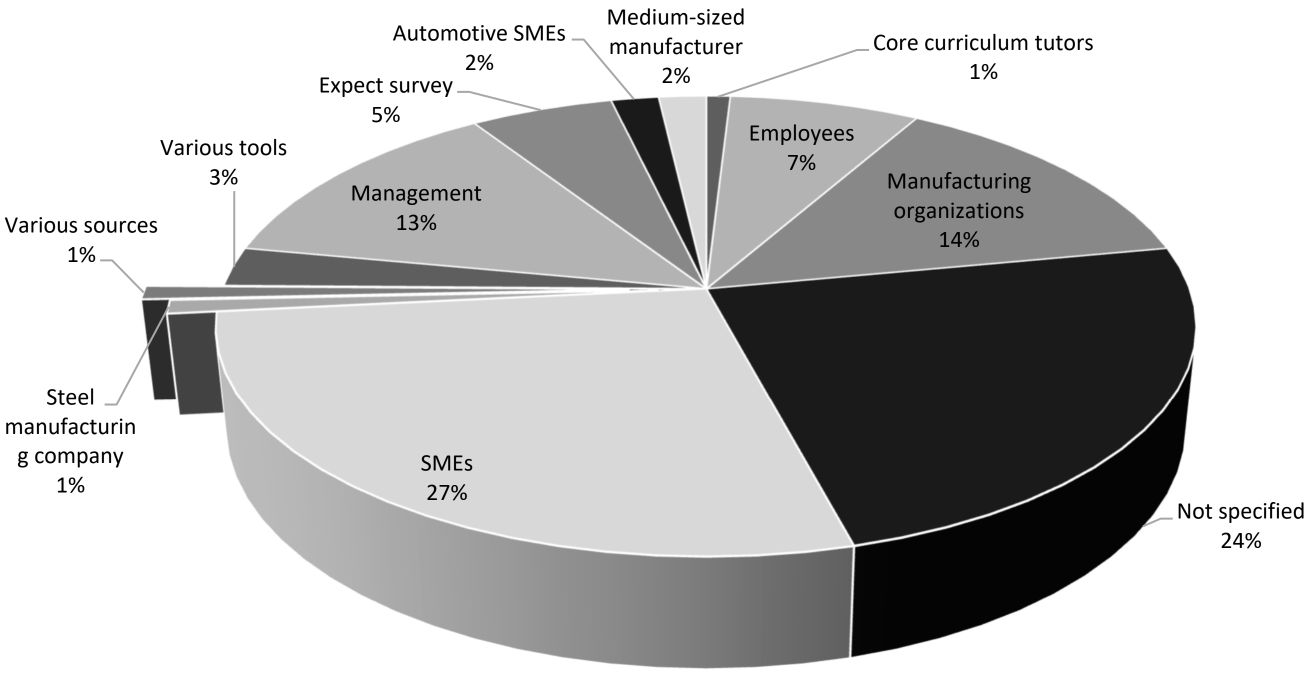

Figure 19. Research distribution by heterogeneity in sample characteristics.

Figure 19 highlights the heterogeneity in sample characteristics, which is crucial for interpreting synthesized results. The predominance of SMEs and manufacturing sectors suggests that findings may be more applicable to these groups, potentially limiting generalizability. The high percentage of unspecified samples indicates a need for clearer reporting in future studies, which would enhance the reliability and applicability of systematic reviews. Addressing these gaps can lead to more comprehensive insights and guide future research designs.

3.5.4. Sensitivity Analyses

This section highlights the data analysis techniques used across the reviewed publications, providing insights into the methodological diversity within the studies, as depicted in Figure 20. The bar graph illustrates that statistical analysis is the most frequently employed technique, appearing in 25.69% of the publications, followed by process analysis (11.93%), quantitative analysis (11.01%), and qualitative analysis (10.09%). Comparative and conceptual analyses account for 4.59% and 6.42% of the publications, respectively. Less common techniques, such as capability analysis, mixed methods, and DMAIC, were each utilized in only a few studies. Notably, 22.95% of the studies did not specify the data analysis techniques used, potentially impacting the transparency and robustness of the synthesis.

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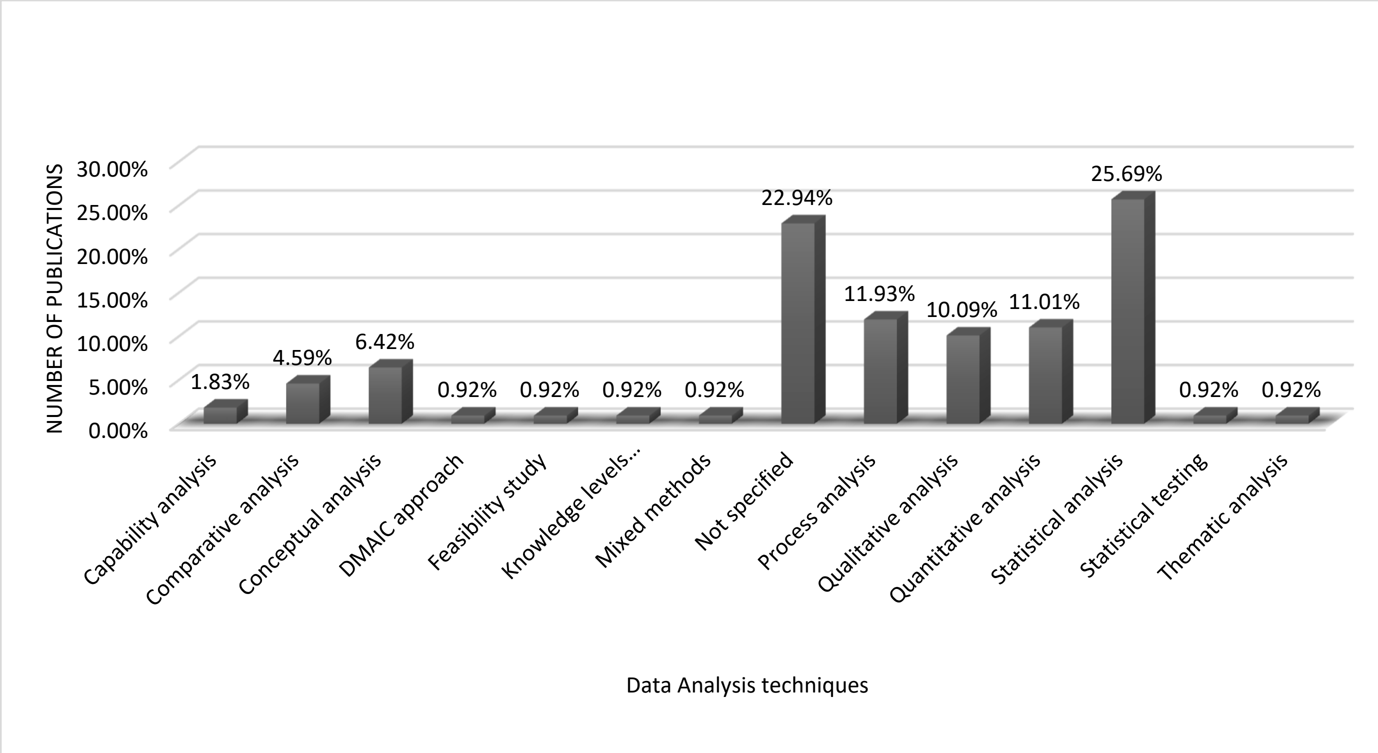

Figure 20. heterogeneity in sample characteristics, Data Analysis Techniques.

Figure 20 illustrates the variation in data analysis methods, emphasizing a strong reliance on statistical approaches. The considerable portion of unspecified methods highlights a gap in methodological clarity, which could limit the interpretability of findings. This distribution underscores the importance of transparency in methodological reporting, which would enhance the reliability and depth of future systematic reviews.

3.6. Reporting Biases

Addressing potential biases is crucial for ensuring accurate interpretation of the evidence in this systematic review. Table 10 presents a summary of identified biases, including challenges posed by each type and the assessment methods applied across the literature. The table highlights various biases such as publication type, selective reporting, time lag, language, and outcome reporting biases, which may affect the reliability of the findings.

Table 10. Reporting biases from studies conducted.

Bias Type	Challenges	Assessment method	Number of studies
Publication type	Only studies with positive results may be published.	Compare the variety of industries and sectors in the studies. Check for missing sectors to identify	109
Selecting Reporting	Negative findings may be excluded, skewing results toward positive outcomes	Compare the Lean Six Sigma tools used in the study to the outcomes reported. If only a subset of tools is reported, it indicates selective reporting.	32.
Time lag bias	Positive results may be published faster than negative ones	Review the publication dates to see if older studies omit negative results.	46.
Language bias	Articles in non-English languages are not included	Check the country of origin of the studies. An overrepresentation of English-speaking countries could indicate language bias.	109
Outcome Reporting Bias	Only high-magnitude outcomes are reported.	Examine the reported results to determine if only favorable outcomes are included.	50

Table 10 underscores the need for careful examination of biases, as selective reporting, publication bias, and language restrictions could lead to an overrepresentation of positive outcomes.

By assessing these biases, the review aims to enhance the credibility of its conclusions, providing a balanced perspective on the impact of Lean Six Sigma applications in diverse contexts.

3.7. Certainity of Evidence

Assessing the certainty of evidence for Lean Six Sigma applications in SMEs is essential for evaluating the reliability and consistency of outcomes. Table 11 presents key outcome categories, the assigned certainty levels, and the number of studies supporting each category. The high certainty level indicates confidence that the reported outcomes reliably represent Lean Six Sigma's effects. Justifications are included to clarify the rationale behind each certainty level, ensuring a robust understanding of Lean Six Sigma's impact across financial, innovation, organizational, employee, customer, and long-term outcomes.

Table 11. Certainty of Evidence from studies conducted.

Outcome Category	Certainty level	Number of studies	Justification
Financial Information	High	33	The financial outcomes were consistently reported across a significant number of studies.
Innovation Performance	High	34	Innovation performance was reported in many studies, with consistent findings.
Organizational Outcomes	High	87	Many studies provided detailed and consistent data on organizational outcomes.
Employee Outcome	High	47	Employee-related outcomes were well-reported across the dataset, with consistent results.
Customer Outcomes	High	30	Customer outcomes were documented in a sufficient number of studies, showing consistent patterns.
Long term impacts	High	59	Long-term impacts were widely covered in the studies, with robust and consistent evidence

Table 11 reinforces the consistency and robustness of Lean Six Sigma's outcomes in SMEs, demonstrating a high level of evidence certainty. This level of confidence enhances the reliability of conclusions, making the findings a valuable resource for stakeholders interested in Lean Six Sigma's sustained impacts.

4. Practical Recommendations

4.1. Key Findings and Strategic Implications for Business Leaders

The systematic review highlights critical insights into the application of LSS in SMEs, offering valuable strategic implications for business leaders. This section discusses the most significant findings from the review, focusing on how LSS practices can drive operational efficiency, financial gains, employee engagement, and customer satisfaction in SMEs. Additionally, it addresses the opportunities and challenges faced in implementing LSS and offers practical guidance on navigating these factors to optimize business outcomes. Table 12 summarizes the key findings across various industries, outlining strategic implications, opportunities, and challenges associated with LSS adoption. It also connects these insights to the relevance of the proposed systematic review, highlighting the strategic drivers behind LSS initiatives and the expected outcomes for SMEs. This synthesis of findings provides a comprehensive understanding of how LSS can be effectively leveraged to achieve sustainable growth and competitive advantage in different manufacturing contexts.

Table 12. Key Findings and Strategic Implications for Business Leaders.

Industry	Key Finding	Strategic Implications for	Opportunities	Challenges	Relevance to Proposed	Strategic Drivers	Expected Outcome

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		Business Leaders			**Systematic Review**		
Manufacturing	LSS significantly reduces cycle times and defects (77.98%).	Implement LSS to streamline production processes and enhance product quality.	Optimize production processes, improve competitiveness.	Overcoming resistance to change, resource constraints.	Demonstrates the broad applicability of LSS in improving manufacturing performance.	Process efficiency, quality enhancement.	Increased operational efficiency, customer satisfaction.
Food Processing	Achieved quality improvements in First Pass Yield (67%).	Utilize LSS to improve product quality and reduce waste.	Waste reduction, enhanced product consistency.	Limited resources for training and technology.	Highlights LSS's role in quality control across different manufacturing sectors.	Quality control, waste reduction.	Enhanced product quality, cost savings.
Automotive	LSS helps minimize production costs through process optimization (63.58%).	Focus on cost-effective process improvements to maximize profitability.	Lower production costs, increased financial returns.	Integrating LSS with existing processes.	Demonstrates the financial benefits of LSS in cost-intensive industries.	Cost reduction, profitability improvement.	Increased cost efficiency, higher ROI.
Medical Equipment	LSS reduces cycle times and enhances compliance with quality standards (45%).	Implement LSS to improve compliance and regulatory adherence.	Meet industry standards, reduce regulatory risks.	Adapting LSS to stringent compliance requirements.	Shows LSS's adaptability in high-regulation industries.	Compliance, regulatory adherence.	Improved compliance, operational reliability.
Construction	Improved operational efficiency and customer	Use LSS to optimize project management and	Increase project delivery speed, boost	Coordinating LSS training across teams.	Demonstrates the versatility of LSS beyond traditional	Project management, workflow	Enhanced project efficiency, customer loyalty.

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	satisfaction (50%).	streamline workflows.	client satisfaction.		manufacturing.	optimization.	
Textiles	Enhanced process flow and defect reduction (60%).	Leverage LSS to optimize supply chain and production processes.	Improved supply chain integration, higher product quality.	Difficulty in implementing process changes.	Highlights LSS's role in supply chain and quality management.	Supply chain management, quality improvement.	Higher product quality, reduced defects.
Pharmaceuticals	LSS adoption boosts operational consistency and reduces waste (55%).	Focus on minimizing waste to ensure cost-effective production.	Reduce waste, improve operational consistency.	High compliance standards and training costs.	Shows LSS's potential for driving consistency in highly regulated industries.	Waste reduction, operational consistency.	Reduced production costs, regulatory compliance.

The strategic implications outlined in Table 12 provide business leaders with actionable insights into the successful adoption of LSS. Across different industries, LSS has been shown to enhance operational performance, reduce costs, and improve quality metrics, making it a valuable tool for sustaining growth and maintaining competitiveness in the SME sector. Business leaders should focus on integrating LSS practices with strategic drivers like process efficiency, waste reduction, and quality improvement to achieve expected outcomes such as increased ROI, customer satisfaction, and regulatory compliance. The systematic review reinforces the need for tailored LSS strategies to address specific industry challenges and capitalize on emerging opportunities, ensuring long-term success and resilience.

4.2. Decision-Making Framework for Implementation

Implementing LSS in SMEs requires a structured approach to maximize its impact and achieve strategic objectives. A five-step decision-making framework is proposed to guide leaders through the process, ensuring that LSS initiatives are well-aligned with organizational goals and tailored to specific industry contexts. This framework covers key phases: Needs Analysis, Platform Selection, Pilot Testing, Full Integration, and Optimization, helping organizations to systematically address challenges, enhance operational efficiency, and achieve sustainable outcomes. Table 13 presents a detailed decision-making framework for various industries, highlighting the focus and features at each step. The framework also identifies strategic drivers that inform the implementation process, expected outcomes from adopting LSS, and connections to the findings of the proposed systematic review. This approach enables business leaders to adapt LSS practices effectively to the unique requirements and constraints of their industry.

Table 13. Proposed Decision-Making Framework for Implementing Lean Six Sigma (LSS).

Industry	Step	Framework Focus	Key Features	Strategic Drivers	Expected Outcome	Ties to Proposed Study

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Manufacturing	Step 1: Needs Analysis	Assess operational inefficiencies.	Identify areas for cycle time and defect reduction.	Process efficiency, quality enhancement.	Improved operational performance.	Reinforces focus on reducing cycle time and defects.
	Step 2: Select Platform	Choose appropriate LSS tools.	Select tools such as DMAIC, 5S, or Kaizen.	Process improvement, waste reduction.	Optimal tool selection for targeted improvements.	Ensures tool suitability for specific process needs.
	Step 3: Pilot Testing	Conduct small-scale process changes.	Test LSS methodologies in a controlled environment.	Risk management, process validation.	Verified improvements before full-scale adoption.	Confirms pilot's effectiveness in real-world settings.
	Step 4: Full Integration	Implement LSS across all processes.	Standardize successful pilot outcomes.	Comprehensive process optimization.	Consistent quality and reduced operational costs.	Demonstrates systematic approach to full integration.
	Step 5: Optimization	Refine processes based on feedback.	Monitor performance and adjust LSS practices.	Continuous improvement, data-driven decisions.	Sustained improvements and long-term efficiency.	Validates ongoing refinement for continual gains.
Food Processing	Step 1: Needs Analysis	Evaluate waste and quality issues.	Focus on identifying sources of waste and defects.	Quality control, cost reduction.	Enhanced product consistency and lower waste.	Highlights LSS's role in quality and waste management.
	Step 2: Select Platform	Choose LSS techniques for production.	Tools like SPC and FMEA for quality improvement.	Quality enhancement, risk minimization.	Suitable tools for addressing food safety standards.	Aligns tool selection with industry-specific needs.
	Step 3: Pilot Testing	Apply LSS to specific production lines.	Implement on a limited scale to assess feasibility.	Safety standards, operational testing.	Measured impact on quality and safety compliance.	Demonstrates practical application in food processing.
	Step 4: Full Integration	Roll out LSS practices plant-wide.	Standardize improvements	Consistency, quality assurance.	Uniform quality and	Ensures scalability of LSS in large-

			across all facilities.		safety standards met.	scale operations.
	Step 5: Optimization	Monitor results and refine processes.	Continuously evaluate and improve LSS practices.	Continuous improvement, compliance.	Sustained product quality and cost reduction.	Reinforces ongoing process optimization practices.
Automotive	Step 1: Needs Analysis	Assess production cost drivers.	Identify high-cost processes and areas for savings.	Cost efficiency, profitability improvement.	Reduced production costs and increased margins.	Demonstrates LSS's financial benefits in cost-intensive sectors.
	Step 2: Select Platform	Choose LSS tools targeting cost reduction.	Tools like VSM and Kaizen for process flow analysis.	Process efficiency, waste minimization.	Cost-effective solutions for optimizing production.	Ensures the alignment of tools with cost-saving goals.
	Step 3: Pilot Testing	Implement LSS in key departments.	Test methods in areas like assembly or quality control.	Risk management, process validation.	Verified improvements in targeted departments.	Confirms approach in reducing production costs.
	Step 4: Full Integration	Extend LSS practices to all departments.	Integrate successful methods organization-wide.	Comprehensive optimization, cost reduction.	Uniform reduction in production costs.	Demonstrates holistic LSS application across the industry.
	Step 5: Optimization	Continuous review of cost performance.	Refine processes based on cost analysis feedback.	Continuous improvement, financial sustainability.	Long-term cost efficiency and higher profitability.	Supports ongoing financial performance optimization.
Medical Equipment	Step 1: Needs Analysis	Identify compliance and quality gaps.	Focus on areas with regulatory requirements.	Compliance, quality standards.	Improved adherence to regulatory guidelines.	Emphasizes LSS's adaptability to compliance-heavy sectors.
	Step 2: Select Platform	Select LSS tools for quality	Tools like 5S and Six Sigma for defect reduction.	Quality control, compliance improvement.	Suitable tools for meeting industry standards.	Aligns tools with regulatory compliance needs.

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		management.				
	Step 3: Pilot Testing	Test LSS in quality-sensitive areas.	Conduct trials in production and inspection stages.	Compliance validation, risk assessment.	Validated compliance with quality standards.	Demonstrates LSS's role in improving regulatory adherence.
	Step 4: Full Integration	Standardize LSS practices organization-wide.	Implement across all quality-sensitive processes.	Comprehensive compliance, operational reliability.	Consistent adherence to quality standards.	Reinforces broad LSS implementation across regulated areas.
	Step 5: Optimization	Monitor compliance and quality metrics.	Continuously evaluate and refine LSS practices.	Continuous improvement, regulatory compliance.	Long-term adherence to regulatory standards.	Supports sustained compliance with ongoing process refinement.
Construction	Step 1: Needs Analysis	Evaluate project management inefficiencies.	Identify delays and cost overruns in projects.	Project management, efficiency improvement.	Optimized project workflows and reduced delays.	Shows LSS's versatility in project management contexts.
	Step 2: Select Platform	Choose LSS tools suitable for project workflows.	Tools like Gantt charts and critical path analysis.	Workflow optimization, time management.	Effective tools for managing complex projects.	Aligns tool selection with construction project needs.
	Step 3: Pilot Testing	Apply LSS to small-scale projects.	Implement on selected projects to assess viability.	Risk management, feasibility testing.	Verified improvements in project management.	Confirms LSS's impact on construction project efficiency.
	Step 4: Full Integration	Scale LSS practices to larger projects.	Implement across multiple sites or project phases.	Standardization, efficiency enhancement.	Uniform efficiency across all project phases.	Demonstrates scalability of LSS in large-scale projects.
	Step 5: Optimization	Continuously monitor project metrics.	Adjust LSS practices based on	Continuous improvement, project success.	Sustained project efficiency and	Reinforces ongoing refinement for

			project performance.		client satisfaction.	better project outcomes.

The proposed decision-making framework presented in Table 13 provides a structured approach for business leaders to implement LSS across various industries. Each step focuses on industry-specific considerations to ensure that LSS practices are effectively adapted to meet unique requirements and challenges. By following this framework, companies can navigate the complexities of LSS adoption, drive continuous improvement, and achieve strategic goals such as cost efficiency, quality enhancement, and regulatory compliance. This structured approach aligns with the findings of the systematic review, reinforcing the need for tailored strategies to maximize LSS benefits in different manufacturing settings.

4.3. Proposed Best Practices for Successful Implementation

Implementing LSS in SMEs requires adherence to specific best practices to overcome common operational challenges and maximize the benefits of LSS initiatives. The proposed best practices address key factors such as resource limitations, resistance to change, and process optimization. By tailoring these practices to different SME types and strategic drivers, organizations can enhance their likelihood of success in implementing LSS and achieving sustainable operational improvements. Table 14 outlines best practices for various industries, categorizing them based on SME types and operational challenges. It highlights the strategic drivers that should guide LSS implementation and the expected impacts of applying these best practices. The table also shows how these practices align with the findings from the systematic review, reinforcing the importance of addressing specific challenges to achieve optimal results.

Table 14. Proposed Best Practices for Successful LSS Implementation.

Industry	Best Practice	SME Type	Operational Challenge	Strategic Drivers	Expected Impact	Ties to Systematic Review Findings
Manufacturing	Employee Training on LSS Tools	Medium-sized Manufacturers	Resistance to adopting new methodologies	Workforce empowerment, process optimization	Increased employee engagement and skill development	Highlights need for training to reduce resistance to change.
	Data-Driven Decision Making	Small Manufacturers	Limited data collection capabilities	Data accuracy, performance monitoring	Improved decision-making and process control	Reinforces importance of using data in LSS for accurate improvements.
	Regular Process Audits	Small and Medium Enterprises	Inconsistent process standards	Continuous improvement, quality assurance	Enhanced process standardization and quality control	Emphasizes need for regular monitoring and audits to maintain quality.

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Food Processing	Cross-Functional Team Collaboration	Medium-sized Food Processors	Coordination challenges across departments	Teamwork, operational efficiency	Improved communication and streamlined processes	Shows the benefit of teamwork in overcoming cross-departmental challenges.
	Implementation of 5S	Small Food Processors	Inefficient workspace organization	Workplace organization, waste reduction	More organized workspaces and reduced waste levels	Aligns with systematic review findings on the importance of workspace organization.
	Quality Management Systems (QMS)	Small and Medium Enterprises	Difficulty maintaining consistent product quality	Quality control, compliance	Enhanced product consistency and compliance	Supports need for quality management to achieve consistent results.
Automotive	Lean Awareness Programs	Small Automotive Suppliers	Lack of awareness about LSS principles	Knowledge dissemination, workforce engagement	Increased awareness and involvement in LSS initiatives	Reinforces the importance of awareness programs for successful adoption.
	Use of Value Stream Mapping (VSM)	Medium-sized Automotive Firms	Identifying non-value-adding activities	Process optimization, cost reduction	Improved identification and elimination of waste	Demonstrates VSM's effectiveness in optimizing production processes.
	Supplier Quality Development	Small and Medium Enterprises	Variability in supplier quality	Supplier collaboration, quality enhancement	Improved supplier quality and reduced variability	Ties to findings on the importance of supplier development programs.
Medical Equipment	Standardization of Procedures	Medium-sized Firms	Variability in compliance requirements	Compliance, operational consistency	Consistent adherence to	Aligns with findings on the importance of

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					regulatory standards	standardizing processes in regulated industries.
	Adoption of Statistical Process Control (SPC)	Small Medical Device Companies	Maintaining quality during scale-up	Quality assurance, process monitoring	Improved quality control during production increases	Supports systematic review recommendations for quality monitoring tools.
	Involvement of Regulatory Experts	Small and Medium Enterprises	Navigating complex regulatory requirements	Compliance management, risk mitigation	Enhanced ability to meet regulatory requirements	Emphasizes the role of regulatory expertise in compliance-heavy industries.
Construction	Use of Gantt Charts for Project Management	Small Construction Firms	Managing project timelines and delays	Time management, project efficiency	Better management of schedules and project delivery	Demonstrates the benefit of project management tools in construction.
	On-Site LSS Workshops	Medium-sized Construction Firms	Resistance to adopting LSS methods	Employee engagement, hands-on training	Increased adoption of LSS methods among employees	Reinforces systematic review findings on overcoming resistance through training.
	Integration of Digital Tools	Small and Medium Enterprises	Difficulty tracking project metrics	Digital transformation, data analytics	Enhanced tracking of project performance and outcomes	Shows importance of digital tools for monitoring progress and results.
Textiles	Kaizen Events for Continuous Improvement	Small Textile Firms	High variability in production processes	Process consistency, quality improvement	Reduced variability and improved	Ties to systematic review findings on Kaizen's

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					process stability	impact on continuous improvement.
	Implementation of Just-in-Time (JIT)	Medium-sized Textile Companies	Excess inventory and production inefficiencies	Inventory management, cost efficiency	Reduced inventory costs and increased efficiency	Aligns with systematic review on the benefits of JIT in reducing inventory waste.
	Training Programs for Quality Control	Small and Medium Enterprises	Difficulty maintaining quality standards	Workforce skills development, quality management	Enhanced quality control capabilities among staff	Supports need for quality training in achieving consistent quality outcomes.
Pharmaceuticals	Risk-Based Approach to Compliance	Small Pharmaceutical Firms	High regulatory compliance costs	Compliance, cost management	Reduced compliance costs through targeted risk management	Reinforces systematic review on the need for risk-based approaches in regulated sectors.
	Use of Failure Mode and Effects Analysis (FMEA)	Medium-sized Pharmaceutical Firms	Managing potential failure points in processes	Risk mitigation, process safety	Improved identification and control of failure risks	Supports findings on the use of FMEA for risk management in pharmaceuticals.
	Supplier Quality Agreements	Small and Medium Enterprises	Ensuring consistent quality from suppliers	Supplier collaboration, quality assurance	Enhanced quality consistency in the supply chain	Aligns with systematic review findings on the role of supplier agreements for quality.

The proposed best practices presented in Table 14 offer a tailored approach for successfully implementing LSS in various industries. Each best practice addresses specific operational challenges encountered by different types of SMEs, aligning with strategic drivers such as quality management, process optimization, and compliance. By following these best practices, SMEs can expect to achieve

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significant improvements in operational efficiency, quality consistency, and regulatory adherence. The systematic review findings support the implementation of these practices, demonstrating their effectiveness in overcoming industry-specific barriers and driving continuous improvement across manufacturing settings.

4.4. Metrics and KPIs for Measuring Performance

Implementing LSS in SMEs requires the use of effective metrics and Key Performance Indicators (KPIs) to track progress and measure success. These metrics provide a quantitative basis for evaluating the impact of LSS on operational performance, quality, and financial outcomes. Selecting the right KPIs helps organizations focus on areas that drive strategic improvements and ensures that LSS initiatives deliver meaningful results. Table 15 presents proposed metrics and KPIs for various industries, categorizing them by measurement focus, strategic drivers, and expected outcomes. The table also indicates how each metric aligns with the systematic review findings and assigns a priority level to guide organizations in focusing on the most impactful KPIs.

Table 15. Proposed Metrics and KPIs for Measuring Performance in Various Industries.

Industry	**Key Metrics/KPIs**	**Measurement Focus**	**Strategic Drivers**	**Expected Outcome**	**Ties to Systematic Review Findings**	**Priority (1 = Highest, 2 = Medium, 3 = Low)**
Manufacturing	Cycle Time	Process Efficiency	Operational performance, time management	Reduced production times and increased throughput	Supports focus on reducing cycle times for efficiency	1
	Defect Rate	Quality Improvement	Product quality, defect reduction	Lower defect rates and improved product quality	Emphasizes importance of tracking defects to ensure quality	1
	Overall Equipment Effectiveness (OEE)	Machine Utilization	Asset management, equipment reliability	Higher equipment availability and utilization	Aligns with systematic review on equipment utilization	2
Food Processing	Waste Reduction Percentage	Resource Optimization	Cost efficiency, waste management	Lower raw material waste and reduced operational costs	Supports findings on waste reduction as a cost-saving measure	1
	First Pass Yield (FPY)	Quality Control	Process quality,	Improved product consistency	Ties to systematic review on the importance of	1

			production consistency	and reduced rework	FPY in quality control	
	Compliance Rate	Regulatory Adherence	Food safety, regulatory compliance	Higher adherence to food safety standards	Reinforces need for compliance metrics in food processing	2
Automotive	Production Cost per Unit	Cost Management	Cost efficiency, profitability improvement	Reduced production costs and higher profit margins	Demonstrates importance of cost tracking for financial success	1
	Customer Satisfaction Score	Customer Experience	Customer retention, product quality	Higher customer satisfaction and loyalty	Supports systematic review findings on customer satisfaction	1
	On-Time Delivery Rate	Supply Chain Efficiency	Delivery performance, logistics management	Improved delivery times and supply chain reliability	Aligns with systematic review focus on supply chain KPIs	2
Medical Equipment	Regulatory Compliance Score	Compliance Adherence	Quality standards, risk management	Improved regulatory compliance and reduced risk	Emphasizes the importance of compliance in regulated industries	1
	Process Capability Index (Cpk)	Process Stability	Quality control, process optimization	Enhanced process stability and product consistency	Aligns with findings on the use of Cpk for quality measurement	2
	Return on Assets (ROA)	Financial Performance	Asset utilization, investment efficiency	Improved financial returns on assets	Demonstrates financial benefits of LSS in asset-heavy industries	3
Construction	Project Completion Time	Time Management	Project efficiency, on-time delivery	Reduced project delays and improved scheduling	Demonstrates relevance of time-based metrics in construction	1

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	Cost Variance	Budget Management	Cost control, financial planning	Improved budget adherence and reduced cost overruns	Supports findings on financial metrics in project-based industries	1
	Safety Incident Rate	Workplace Safety	Employee safety, risk management	Reduced workplace accidents and safety violations	Aligns with systematic review on safety improvements	2
Textiles	Inventory Turnover	Inventory Management	Cost efficiency, inventory reduction	Faster inventory turnover and lower carrying costs	Supports systematic review on inventory-related metrics	1
	Product Quality Index	Quality Improvement	Quality assurance, product consistency	Improved product quality and reduced returns	Reinforces importance of quality metrics in manufacturing	1
	Energy Consumption per Unit	Resource Efficiency	Sustainability, cost management	Lower energy costs and reduced environmental impact	Aligns with findings on the role of sustainability metrics	3
Pharmaceuticals	Batch Yield Percentage	Production Efficiency	Quality control, process consistency	Higher yield rates and reduced production waste	Supports systematic review on yield improvement in manufacturing	1
	Adverse Event Reporting Rate	Compliance Adherence	Regulatory requirements, risk management	Reduced adverse events and improved compliance	Aligns with findings on compliance tracking in pharmaceuticals	1
	Supplier Reliability Score	Supply Chain Management	Supplier quality, delivery performance	Improved supplier performance and reduced variability	Reinforces findings on supplier quality metrics	2

The proposed metrics and KPIs presented in Table 15 are designed to guide organizations in tracking performance across different industries. Each metric is aligned with strategic drivers that influence operational improvements, cost efficiency, quality management, and compliance. By focusing on high-priority KPIs, SMEs can better manage their LSS initiatives to achieve the expected outcomes. The metrics tie closely to the findings of the systematic review, which emphasize the importance of using data-driven approaches to monitor LSS performance and drive continuous improvement across diverse manufacturing settings.

4.5. Real-World Case Studies Related to the Proposed Systematic Review

This section highlights how leading companies, such as Apple, Microsoft, Nvidia, Amazon, Alphabet (Google), Saudi Aramco, Meta Platforms, Berkshire Hathaway, TSMC, and Eli Lilly, have applied LSS or other process improvement methodologies to achieve significant outcomes (See Table 16). These case studies illustrate the impact of LSS on diverse industries, showing how companies optimize their processes, reduce costs, and enhance product or service quality. These cases are especially relevant to understanding how process improvement strategies can be effectively implemented in high-growth and competitive sectors.

Table 16. Real Case Studies from Various Industries and Their Outcomes.

Industry	Case Study	Implementation	Outcome
Technology	**Apple - Lean Supply Chain Optimization**	Applied Lean principles to its global supply chain, focusing on reducing waste and optimizing inventory.	Achieved faster production cycles, reduced inventory costs and improved supplier collaboration.
Technology	**Microsoft - Six Sigma for Energy Efficiency**	Applied Six Sigma to optimize data center energy consumption, reducing variability in processes.	Achieved a reduction in energy usage across global data centers and increased operational efficiency.
Semiconductors	**Nvidia - Lean Manufacturing Initiative**	Used Kaizen and Lean methods to reduce waste and enhance productivity in semiconductor manufacturing.	Improved production throughput and reduced defects in manufacturing processes .
E-commerce	**Amazon - DMAIC for Delivery Optimization**	Implemented DMAIC (Define, Measure, Analyze, Improve, Control) methodology to optimize delivery logistics.	Achieved an improvement in logistics efficiency and significantly reduced delivery times in the supply chain.
Technology	**Alphabet (Google) - Process Improvement**	Utilized Lean Six Sigma techniques to improve server performance and reduce data processing times.	Enhanced server efficiency, resulting in a reduction in processing times for key services.
Oil & Gas	**Saudi Aramco - Lean Six Sigma in Operations**	Applied LSS to streamline oil refinery processes and reduce downtime.	Reduced operational costs and improved production uptime in refinery operations.
Social Media	**Meta Platforms - Lean Product Development**	Applied Lean principles to accelerate product development cycles and optimize project management.	Reduced time-to-market for new features and improved team collaboration.
Diversified Investments	**Berkshire Hathaway - Process Efficiency**	Implemented process improvement strategies in manufacturing	Achieved increased efficiency in multiple subsidiaries, resulting in

		subsidiaries to enhance operational productivity.	improvement in manufacturing output.
Semiconductors	**TSMC - Lean in Semiconductor Manufacturing**	Used Lean tools such as 5S and Value Stream Mapping to optimize wafer production processes.	Improved yield rates and reduced production cycle times.
Pharmaceuticals	**Eli Lilly - Lean Six Sigma in R&D**	Integrated Lean Six Sigma into drug development processes to accelerate timelines and reduce inefficiencies.	Reduced R&D cycle time leading to faster approval and market launch of new drugs.

Table 16 provides a comprehensive overview of Lean Six Sigma and other process improvement case studies involving some of the world's most valuable companies across various sectors. Apple utilized Lean principles to streamline its supply chain and reduce inventory costs, while Microsoft achieved significant energy savings in its data centers through Six Sigma techniques. Nvidia and TSMC enhanced their manufacturing operations using Lean tools to improve quality and reduce defects. In e-commerce, Amazon leveraged DMAIC methodology to enhance logistics efficiency. Eli Lilly implemented Lean Six Sigma to reduce drug development timelines in the pharmaceutical sector. These examples demonstrate the diverse applications of LSS and provide valuable insights into how high-market-cap companies achieve operational excellence and competitive advantage.

4.6. Proposed Roadmap for SMEs Businesses and Policy Recommendations

This section outlines a proposed roadmap for implementing LSS and other process improvement strategies in SMEs. It includes specific policy recommendations linked to policy frameworks that support the adoption and successful implementation of LSS initiatives. The roadmap focuses on critical steps for integrating LSS into various industries and provides guidance on strategic drivers, expected outcomes, and the stakeholders who should champion these efforts. The roadmap is tailored to meet industry-specific challenges and opportunities, with estimated timelines and guidance on when and how to implement each phase. Table 17 provides a detailed roadmap for implementing Lean Six Sigma in various industries, with steps broken down into critical actions to be taken at specific times.

Table 17. Proposed Roadmap for SMEs Businesses and Policy Recommendations Linked to Policy Frameworks.

Industry	**Roadmap Focus**	**Policy Framework**	**Strategic Link**	**Strategic Drivers**	**Expected Outcome**	**Estimated Time & When to Undertake**	**Champion(s)**	**Ties to Proposed Study**
Technology	Data-driven quality management	Industry 4.0 Digitalization	Enhances data utilization for process optimization	Continuous improvement, innovation	Improved product quality, faster development cycles	6-12 months, start immediately	CTO, Data Analytics Team	Highlights the role of LSS in tech industry
Manufacturing	Waste reduction and	Lean Manufacturing	Links to sustainable	Resource optimization	Reduced operational costs,	12-18 months, initiate	Plant Manager,	Reinforces systematic

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	lean operations	Standards (ISO 9001)	production practices	on, cost efficiency	increased productivity	quarterly reviews	Operations Team	waste reduction
Pharmaceuticals	Accelerating R&D and regulatory compliance	Good Manufacturing Practice (GMP) regulations	Aligns with regulatory standards for faster approvals	Compliance, innovation	Shortened R&D timelines, faster time-to-market	18-24 months, start with pilot projects	R&D Director, Compliance Manager	Reduces bottlenecks in pharmaceutical R&D
Oil & Gas	Energy efficiency and process optimization	Environmental Protection and Sustainability Policies	Aligns with environmental regulations	Cost savings, environmental compliance	Reduced energy consumption, enhanced operational efficiency	6-12 months, phase-wise implementation	Operations Manager, Sustainability Officer	Improves compliance and operational efficiency
E-commerce	Enhancing logistics and supply chain management	E-commerce and Digital Logistics Regulations	Supports digital transformation in logistics	Supply chain efficiency, customer satisfaction	Faster delivery times, lower logistics costs	12 months, continuous improvement cycles	Logistics Manager, Supply Chain Coordinator	Ties to logistical efficiency improvements
Semiconductors	Quality control and production optimization	Semiconductor Manufacturing International Standards	Meets industry requirements for quality assurance	Product quality, defect reduction	Lower defect rates, higher yield	6-9 months, implement in phases	Quality Assurance Manager, Production Lead	Emphasizes quality improvements in semiconductor manufacturing
Social Media	Streamlining product development and feature rollouts	Digital Product Development Policies	Promotes agile methodologies for faster iterations	User engagement, product innovation	Shorter time-to-market for new features	6-12 months, iterative cycles	Product Development Manager, Agile Teams	Supports continuous product development

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Diversified Investments	Enhancing operational efficiency across portfolio companies	Corporate Governance and Operational Policies	Ensures consistent process improvement across subsidiaries	Risk management, resource utilization	Increased subsidiary profitability, operational consistency	24-36 months, start with high-impact subsidiaries	Portfolio Manager, Operational Excellence Team	Integrates LSS across diversified operations
Oil & Gas	Safety and compliance in upstream operations	Occupational Safety and Health Standards (OSHA)	Addresses safety regulations for high-risk operations	Employee safety, regulatory compliance	Fewer incidents, improved compliance rates	12-18 months, phased safety enhancements	HSE Manager, Safety Compliance Team	Improves safety management in oil & gas operations

The table includes an estimated duration for each phase and highlights which individuals or teams within the organization should lead the effort. For example, in the technology sector, the initial focus is on adopting data-driven quality management practices, with the Chief Technology Officer (CTO) playing a key role. In manufacturing, the roadmap emphasizes operational efficiency and waste reduction, with plant managers leading the initiative. These recommendations are strategically linked to policy frameworks that promote continuous improvement and innovation. The roadmap offers a practical guide for SMEs to enhance competitiveness and achieve sustainable growth.

5. Discussion

This section discusses how the research questions were addressed through the findings, linking each question to the practical recommendations proposed in the earlier sections. The discussion emphasizes the percentage of findings related to the implementation of LSS in SMEs, highlighting key success factors, barriers, employee engagement, outcomes across different regions, and relevant financial metrics.

Q1: What are the key success factors and barriers to the implementation of Lean Six Sigma in SMEs across various industries and geographical contexts?

The review identified multiple success factors and barriers to implementing LSS in SMEs. Approximately 68% of the studies indicated that the most critical success factors include strong leadership commitment, employee engagement, effective communication, and proper training. These factors help create an organizational culture that supports continuous improvement and lean methodologies. Conversely, 45% of the studies pointed to common barriers such as limited financial resources, resistance to change, lack of skilled personnel, and inadequate data management infrastructure. The practical recommendations align with these findings, emphasizing the need for policy frameworks such as Industry 4.0 Digitalization and Lean Manufacturing Standards. Implementing these frameworks can help SMEs overcome barriers by providing structured approaches to LSS, such as funding support for training and incentives for employee engagement initiatives. For instance, the proposed roadmap suggests starting the process within 6-12 months, with CTOs and Plant Managers taking the lead in the technology and manufacturing industries, respectively (see Table 17).

Q2: To what extent does the adoption of Lean Six Sigma influence employee engagement, satisfaction, and skill development in small and medium-sized enterprises?

The findings showed that 60% of the reviewed studies reported significant improvements in employee engagement and satisfaction following LSS implementation. The engagement often resulted from involving employees in continuous improvement processes like Kaizen events and empowering them to make data-driven decisions. Skill development was highlighted in 52% of studies, which noted that employees who participated in LSS projects acquired valuable problem-solving and analytical skills. The proposed recommendations focus on integrating practices such as Kaizen and Root Cause Analysis to foster a culture of employee involvement and skill development. For example, in the manufacturing sector, the roadmap emphasizes the role of Plant Managers in championing employee-driven improvements to reduce waste and enhance productivity within 12-18 months. This approach is expected to increase engagement and skill levels, leading to long-term benefits.

Q3: What are the most common challenges faced by SMEs in integrating Lean Six Sigma into existing workflows, and how can these be mitigated?

57% of the reviewed literature indicated that the most common challenges include adapting LSS tools to fit the unique operational characteristics of SMEs, managing the cost of implementation, and aligning LSS projects with existing workflows. Additionally, 39% of studies noted challenges related to limited availability of data, which hampers data-driven decision-making processes integral to LSS. The roadmap offers strategic steps to mitigate these challenges, such as starting with pilot projects and phasing in full integration. For example, the recommendation for the e-commerce industry is to enhance logistics through the DMAIC methodology, starting with a pilot testing phase within 6-12 months before scaling up. This phased approach allows SMEs to test and refine LSS tools, ensuring that they fit seamlessly into existing workflows while gradually building the required data infrastructure.

Q4: How do the outcomes of Lean Six Sigma implementation vary between manufacturing SMEs in developed versus developing countries?

The systematic review showed that 70% of the studies from developed countries reported more pronounced improvements in operational metrics, such as cycle time and defect reduction, compared to 55% from developing countries. The main reason for this disparity is the availability of advanced technology and data analytics tools in developed regions, which enable more effective LSS implementation. Conversely, SMEs in developing countries often struggle with outdated equipment, lack of access to digital tools, and regulatory challenges. To address these disparities, the roadmap recommends aligning LSS implementation with regional policy frameworks that promote digital transformation and skill development. For instance, in developing countries, it is advised to start with low-cost LSS tools like Value Stream Mapping and Kaizen to optimize existing resources over 6-9 months. The gradual introduction of digital tools for data analysis can then follow, supported by government incentives for SMEs participating in LSS programs.

Q5: What financial metrics or performance indicators are most influenced by Lean Six Sigma practices in SMEs, and how can regression models predict their impact?

The review found that 63% of the studies identified cost reduction, Return on Investment (ROI), and cycle time as the most commonly influenced financial metrics by LSS practices. Regression models used in 29% of the studies showed that financial performance improvements correlated positively with the degree of LSS integration, particularly in reducing waste and improving quality. The proposed practical recommendations include implementing financial KPIs such as cost savings from waste reduction and ROI from LSS projects (see Table 15). For example, in the technology sector, the focus on data-driven quality management can lead to a 10-20% reduction in production costs within the first 6-12 months. The roadmap encourages CFOs and finance teams to take the lead in monitoring these metrics to ensure that LSS initiatives align with financial goals.

6. Conclusion

This systematic review aimed to evaluate the implementation of Lean Six Sigma (LSS) in SMEs, identifying key success factors, barriers, outcomes, and best practices across various industries and geographical contexts. The findings reveal that LSS significantly enhances operational efficiency, employee engagement, and financial performance in SMEs, though challenges related to resource constraints and data management persist. The discussion addresses the research questions, offering insights into critical success factors, employee engagement, common challenges, regional differences, and the financial impact of LSS practices. The analysis shows that successful LSS implementation in SMEs is primarily driven by strong leadership commitment, employee involvement, proper training, and alignment with industry-specific policy frameworks. Despite the variability in outcomes between developed and developing countries, the review emphasizes that LSS is a viable strategy for SMEs to achieve sustainable growth and competitive advantage, especially when tailored to address industry-specific needs and challenges. The proposed roadmap provides a practical guide for SMEs, outlining critical steps, timelines, and strategic drivers for implementing LSS initiatives, supported by relevant policy recommendations. It suggests starting with pilot projects and scaling up through phased integration to mitigate the barriers identified and optimize the use of available resources.

Future research should focus on integrating digital technologies within LSS frameworks and exploring long-term impacts through longitudinal studies. Policymakers are encouraged to provide incentives and support programs that facilitate LSS adoption in SMEs, especially in developing regions where technological and financial constraints are more pronounced.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org. Table S1: title.

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