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INTEGRATING LEAN METHODOLOGIES AND SIMULATION MODELING TO ACCELERATE PATIENT FLOW AND REDUCE WAITING TIMES: A DESK ANALYSIS

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Abstract

The effectiveness and calibration of the healthcare system worldwide are still threatened by lengthy wait times for patients. The purpose of this systematic review is to critically assess how Discrete Event Simulation (DES) and Lean Methodologies (LM) can reduce patient wait times in various healthcare settings. Using the PRISMA guidelines, 35 peer-reviewed articles from four major databases, published between 2015 and 2025, were carefully selected. Data was extracted to identify applied tools, study contexts, and validated outcomes. The findings demonstrate that, particularly in outpatient and emergency settings, a stand-alone Lean tool enhances patient flow and reduces delays. However, by enabling real-time scenario testing and streamlining workflow modifications without interfering with operations, the integration of LM with DES provides additional advantages. The results also show a lack of long-term sustainability strategies in LM or DES projects and a research gap in low- and middle-income countries. In addition, cross-functional teamwork and leadership engagement were crucial success factors, whereas staff disengagement and a lack of real-time monitoring were major obstacles.In summary, the combined application of LM and DES offers a practical and cost-effective approach to addressing patient flow issues. To improve implementation outcomes, future research should prioritise stakeholder involvement, digital performance tracking, and sustainability.

***Keywords**:* Discrete Event Simulation, Healthcare Efficiency, Lean Management, Patient Waiting Time, Simulation Modelling

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Introduction

The growing demand for healthcare services, combined with constrained resources, has led to prolonged patient waiting times, a significant issue that negatively impacts patient satisfaction and the overall quality and effectiveness of healthcare systems (Gupta & Denton, 2008). To overcome this challenge, innovative strategies that aim to enhance resource allocation and optimise operational processes are becoming more prominent. Among these strategies, lean methodologies and simulation are among the most popular tools within the healthcare settings (S. Robinson et al., 2012).

Lean principles, which originated from the Toyota Production System (TPS), focus on eliminating waste and enhancing operational value for customers (Womack & Jones, 1997). Although Lean originated in manufacturing, Lean has been successfully adapted to healthcare settings since the early 2000s, showing significant potential to enhance patient flow and improve overall service quality (Antonelli & Bruno, 2015). Several systematic reviews have consolidated the evidence base. Tlapa et al. (2020) demonstrated that Lean healthcare interventions significantly improve patient flow and reduce inefficiencies across multiple care settings. Building on this, Tlapa et al. (2022) provided a broader synthesis combining Lean, Six Sigma, and simulation, highlighting the emerging synergy between these approaches. Similarly, Souza et al. (2021) focused specifically on emergency departments and confirmed Lean's capacity to reduce delays, though sustainability and scalability remain unresolved.

When Lean Methodology (LM) is combined with simulation, particularly Discrete Event Simulation (DES), it provides a robust set of tools for managing the challenges associated with reducing patient waiting times. Simulation modelling enables the computer-generated representation of healthcare systems, facilitating the evaluation of different scenarios without disrupting ongoing operations within the system (Tako et al., 2010).

Lean thinking in healthcare*:* LM in healthcare prioritises mainly a patient-centred approach to improve clinical and administrative processes continuously. It targets various forms of waste, such as unnecessary movement, waiting, over-processing, and underutilised skills, which directly translate from manufacturing to the healthcare environment (Hammoudeh et al., 2020).

Various lean tools have been developed to uphold this philosophy across different sectors. These tools can be classified into four categories: assessment tools, improvement tools, monitoring tools, and assessment, improvement/monitoring tools (Al-Zuheri et al., 2021). Among the lean tools identified, according to Kovacevic et al. (2016), the most utilised lean tools in healthcare include 5S, Kaizen, Value Stream Mapping, and Visual Management.

Simulation techniques in healthcare: Simulation has become increasingly popular in healthcare for its ability to model and analyse complex systems. Discrete-event simulation is most valuable for modelling patient flow in healthcare settings. Other types of simulations also offer unique strengths in modelling various aspects of healthcare delivery.

The application of simulation in healthcare extends to various domains. For example, simulation is also crucial in improving healthcare quality and safety. It provides a safe environment for healthcare professionals to practice and refine their skills, especially in high-risk scenarios. By identifying potential risks and vulnerabilities, simulation contributes to a culture of continuous improvement and patient safety (Lamé & Dixon-Woods, 2018).

Motivation for This Review

Despite various initiatives aimed at enhancing healthcare efficiency (Ahmad et al., 2021; Hammoudeh et al., 2020; Le et al., 2021), patient waiting times remain a significant burden in numerous healthcare sectors worldwide. Although both LM and simulation methods have shown potential in addressing the issue of long waiting times, their joint application has not been sufficiently explored. There is a necessity for a thorough evaluation of the existing evidence to comprehend how these methodologies have been applied in practice and to identify the gaps that still exist within the current body of knowledge.

The primary objective of this research is to conduct a critical assessment of how Lean Methodology (LM), both independently and when integrated with Discrete Event Simulation (DES), contributes to reducing patient waiting times in diverse healthcare settings. Instead of restricting the analysis to a particular department, this review aims to encompass any healthcare scenario where patient wait time is the primary concern. This study aims to review the practical application of these approaches and identify gaps in the current literature. Although a range of simulation techniques, such as System Dynamics (SD) and Agent-Based Modelling (ABM), have been utilised within the studies of healthcare operations, this research specifically focuses on Discrete Event Simulation (DES). The reason is that DES and LM are generally implemented at the operational level to address inefficiencies within patient care processes. At the same time, SD is more suitable for strategic-level decision-making, and ABM places more emphasis on the actions of individual agents and their interactions, even though it is capable of modelling operational systems. This added complexity may cause difficulties in model validation, which makes DES a more practical option for investigations aimed at operational efficiency (Demirli et al., 2021).

The expected outcomes of this study include a comprehensive synthesis of existing research employing LM, DES, or their integration to address patient waiting time issues, the identification of proven strategies and techniques that have enhanced service efficiency, and the formulation of recommendations for both future academic inquiry and practical implementation to improve healthcare delivery systems.

Methodology

Search Strategy

To ensure thorough coverage of relevant literature, a systematic search strategy was developed and implemented across six major academic databases: PubMed, Research Gate, ScienceDirect, Scopus, Embase, and Web of Science. Finding key terms associated with the subject, such as "Lean healthcare," "Lean management," "simulation," "Discrete Event Simulation," and "patient waiting time," was the first step in the search process. Boolean operators were applied to refine the search queries. For example:

- ("Lean healthcare" OR "Lean thinking" OR "Lean management") AND ("simulation" OR "Discrete Event Simulation" OR "DES") AND ("patient waiting time" OR "waiting time reduction") AND ("healthcare" OR "hospital" OR "clinical settings")

Each database was searched independently using customised search strings appropriate to its specific syntax and interface. To refine the search, specific inclusion criteria were set: eligibility was restricted to peer-reviewed articles published between 2015 and 2025 to ensure contemporary relevance. This period marks the methodological maturity of LM and DES studies, the broader adoption of digital healthcare technologies, and evidence that is more representative of current operational challenges.

Refining, Filtering, and Screening

After gathering the initial set of literature, the filtering process was conducted according to the PRISMA (Fig. 1) methodology. The refining process began with the removal of duplicate records identified across the databases. Then, a systematic two-step screening and selection procedure was employed to ensure the quality and applicability of the studies. First, the titles and abstracts of all retrieved articles were reviewed manually to assess their alignment with the research topic. Articles considered relevant at this stage were subjected to full-text analysis to confirm eligibility. The following criteria were used in this instance.

- Include studies conducted in real-world healthcare settings.
- Include studies that aim to reduce patient waiting time and enhance efficiency.
- Exclude studies applying lean or simulation without addressing patient waiting time or patient flow.
- Exclude theoretical papers, reviews, editorials, or opinion articles lacking empirical validation.

The screening process was conducted by a single reviewer, which may introduce selection bias; this limitation is acknowledged as a potential constraint on reproducibility.

Data Extraction

The final set of 36 papers was extracted using a standardised template developed in Microsoft Excel. To ensure clarity and completeness, the extraction form was piloted on a small subset of studies before being applied to the full dataset. Extracted information included study title, authors, publication year, country, journal, healthcare setting, Lean or simulation techniques applied, methodology, outcomes measured (e.g., patient waiting-time reduction, throughput, patient satisfaction), and key findings. A single reviewer primarily conducted data extraction; however, the entries were cross-checked against the original articles to minimise errors.

To strengthen methodological rigour, a quality appraisal of the included studies was conducted using the Risk of Bias in Non-randomised Studies of Interventions (ROBINS-I) tool. Each study was assessed across seven domains (confounding, participant selection, classification of interventions, deviations from intended interventions, missing data, measurement of outcomes, and selection of reported results). Studies were then categorised as having low, moderate, or serious risk of bias. This allowed the synthesis to consider the relative strength of evidence, rather than treating all included studies as equally reliable.

Disagreements during the screening and appraisal stages were resolved through discussion and consensus with a second reviewer, ensuring consistency and transparency throughout the process. This review was not prospectively registered in PROSPERO due to institutional limitations. However, the systematic search strategy, inclusion/exclusion criteria, and quality appraisal process were rigorously documented to maintain transparency and reproducibility.

Results

Descriptive Analysis

Geographical distribution: The included studies represent a diverse range of countries, with the highest number of studies originating from the United States (n = 8), followed by Canada (n = 3), Jordan (n = 3), Thailand (n = 2), Kuwait (n=2), Brazil (n=2), Ireland (n=2) and Taiwan(n=2). The remaining countries, including India, China, Pakistan, Indonesia, Malaysia, Egypt, Iraq, and others, contributed one study. The geographical spread of the selected studies is illustrated in Fig. 2.

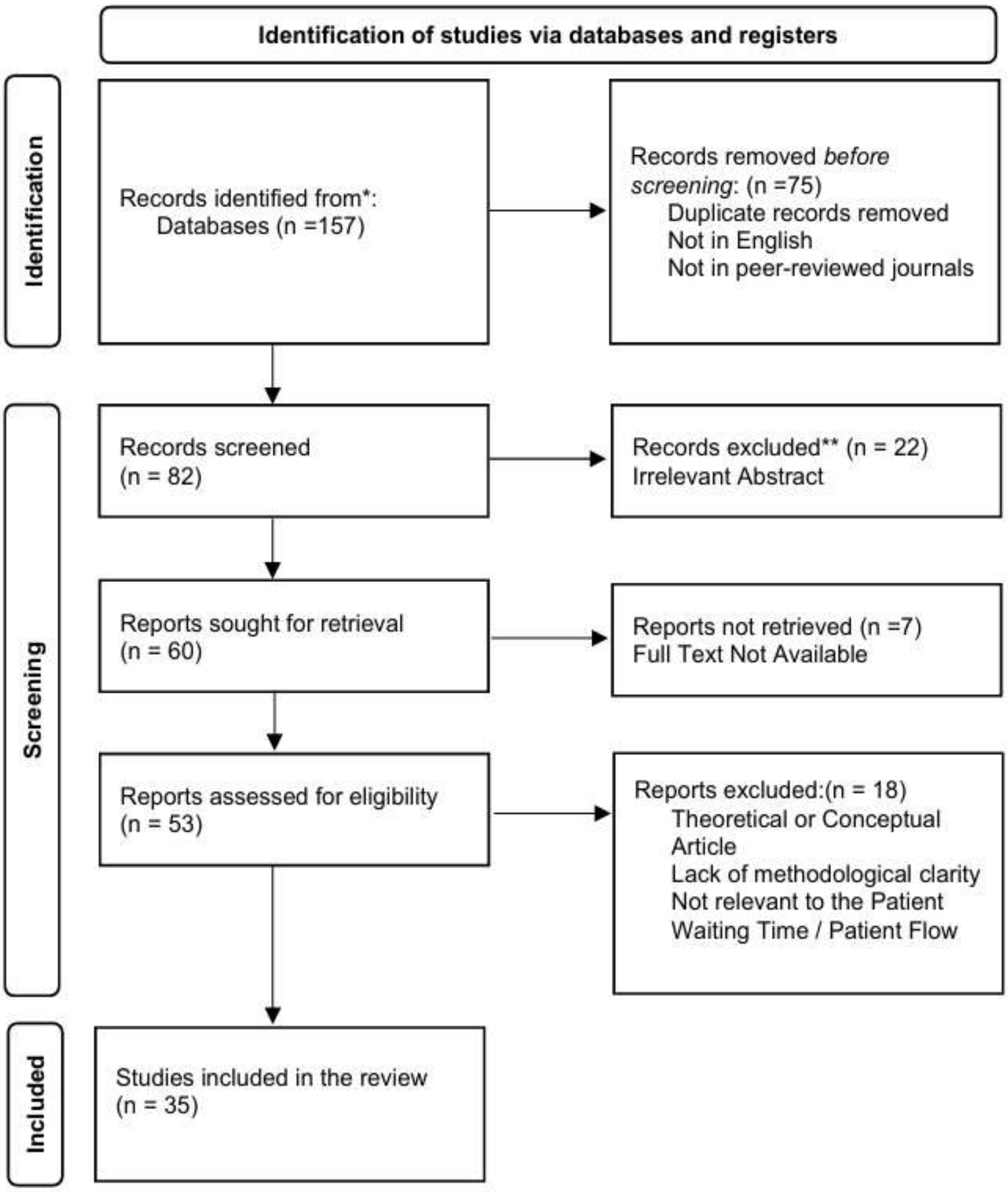

Figure 01: Systematic Review Following PRISMA Framework

However, a clear difference exists between the contributions from developed and developing countries. Most studies originate from developed countries in North America and Europe, where healthcare systems are well-resourced. In contrast, developing nations, despite facing more urgent challenges related to patient waiting times and resource constraints, were underrepresented in the literature. This suggests an opportunity and a need for further research in low and middle-income countries, where LM and DES approaches could offer significant operational value.

Publication trends over time: Fig. 3 illustrates the publication trends from 2015 to 2025 regarding the application of LM and the integration of LM with DES in healthcare settings. An upward trend in studies focusing solely on LM is observed, with notable increases in 2018 (n = 7) and a peak in 2021 (n = 8). Research integrating both LM and DES first appeared in 2015 (n = 1) (Wang et al., 2015), followed by a re-emergence in 2019 (n = 1) (Al-Zain et al., 2019), with a notable increase in 2021 (n = 2) (Rocha &

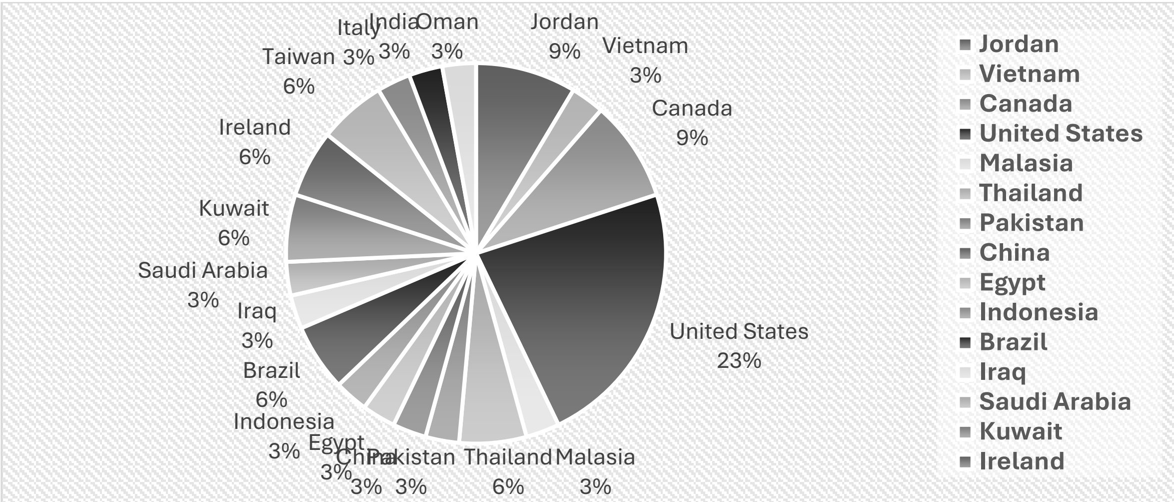

Figure 02: Distribution of Countries of the Selected Articles

Vasconcelos, 2021; Ahmad et. al., 2021) and 1 study in 2023 (Mistarihi et al., 2023) and a resurgence in 2024 (n = 3) (Ngaorungsi & Chutima, 2024; Hassan et al., 2024; Ketan et al., 2024). Despite these advancements, there are still relatively few studies that combine LM and DES, compared to those using LM approaches alone. This variance highlights a continuing gap in the literature and emphasises the potential for further exploration of synergistic interventions aimed at reducing patient waiting time in healthcare settings.

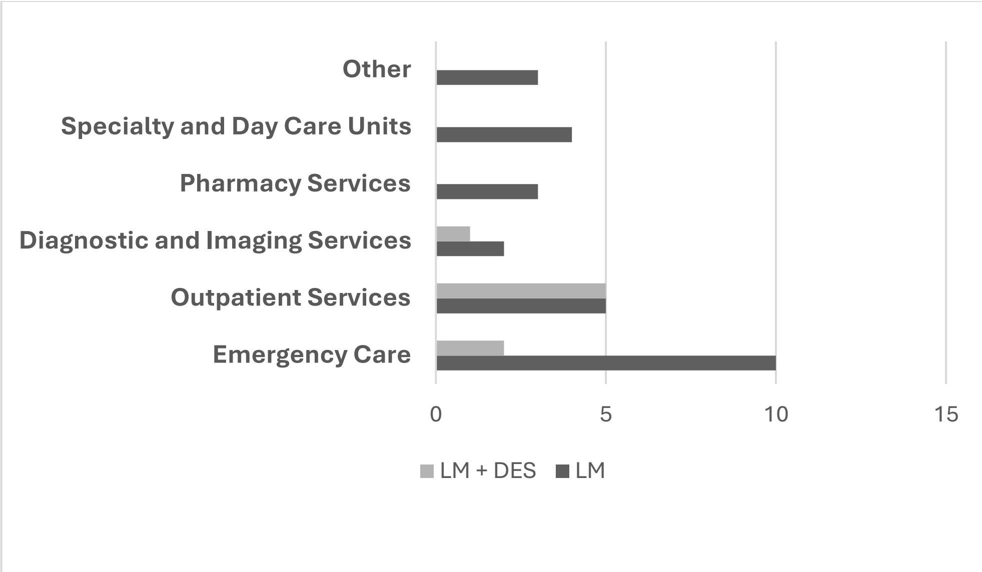

Figure 03: Distribution of Healthcare Settings

Healthcare setting: The selected studies were conducted across a broad range of departments and clinical environments, including emergency departments, outpatient clinics, oncology units, pharmacies, radiology departments, surgical wards, and specialised services such as paediatrics, obstetrics and gynaecology, and liver transplant clinics. This variety demonstrates how LM and DES approaches are flexible and applicable in a range of healthcare settings. In fact, Souza et al. (2021) provided a systematic review focused specifically on Lean applications in emergency departments, reinforcing the observation that emergency departments are among the most common sites for Lean interventions. Fig. 4 illustrates the distribution of the selected studies according to their healthcare setting, classified as Emergency Care, Outpatient Services, Diagnostic and Imaging Services, Speciality and Day Care Units, Pharmacy Services, and others, and this indicates that Outpatient Services and Emergency Care are the most common settings where LM and DES have been applied. Emergency Care shows the highest number of stand-alone LM applications, while Outpatient Services shows a balanced utilisation of both LM and DES.

Methodological Analysis

A variety of LM and DES software have been employed in the selected studies to enhance the effectiveness of healthcare processes. Value Stream Mapping (VSM), 5S, Kaizen, and Root Cause Analysis were among the most applied lean tools. To provide a structured overview, the lean tools were categorised according to the classification proposed by Al-Zuheri et al. (2021), which groups them into four categories. Table 1 summarises the relevant lean tools identified under each category, along with the corresponding research articles that applied them.

As illustrated in Fig. 5, the frequency of specific lean tools varied across the reviewed studies. VSM was the most prominently used tool (n = 20), followed by Lean Six Sigma/DMAIC (n = 14), Root Cause Analysis (n = 7), and 5S (n = 7). Less frequently applied tools included Fishbone diagrams, PDCA, and Visual Management, indicating varying levels of methodological emphasis among studies. Regarding DES, various simulation software platforms were utilised for implementation.

Table 01: Lean Tools and Methods Applied in the Included Studies

Category	Lean Tools and Methods	Articles
Assessment	5 Whys	Hussein et al., 2025
	A3	Hammoudeh et. al., 2020; Hussein et al., 2025; Lot et. al., 2018; Alowad et. al., 2020
	Ishikawa/ Fishbone Diagram	Hammoudeh et. al., 2020; Hassan et. al., 2024; Hussein et al., 2025; Al-Zain et al., 2019; Daly et al., 2021
	Process Mapping	Fu et. al., 2021; Hussein et al., 2025; Robinson et al., 2020; Alowad et. al., 2020; Vashi et al., 2018; Miller and Chalapati, 2015; Daly et al., 2021
	Value Stream Mapping	Hammoudeh et. al., 2020; Le et. al., 2021; Yu et. al., 2021; Ahmad et. al., 2021; Hroub et al., 2019; Trakulsunti and Trakoonsanti, 2021; Hassan et. al., 2024; Lot et. al., 2018; Rocha and Vasconcelos, 2021; Robinson et al., 2020; Alowad et. al., 2020; Vashi et al., 2018; Davies et al., 2019; Wang et al., 2015; Sampalli et al., 2015; Mistarihi et al., 2023; Improta et al., 2018; Miller and Chalapati, 2015; Elamir, 2018
	Gemba Walk	Hassan et. al., 2024; Hussein et al., 2025; Lot et. al., 2018; Daly et al., 2021;
Improvement	Spaghetti diagram	Hammoudeh et. al., 2020; Mangum et al., 2021
	Kaizen event	Yu et. al., 2021; Ahmad et. al., 2021; Hassan et. al., 2024; Yuliati and Andriani, 2021; Improta et al., 2018; Fu et. al., 2021
	Pull system/Kanban	Hassan et. al., 2024
	Poka-yoke	Ngaorungsi and Chutima, 2024
	Process redesign	Davies et al., 2019
	Standardised work	Fu et. al., 2021; Vashi et al., 2018
	5S	Ahmad et. al., 2021; Trakulsunti and Trakoonsanti , 2021; Hassan et. al., 2024; Fu et. al., 2021; Mangum et al., 2021; Improta et al., 2018; Daly et al., 2021
Monitoring	Visual management	Ngaorungsi and Chutima, 2024; Fu et. al., 2021; Vashi et al., 2018
Assessment/ Improving/ Monitoring	Six Sigma DMAIC (define-Measure analyse-improve-control)	Godley and Jenkins, 2018; Kam et. al., 2021; Hassan et. al., 2024; Hussein et al., 2025; Ketan et. al., 2024; Robinson et al., 2020; Davies et al., 2019; Mistarihi et al., 2023; Furterer, 2018; Daly et al., 2021; Chang et al., 2018; Dayeh et al., 2025, Al-Zain et al., 2019; Kovach and Ingle, 2019
	PDCA (Plan-do-check-action)	Yuliati and Andriani, 2021; Robinson et al., 2020; Vashi et al., 2018; Al-Zain et al., 2019; Kovach and Ingle, 2019

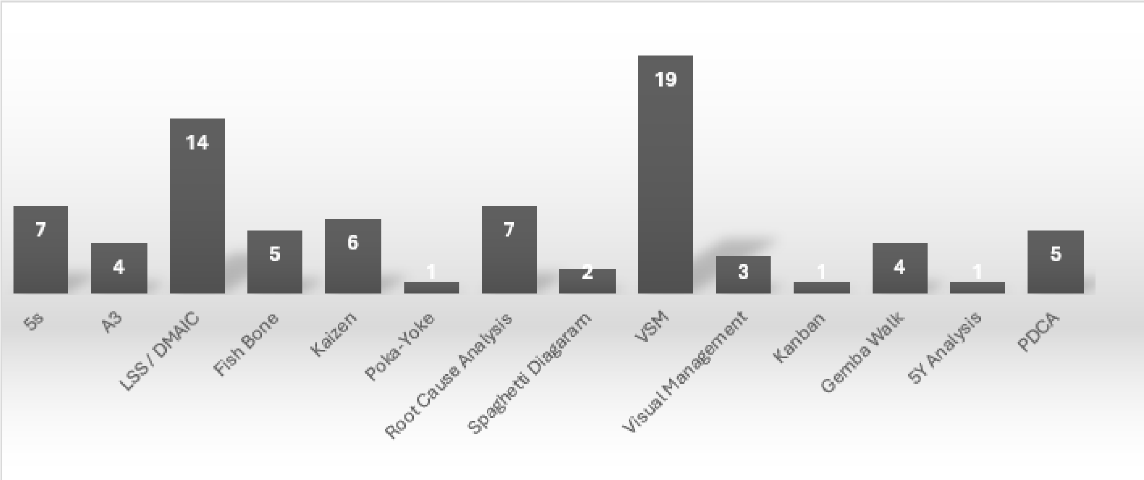

Figure 04: Distribution of Lean Tools

Fig. 5 illustrates the distribution of Lean tools, and Fig. 6 illustrates the distribution of simulation software used. Here, Arena was the dominant platform, used in 75% of studies (6 articles).

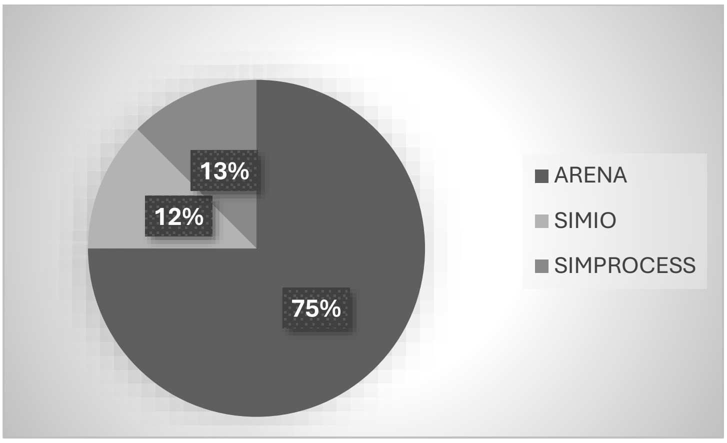

Figure 05: Distribution of Simulation Software

Furthermore, Fig. 7 categorises the reviewed studies into four groups: (1) stand-alone application of LM (16 studies), (2) Lean Six Sigma approaches combining LM with DMAIC principles (11 studies), (3) integration of LM with DES (5 studies), and (4) combined LM, Six Sigma, and DES interventions (3 studies). This breakdown, further illustrated in the Venn diagram (Fig. 7), clarifies the methodological distinctions between LM-only, Lean Six Sigma, and LM+DES approaches, ensuring precision when comparing their reported outcomes.

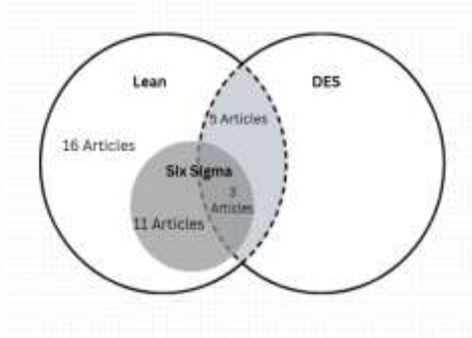

Figure 06: Classification of studies by Methodical Approach

To facilitate a deeper understanding of the reviewed articles, Table 2 presents a comprehensive classification matrix of the 35 studies. This structured synthesis not only supports cross-study comparisons but also helps to identify prevailing methodologies trends, underexplored combinations, and potential research gaps within the domain of healthcare process improvement.

Table 02: Categorisation of Articles

	Author & Year	Objectives			Data Collection Techniques			Validated Outcomes			
		Reduce Patient Waiting Time	Improve Operational Efficiency	Enhance Patient Satisfaction	Qualitative	Quantitative	Mixed Method	Reduction in Waiting Time	Improved Patient Satisfaction	Increased Throughput / Patient Volume	Better Resource Utilisation
1	Hammoudeh et al., 2020	✓		✓			✓	✓			
2	Le et al., 2021	✓		✓		✓		✓	✓		
3	Yu et al., 2021	✓					✓	✓		✓	✓
4	Godley & Jenkins, 2018	✓		✓		✓		✓	✓		
5	Ahmad et al., 2021	✓		✓	✓			✓		✓	
6	Hroub et al., 2019	✓		✓		✓		✓	✓		
7	Kam et al., 2021	✓				✓		✓		✓	
8	Ngaorungsi & Chutima, 2024		✓				✓	✓			
9	Trakulsunti & Trakoonsanti, 2021	✓				✓		✓			
10	Hassan et al., 2024	✓		✓		✓		✓			
11	Fu et al., 2021	✓		✓		✓		✓	✓		
12	Hussein et al., 2025		✓				✓		✓		✓
13	Yuliati & Andriani, 2021	✓					✓	✓			
14	Mangum et al., 2021	✓					✓	✓		✓	
15	Lot et al., 2018	✓					✓	✓			

16	Rocha & De Vasconcelos, 2021	✓					✓	✓			
17	Ketan et al., 2024	✓	✓			✓		✓			✓
18	S. Robinson et al., 2012	✓				✓		✓	✓		
19	(Alowad et al., 2020)										
20	Vashi et al., 2018	✓			✓			✓			
21	Al-Zain et al., 2019	✓		✓		✓		✓			
22	Kovach & Ingle, 2019	✓	✓	✓	✓			✓	✓	✓	✓
23	Davies et al., 2019		✓	✓			✓	✓	✓		
24	Wang et al., 2015	✓				✓		✓			✓
25	Sampalli et al., 2015	✓		✓			✓	✓			
26	Mistarihi et al., 2023	✓	✓				✓	✓			
27	Improta et al., 2018	✓					✓	✓			
28	Jayasinha, 2016	✓		✓			✓	✓			
29	Furterer, 2018	✓			✓			✓	✓	✓	
30	Miller & Chalapati, 2015	✓					✓	✓			
31	Allaudeen et al., 2017	✓			✓			✓			
32	Daly et al., 2021	✓				✓		✓			
33	Chang et al., 2018	✓	✓	✓		✓		✓			
34	Elamir, 2018	✓				✓					
35	Dayeh et al., 2025	✓	✓			✓		✓	✓		✓
	Total	32	8	13	5	15	15	33	10	6	6
	%	91.43 %	22.86%	37.14%	14.29 %	42.86 %	42.86 %	94.28%	28.57%	17.14%	17.14%

As shown in Table 2, the majority of studies (91.4%) explicitly targeted reducing patient waiting time, and nearly all (94.28%) validated this outcome using quantitative measures. While some studies also examined operational efficiency (22.9%) and patient satisfaction (37.1%), reducing waiting time was consistently the primary focus of Lean and simulation interventions.
A quantitative synthesis of reported outcomes is presented in Table 3, which summarises waiting-time reductions across studies according to intervention type (LM or LM+DES).

Table 03: Summary of Waiting-Time Reduction Outcomes by Intervention Type

	Author & Year	Intervention Type	Reduction of Waiting Time (Summary)
1	Hammoudeh et. al., 2020	LM	For prescriptions with fewer than three medications: 63.7%
			For prescriptions with three or more medications: 49.4%
2	Le et. al., 2021	LM	33.48%
3	Yu et. al., 2021	LM + DES	36.30%
4	Godley and Jenkins, 2018	LM	44.46%
5	Ahmad et. al., 2021	LM + DES	15.20%
6	Hroub et al., 2019	LM	First post-intervention: 73.1%
			Second post-intervention: 71%
7	Kam et. al., 2021	LM	18.32%
8	Ngaorungsi and Chutima, 2024	LM + DES	8.95%
9	Trakulsunti and Trakoonsanti, 2021	LM	34.45%
10	Hassan et. al., 2024	LM + DES	Routine patients: 72%
			Procedure patients: 60%

11	Fu et. al., 2021	LM	40.91%
12	Hussein et al., 2025	LM	Not quantified
13	Yuliati and Andriani, 2021	LM	Non-concoction prescriptions: 94.46%
			Concoction prescriptions: 84.25%
14	Mangum et al., 2021	LM	30%
15	Lot et. al., 2018	LM	50%
16	Rocha and Vasconcelos, 2021	LM + DES	37.92%
17	Ketan et. al., 2024	LM + DES	50%
18	Robinson et al., 2020	LM	11.26%
19	Alowad et. al., 2020	LM	Not quantified
20	Vashi et al., 2018	LM	36.31%
21	Al-Zain et al., 2019	LM + DES	Saturday appointment patients: 67%
			Saturday walk-in patients: 55%
			Weekday appointment patients: 63%
			Weekday walk-in patients: 46%
22	Kovach and Ingle, 2019	LM	22.01%
23	Davies et al., 2019	LM	6.30%
24	Wang et al., 2015	LM + DES	51.28%
25	Sampalli et al., 2015	LM	39.58%
26	Mistarihi et al., 2023	LM + DES	73%

27	Improta et al., 2018	LM	6.80%
28	Jayasinha, 2016	LM	20.35%
29	Furterer, 2018	LM	83.95%
30	Miller and Chalapati, 2015	LM	75%
31	Allaudeen et al., 2017	LM	26.40%
32	Daly et al., 2021	LM	Not quantified
33	Chang et al., 2018	LM	32%
34	Elamir, 2018	LM	Not quantified
35	Dayeh et al., 2025	LM	32.05%

Table 3 demonstrates that most of the studies reported substantial reductions in patient waiting time following Lean or Lean + DES interventions. Lean-only approaches achieved reductions ranging from 6.3% to 94.5%, while Lean + DES studies reported improvements between 8.9% and 73%. Although some studies did not provide quantified values, the overall trend indicates that integrated Lean + DES interventions consistently produced higher median reductions compared to Lean alone.

Discussion

The purpose of this systematic review was to evaluate the effects of Lean methodologies (LM) and discrete-event simulation (DES) interventions on reducing patient waiting times in healthcare. When synthesised across the included studies, Lean-only interventions achieved reductions ranging from 6.3% to 94.5% (median ≈ 30%), while Lean combined with DES interventions reported improvements between 8.9% and 73% (median ≈ 45%). These pooled findings suggest that although Lean tools alone yield meaningful efficiency gains, integrating simulation tends to produce larger and more consistent reductions in patient waiting times.

Lean-only interventions were frequently successful in streamlining processes and eliminating non-value-added activities. For example, in a Thai public hospital, pharmacy waiting times were significantly reduced through the restructuring of workflows and the application of 5S and Value Stream Mapping (Trakulsunti & Trakoonsanti, 2021). Similarly, Lot et al. (2018) reported a 4.5-hour reduction in wait times in a liver transplant outpatient clinic using Value Stream Mapping, A3, and Gemba Walk. Although Lean-only interventions dominate the literature and have yielded significant short-term gains, the most consistent and higher-magnitude improvements have been reported in studies integrating Lean with DES (Mistarihi et al., 2023; Ketan et al., 2024). This suggests that the real added value lies in hybrid approaches, which remain comparatively underexplored**.** Mistarihi et al. (2023) demonstrated that integrating Lean Six Sigma with simulation in an emergency department improved waiting-time metrics by 73% and overall performance by 83%. Such studies demonstrate the value of simulation in modelling alternative patient flow strategies, evaluating queue dynamics, and predicting the performance of changes before implementation. Tlapa et al. (2022) also highlighted the growing synergy between Lean, Six Sigma, and simulation approaches, though most existing studies remain fragmented and context-specific. This supports the need for more integrative frameworks, such as the LM+DES combination assessed in this review**.**

The reviewed literature also highlighted critical success factors (CSFs) and critical failure factors (CFFs) that shape the outcomes of Lean and simulation initiatives. Success was strongly associated with leadership engagement (Trakulsunti & Trakoonsanti, 2021; Ngaorungsi & Chutima, 2024), cross-functional participation (Davies et al., 2019), early stakeholder involvement (Miller & Chalapati, 2015), and the use of simulation to validate process designs (Hassan et al., 2024; Ketan et al., 2024). Conversely, common barriers included limited staff engagement (Hammoudeh et al., 2020), inadequate training in Lean and simulation methods, fragmented tool application without alignment to broader strategies (Improta et al., 2018), short project durations, and absence of real-time monitoring systems (Hassan et al., 2024).

Sustainability of improvements was rarely evaluated in depth. Most interventions monitored outcomes only in the short term, typically under six months, and few studies incorporated feedback loops or continuous monitoring systems. Sustainability challenges were evident in three dimensions: (1) process adherence, i.e., whether redesigned workflows continued beyond pilot projects; (2) workforce adoption, including long-term staff engagement and training; and (3) operational feasibility, relating to financial resources, leadership commitment, and monitoring infrastructure. Without reinforcement in these areas, even substantial early gains risked process drift, as demonstrated by Improta et al. (2018). Souza et al. (2021) also noted similar sustainability challenges in emergency departments, where resource limitations and staff turnover often undermined Lean improvements.

Several limitations must be acknowledged. The reliability of the pooled findings depends on the methodological quality of the included studies. While many reported substantial reductions in waiting time, few employed rigorous bias assessments, and designs varied considerably. Without a structured appraisal, such as the ROBINS-I, it is challenging to assess the strength and generalizability of the evidence base fully. In addition, publication bias is likely. Most published studies emphasised positive impacts, while unsuccessful or null interventions may remain underreported. This selective reporting could inflate the apparent effectiveness of LM and DES interventions, underscoring the need for systematic reporting of both positive and negative results.

Finally, evidence on cost-effectiveness was largely absent. While Lean + DES interventions improved efficiency and resource utilisation in several studies, none provided formal economic evaluations. Thus, although the combined approach shows potential for being cost-efficient, definitive conclusions about cost-effectiveness cannot yet be drawn. Similar findings were reported by Tlapa et al. (2022) and Souza et al. (2021), who emphasised that despite clear efficiency gains, Lean and simulation studies rarely incorporate economic evaluations. The heterogeneity of outcome measures and settings further limited the ability to perform a formal meta-analysis; however, descriptive pooling provided meaningful insights into the range of effects.

In summary, this review confirms that Lean tools consistently reduce patient waiting times, and the integration of DES offers additional predictive and planning capabilities that enhance effectiveness. However, the durability of improvements remains uncertain without sustained monitoring, workforce engagement, and institutional support. Future research should prioritise long-term evaluations, cost-effectiveness analyses, and multi-site studies to generate more substantial, more generalisable evidence on the integration of Lean and simulation in healthcare.

Conclusion

Long patient waiting times remain a persistent and global concern, significantly impacting patient satisfaction and compromising the performance of healthcare systems. In response to this ongoing challenge, Lean Methodology (LM) and simulation techniques, particularly Discrete Event Simulation (DES), have gained increasing attention for their potential to improve healthcare efficiency. However, despite their individual merits, the combined application of LM and DES remains underexplored in both academic and practical domains.

This research aimed to critically evaluate the effectiveness of LM, both alone and in conjunction with DES, in reducing patient waiting times across various healthcare environments. The primary objectives were to examine how these methodologies have been practically applied, assess their impact, and identify gaps in the current body of knowledge.

To achieve these aims, a systematic review of 35 empirical studies was conducted, synthesising evidence on the application of Lean tools and simulation modelling in healthcare. The review revealed that LM tools such as Value Stream Mapping (VSM), 5S, Kaizen, and Root Cause Analysis have been widely implemented to eliminate non-value-adding activities and streamline patient flow, particularly in high-pressure settings such as outpatient departments, emergency units, and diagnostic services.

A key outcome of this study is the identification of effective strategies and tools that have successfully reduced waiting times and enhanced operational efficiency. Importantly, the integration of LM with DES, particularly through the use of simulation platforms such as Arena, was found to enhance planning precision and implementation success significantly. Simulation models allow healthcare administrators to test changes under controlled conditions, anticipate system behaviours, and make informed decisions regarding resource allocation and appointment scheduling without disrupting actual operations.

However, the review also uncovered several recurring critical failure factors (CFFs), including limited staff engagement, insufficient training, short project durations, and a lack of performance monitoring. These issues often undermine the sustainability of improvements, highlighting the importance of fostering a culture of continuous improvement supported by strong leadership, cross-functional collaboration, and long-term investment in simulation capabilities.

In conclusion, this research underscores the vital role that a combined LM-DES approach can play in addressing patient flow inefficiencies. When applied thoughtfully and systematically, these tools offer a resource-efficient and evidence-based solution to one of healthcare's most pressing operational challenges. The findings provide valuable guidance for healthcare managers, policymakers, and researchers, offering recommendations for future initiatives that prioritise sustainability, digital integration, and the inclusion of patient and staff satisfaction as key performance metrics. This study thus fills an important knowledge gap and contributes to the advancement of safer, more efficient, and higher-quality healthcare delivery worldwide.

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