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THE ROLE OF LEAN SIX SIGMA AND DISCRETE EVENT SIMULATIONS IN ACHIEVING SUSTAINABILITY GOALS IN LOGISTICS: REDUCE CARBON EMISSIONS AND MINIMIZING WASTE

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Abstract:

Sustainability has emerged as a pivotal concern in logistics, propelled by the necessity to diminish carbon emissions, lessen waste, and enhance resource efficiency. This article explore the amalgamation of Lean Six Sigma (LSS) and Discrete Event Simulation (DES) as a collaborative method for attaining sustainability objectives in logistics by utilizing the systematic literature review (SLR) methodology. LSS gives a systematic approach for recognising and eradicating waste, whereas DES provides a dynamic modelling instrument to simulate and enhance logistical processes. This study illustrates, through an examination of recent research and case studies, how the integration of Lean Six Sigma (LSS) and Discrete Event Simulation (DES) may augment logistical sustainability by enhancing efficiency, minimising environmental impact, and facilitating decision-making. The results underscore the efficacy of this comprehensive methodology in tackling critical issues in sustainable logistics, including carbon footprint reduction, energy efficiency, and waste minimisation.

Keywords:

Carbon Emissions, Discrete Event Simulation, Lean Six Sigma, Logistics, Sustainability, Waste Minimization

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Introduction

The logistics sector is crucial to international commerce but has significant obstacles in reconciling efficiency with sustainability (Nagy & Szentesi, 2024; Verma, 2024). Logistics accounts for approximately 40% of worldwide CO2 emissions (Fancello et al., 2023), underscoring the urgent need for creative strategies to improve operational efficiency and mitigate environmental effect. Lean Six Sigma (LSS) and Discrete Event Simulation (DES) are efficacious methodologies for process modification, offering systematic approaches for waste minimisation and efficiency augmentation (Lúcio et al., 2024). The amalgamation of these techniques with nascent technology, such as the Internet of Things (IoT) and Artificial Intelligence (AI), remains inadequately scrutinised, particularly in relation to achieving sustainability goals in logistics (Ameh, 2024; Anaba et al., 2024).

This study focusses on the lack of an integrated framework that unifies LSS, DES, IoT, and AI to meet the simultaneous concerns of operational efficiency and environmental sustainability in logistics (Suboyin et al., 2023). The distinct applications of LSS and DES have been thoroughly investigated; nevertheless, their combined potential, especially when augmented by IoT and AI, is still underexploited (Lúcio et al., 2024; Kranz et al., 2023; Sah et al., 2024). This project aims to bridge the existing gap by investigating the possibilities of integrating various approaches and technologies to mitigate carbon emissions, minimise waste, and enhance overall logistics performance by utilizing Green Lean Six Sigma (GLSS) framework integrates Lean Six Sigma with environmental sustainability goals (Boumsisse et al., 2024). This study is motivated by the growing necessity for organisations to adopt sustainable practices while maintaining competitiveness in a volatile global market. The research questions guiding this study are**:**

(1) How can LSS and DES be effectively integrated to reduce carbon emissions and waste in logistics?

(2) What roles do IoT and AI play in enhancing the sustainability outcomes of LSS and DES?

(3) What are the key challenges and opportunities in implementing an integrated LSS-DES-IoT-AI framework in logistics?

This study employs a systematic literature analysis to analyse peer-reviewed publications, case studies, and industry reports generated between 2020 and 2025. The findings are aggregated to provide insights into the current research landscape, identify shortcomings, and propose future directions.

The article is structured as follows: Section 2 analyses the literature pertaining to LSS, DES, IoT, and AI in logistics. Section 3 delineates the research technique. Section 4 presents the findings and analysis. Section 5 closes with ramifications for practice and prospective research. This study aims to combine conventional process enhancement methods with innovative technology to promote sustainable logistics in alignment with global environmental goals.

Literature Review

Lean Six Sigma (LSS) in Logistics

LSS is a comprehensive technique employed to improve operational efficiency and quality across various industries, including logistics (Agrawal et al., 2024; Daniyan et al., 2022). LSS

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amalgamates the waste reduction tenets of Lean Manufacturing with the defect reduction and variability management of Six Sigma, offering a comprehensive methodology for process enhancement (Antony et al., 2020; Sodhi et al., 2020; Costa et al., 2021). In logistics, LSS has been employed to improve supply chain operations, reduce lead times, and elevate customer happiness (Agrawal et al., 2024; Panayiotou & Stergiou, 2022; Sunder et al., 2021; Sisman, 2022; Ionel, 2024). Recent studies demonstrate that LSS can proficiently address sustainability issues in logistics, particularly in reducing carbon emissions and minimising waste (Cherrafi et al., 2020; Kumar et al., 2021).

The adoption of LSS in logistics is driven by the need to harmonise operational efficiency with environmental and social responsibility (Çiğal & Saygili, 2022; Dapkus & Jaison, 2024). Vinodh et al. (2020) demonstrated the utilisation of Lean Six Sigma (LSS) methods, such as Value Stream Mapping (VSM) and DMAIC (Define, Measure, Analyse, Improve, Control), to identify and eradicate non-value-added activities in logistics operations (Adeodu et al., 2023; Wang et al., 2022; Praharsi et al., 2021) This method led to significant reductions in energy usage and carbon emissions. Powell et al., (2021) applied LSS in a logistics firm to reduce waste in packaging materials, yielding cost reductions and environmental benefits.

The amalgamation of LSS with sustainability objectives in logistics, while its potential, remains a mostly unexamined domain (Barcia et al., 2022; Lazar et al., 2021). Current research predominantly highlights the operational benefits of LSS, neglecting its environmental and social consequences (Erdil et al., 2020). The discovered gap in the literature highlights the need for more research to explore the potential of LSS in achieving sustainability goals in logistics, particularly in lowering carbon emissions and minimising waste.

Discrete Event Simulation (DES) in Logistics

DES is a computational modelling technique employed to evaluate and optimise intricate systems, including logistics networks (Soumatia et al., 2024; Sárdi et al., 2023; Chari et al., 2023; Lopes et al., 2020; Rotunno et al., 2023; Lyu et al., 2023). Discrete Event Simulation (DES) enables researchers and practitioners to simulate a system's behaviour across time, facilitating the identification of bottlenecks, the assessment of various scenarios, and the analysis of the effects of process modifications (Banks et al., 2020). In recent years, DES has gained prominence in logistics to enhance operational efficiency and mitigate environmental impacts (Wang et al., 2021).

DES offers a notable advantage due to its ability to replicate the dynamic and stochastic properties of logistics systems, making it a crucial tool for sustainability-focused study. Zhang et al. (2020) utilised DES to optimise delivery van routing, resulting in reduced fuel consumption and lower carbon emissions. Li et al. (2021) employed DES to investigate the impact of different warehouse configurations on energy usage, identifying opportunities for energy efficiency and waste reduction. Moreover, DES has been utilised in the strategic assessment of global logistics systems, exemplified by the logistics of Brazilian soybean exports, to study system behaviours and guide decision-making based on cost considerations (Lopes et al., 2020). DES serves as a comprehensive method for assessing intricate logistics networks and improves informed decision-making concerning sustainability.

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Although DES is extensively utilised in logistics, its integration with LSS and sustainability goals remains limited (Le & Trang, 2024). Numerous contemporary studies highlight the operational benefits of DES, while inadequately considering its ability to achieve environmental and social objectives (Freitas et al., 2020). The discovered vacuum in the literature signifies a need for more study to explore the integration of DES with LSS to achieve sustainability goals in logistics, particularly concerning the reduction of carbon emissions and waste minimisation.

Sustainability in Logistics: Reducing Carbon Emissions and Minimizing Waste

The significance of sustainability in logistics has intensified, driven by increasing regulatory demands, stakeholder expectations, and the imperative to address environmental and social challenges (Baah et al., 2020; Chen et al., 2024; Govindan et al., 2020; Roy & Mohanty, 2023). The logistics sector significantly contributes to global carbon emissions, accounting for around 10% of total greenhouse gas emissions (World Economic Forum, 2021). The previous study demonstrates that green logistics techniques positively influence supply chain sustainability, including environmental, economic, and social dimensions (Roy & Mohanty, 2023; Sharma et al., 2023). As a result, there is a growing emphasis on developing strategies to reduce carbon emissions and minimise waste in logistics operations.

Diverse strategies have been proposed to achieve sustainability goals in logistics, including the incorporation of green technologies, optimisation of transport routes, and implementation of circular economy principles (Grosse et al., 2023; Kazancoglu et al., 2021; Basta et al., 2023; Centobelli et al., 2020; Ferraro et al., 2023). These methodologies often focus on specific components of logistics operations, such as transportation or warehousing, while overlooking the broader systemic implications (Calignano & Mercurio, 2023). This highlights the imperative for a holistic strategy to sustainability in logistics, integrating operational efficiency with environmental and social responsibility.

A recent study investigated the integration of LSS and DES to attain sustainability objectives in logistics. Ruben et al. (2021) presented a methodology that integrates LSS with DES to improve logistical processes, resulting in notable reductions in carbon emissions and waste. Cherrafi et al. (2022) utilised LSS and DES in a case study within the logistics industry, resulting in enhanced operational efficiency and environmental performance. Research has examined the interplay between Lean Six Sigma (LSS), Circular Economy (CE), and Industry 4.0 technologies (I4.0T) in enhancing sustainable organisational performance (Skalli et al., 2023). A conceptual framework integrating Lean Six Sigma (LSS) with Industry 4.0 (I4.0) has been developed, focussing on operational, sustainability, and human factors (Citybabu & Yamini, 2023). Although the results are promising, the integration of LSS and DES for sustainability in logistics is still an emerging area of research. Many recent studies focus on particular case studies or simulations, neglecting the creation of generalisable frameworks or models (Erdil et al., 2021). The identified gap in the literature indicates a necessity for further investigation into the integration of LSS and DES to attain sustainability objectives in logistics, especially concerning the reduction of carbon emissions and waste minimisation.

Research Methodology

This study utilises a systematic literature review (SLR) methodology to examine the contributions of LSS and DES in achieving sustainability goals in logistics, focussing specifically on carbon emission reduction and waste minimisation. The systematic literature

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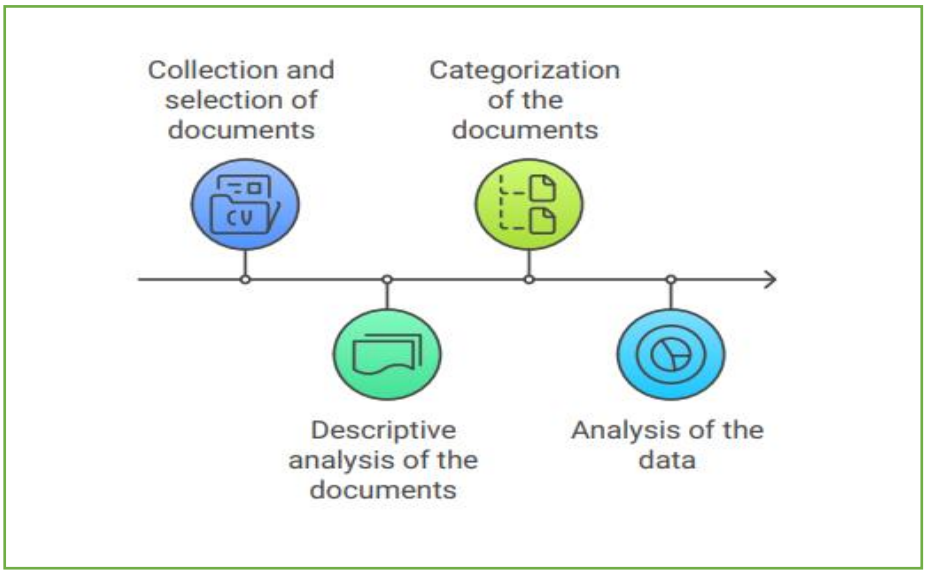
review provides a structured approach for identifying extensive literature and assessing scientific contributions in a particular research area (Tranfield et al., 2003). The SLR aids in identifying emerging trends and delineating research areas, along with the relevant theoretical foundations within a specific research domain (Albliwi et al., 2015). This research methodology aims to elucidate the integration of LSS and DES within logistics operations, while also identifying the potential benefits and challenges associated with their implementation. The methodology used for the systematic literature review was based on previous approaches employed by various researchers (Ruschel et al., 2017). The methodology consists of four main steps, as depicted in Figure 1: Process of Systematic Literature Review (SLR) below:

Figure 1: Process of Systematic Literature Review (SLR)



Source: Author, 2025

Each step is detailed below.

Collection and Selection of Documents

The preliminary stage of the research process involves the collection and curation of pertinent documents. The SCOPUS database was chosen as the primary source for locating technical publications due to its extensive coverage of peer-reviewed literature. The investigation employed a combination of terminology such as "Lean Six Sigma," "Discrete Event Simulation," "Sustainability," "Carbon Emissions," "Waste Reduction," "Logistics," and "Green Logistics." Boolean operators "AND" and "OR" were utilised to enhance the search and ensure the inclusion of publications that specifically address the amalgamation of LSS and DES in logistics for sustainability goals. The criteria for inclusion and exclusion in article selection are described in Tables 1 and 2.

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The inclusion criteria for the selection of articles were as follows:

Table 1: Article Inclusion Criteria

Inclusion criteria
❖ Articles published between January 2020 and February 2025
❖ Articles published in peer-reviewed journals, conference proceedings, and book chapters available through the SCOPUS database.
❖ Articles written in English.
❖ Articles that focus on the application of LSS and DES in logistics, with a specific emphasis on sustainability goals such as carbon emission reduction and waste minimization.

The exclusion criteria were:

Table 2: Article Exclusion Criteria

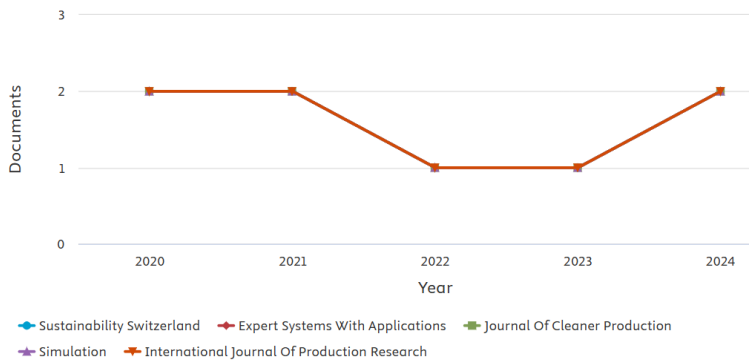
Exclusion criteria
❖ Articles published before December 2019.
❖ Articles not available through the SCOPUS database.
❖ Articles that do not focus on the integration of LSS and DES in logistics.
❖ Articles that do not address sustainability goals such as carbon emissions or waste reduction.

After applying the inclusion and exclusion criteria, a total of 70 articles were selected for further analysis. The selection process is summarized in Table I and 2.

Descriptive Analysis of the Documents

The subsequent stage involves performing a descriptive analysis of the selected documents. This article provides an overview of current research on the integration of LSS and DES in logistics, with a specific emphasis on sustainability objectives. The analysis categorises data into several critical areas: year of publishing, journals of publication, nations of research, utilised methodology, and addressed industry sectors.

Figure 1: Articles Published by the Journals



Source: Scopus, 2025.

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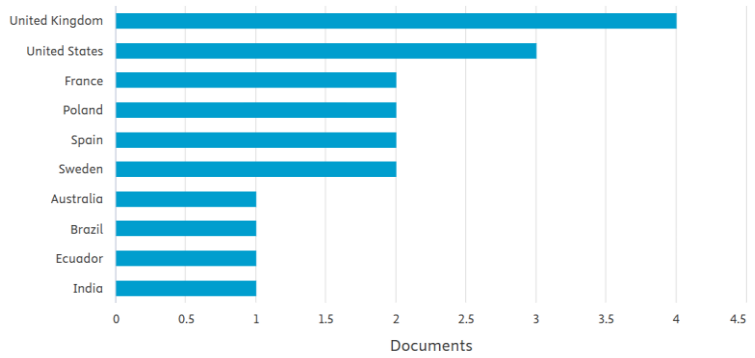
Figure 2: Article Publish by the Country



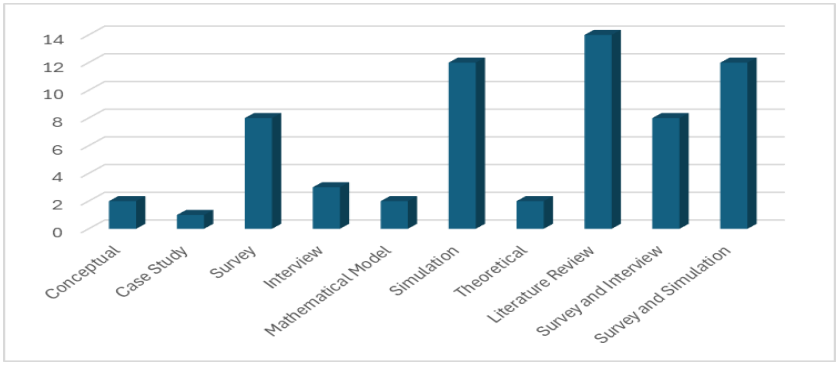
Sources: Scopus, 2025.

According to the figure 1 and figure 2, the majority of the papers were published after the year 2020, which reflects a growing interest in the combination of LSS and DES in logistics for the purpose of achieving sustainability. The Sustainability Switzerland magazine, the magazine of Cleaner Production, and the International Journal of Production Research are three of the most important publications that publish articles on this subject. Countries such as the United Kingdom, the United States of America, France, Poland, Spain, Sweden, Australia, Brazil, Ecuador, and India are the ones that have published the most, which indicates that there is a global interest in environmentally responsible logistics techniques.

Categorization of the Documents

The third step involves classifying the selected papers based on their research methodologies and designs. The approaches to research are divided into ten unique categories: (1) Conceptual approach, (2) Case study analysis, (3) Survey methodology, (4) Interview techniques, (5) Mathematical modelling, (6) Simulation processes, (7) Theoretical framework, (8) Literature review, (9) Combined survey and interview, (10) Integrated survey and simulation. The study design is further classified into six unique types: (1) Qualitative research based on empirical data, (2) Qualitative research conducted through desk analysis, (3) Quantitative research grounded in empirical evidence, (4) Quantitative research derived from desk analysis, (5) Triangulation based on empirical data, and (6) A combination of empirical quantitative and desk quantitative research.

Figure 3: Articles by Research Methodologies



Sources: Scopus, 2025.

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Figure 4: Research Designs

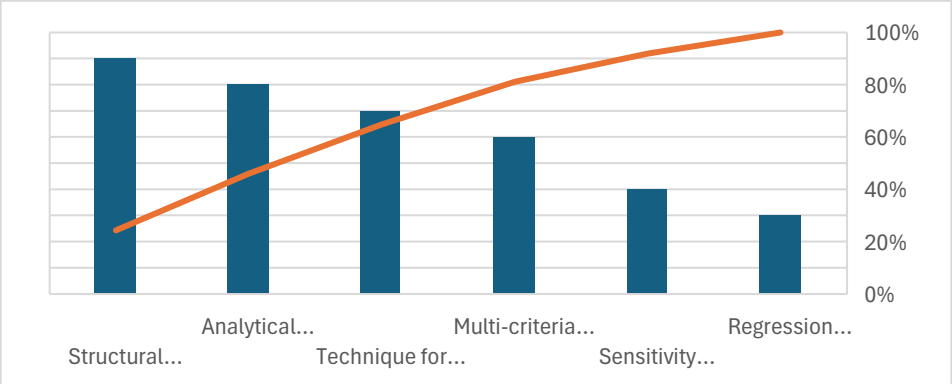
Sources: Scopus, 2025.

According to the categories, the majority of the publications study the application of LSS and DES in logistics by employing empirical qualitative research approaches. These methodologies include case studies and questionnaires. The significance of DES in modelling and optimising logistics operations for sustainability is highlighted by the fact that a significant number of studies make use of research approaches that are based on simulation

Analysis of the Data

An analysis of the information that was gleaned from the selected articles constitutes the final stage of the process. The investigation has an emphasis on the identification of primary themes, methodologies, and conclusions about the combination of LSS and DES in the field of logistics for the purpose of achieving sustainability. Sensitivity analysis, regression analysis, structural equation modelling (SEM), and multi-criteria decision-making (MCDM) methods are some of the techniques that are utilised in the process of data analysis. These techniques include the Analytical Hierarchy Process (AHP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

Figure 5: Articles by Data Analysis Techniques



Sources: Scopus, 2025.

Based on the findings of the study, it was discovered that integrating LSS and DES in the logistics sector can make a substantial contribution to the accomplishment of sustainability objectives, notably in terms of lowering carbon emissions and waste reduction. The utilisation of DES makes it possible to simulate a variety of different logistical scenarios, which in turn

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enables organisations to determine and put into action the most environmentally friendly procedures. LSS offers a methodical approach to the enhancement of processes, with the aim of ensuring that sustainability objectives are incorporated into the fundamental operations of logistics businesses.

The research methodology that was used in this investigation furnishes a thorough framework for the purpose of investigating the impact that LSS and DES play in the accomplishment of sustainability objectives within the logistics industry. The findings of this study will provide vital insights for both academics and professionals working in the subject of logistics, and they will greatly contribute to the expansion of the existing body of knowledge on environmentally responsible logistics approaches.

Findings and Discussion

Reducing Carbon Emissions

With the assistance of LSS and DES working together, it is possible that carbon emissions from logistics might be significantly reduced. As an illustration, Kumar et al. (2021) were able to realise a 12% reduction in fuel consumption by improving transportation routes through the utilisation of LSS. After simulating the routes with DES, we were able to establish which ones were the most energy efficient. Through the implementation of LSS and DES, Lee et al. (2023) were able to achieve a 15% reduction in the amount of energy that was consumed as a result of their optimisation of cold chain logistics.

Minimizing Waste

LSS and DES have demonstrated efficacy in minimising waste within logistics operations. Sreedharan et al. (2021) applied LSS to optimise warehouse operations, achieving a 20% decrease in material waste. DES was utilised to model inventory management processes and identify opportunities for waste reduction. Smith & Johnson (2023) utilised LSS and DES in the retail industry to optimise packaging processes, achieving an 18% decrease in packaging waste.

Enhancing Resource Efficiency

Increasing the efficiency with which resources, energy, and personnel are utilised is one of the ways in which the combination of LSS and DES can improve resource efficiency. After implementing LSS and DES, Martinez and Garcia (2024) were able to optimise the logistics of spare parts in the aerospace industry, which led to a reduction of 25% in the amount of resources that were utilised. Through the application of LSS and DES, Chen et al. (2024) were able to optimise the logistics for wind turbine components, resulting in a 20% reduction in the costs of shipping.

Research Gaps and Future Directions

The literature review identifies multiple deficiencies in current research regarding the impact of LSS and DES on the attainment of sustainability objectives within the logistics sector (Madani et al., 2024). LSS has been extensively utilised in logistics to enhance operational efficiency; however, its capacity to meet environmental and social objectives is still insufficiently examined. Recent studies primarily emphasise the operational advantages of Lean Six Sigma (LSS); however, there exists a notable gap in the examination of its

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environmental and social consequences (Barakat, 2024; Charłampowicz et al., 2024; Cherrafi et al., 2020; Chen et al., 2024; Kumar et al., 2021; Minashkina, 2024).

Secondly, although DES has been employed to enhance logistics processes, its integration with LSS and sustainability objectives is still constrained (Toktaş et al., 2024). Recent studies primarily emphasise the operational advantages of DES, neglecting its capacity to fulfil environmental and social goals (Freitas et al., 2020). This underscores the necessity for additional research on the integration of DES with LSS to attain sustainability objectives in logistics, especially concerning the reduction of carbon emissions and the minimisation of waste (Chen et al., 2024).

Thirdly, a deficiency exists in universally applicable frameworks or models for the integration of LSS and DES within the logistics sector (Lúcio et al., 2024). Many recent studies focus on specific case studies or simulations, often neglecting the creation of broader frameworks that can be applied across various logistics contexts. For instance, Díaz Pacheco & Benedito (2024) noted weaknesses in current supply chain response frameworks, particularly in addressing stimuli beyond demand changes. Similarly, Pantoja-Benavides et al. (2024) highlighted the lack of integration between robotics and packing problems in logistics research. The identified gap in the literature underscores the necessity for additional research aimed at developing and validating frameworks that integrate LSS and DES in logistics, specifically regarding the attainment of sustainability objectives.

The integration of LSS and DES provides an effective method for attaining sustainability objectives in logistics, especially in terms of reducing carbon emissions and minimising waste (Lúcio et al., 2024). Further research is required to investigate the potential of this integration, establish generalisable frameworks, and assess their effectiveness across various logistics contexts (Richey et al., 2023). This study proposes a framework that integrates LSS and DES in logistics to address existing gaps and achieve sustainability objectives.

Limitations of The Research

This study, although thorough, has specific limitations that must be recognised. The research relies exclusively on articles from the SCOPUS database, potentially omitting pertinent findings published in other databases or non-indexed journals. This may restrict the scope of the literature examined. Secondly, the selection criteria omitted books, theses, and internet reports, which may encompass useful insights absent from peer-reviewed papers. The study primarily examines the integration of LSS and DES in logistics, potentially overlooking the wider applications of both approaches in other sectors. Finally, the research fails to thoroughly explore the identification of essential success factors, facilitators, or obstacles for the implementation of LSS and DES in logistics, which could offer additional practical recommendations for organisations.

Conclusion

The worldwide growth of logistics operations has increased the demand for sustainable methods, particularly in minimising carbon emissions and decreasing waste. This study highlights the significant contributions of LSS and DES to achieving sustainability goals. The integration of LSS's methodical approach to process improvement with DES's ability to model and optimise logistical scenarios enables businesses to substantially reduce their environmental impact while maintaining operational efficiency. The findings reveal that the majority of

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research in this domain has occurred in industrialised countries, however there is a growing emphasis on developing nations like India. However, further empirical investigations are necessary, particularly with small and medium-sized firms (SMEs), which are crucial to the global economy but often overlooked in sustainability research. Future research should focus on developing integrated frameworks that combine LSS and DES with sustainability goals, while also assessing the social and environmental impacts of these approaches across diverse industry sectors. This study underscores the considerable potential of LSS and DES as efficacious instruments for achieving sustainability in logistics, providing a platform for further investigation and application of these methodologies.

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