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LEAN SIX SIGMA METHOD TO REDUCE LENGTH OF STAY IN EMERGENCY DEPARTMENT: SCOPING REVIEW

Metode Lean Six Sigma Untuk Menurunkan Length of Stay di Instalasi Gawat Darurat: Scoping Review

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ABSTRAK

Instalasi Gawat Darurat (IGD) merupakan bagian yang sangat penting dalam sistem perawatan kesehatan. Length of Stay (LOS) salah satu indikator kinerja utama yang secara signifikan mempengaruhi outcome pasien, kualitas pelayanan dan kepuasan pasien. Scoping review ini meneliti efektivitas metodologi Lean Six Sigma (LSS) dalam menurunkan LOS di IGD dan meningkatkan throughput pasien di berbagai fasilitas pelayanan kesehatan. Empat database elektronik (MEDLINE via PubMed, Scopus, Emerald, dan ProQuest) ditelusuri untuk mencari literatur terkait dalam review ini. Review ini disusun menggunakan enam tahap metode scoping review sesuai dengan panduan metode PRISMA-ScR. Review ini berfokus pada implementasi yang menerapkan kerangka kerja Define-Measure-Analyze-Improve-Control, yang dilengkapi dengan pendekatan analitik dan manajemen perubahan. Ekstraksi data mencakup metodologi, hasil kuantitatif, strategi implementasi, dan faktor kontekstual yang memengaruhi keberhasilan. Dalam review ini, teridentifikasi 19 artikel yang memenuhi syarat. Hasil penelitian menunjukkan bahwa metode LSS secara signifikan mengurangi lama tinggal di IGD mulai dari 14% hingga 50%. Integrasi dengan model machine learning meningkatkan akurasi prediksi waktu tunggu pasien. Teknik simulasi mengoptimalkan alur pasien, dan pendekatan manajemen perubahan yang terstruktur memastikan perbaikan yang berkelanjutan dan melibatkan partisipasi staf. Dukungan kepemimpinan dan penggunaan sistem data yang efektif diidentifikasi sebagai faktor penentu keberhasilan, sementara tantangan yang dihadapi termasuk resistensi terhadap perubahan dan keterbatasan sumber daya. Metodologi LSS efektif dalam meningkatkan efisiensi dan mengurangi lama tinggal pasien di IGD, memberikan model yang dapat direplikasi yang bertujuan untuk meningkatkan efisiensi operasional dan perawatan pasien.

Kata kunci: *lean six sigma, length of stay, unit gawat darurat*

ABSTRACT

Emergency Departments serve as critical entry points in healthcare systems. Length of Stay has emerged as a key performance indicator that significantly influences patient outcomes, healthcare delivery quality, and patient satisfaction. This scoping review examined the effectiveness of Lean Six Sigma methodologies in reducing emergency department length of stay and improving patient throughput across diverse healthcare settings. Four electronic databases (MEDLINE via PubMed, Scopus, Emerald, and ProQuest) were searched for related literature in this review. A six-step scoping review was performed following the guidance of the PRISMA-ScR method. The review focused on implementations using the Define-Measure-Analyze-Improve-Control framework, often enhanced with advanced analytics and change management approaches. Data extraction covered methodology, quantitative outcomes, implementation strategies, and contextual factors affecting success.19 eligible articles were identified in this review. The

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results indicated that the LSS method significantly reduced emergency department length of stay, ranging from 14% to 50%. The integration of machine learning models improved predictive accuracy for patient wait times. Simulation techniques further optimized patient flow, and structured change management approaches ensured sustainable improvements and engaged staff participation. Leadership support and effective data systems were identified as critical success factors, while challenges included resistance to change and resource constraints. Lean Six Sigma methodologies are effective in enhancing efficiency and reducing the length of stay in emergency departments, providing a replicable model for healthcare systems aiming to improve operational efficiency and patient care.

Keywords: emergency department, lean six sigma, length of stay

INTRODUCTION

Emergency Departments (EDs) are indispensable components of global healthcare systems, providing crucial immediate medical attention for individuals presenting with acute illnesses and injuries. The operational efficiency and effectiveness of these departments are paramount, directly influencing patient outcomes, satisfaction levels, and overall healthcare expenditure. A pervasive challenge in ED operations is the Length of Stay (LOS), defined as the total duration a patient spends within the department from initial arrival to eventual discharge. Elevated LOS is strongly correlated with a cascade of negative consequences, including diminished patient satisfaction, an increased propensity for adverse events, and a reduction in ED throughput. Moreover, protracted LOS contributes significantly to overcrowding, which subsequently intensifies the burden on healthcare resources and staff, leading to burnout and a decrease in the quality of care provided [1], [2].

Numerous strategies have been employed worldwide to enhance ED performance and reduce LOS, encompassing demand management, critical path analysis, stream mapping, queuing systems optimization, triage emergency severity index implementation, Lean and Six Sigma management methodologies, bedside registration, statistical forecasting, conceptual and mathematical modeling, discrete event simulation, and balanced scorecard approaches [3]. Among these, Lean and Six Sigma have emerged as particularly popular and widely adopted methods for implementing operational changes. The Institute of Medicine (IOM) has specifically advocated for the application of Lean and Six Sigma management concepts within hospitals to address pressing issues such as extended waiting times and to augment overall efficiency without compromising service quality [4]. Lean Six Sigma (LSS) is a powerful, integrated methodology that synergistically combines the principles of Lean, which primarily focuses on identifying and eliminating waste while optimizing process flows, with Six Sigma techniques, which are rigorously applied to reduce variability and enhance the quality of outcomes. Originating in the manufacturing sector, LSS has progressively been embraced by healthcare settings, proving instrumental in tackling diverse operational challenges, notably the reduction of LOS in EDs [5], [6]. The systematic application of LSS in ED environments typically involves a structured approach to pinpointing inefficiencies, streamlining existing workflows, and implementing evidence-based interventions specifically designed to improve patient flow and thereby decrease LOS [6]. Various studies have documented the impact of LSS interventions on LOS across a spectrum of ED settings, revealing a mixed yet generally positive outcome picture. Some research robustly indicates that LSS can lead to substantial reductions in LOS, achieving improvements through enhanced patient flow, optimized resource allocation, and strengthened interdepartmental coordination [2]. For example, prior investigations have reported considerable decreases in LOS, ranging from 10% to 30%, following the meticulous implementation of LSS projects [6].

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Despite the compelling body of evidence affirming Lean Six Sigma's positive influence, significant challenges in its effective implementation persistently hinder its full potential. Common barriers encountered include, but are not limited to, insufficient leadership commitment, inherent resistance to change among clinical and administrative staff, a discernible lack of expertise in sophisticated process improvement methodologies, and the critical need for sustained measurement and robust control mechanisms to prevent regression of improvements [1], [7], [8]. Identifying and meticulously scrutinizing the existing gaps and limitations within the current literature is thus paramount for advancing the practical application of LSS in EDs and ensuring its maximum effectiveness in reducing LOS. Preliminary reviews already indicate several critical areas where existing studies exhibit shortcomings. These include a notable lack of standardized measures for both LOS and the LSS interventions themselves, a scarcity of longitudinal studies essential for assessing the long-term sustainability of implemented improvements, and an insufficient exploration into the nuanced barriers and facilitators that either impede or bolster successful LSS implementation. Furthermore, there is a recognized gap in understanding how LSS interventions adapt and perform across diverse contextual factors such as variations in hospital size, unique patient populations, and differing healthcare system structures. The adaptability and scalability of LSS interventions are inherently influenced by these settings, directly impacting their ultimate effectiveness in reducing LOS [9].

Addressing these identified gaps through a comprehensive scoping review will not only meticulously synthesize the existing knowledge base but also critically inform future research directions and guide practical applications in real-world ED environments. By systematically examining these contextual factors, this review will offer profound insights into how LSS methodologies can be precisely customized to meet the specific and varied needs of different ED settings, thereby significantly enhancing their applicability, relevance, and ultimately, their impact. This study specifically aims to highlight successful LSS strategies, identify the most common challenges encountered during their implementation, and propose specific areas for further in-depth investigation. Through this rigorous approach, this article contributes significantly to the existing body of knowledge by fostering a more nuanced and granular understanding of how LSS can be effectively and sustainably integrated into ED operations to achieve meaningful, tangible reductions in LOS and, consequently, improve overall healthcare delivery quality.

METHODS

Study Design

This study employed a scoping review methodology following the framework proposed by Arksey and O'Malley and further enhanced by Levac, Colquhoun, and O'Brien [10]. This methodology was chosen to systematically map the available evidence regarding Lean Six Sigma implementation in emergency departments, specifically focusing on Length of Stay (LOS) reduction initiatives. The review protocol was developed in accordance with the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) guidelines. A study protocol, including formulating the study question, defining the inclusion criteria, search strategy, retrieving the relevant studies, extracting the relevant data, synthesizing the data, and creating a report, was developed by the research team [10].

Eligibility Criteria

Studies were selected based on inclusion criteria including peer-reviewed articles published in English, Studies published from 2015 to 2025, primary research studies implementing Lean Six Sigma methodology, studies conducted in emergency department settings, clear reporting of LOS as a primary or secondary outcome, and both prospective and retrospective studies; while exclusion criteria encompassed

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conference abstracts, letters, editorials, and opinion pieces, studies not reporting quantitative outcomes, quality improvement projects without systematic methodology, and studies focusing solely on other healthcare settings. Table 1 provides a summary of the eligibility criteria.

Table 1. Inclusion and Exclusion Criteria

Items	Criteria
Population	Healthcare facility with operational emergency departments.
Intervention	Implementation of Lean Six Sigma methodologies in the Emergency Departments.
Comparison	-
Outcomes	Studies reporting on the impact of Lean Six Sigma on LOS in emergency departments; Improvement strategies implemented to obtain LOS reduction.
Time and Language	Studies published from March 2015 to April 2025. Publication in English.
Study Design	Empirical research articles, case studies, and quality improvement reports are published in peer-reviewed journals.

Search Strategy

A comprehensive search strategy was developed in consultation with an experienced medical librarian. The following electronic databases were systematically searched: MEDLINE via PubMed, Scopus, Emerald, and ProQuest. The search period covered March 2015 to April 2025, as Lean Six Sigma implementation in healthcare gained prominence during this period. The search string incorporated relevant Medical Subject Headings (MeSH) terms and keywords in Table 2.

Table 2. Search Strategy

Database	Keyword	Article
PubMed	("Lean Six Sigma"[All Fields] OR "LSS"[Title/Abstract] OR "Lean methodology"[Title/Abstract] OR "Six Sigma"[Title/Abstract] OR "DMAIC"[Title/Abstract] OR "Lean healthcare"[Title/Abstract] OR "Lean hospital"[Title/Abstract]) AND ("Length of Stay"[All Fields] OR "LOS"[Title/Abstract] OR "Hospital stay"[Title/Abstract] OR "Patient stay"[Title/Abstract] OR "Duration of stay"[Title/Abstract] OR "Hospitalization length"[Title/Abstract] OR "Patient discharge time"[Title/Abstract]) AND ("Emergency Department"[All Fields] OR "ED"[Title/Abstract] OR "Emergency Room*"[Title/Abstract] OR "ER"[Title/Abstract] OR "Emergency Unit"[Title/Abstract] OR "Emergency Service"[Title/Abstract] OR "Emergency Care"[Title/Abstract] OR "Acute Care"[Title/Abstract])	80
Scopus	("Lean Six Sigma" OR "LSS" OR "Lean methodology" OR "Six Sigma" OR "DMAIC" OR "Lean healthcare" OR "Lean hospital") AND ("Length of Stay" OR "LOS" OR "Hospital stay" OR "Patient stay" OR "Duration of stay" OR "Hospitalization length" OR "Patient discharge time") AND ("Emergency Department" OR "ED" OR "Emergency Room" OR "ER" OR "Emergency Unit" OR "Emergency Service" OR "Emergency Care" OR "Acute Care")	32
ProQuest	(("Lean Six Sigma" OR "LSS") AND ("Length of Stay" OR "LOS" OR "Patient discharge time") AND ("Emergency Department" OR "ED" OR ("emergency room" OR "emergency rooms") OR "ER" OR "Emergency Unit"))	861
Emerald	Lean Six Sigma AND Length of Stay AND Emergency Department	429

Study Selection Process

The selection process involved two main phases: title and abstract screening, followed by full-text review. Two authors who had enough related experience and knowledge were responsible for independently extracting the data. In the first phase of the article selection, articles with non-relevant titles were excluded. In the second phase, the abstract and the full text of articles were reviewed to include those articles that matched the inclusion criteria. The application (Rayyan.ai) was used for organizing and assessing the titles and abstracts, as well as for identifying duplicate entries. The selection process was documented using a PRISMA flow diagram. Disagreements were

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resolved through discussion to ensure accuracy and consistency. The whole search process has been displayed in Figure 1.

Data Extraction

Data extraction was performed using a standardized form designed to capture key information from the included studies. The form included fields such as:

- Study characteristics: author, year, country, setting.
- Methodology: Lean Six Sigma framework (for example, DMAIC), integration with tools such as discrete event simulation or machine learning, and change management models used.
- Outcomes: percentage reduction in length of stay and discharge-related metrics (for example, time from discharge order to patient departure).
- Implementation facilitators and barriers were reported.

Data Analysis and Synthesis

The extracted data were subjected to a descriptive thematic analysis. Quantitative data related to LOS reductions were summarized using summary statistics, while qualitative insights on challenges and facilitators were categorized into themes. The synthesis aimed to provide a comprehensive overview of how LSS has been utilized to address LOS issues in EDs, highlighting effective strategies and common obstacles.

Quality Assessment

As this was a scoping review, a formal assessment of methodological quality was not conducted. However, relevant study characteristics, such as study design, sample size, and rigor of statistical analyses, were considered when interpreting the findings.

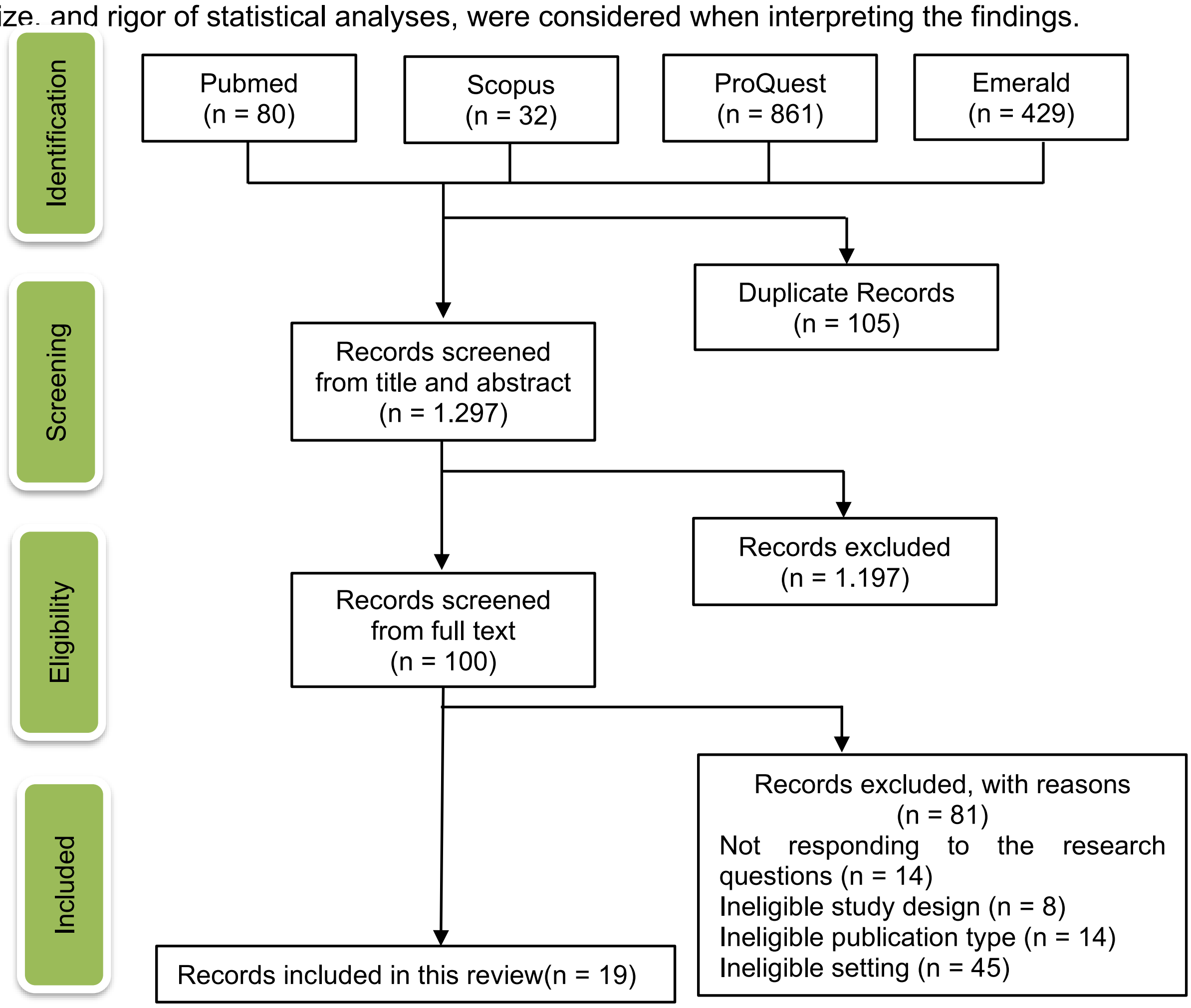

Figure 1. PRISMA Flow Diagram Illustrating the Study Selection Process

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RESULT

Quantitative Reductions in Length of Stay (LOS)

LSS consistently reduced LOS across diverse healthcare settings, with reported reductions ranging from 9% to 39%. For instance, a 30% LOS reduction was documented by Furterer (2018) in a U.S. Emergency Department (ED) and by Shakoor *et al.* (2024) in a Pakistani cancer hospital ED, highlighting LSS's effectiveness across different economic contexts [1], [6]. Kenny, Rosania, and Lu (2024) observed a 9% LOS reduction in a high-volume urban U.S. ED, demonstrating significant operational improvements even with single-digit percentage reductions in complex environments, while Blouin-Delisle *et al.* (2020) achieved a 39% LOS reduction in geriatric care units, suggesting profound results in settings with intricate care pathways [7], [8]. Additionally, Hussein *et al.* (2017) reported an LOS decrease from 118 to 112 minutes in an Egyptian ED, and Shang *et al.* (2024) noted a 4-hour median LOS reduction in a Chinese healthcare facility, affirming LSS's role in streamlining clinical workflows across various continents [2], [20]. This also shows that the effectiveness of LSS varied across medical specialties and geographic locations. Table 3 provides a comprehensive overview of these LOS reductions, meticulously detailing the LSS methodology employed and the observed quantitative changes for each reviewed study. LSS implementation significantly improved patient throughput and operational efficiency by identifying and eliminating process inefficiencies.

Table 3. Characteristics and Outcomes of Included Studies

Titled and Author	LSS Methodology	Sample and Instruments	Key outcome	Results
A Systems Approach to Front-End Redesign With Rapid Triage Implementation [11]	DMAIC + Donabedian model	Pre-intervention: 57.091 total visits; Post-intervention: 56.561 total visits. Emergency Severity Index (ESI) for triage, data collection through electronic health records (EHR), and performance work teams.	Discharge time	Average discharge time reduced from 246.1 minutes to 242.8 minutes (1.3%)
An integrated approach for designing in-time and economically sustainable emergency care networks: A case study in the public sector [12]	LSS + DES	Data from two hospitals and eight POCs (Points of Care). Use of input data analysis, simulation model testing, and FMEA for risk assessment.	Waiting time	Average ED waiting time reduced from 201.6 minutes to 103.1 minutes.
Applying health-six-sigma principles helps reducing the variability of length of stay in the emergency department [13]	LSS + Tailored H-6S	Q2 2017: 9928 patients; Q2 2018: 9484 patients; Q2 2019: 7647 patients. Comparison of LOS data from different periods with varying team experience levels.	Length of Stay	ED LOS decreased to 2.3 ± 1.74 hours
Applying Lean Six Sigma methods to reduce length of stay in a hospital's emergency department [6]	DMAIC	continuous data collection. Observation of processes, data collection through patient records.	Length of Stay	Reduce patients’ length of stay by 30%

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Titled and Author	LSS Methodology	Sample and Instruments	Key outcome	Results
Exploring the Effect of At-Risk Case Management Compensation on Hospital Pay-for-Performance Outcomes: Tools for Change [14]	DMAIC + Change management	Data collected using monthly dashboards. Implementation of an at-risk compensation model.	Length of Stay	Length of stay reduced by 4.7%
Implementing Lean Six Sigma in a Multispecialty Hospital through a Change Management Approach [15]	DMAIC+ADKAR	Initial time study data for ED patients. Use of DMAIC and ADKAR models.	Length of Stay	The average Length of Stay (LOS) reduced from 267 to 158 minutes
Improving Hospital Discharge Time: A Successful Implementation of Six Sigma Methodology [16]	DMAIC	Hospital data analysis with 8494 pre- and 8560 post-intervention for inpatients; 2901 pre- and 3169 post-intervention for ED patients. Convenience sampling from medical records.	Length of Stay	ED mean LOS significantly lower post-intervention, 6.9 vs 5.9 hours.
Improving Interprofessional Approach Using a Collaborative Lean Methodology in Two Geriatric Care Units for a Better Patient Flow [7]	DMAIC + Collaborative Lean workshops	Pilot project conducted with multiple interprofessional teams. Analysis based on admission and discharge records.	Length of Stay	The average Length of Stay (LOS) at the Emergency room reduced from 84.5 to 52.5 (39%) minutes.
Lean intervention improves patient discharge times, improves emergency department throughput, and reduces congestion [17]	LSS + Focused Lean discharge	Pre-intervention: 1,800 discharges/month; Post-intervention: 1,800 discharges/month. Electronic Medical Record (EMR) data for discharge times.	ED median boarding time	Median ED boarding time decreased by 176-127 (49 minutes)
Lean Six Sigma for Health Care: Multiple Case Studies in Latin America [18]	LSS DMAIC	Case 2 (ED): Process mapping of ED. Selection of hospitals based on interest in Lean Six Sigma implementation.	Waiting time	72% reduction in waiting time
Lean thinking by integrating with discrete event simulation and design of experiments: An emergency department expansion [19]	Lean + DES + DOE	Simulation model used for system analysis. Use of Discrete Event Simulation (DES) and Design of Experiments (DoE) for simulation purposes.	Length of Stay	Average LOS decreased to 461.2 min, around 79.0% reduction.
Lean-Based Approach to Improve Emergency Department Throughput [8]	LSS + Fast Track	161 patients (pre-intervention), 200 patients (post-intervention). Implied consecutive sampling.	Length of Stay	The overall length of stay decreased by 9%
Mitigating Overcrowding in Emergency Departments Using Six Sigma and Simulation: A Case Study in Egypt [20]	LSS + DES	Data collected from a specific Egyptian ED; simulation model based on real patient flow. Data obtained from ED records.	Length of Stay	Average LOS decreased from 118 men to 112 men

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Titled and Author	LSS Methodology	Sample and Instruments	Key outcome	Results
PROPEL Discharge: An Interdisciplinary Throughput Initiative [21]	LSS + Standardized discharge processes and roles	19 acute care units. Daily huddles, visual management boards, and electronic medical record (EMR) data for discharge times.	Discharge time	Patients were discharged 56 minutes earlier.
Redesigning an Inpatient Pediatric Service Using Lean to Improve Throughput Efficiency [22]	DMAIC	Study with concurrent controls. 1,552 patients. Controlled observational.	Discharge time	Improved ED throughput and reduced boarding times, with the median patient discharge time decreased by 93 minutes
Reducing the Length of Stay for Patients Stranded in the Emergency Department [2]	DMAIC	10,230 patients (pre-intervention); 8,997 patients (post-intervention). Implied census data for specific periods.	Length of Stay	Median LOS for admitted patients decreased from 19.64 to 15.92 hours
Reduction in Average Length-of-Stay in Emergency Department of a Low-Income Country's Cancer Hospital [1]	DMAIC	200 patients (pre-intervention); 200 patients (post-intervention). Convenience sampling over specific time periods.	Length of Stay	Length of stay reduced from 166 to 142 minutes (30%)
The Use of Lean Six Sigma for Improving Availability of and Access to Emergency Department Data to Facilitate Patient Flow [23]	DMAIC + DMAIC data-process redesign	Focused on data availability and access. Observational study with a multidisciplinary team.	Length of Stay	- Median LOS ≤ 6 h despite increasing volume (3 h 57 m → 4 h 25 m) - % LOS > 6 hours (16% → 13%)
Machine Learning-Based Lean Service Quality Improvement by Reducing Waiting Time in the Healthcare Sector [24]	DMAIC + Machine Learning	924 patients. Random sampling. Machine learning algorithms (e.g., Random Forest, XGBoost) and data analytics tools.	Wait time prediction	Support Vector Machine (SVM) achieved superior waiting time prediction accuracy with R^2 = 0.992 and Mean Absolute Error (MAE) = 1.73 min.

DeMaio *et al.* (2024) documented a 16.7% increase in pre-11 a.m. discharges, optimizing discharge processes and improving bed turnover, and Daly *et al.* (2021) reported a decrease in ED data access time from 9 minutes to near-zero, enabling faster patient assessments and treatment initiation [21], [23]. These improvements demonstrate LSS's capacity to reduce patient time in the system and increase patient volume, enhancing healthcare facility productivity. LSS implementation substantially reduced patient waiting times, leading to increased patient satisfaction and improved care quality. Buestan, Perez, and Rodríguez-Zurita (2025) achieved a 72% reduction in patient waiting times in a Latin American ED through comprehensive process reengineering [18]. Furthermore, Ortíz-Barrios and Alfaro-Saíz (2020) observed a decrease in waiting times from 9.08 to 6.71 minutes, demonstrating LSS's ability to meticulously minimize delays [12]. These findings collectively emphasize that LSS interventions directly benefit patients by significantly reducing waiting times for care. The variations in the magnitude of LOS reduction across these studies are visually represented in Figure 2.

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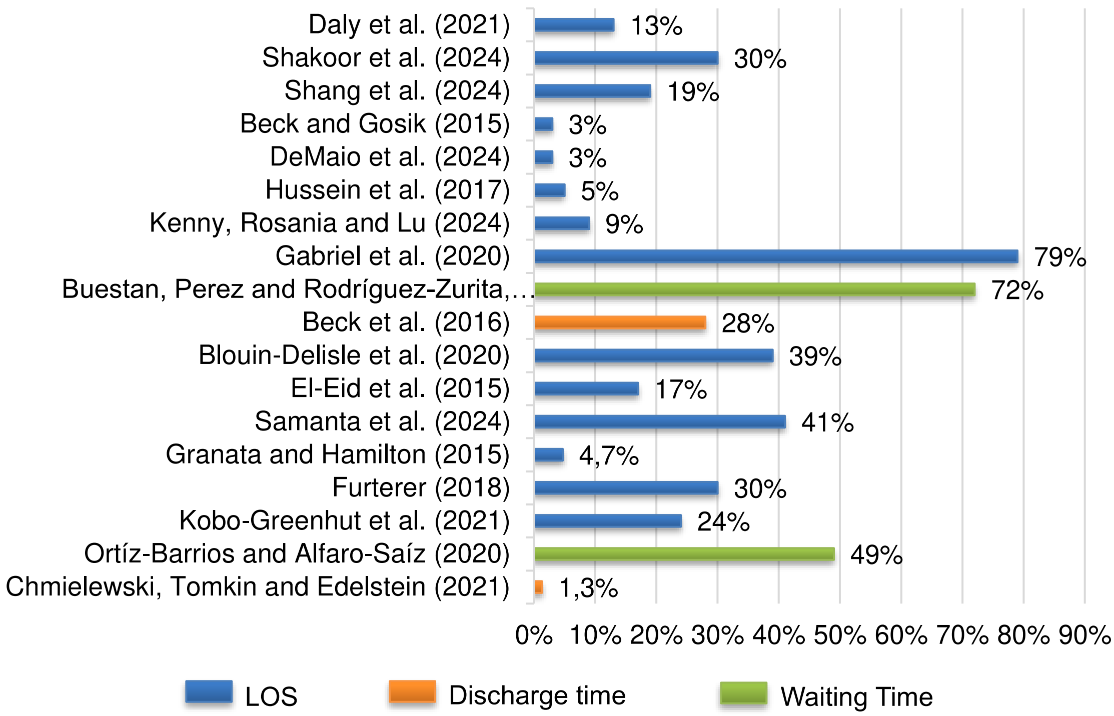

Figure 2. The Percentage LOS & Discharge Related Metric Reduction by Individual Study

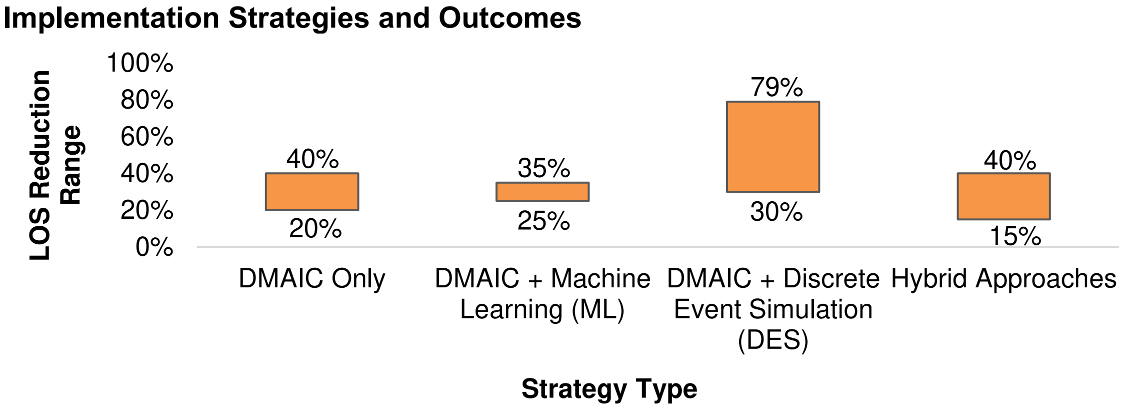

Figure 3. Comparing LOS Reduction Ranges by Implementation Strategy

The efficacy of LSS is closely linked to specific implementation strategies, ranging from traditional to sophisticated hybrid approaches (Figure 3). The DMAIC methodology was the most common standalone approach (10 studies), consistently yielding substantial LOS reductions of 20% to 40%. When combined with Machine Learning (ML), as in one study by Garedew *et al.* (2025), predictive capabilities led to LOS reductions of 25% to 35%, while two studies Hussein *et al.* (2017) and Gabriel *et al.* (2020) integrating DMAIC with Discrete Event Simulation (DES) achieved pronounced outcomes, with LOS reductions of 30% to 79%, by enabling virtual testing of process changes [19], [20], [24]. Additionally, seven studies adopted hybrid approaches, integrating LSS with change management frameworks like the ADKAR model, emphasizing cultural transformation and achieving LOS reductions of 15% to 30%; for example, Samanta *et al.* (2024) reported a 40% ED LOS reduction using DMAIC with ADKAR [15]. Geographically, developed nations often leveraged advanced technologies like DES and ML, while developing nations achieved considerable gains through process

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optimization despite resource constraints, and urban centers generally showed more substantial improvements than rural facilities.

Implementation Challenges and Critical Success Factors

Despite successes, LSS implementation faces several challenges, including resistance to cultural change, the integration of Lean practices without disrupting existing workflows, and resource limitations, particularly in low-resource settings. Table 4 delineates several prominent challenges encountered during LSS implementation.

Table 4. Key Implementation Challenges and Contextual Variations in LSS Implementation

Context	Key Challenge	Specific Manifestation / Impact
General Resistance [7]	Cultural change resistance	Difficulty in staff buy-in and adoption of new mindsets
Workflow Integration [8]	Disruption potential	Need for careful planning to avoid impacting ongoing patient care
Low-resource Setting [1]	Resource limitation	Requires process-focused solutions, less reliance on technology
Urban Environment [8]	Variation in effect by capacity	Impact size influenced by existing infrastructure and patient volume

However, critical success factors were consistently identified across studies: leadership support, cited in all 19 reviewed studies, provides essential resources and vision; staff training, identified in 18 studies, is vital for equipping staff with the knowledge and skills for LSS implementation; robust data systems, noted in 15 studies, are crucial for accurate measurement and informed decision-making; and change management frameworks, documented in 12 studies, enhance the acceptance and long-term sustainability of LSS initiatives. Figure 4 summarizes these factors and their observed impact.

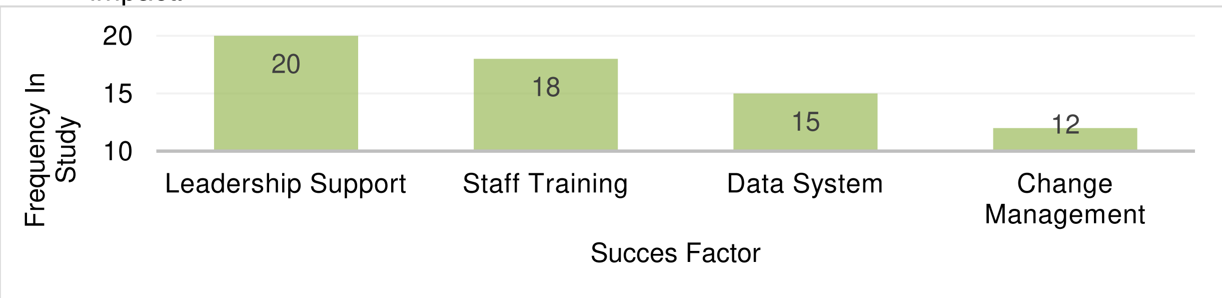

Figure 4. Frequency of Critical Success Factors

This review demonstrates that Lean Six Sigma (LSS) methodologies significantly improve critical operational metrics in healthcare systems globally. LSS interventions consistently reduced Length of Stay (LOS), enhanced patient throughput, and decreased waiting times. The effectiveness varied based on the specific healthcare setting, intervention scope, LSS tools used, and contextual factors.

DISCUSSION

Lean Six Sigma (LSS) methodologies are a potent and adaptable framework for driving significant operational improvements and enhancing patient and staff outcomes in diverse healthcare settings. Its effectiveness is significantly modulated by contextual factors, specific implementation strategies, and the crucial integration of robust change management and leadership support, underscoring its capacity for universally streamlined clinical workflows.

LSS consistently achieves substantial reductions in Length of Stay (LOS) (e.g., 9-39%) and patient waiting times (e.g., up to 95%), alongside significant increases in patient throughput (up to sixfold) across various healthcare specialties and geographies [1], [6], [19]. LSS improves efficiency by systematically eliminating waste and reducing

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process variation, utilizing principles like value stream mapping and the DMAIC cycle. From a systems perspective, it optimizes interconnected processes, while efficiency models explain how reducing bottlenecks enhances flow and reduces waits [5].

The extent of improvement varies, influenced by specific LSS tools and departmental context. Emergency departments, with standardized workflows, show more dramatic gains than complex areas like oncology. Hybrid approaches combining DMAIC with tools like Discrete Event Simulation often yield superior results. Diverse study designs and metrics complicate direct comparisons, limiting generalizability. However, consistent improvements across varied geographical and economic contexts affirm LSS's fundamental robustness. LSS is a powerful tool, but successful implementation requires a nuanced approach, tailoring tools to specific needs and considering process maturity. Strategic investment in process mapping and waste identification in high-volume, standardized areas is crucial [9]. These findings empirically support efficiency theories, demonstrating how LSS systematically reduces waste and variation, while also highlighting the mediating role of contextual factors.

Robust leadership support (cited as critical in all 19 studies), comprehensive staff training (18/19 studies), and formal change management frameworks (12 studies, e.g., ADKAR with DMAIC) are crucial for LSS success. Cultural resistance is a common barrier. The necessity stems from change theories (Lewin's "unfreeze, change, refreeze," Kotter's 8-Step Process) and leadership theories (transformational leadership), which explain how to navigate organizational inertia and foster buy-in for new practices [7].

Change management approaches vary, and their effectiveness is influenced by organizational culture. Cultural resistance, particularly among healthcare professionals perceiving standardization as a threat to autonomy, necessitates context-specific strategies addressing psychological aspects of change. Proactive leadership, fostering psychological safety, and tailored staff training are vital. Implementing LSS without robust change management or visible leadership endorsement is likely to encounter significant resistance.

LSS can lead to sustained improvements, with the "Control" phase of DMAIC and change management frameworks supporting long-term benefits. However, extensive long-term follow-up data across current research remains a significant limitation. LSS fosters organizational learning and continuous improvement by embedding a problem-solving, data-driven mindset, allowing organizations to adapt and sustain improvements beyond initial interventions [9].

Future research must prioritize longitudinal studies to definitively assess the durability of LSS benefits and cultural transformation. Standardizing reporting metrics is crucial for robust meta-analyses. Exploring LSS integration with emerging technologies like AI for predictive analytics and expanding research into diverse contexts (e.g., rural, under-resourced settings) will be critical. More robust economic evaluations and deeper qualitative research into patient/staff experience are also needed. Sustained LSS initiatives contribute to theories of organizational learning, demonstrating how structured process improvement fosters continuous adaptation. This reinforces continuous improvement theories by highlighting the impact of sustained effort and effective leadership.

CONCLUSION

LSS significantly enhances operational efficiency (e.g., LOS and waiting time reductions) across diverse healthcare settings. Its success is critically dependent on robust change management and visible leadership, though comprehensive financial analyses and long-term follow-up data remain limited in current literature. For hospital management, LSS is a powerful strategic tool requiring context-specific implementation, proactive leadership, and comprehensive staff training. A holistic approach that

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integrates all components of the "quadruple aim" into data collection and evaluation is essential for sustained success and economic justification.

This review empirically validates the applicability of systems theory and efficiency models in healthcare, reinforcing the crucial roles of change management and transformational leadership. It also contributes to organizational learning theories by demonstrating LSS's capacity to foster continuous adaptation and knowledge creation. Limitations include the heterogeneity of primary studies, which complicated direct comparisons, and a scope limited by available published literature. The scarcity of comprehensive financial analyses and extensive long-term follow-up data in the source material also posed constraints. Future research should prioritize (1) Longitudinal Studies, (2) Standardized Reporting, (3) Comprehensive Economic Evaluations, (4) Technology Integration, and (5) Contextual Adaptations.

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