LEAN AND SIX SIGMA IN MARITIME OPERATIONS: A TEN-YEAR SYSTEMATIC LITERATURE REVIEW

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ABSTRAK

Studi ini menyajikan tinjauan sistematis penerapan Lean dan Six Sigma (LSS) di sektor maritim untuk periode 2016–2025, yang mencakup konteks pelabuhan, galangan kapal, logistik, industri LNG, perikanan, dan desain kapal. Artikel ini mengungkapkan pergeseran fokus dari awal studi kasus ke implementasi strategis yang terintegrasi dengan transformasi digital, ketahanan rantai pasokan, dan keberlanjutan. Metodologi DMAIC dan Value Stream Mapping mendominasi sebagai kerangka kerja utama, didukung oleh integrasi teknologi Industri 4.0 dan analitik data untuk memaksimalkan efisiensi proses. Bukti kuantitatif menunjukkan pengurangan waktu proses, penurunan tingkat cacat, dan penghematan biaya operasional yang signifikan. Namun, keberhasilan implementasi LSS sangat dipengaruhi oleh dukungan manajemen, kesiapan sumber daya manusia, dan ketersediaan data yang andal, dengan kendala utama adalah budaya resistensi, investasi awal yang terbatas, dan kurangnya pelatihan. Studi ini menegaskan bahwa masa depan LSS di sektor maritim bergerak menuju model hibrida yang menggabungkan prinsip-prinsip Lean, Six Sigma, digitalisasi, dan keberlanjutan, yang berpotensi menjadi praktik terbaik global dalam meningkatkan daya saing industri maritim di era persaingan dan ketidakpastian dalam rantai pasokan global.

Kata kunci: *Lean Six Sigma, DMAIC, Maritime Industry, Industry 4.0, Sustainability*

ABSTRACT

This study presents a systematic review of Lean and Six Sigma (LSS) implementation in the maritime sector for the period 2016–2025, encompassing the contexts of ports, shipyards, logistics, the LNG industry, fisheries, and ship design. The analysis reveals a shift in focus from initial case studies to strategic implementation integrated with digital transformation, supply chain resilience, and sustainability. DMAIC and Value Stream Mapping methodologies dominate as the primary framework, supported by the integration of Industry 4.0 technologies and data analytics to maximize process efficiency. Quantitative evidence demonstrates the reduction in process time, reduction in defect rates, and significant operational cost savings. However, the success of LSS implementation is highly influenced by management support, human resource readiness, and the availability of reliable data, with the main obstacles being cultural resistance, limited initial investment, and lack of technical training. This study confirms that the future of LSS in the maritime sector is moving towards a hybrid model that combines Lean, Six Sigma, digitalization, and sustainability principles, which has the potential to become a global best practice in increasing the competitiveness of the maritime industry in an era of competition and uncertainty in the global supply chain.

Keywords: *Lean Six Sigma, DMAIC, Maritime Industry, Industry 4.0, Sustainability*

INTRODUCTION

The maritime industry plays a vital role in global trade, with approximately 80% of international trade transported by sea [1]. Operational complexity, high logistics costs, and the demand for maintaining service quality drive maritime companies to seek strategies for continuous efficiency and productivity improvement [2][3]. In the past two decades, Lean and Six Sigma have been recognized as effective process management approaches for reducing waste , improving quality, and minimizing process variability [4]. The application of Lean in the maritime sector focuses on identifying and eliminating non-value-added activities, while Six Sigma emphasizes variation control and data - driven quality improvement [5][6][7]. The integration of the two, known as Lean Six Sigma (LSS), is gaining popularity due to its ability to simultaneously combine the speed of process improvement with quality accuracy [8].

While the success of LSS has been widely documented in the manufacturing and service sectors, research in the maritime industry remains relatively limited and fragmented [9][10][11][12][13][14][15][16]. Yet, the unique characteristics of this sector, such as long cycle times , supply chain complexity, and high operational costs make it highly suitable for LSS applications. Therefore, a comprehensive literature review is needed to map developments, trends, challenges, and future research opportunities.

This study aims to conduct a systematic review of the literature from 2016–2025 on the application of LSS in the maritime industry, focusing on identifying research trends, methodologies used, application contexts, tools utilization and existing knowledge gaps. The study integrates findings from various contexts, including ports, shipping, shipyards, logistics, LNG, fisheries, and ship design, to provide a comprehensive overview of the effectiveness of LSS in improving operational efficiency, reducing waste, and enhancing service quality.

The novelty of this research lies in its comprehensive mapping of LSS implementation in the maritime sector during 2016–2025, integrating analysis of methodological trends, cross-subsector contexts, and dominant LSS tools. This study reveals a strategic shift towards a hybrid Lean–Six Sigma–digital–sustainability model, while identifying research gaps in underexplored subsectors. These findings offer development directions based on the integration of Industry 4.0 technology and sustainability principles to strengthen the competitiveness of the maritime industry at the global level [17][18].

LITERATURE REVIEW

Lean Six Sigma

Lean Management is a management approach that focuses on reducing waste and increasing customer value through continuous improvement [19][20]. The Lean concept was first developed by the Toyota Production System (TPS) and has since been widely adopted across various industries, including manufacturing, services, and transportation [21][5]. In the maritime context, Lean can be used to improve port operational efficiency, optimize loading and unloading processes, and reduce ship waiting times [3][14]. The main principles of Lean include identifying customer value, mapping value streams, seamless process flows, implementing creating pull systems, and pursuing perfection [21]. Six Sigma is a data-driven methodology that aims to reduce process variation and improve quality by using structured statistical tools [22][23]. Developed by Motorola in the late 1980s, Six Sigma relies on the DMAIC (Define, Measure, Analyze, Improve, Control) cycle to solve problems and improve performance [8]. In the maritime industry, Six Sigma can help reduce logistics costs, accelerate administrative processes, optimize port utilization, and improve the reliability of maritime logistics supply chains, among other things [3][24][25]. Lean Six Sigma (LSS) combines the advantages of Lean in eliminating waste with the power of Six Sigma in controlling process variation [26][27]. This integration results in a holistic approach to performance improvement, both in terms of efficiency and quality [28][29][30]. LSS applications in the maritime industry include optimizing fleet maintenance processes, managing port terminals, improving work safety in shipyards, and improving supply chain efficiency [31].

Lean Six Sigma In The Maritime Industry

The application of Lean Six Sigma (LSS) principles in the maritime sector has shown significant results in increasing operational capacity and efficiency, particularly in the context of ports and shipyards. A study by [3] at ports showed that LSS was effective in identifying non-value-added activities, optimizing workflows, and reducing berth waiting times . These improvements not only impact technical efficiency but also increase the overall

port service capacity. Similar findings were also seen in research by [14] which confirmed the effectiveness of Lean in the maritime industry, including ship construction and port infrastructure. Key benefits identified include reduced production cycle times through process standardization and value stream mapping, reduced costs through the elimination of non-value-added activities, layout optimization for more efficient space utilization, and reduced wasteful worker movement and component movement. The cumulative impact of these improvements is reflected in increased productivity, accelerated project completion, and enhanced customer satisfaction, ultimately strengthening the global competitiveness of the maritime sector.

The implementation of Lean Manufacturing in Tunisian shipyards [32] has proven consistent results, where the 5S principles, value stream mapping , and waste elimination have succeeded in reducing production cycle time, increasing quality, lowering costs, improving delivery timeliness, and increasing process flexibility. Furthermore, the integration of LSS with the concept of supply chain resilience during the COVID-19 pandemic [33] enabled companies in the shipbuilding, logistics, and shipping sectors to maintain and even improve supply chain performance amid global disruptions. The DMAIC approach was used to identify waste, improve internal processes, and implement effective resilience measures.

The implementation of LSS in the ship production process [34][35][36][2][37] has also been proven to reduce waste, lower costs, accelerate production cycles, and create sustainable productivity. Meanwhile, the integration of the Six Sigma model with system dynamics [38][39] is effective in measuring port performance, reducing waste, and optimizing operational quality and efficiency. However, the literature also highlights several challenges in implementing LSS in the maritime sector. Key barriers include limited trained human resources, resistance to organizational change, and a lack of adequate digital technology support [40][41][13]. Therefore, a comprehensive literature review is needed to understand implementation trends, identify barriers, and explore opportunities for LSS development in the maritime sector. This approach is expected to produce a more effective implementation strategy, adaptable to modern challenges, and aligned with the demands of digital transformation and industry sustainability.

RESEARCH METHODS

This research was conducted using a literature review approach with a focus on relevant journals regarding the implementation of Lean and Six Sigma in the maritime industry during the period 2015–2025. A comprehensive literature search was conducted through the Google Scholar database using structured keywords that included the terms Lean and Six Sigma methodology and maritime subsectors such as ports, shipyards, sea transportation, and maritime logistics. Selected articles had to meet the inclusion criteria of peer-reviewed publications reporting empirical studies or case studies in the maritime context. Non-scientific publications, articles before 2015, and studies outside the maritime scope were excluded. Data from selected articles were extracted using a standard format that included study identity, the maritime sector studied, research methodology, Lean Six Sigma tools used, and reported quantitative and qualitative results. The review results were then analyzed using a thematic narrative to identify implementation trends, successes, barriers, and research gaps.

RESULTS AND DISCUSSION

Of the 50 journals collected, 34 publications met the research criteria, specifically addressing the application of Lean and Six Sigma in the maritime industry. These publications were then analyzed in depth to identify research trends, methodologies used,

application contexts, tools used, and challenges across various maritime subsectors. Publications on Lean Six Sigma (LSS) in the maritime sector have been consistently appearing since 2016, but have seen a significant increase in the 2020–2025 period. This surge is driven by four main factors: the need for efficiency, the adoption of digitalization and Industry 4.0 in ports and shipyards, the disruption caused by the COVID-19 pandemic, which has driven the integration of LSS with supply chain resilience frameworks, and the increasing global focus on maritime industry sustainability. These developments demonstrate a strong push to shift maritime operational approaches from traditional to data-driven efficiency and sustainability.

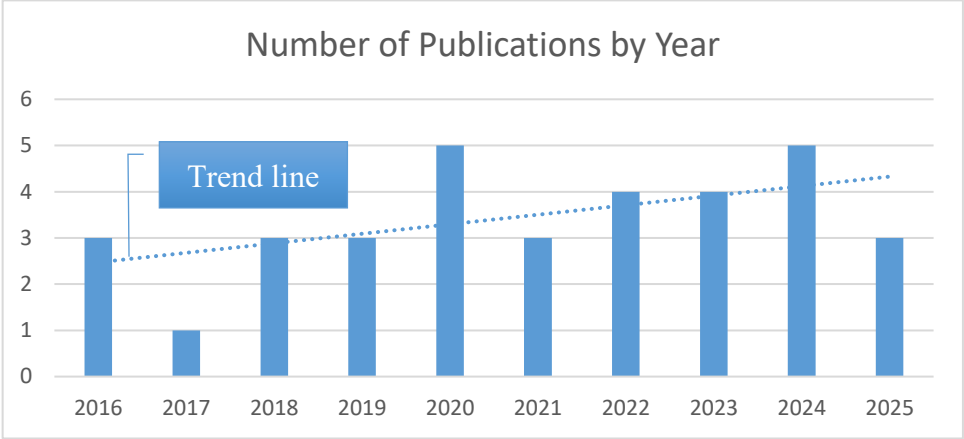

Figure 1. Publication Distribution by Year

The publication distribution analysis in Figure 1 shows an increasing trend of interest in Lean and Six Sigma research in the maritime sector from 2016 to 2025. After an initial period of relative stability in 2016–2019 (3 publications/year), a surge occurred in 2020 (5 publications), coinciding with increased attention to digitalization and the integration of *Industry 4.0* for operational efficiency. A temporary decline in 2021 (3 publications) was likely influenced by the disruption of the COVID-19 pandemic, but the trend rebounded in 2022–2024, reaching a peak of 5 publications in 2024. The decline in 2025 (3 publications) may be due to limitations of incomplete annual data. Overall, the trajectory of trend line indicates a sustained and growing academic interest in the Lean and Six Sigma topic in the maritime domain.

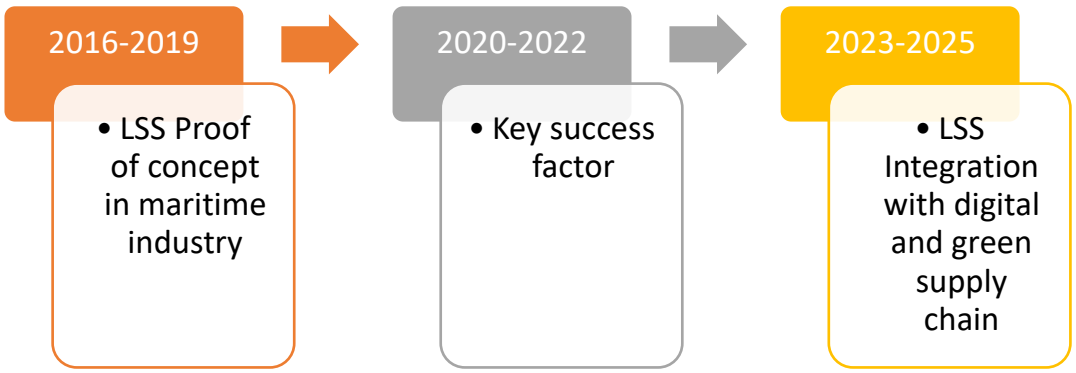

Figure 2. Topic Trend last 10 years

The evolution of LSS implementation can be divided into three phases, as shown in Figure 2. In the 2016–2019 period, research focused on studies practical implementation of concept and small-scale implementations to demonstrate the relevance of LSS in the

maritime environment. The 2020–2022 period saw an increase in studies identifying implementation barriers and critical success factors, particularly in developing countries. Meanwhile, the 2023–2025 period was marked by the integration of LSS with digital transformation, supply chain resilience strategies, and the green supply chain concept.

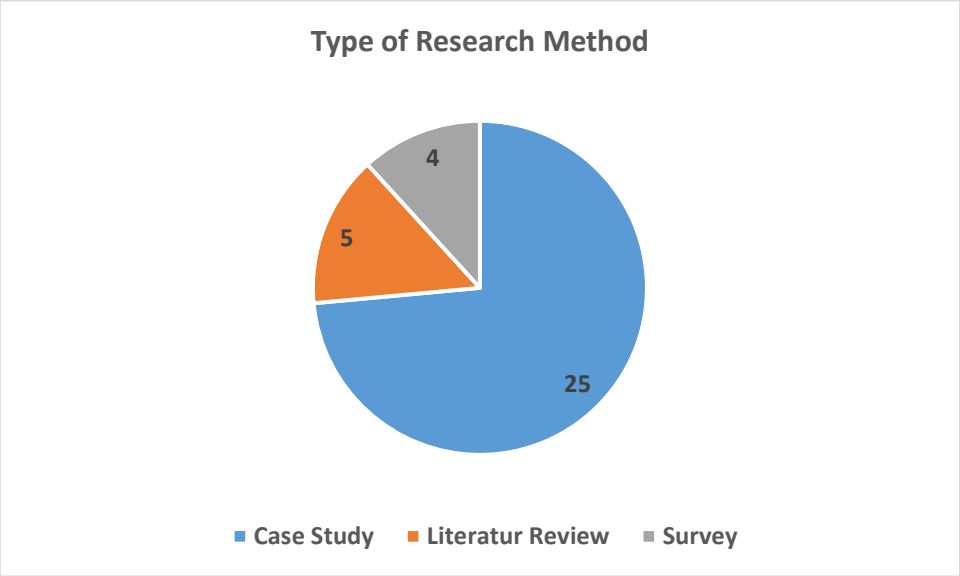

Figure 3. Type of Research Method

Based on the distribution of research types, it appears that case studies dominate with 25 publications, followed by literature reviews (5 publications) and surveys (4 publications) as shown in Figure 3. The dominance of case studies indicates that Lean Six Sigma research in the maritime sector tends to focus on practical implementation in the field, such as implementation in ports, shipyards, and maritime supply chains [36]. This is understandable because LSS is a process-based management approach that requires direct evidence through operational data and tangible improvements. This pattern confirms the focus of Lean Six Sigma research in the maritime sector on empirical evidence in the field, while conceptual studies and surveys are still limited, thus opening up opportunities for broader synthesis studies and perception analysis.

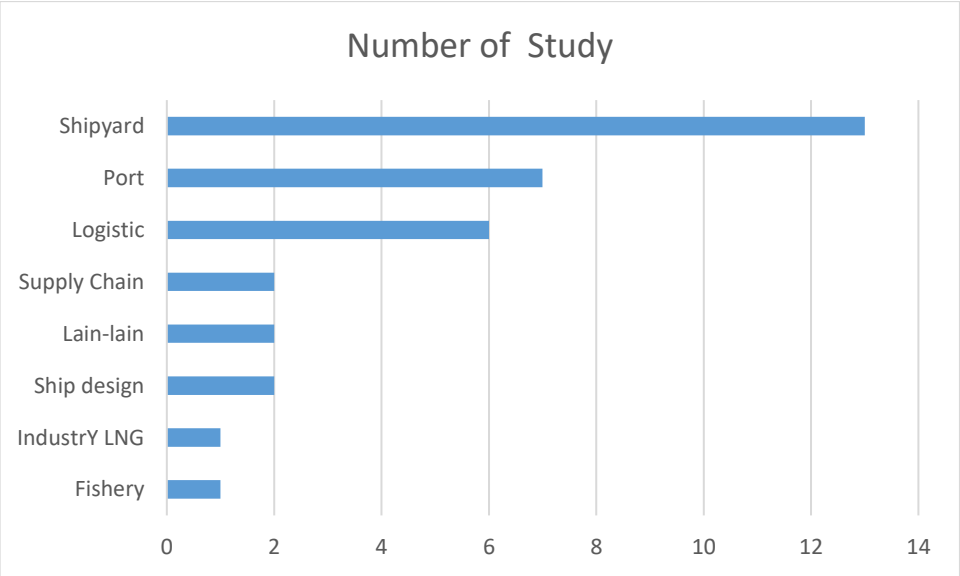

Figure 4. Implementation Context

Analysis of the maritime context shows that shipyards (13 studies) and ports (7 studies) are the main focus of Lean Six Sigma research, followed by maritime logistics (6 studies), supply chain and ship design (2 studies each), and the LNG and fisheries industries (1 study each). The dominance of ports, logistics, and shipyards can be explained by the high cycle times, process complexity, and high operational costs inherent in these sectors, which create significant opportunities for LSS implementation to significantly impact productivity and cost efficiency (Şişman, 2023). The most widely used tool is Value Stream Mapping (VSM), which is the most dominant Lean tool for mapping material and information flows, followed by root cause analysis techniques such as Root Cause Analysis (RCA), fishbone diagrams, and Failure Modes and Effects Analysis (FMEA). Since 2020, the integration of technologies 4.0 has begun to be used to support more accurate analysis and real-time monitoring [18][42].

Key contributions identified include the effectiveness of LSS in both the public and private sectors, the significant role of digital technology integration in amplifying the impact of Lean, and its significant potential in developing countries, despite cultural constraints, limited skilled labor, and inadequate data infrastructure. Since 2022, a research trend has emerged in Green Lean Six Sigma, which combines process efficiency with achieving environmental sustainability targets. However, implementation challenges consistently emerge across various contexts. The most common barriers are resistance to change at the organizational level, limited real-time operational data , low technical skills in using Lean tools and statistical methods, and high initial investment in supporting technology infrastructure [40]. These challenges require a more adaptive implementation strategy tailored to local conditions.

CONCLUSION

A systematic analysis of Lean Six Sigma (LSS) publications in the maritime sector from 2016 to 2025 shows a significant shift from limited-scale case studies to implementation strategies integrated with digital transformation, supply chain resilience, and sustainability. The predominance of research in the shipyard, port, and logistics context reflects a focus on areas with long cycle times, high process complexity, and high operational costs, thus providing optimal opportunities for productivity and efficiency improvements [43][31][44][45]. Value Stream Mapping have proven to be the most dominant and effective methodologies and analytical tools for identifying and eliminating waste. The integration of Industry 4.0 technologies such as IoT, RFID, and data analytics strengthens LSS's capabilities in real-time monitoring and data-driven decision-making. Quantitative evidence from various studies reports reductions in process time, reductions in defect rates, and significant operational cost efficiencies [46][47][42][37]. The success of LSS implementation remains heavily influenced by organizational and resource factors, including top management support, human resource readiness, and the availability of reliable data. Barriers such as resistance to change, limited initial investment, and minimal technical training indicate the need for a holistic strategy that integrates change management, technology investment, and human resource capacity building. These findings have direct implications for practitioners and policymakers in the maritime sector, including encouraging the adoption of a hybrid LSS digital sustainability approach as a best practice standard, prioritizing high-impact quick wins projects to build trust and reduce resistance, and integrating real-time information systems as part of long-term operational strategies. Future research should focus on developing an LSS integration model with a digital transformation for maritime process optimization, adapting LSS to the context of developing countries with limited digital infrastructure, and evaluating the impact of Green Lean Six Sigma on environmental sustainability in the port and shipyard sectors. By combining Lean

and Six Sigma principles with digital transformation and sustainability agendas, LSS has the potential to become a global best practice in improving the competitiveness of the maritime industry amidst the increasingly complex challenges of efficiency, sustainability, and uncertainty in global supply chains.

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