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Enhancing Industrial Logistics Efficiency Through Lean and Simulation

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Abstract: This study presents an applied engineering approach to the reorganization and optimization of logistics operations in an industrial manufacturing environment. The research addresses inefficiencies identified in warehouse layout, internal transportation, production planning, and expedition processes within a construction materials facility. The primary objective was to enhance operational performance by reducing material handling waste, improving customer service levels, increasing safety conditions, and optimizing space utilization. A structured methodology was adopted, combining lean principles, inventory parameter revision, ABC classification, Kanban-based production control, layout redesign, and discrete-event simulation modeling. Time studies and value stream mapping were conducted to diagnose the current state and identify critical bottlenecks. Based on the findings, a new storage configuration organized by product rotation and production flow was implemented, along with standardized loading procedures and improved traffic circulation zones. A digital Kanban tool was developed to stabilize production planning and reduce variability in stock levels. To validate the proposed improvements, a simulation model was developed representing the current and redesigned systems. The results demonstrate a reduction of over 10 kilometers in daily forklift travel distance, nearly two hours of labor time saved per day, and a 28-second decrease in loading time per pallet. The findings confirm that integrating lean engineering practices with simulation technology enables measurable performance gains and supports data-driven decision-making in industrial logistics systems.

Keywords: Industrial engineering, Operations management, Arena simulation software, Lean logistics, Supply chain optimization.

Introduction

Industrial logistics plays a fundamental role in manufacturing competitiveness by ensuring that materials, products, and information flow efficiently throughout the production system. In many industrial facilities, however, warehouse layouts, storage policies, production planning, and internal transportation evolve incrementally in response to operational needs rather than through systematic engineering design. As a result, companies often experience excessive forklift travel, inefficient material handling, congestion in loading areas, unstable inventory levels, and underutilization of warehouse space. Although these inefficiencies may appear minor when analysed individually, their cumulative effect can significantly reduce productivity, increase operating costs, compromise safety, and negatively affect customer service.

Lean Manufacturing provides a structured framework for identifying and eliminating activities that do not add value to the customer. Within logistics operations, Lean principles have been widely applied to improve warehouse organization, material flow, inventory management, visual control, and process standardization. Tools such as Value Stream Mapping (VSM), ABC classification, Kanban systems, and standardized work contribute to reducing transportation, waiting times, excess inventory, and unnecessary movements. Nevertheless, implementing Lean improvements in complex logistics environments often involves substantial operational changes, making it difficult to predict their impact before implementation. Discrete-event simulation (DES) complements Lean methodologies by enabling engineers to analyse dynamic logistics systems, evaluate alternative operating scenarios, and quantify the expected benefits of proposed improvements without disrupting

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real operations. By modelling material flows, resource utilization, operational constraints, and process variability, simulation supports evidence-based decision-making and reduces the risks associated with layout modifications and process redesign. Consequently, the integration of Lean methodologies with simulation has emerged as an effective approach for improving manufacturing and warehouse performance.

Although previous studies have investigated Lean logistics, warehouse layout optimization, inventory control, Kanban systems, and discrete-event simulation independently, relatively few applied studies present an integrated engineering approach that combines these techniques within a real industrial environment and validates the proposed improvements through quantitative simulation. In particular, there remains a need for case studies demonstrating how layout redesign, inventory parameter revision, production planning, and standardized logistics procedures can be jointly implemented and evaluated using measurable operational indicators.

This paper addresses this gap through a case study conducted in a Portuguese construction materials manufacturing company. The research focuses on improving warehouse operations by integrating Lean engineering principles with discrete-event simulation. The proposed improvement programme combines warehouse layout redesign, ABC-based storage allocation, inventory parameter revision, digital Kanban implementation, standardized loading procedures, and traffic flow reorganization. To assess the effectiveness of these interventions, a simulation model was developed in Arena® Simulation Software, representing both the current and redesigned logistics systems under identical operating conditions. The study seeks to answer the following research questions:

- How can Lean tools be applied to identify and reduce waste in industrial logistics operations?
- How can warehouse layout redesign and ABC-based storage allocation improve material handling efficiency?
- To what extent can digital Kanban and revised inventory parameters contribute to more stable production planning?
- How can discrete-event simulation support the evaluation of logistics improvement initiatives before implementation?

The proposed improvements are assessed using key logistics performance indicators, including forklift travel distance, labour time, and pallet loading time. The results demonstrate substantial reductions in unnecessary internal transportation, improvements in warehouse organization and loading efficiency, and enhanced production planning stability. These findings illustrate the practical value of integrating Lean methodologies with simulation-based analysis to support data-driven logistics decision-making.

The main contribution of this research is the presentation of a comprehensive industrial engineering framework that combines Lean logistics practices and discrete-event simulation to redesign warehouse operations and quantitatively validate the expected operational improvements. Beyond its contribution to the academic literature, the study provides practitioners with a structured methodology that can be adapted to similar manufacturing environments seeking to improve logistics performance while minimizing implementation risk.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature on Lean logistics, warehouse optimization, inventory management, and discrete-event simulation. Section 3 describes the research methodology and case study. Section 4 presents the simulation model and discusses the experimental results. Finally, Section 5 summarizes the main conclusions, practical implications, limitations, and directions for future research.

Literature Review

Lean Logistics and Warehouse Optimization

Lean thinking seeks to maximize customer value by systematically eliminating activities that do not add value while promoting continuous improvement and flow efficiency (Womack & Jones, 1997). Within industrial logistics, Lean principles have been successfully applied to reduce transportation, waiting time, excessive inventory, unnecessary motion, and process variability through techniques such as Value Stream Mapping (VSM), standardized work, visual management, pull systems, and continuous improvement (Alejandro-Chable et al., 2024; Hines et al., 2004; Rother & Shook, 2003; Wronka, 2017).

Warehouse performance depends heavily on layout design, storage allocation, and material flow. Poorly designed warehouses increase travel distance, congestion, handling effort, and safety risks, whereas layouts based on

product flow and operational priorities improve accessibility, throughput, and resource utilization (Bartholdi & Hackman, 2014; Boysen et al., 2019; de Koster et al., 2007; Gu et al., 2010). Although these contributions remain foundational, recent research emphasizes that modern warehouses must also accommodate increasing product variety, shorter lead times, and greater operational flexibility (Boysen et al., 2019; van Gils et al., 2019).

ABC classification remains one of the most widely adopted approaches for warehouse optimization because it aligns storage locations with product movement frequency. High-rotation items are positioned closer to picking or shipping areas, reducing travel distances and material handling effort (Bartholdi & Hackman, 2014; Frazelle, 2016). Recent studies continue to demonstrate that ABC-based storage assignment contributes to improved warehouse productivity and more efficient resource utilization, particularly when combined with data-driven warehouse management systems (Kusrini et al., 2018; Zhen & Li, 2022).

Warehouse design must also consider safety and traffic management. Clearly defined circulation routes, appropriate segregation between pedestrians and forklifts, and efficient loading areas reduce congestion and improve operational reliability (Richards, 2014; Tompkins et al., 2010). Consequently, warehouse layout should be regarded as an integrated logistics system rather than merely a physical arrangement of storage locations.

Inventory Control and Digital Kanban

Effective inventory management balances product availability with inventory holding costs while supporting production stability and customer service (Chopra & Meindl, 2019; Silver et al., 2017). Inventory policies based on appropriate reorder points, safety stocks, lot sizes, and replenishment rules reduce stockouts, unnecessary inventory accumulation, and operational variability (Axsäter, 2015; Chopra, 2020). Since inventory decisions directly influence warehouse occupancy, production planning, and internal transportation, they should be integrated with logistics and warehouse management rather than treated as isolated planning activities (Jacobs & Chase, 2018; Martin Christopher, 2016).

Kanban systems complement inventory management by synchronizing production with actual consumption through pull-based replenishment mechanisms (Monden, 2012; Ohno, 1988). Unlike forecast-driven push systems, Kanban limits work-in-process inventory while improving production flow and coordination between manufacturing and logistics (Slack & Lewis, 2019). The effectiveness of Kanban depends on well-defined operating parameters and stable production processes (Lage & Filho, 2008; Thürer et al., 2016).

Recent advances in Industry 4.0 have extended traditional Kanban into digital environments. Digital Kanban systems improve information visibility, communication speed, and decision consistency by integrating enterprise information systems and real-time operational data (Buer et al., 2018; Rahardjo et al., 2023). This evolution reflects the broader concept of Lean 4.0, where digital technologies strengthen Lean implementation without replacing its fundamental principles (Kolberg & Zühlke, 2015; Mayr et al., 2018; Tortorella & Fettermann, 2018). Nevertheless, several authors emphasize that digitalization should support clearly identified operational problems rather than being implemented as an objective (Abi Saad et al., 2024; Ciano et al., 2021).

Discrete-Event Simulation for Logistics Improvement

Discrete-event simulation (DES) has become one of the most widely used techniques for analysing complex manufacturing and logistics systems because it allows alternative scenarios to be evaluated before physical implementation (Banks et al., 2010; Law, 2015; Robinson, 2014). By representing entities, resources, queues, operational constraints, and process variability, DES enables engineers to estimate system performance under realistic operating conditions while avoiding costly trial-and-error interventions.

Arena® Simulation Software is particularly suited to modelling warehouse and manufacturing operations due to its process-oriented architecture, which supports the representation of material flows, resource allocation, storage operations, loading activities, and internal transportation. Simulation outputs typically include waiting times, throughput, queue lengths, travel distances, and resource utilization, providing quantitative evidence for evaluating operational improvements (Law, 2015). Simulation has been extensively applied to warehouse management, material handling, production planning, and supply chain optimization (Detty & Yingling, 2000; Mourtzis, 2020; Negahban & Smith, 2014; Tako & Robinson, 2012). More recently, simulation has increasingly been integrated with digital manufacturing technologies, digital twins, machine learning, and reinforcement

learning to support data-driven logistics decision-making (Agalianos et al., 2020; De Vito et al., 2024; Kogler & Maxera, 2025; Leon et al., 2023; Skapinyecz, 2025; Wooley et al., 2025).

The complementary nature of Lean methodologies and simulation has been widely recognised. Lean identifies sources of operational waste and proposes process improvements, whereas simulation provides a quantitative framework for validating these improvements before implementation. Integrating both approaches enables organizations to reduce decision uncertainty, evaluate multiple alternatives, and support evidence-based logistics redesign.

Although previous studies have examined Lean logistics, warehouse optimization, inventory management, Kanban systems, and discrete-event simulation separately, fewer contributions have integrated these techniques within a single industrial case study while quantitatively validating the proposed improvements through simulation. This research addresses that gap by combining Lean logistics tools, inventory parameter optimization, warehouse layout redesign, digital Kanban, and discrete-event simulation into a unified framework for improving industrial logistics performance.

Methodology

Research Design

This research adopted a quantitative case study methodology integrating Lean engineering principles with discrete-event simulation (DES) to improve warehouse logistics in a Portuguese construction materials manufacturing company. The objective was to identify operational inefficiencies, redesign logistics processes, and quantitatively evaluate the proposed improvements before implementation.

The methodological framework consisted of six sequential phases (Figure 1): (i) diagnosis of the current logistics system; (ii) identification of operational waste; (iii) design of Lean improvement actions; (iv) development and validation of a discrete-event simulation model; (v) comparison of the current and proposed scenarios; and (vi) evaluation of operational performance using quantitative key performance indicators (KPIs).

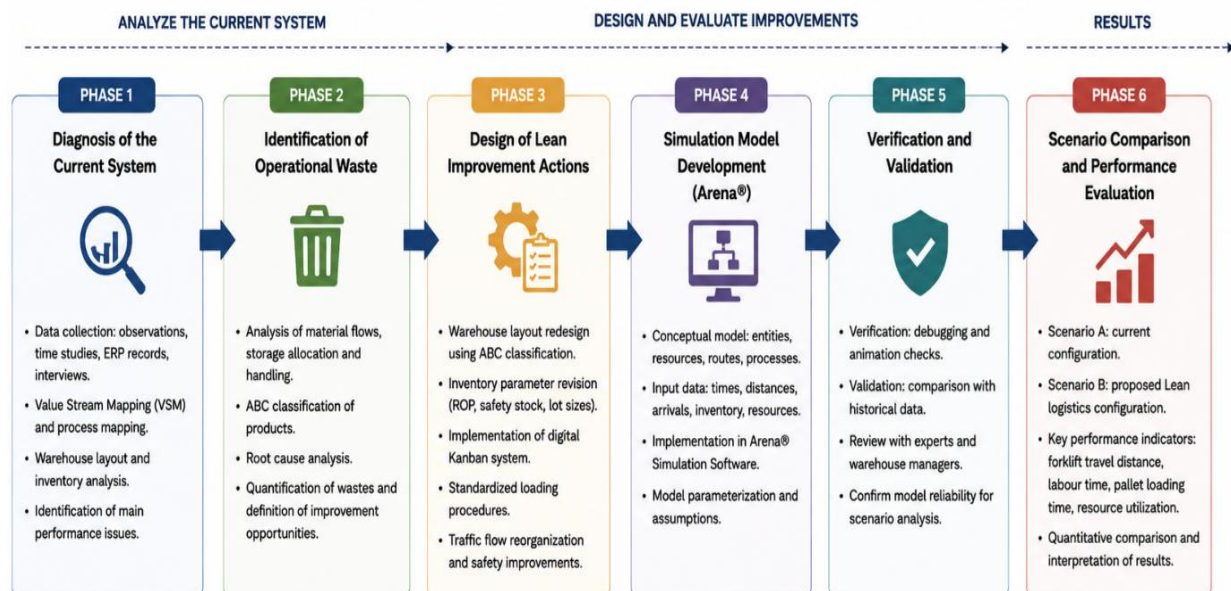


Figure 1. Summarizes the overall research framework adopted in this study

The methodology follows a structured engineering workflow that integrates Lean improvement techniques with discrete-event simulation to support evidence-based warehouse redesign. Each phase produces specific outputs that serve as inputs for the subsequent stage. Table 1 summarizes the objectives, techniques, and expected outcomes of each methodological phase. This structured approach combines process improvement techniques with simulation-based decision support, allowing engineering solutions to be assessed under realistic operating conditions while avoiding disruption to the actual production system.

Table 1. Research methodology

Phase	Objective	Main Techniques	Outputs
1. System Diagnosis	Understand the current logistics system	Direct observation, time studies, interviews, ERP data, Value Stream Mapping (VSM), process mapping	Current-state analysis and identification of operational issues
2. Waste Identification	Detect non-value-added activities	ABC classification, warehouse layout analysis, process analysis	Improvement opportunities and root causes of inefficiencies
3. Lean Improvement Design	Develop engineering solutions	Layout redesign, inventory parameter revision, Digital Kanban, standardized procedures, traffic flow redesign	Proposed Lean logistics configuration
4. Simulation Model Development	Build the DES model	Arena® Simulation Software, conceptual modelling, model parameterization	Validated simulation model of the logistics system
5. Verification and Validation	Ensure model reliability	Debugging, animation analysis, comparison with historical data, expert validation	Verified and validated simulation model
6. Performance Evaluation	Assess the proposed improvements	Scenario comparison, KPI analysis	Quantitative evaluation of operational performance improvements

Data Collection and System Diagnosis

Data collection was conducted over four consecutive weeks within the company's logistics department. Information was obtained through direct observation, time studies, interviews with warehouse supervisors and forklift operators, ERP production records, warehouse inventory reports, and customer dispatch records. The collected data included pallet production rates, forklift travel distances, loading times, truck arrivals, warehouse occupancy, inventory levels, production schedules, and product rotation frequencies. These data served both to diagnose the current logistics system and to parameterize the simulation model. The diagnosis combined Value Stream Mapping (VSM), process mapping, warehouse layout analysis, and ABC inventory classification. Five major sources of operational waste were identified:

- excessive forklift transportation;
- inefficient storage allocation;
- unnecessary material handling;
- congestion in loading areas;
- unstable production planning caused by outdated inventory parameters.

Among these issues, excessive forklift travel represented the largest proportion of non-value-added activities, largely because high-demand products were stored far from expedition areas. The analysis also revealed considerable variability in loading operations due to inconsistent working procedures and inefficient traffic circulation.

Lean Improvement Design

Based on the diagnosis, a set of complementary Lean improvement actions was developed to optimize material flow and warehouse performance. The warehouse layout was redesigned using ABC classification, relocating high-rotation products closer to loading docks while allocating low-demand products to more distant storage locations. Inventory policies were revised through adjustments to reorder points, safety stock levels, and production lot sizes in order to stabilize production planning and reduce inventory variability.

A digital Kanban system was introduced to synchronize production with warehouse consumption, replacing manual planning procedures with a pull-based replenishment mechanism. In addition, standardized loading procedures and dedicated forklift circulation routes were established to reduce process variability, eliminate unnecessary movements, and improve operational safety. Rather than implementing isolated improvements, the proposed solution integrates layout redesign, inventory optimization, visual production control, and process standardization into a unified logistics improvement framework.

Simulation Model Development

Following the design of the Lean improvement strategy, a discrete-event simulation (DES) model was developed using Arena® Simulation Software to evaluate the proposed logistics improvements before implementation. The conceptual model represents the complete warehouse logistics process, beginning with pallet production and ending with truck dispatch. Pallets and customer orders were modelled as entities, while forklifts, loading operators, and loading docks were defined as system resources. The model incorporates routing logic based on warehouse layout, product classification, loading priorities, and resource availability, thereby reproducing the operational behaviour of the real logistics system. Model input parameters were obtained from the operational data collected during the diagnosis phase. These included pallet production rates, forklift travel distances, loading times, truck arrivals, warehouse occupancy, inventory levels, and production schedules. Whenever appropriate, stochastic variables were represented using probability distributions fitted to the observed data, enabling the model to capture the variability inherent in warehouse operations. The Arena implementation followed the conceptual model without altering the observed logistics logic. The model was designed to support scenario analysis by allowing warehouse layouts, inventory policies, traffic routes, and loading procedures to be modified while maintaining identical operating conditions across experiments. Figure 2 presents the conceptual framework of the simulation model, while Figure 3 illustrates its implementation in Arena® Simulation Software.

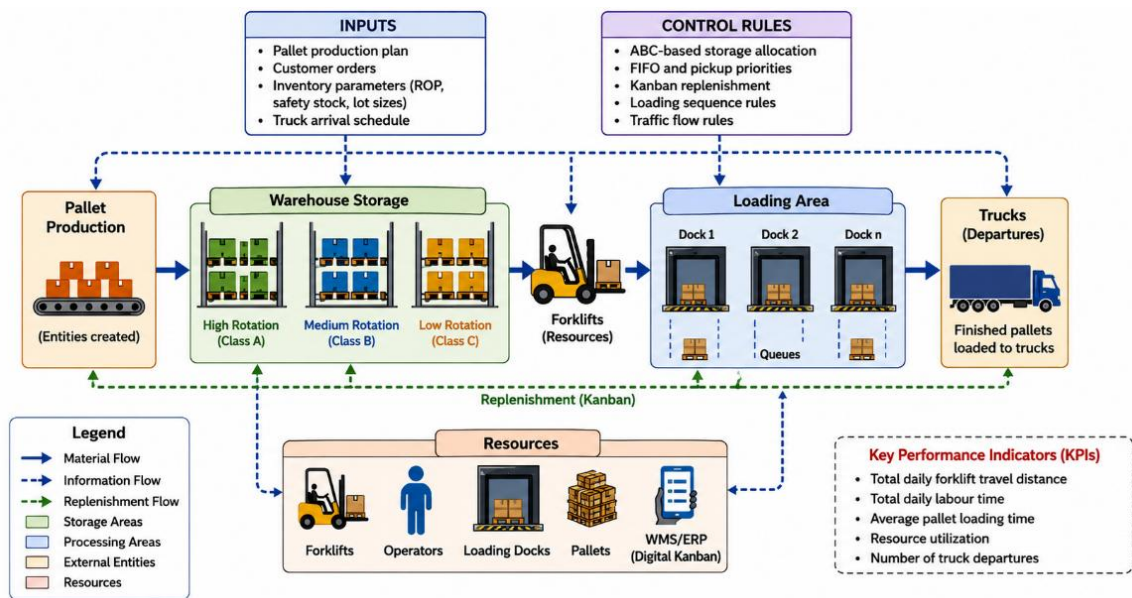


Figure 2. Conceptual model of the warehouse logistics system

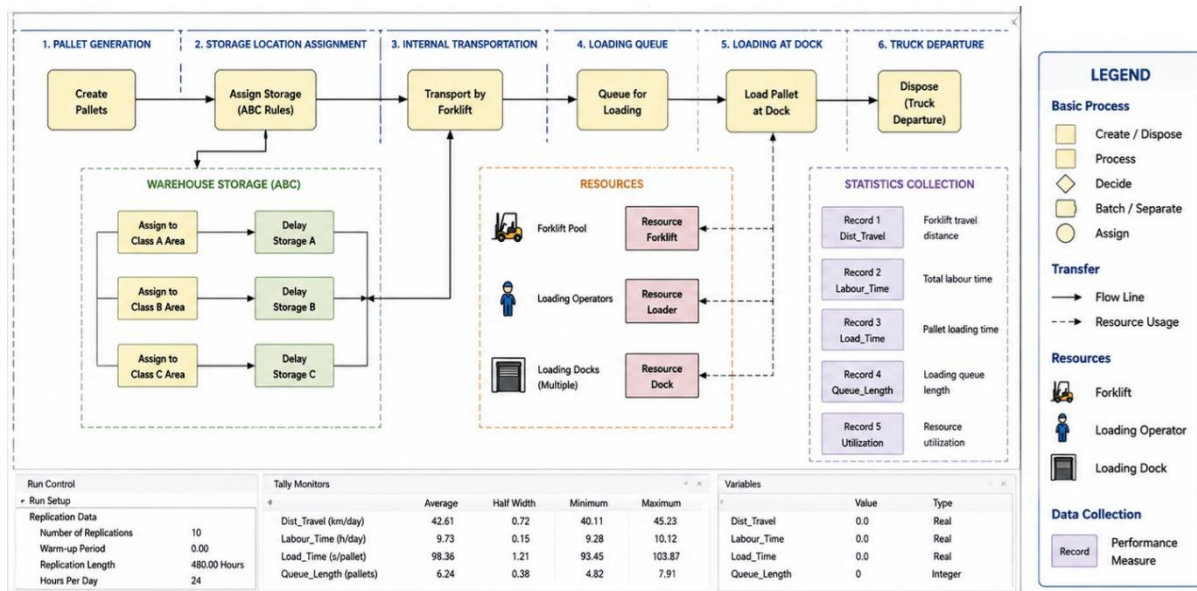


Figure 3. Arena simulation model implementation of the warehouse logistics system

Model Verification and Validation

Model credibility was established through both verification and validation procedures following recommended practices for discrete-event simulation studies. Verification was conducted throughout model development to ensure that the Arena implementation accurately reflected the conceptual model. This process included step-by-step debugging, animation analysis, logical consistency checks, and verification of entity routing, resource allocation, queue behaviour, and event sequencing. Multiple trial simulations were performed to confirm that the model operated without logical or computational errors.

Validation focused on assessing whether the simulation adequately represented the behaviour of the real logistics system. Simulation outputs for the current warehouse configuration were compared with historical operational data, including forklift travel distances, pallet loading times, and daily operational performance. In addition, the conceptual model, assumptions, and preliminary simulation results were reviewed with warehouse managers and logistics specialists to confirm that the model realistically represented actual operating conditions. The combined verification and validation procedures increased confidence that the simulation model was suitable for evaluating alternative warehouse configurations and supporting engineering decision-making.

Experimental Design

Two simulation scenarios were analysed:

- **Scenario A** - Current warehouse configuration.
- **Scenario B** - Proposed Lean logistics configuration incorporating layout redesign, revised inventory policies, digital Kanban, standardized loading procedures, and optimized forklift circulation.

Both scenarios used identical demand patterns, production schedules, and resource availability to ensure that any observed performance differences resulted exclusively from the proposed engineering improvements. The simulation experiments focused on three primary key performance indicators (KPIs):

- total daily forklift travel distance;
- total labour time required for warehouse operations;
- average pallet loading time.

Additional indicators, including warehouse flow efficiency and resource utilization, were analysed to support the interpretation of the simulation results.

Performance Evaluation

Simulation outputs obtained from the current and proposed scenarios were compared to quantify the operational impact of the proposed Lean interventions. The evaluation focused on reductions in non-value-added transportation, improvements in loading efficiency, labour savings, and overall warehouse performance. Percentage improvements were calculated for each KPI, allowing the effectiveness of the proposed logistics redesign to be objectively assessed.

The resulting performance indicators provide quantitative evidence supporting the implementation of the proposed warehouse configuration and demonstrate the value of integrating Lean methodologies with discrete-event simulation for industrial logistics optimization.

Results and Discussion

The simulation experiments compared the current warehouse configuration (Scenario A) with the proposed Lean logistics system (Scenario B) under identical operating conditions. Thirty independent simulation replications were performed for each scenario, and 95% confidence intervals were calculated for all key performance indicators (Table 2). This experimental design ensured that the observed differences resulted exclusively from the proposed engineering improvements rather than variations in demand or operational conditions.

Table 2. Comparison of logistics performance indicators obtained from the simulation of the current (Scenario A) and proposed (Scenario B) warehouse configurations

Performance Indicator	Unit	Current System (Scenario A)	Proposed System (Scenario B)	Improvement	Improvement (%)
Forklift travel distance	km/day	34.82	24.31	-10.51	-30.2%
Labour time	h/day	15.84	13.87	-1.97	-12.4%
Average loading time	sec/pallet	101.6	73.5	-28.1	-27.7%
Forklift utilization	%	86.4	74.1	-12.3 pp	-14.2%
Loading dock utilization	%	78.9	69.6	-9.3 pp	-11.8%
Throughput	pallets/day	214	219	+5	+2.3%
Average queue length	pallets	7.8	4.6	-3.2	-41.0%
Order completion time	min/order	46.2	37.4	-8.8	-19.0%

Table 2 summarizes the quantitative results obtained from the simulation experiments, while Figure 4 illustrates the relative percentage improvement achieved by the proposed Lean logistics configuration compared with the current warehouse system. The comparison demonstrates that the redesigned warehouse consistently outperformed the existing configuration across all evaluated key performance indicators (KPIs). Significant reductions were observed in internal transportation, labour requirements, loading time, queue length, and order completion time, while warehouse throughput was maintained and slightly increased. These results indicate that the proposed engineering interventions successfully eliminated non-value-added activities without compromising operational capacity.

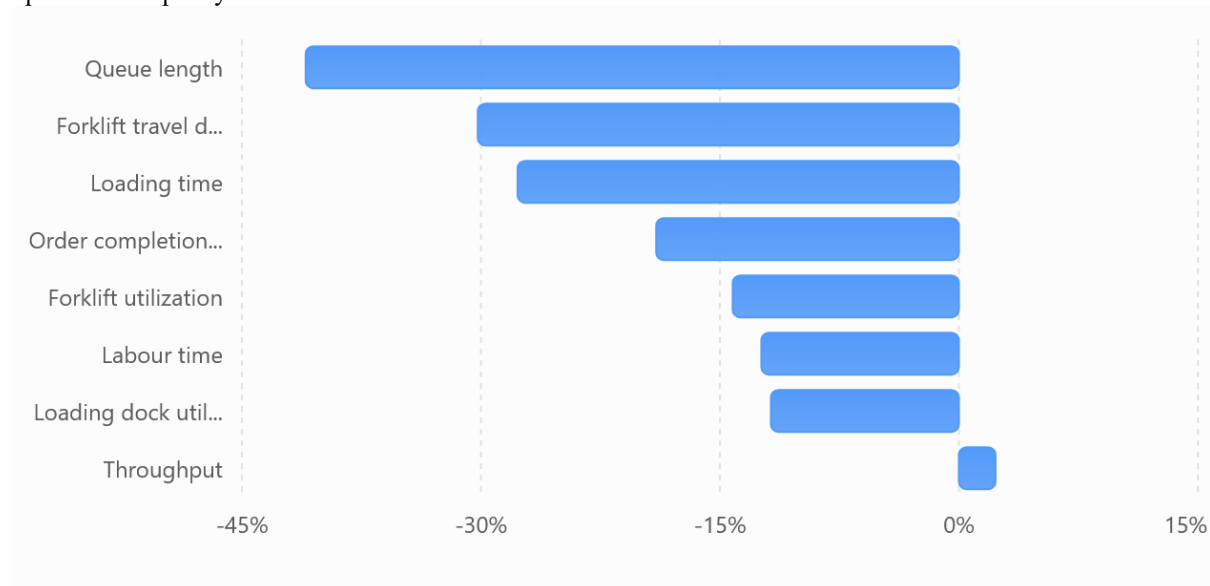


Figure 4. Percentage improvement of key logistics performance indicators

The observed improvements are not attributable to a single modification but rather to the combined implementation of complementary Lean initiatives, including warehouse layout redesign, ABC-based storage allocation, revised inventory parameters, digital Kanban implementation, standardized loading procedures, and optimized forklift circulation. The integration of these measures produced a more balanced logistics system, demonstrating the benefits of adopting a holistic engineering approach instead of isolated process improvements. The following subsections analyse each performance indicator individually and discuss the engineering implications of the observed improvements, relating the simulation results to Lean logistics principles and previous research.

Reduction of Internal Transportation

The most significant improvement was observed in daily forklift travel distance, which decreased from 34.82 km/day to 24.31 km/day, corresponding to a reduction of 10.51 km/day (approximately 30%). This reduction was primarily achieved through the relocation of high-rotation products closer to the expedition area using ABC-based storage allocation, together with the redesign of internal circulation routes.

From a Lean perspective, transportation represents one of the seven classical forms of operational waste (Ohno, 1988). The proposed warehouse layout directly addresses this source of waste by minimizing unnecessary movements while improving the proximity between storage locations and loading docks. Similar improvements have been reported by Bartholdi and Hackman (2014), who demonstrated that optimized storage allocation substantially reduces travel distances and material handling effort. Likewise, Zhen and Li (2022) observed significant productivity gains following warehouse layout optimization based on product rotation. Beyond reducing travelled distance, the redesigned layout is expected to decrease forklift operating time, equipment wear, energy consumption, and operator fatigue while simultaneously improving workplace safety through more organized traffic circulation.

Improvement of Labour Productivity

Total labour time decreased from 15.84 h/day to 13.87 h/day, representing a saving of 1.97 h/day (approximately 12%). This improvement was not associated with workforce reduction but rather with increased operational efficiency. Shorter travel routes, improved storage accessibility, standardized loading procedures, and reduced searching time collectively eliminated several non-value-added activities previously performed during warehouse operations.

These findings reinforce the central Lean principle that productivity improvements should be achieved by eliminating waste rather than increasing employee workload. Similar conclusions were reported by Alejandro-Chable et al. (2024), who demonstrated that integrating Lean logistics practices improves operational performance primarily through process redesign rather than additional resource investment. From a managerial perspective, labour savings of nearly two hours per operational day may be reallocated to value-adding logistics activities or provide additional operational flexibility during periods of higher demand.

Loading Performance

Average pallet loading time decreased from 101.6 s/pallet to 73.5 s/pallet, corresponding to an improvement of 28.1 seconds per pallet. Although the reduction for a single pallet appears relatively small, its cumulative impact becomes substantial when hundreds of pallets are dispatched each day. Faster loading operations reduce truck waiting times, improve dock availability, and increase warehouse responsiveness without requiring additional loading resources.

The observed improvement resulted from three complementary interventions: improved product positioning, reduced congestion near loading docks, and standardized loading procedures. This demonstrates that relatively simple organizational changes can generate measurable operational gains when implemented as part of an integrated Lean logistics strategy.

Resource Utilization and System Balance

The proposed warehouse configuration also produced a more balanced utilization of logistics resources. Forklift utilization decreased from 86.4% to 74.1%, while loading dock utilization decreased from 78.9% to 69.6%. Although lower utilization might initially appear undesirable, these results indicate a reduction in operational bottlenecks and provide additional capacity to accommodate demand variability without creating excessive queues or delays. Highly utilized logistics resources frequently become system bottlenecks, reducing operational flexibility and increasing the likelihood of congestion.

Consistent with this interpretation, the average queue length decreased from 7.8 to 4.6 pallets, while average order completion time was reduced from 46.2 to 37.4 minutes. These improvements demonstrate that the redesigned warehouse achieved smoother material flow and more balanced resource allocation throughout the logistics process.

Throughput Performance

An important observation is that warehouse throughput remained stable despite the substantial reduction in resource utilization. Daily throughput increased slightly from 214 to 219 pallets, indicating that the proposed

improvements enhanced operational efficiency without reducing production capacity. This finding confirms that the observed performance gains resulted from eliminating operational waste rather than reducing system workload. Similar conclusions have been reported in previous studies combining Lean principles with simulation-based analysis, where productivity improvements were achieved primarily through better process organization rather than increased resource availability (Detty & Yingling, 2000; Robinson, 2014). Maintaining throughput while reducing transportation effort and labour requirements represents one of the strongest indicators that the proposed engineering solution effectively improves warehouse performance.

Engineering Implications

The results demonstrate that significant logistics improvements can be achieved without major capital investment. Most of the observed gains resulted from redesigning warehouse layout, revising inventory parameters, implementing digital Kanban, and standardizing operating procedures rather than acquiring additional equipment or increasing staffing levels.

The study also confirms the complementary relationship between Lean methodologies and discrete-event simulation. Lean tools provided a systematic framework for identifying operational waste and designing improvement actions, whereas simulation enabled these alternatives to be quantitatively evaluated before implementation. This reduced implementation risk while providing objective evidence to support engineering decision-making.

Overall, the findings demonstrate that integrating Lean engineering practices with discrete-event simulation constitutes an effective and replicable methodology for improving warehouse logistics performance in manufacturing environments. The proposed framework may therefore serve as a practical decision-support approach for organizations seeking to optimize warehouse operations while minimizing operational disruption.

Conclusion

This study presented an integrated engineering approach to improving warehouse logistics in a construction materials manufacturing company through the combination of Lean methodologies and discrete-event simulation. The research addressed operational inefficiencies associated with warehouse layout, internal transportation, inventory management, production planning, and loading operations. By integrating Value Stream Mapping (VSM), ABC-based storage allocation, inventory parameter revision, digital Kanban implementation, standardized loading procedures, and warehouse layout redesign, a comprehensive logistics improvement strategy was developed and evaluated using Arena® Simulation Software.

The simulation results demonstrated that the proposed warehouse configuration generated measurable improvements across all analysed logistics performance indicators. Daily forklift travel distance was reduced by more than 10 km, labour requirements decreased by nearly two hours per day, and average pallet loading time was reduced by approximately 28 seconds. Additional improvements were observed in queue length, order completion time, and resource utilization, while warehouse throughput was maintained and slightly increased. These findings indicate that significant operational gains can be achieved through process redesign and improved material flow without requiring major capital investment or additional logistics resources.

Beyond the quantitative improvements, the study highlights the complementary roles of Lean engineering and discrete-event simulation. Lean methodologies provided a systematic framework for identifying operational waste and designing process improvements, whereas simulation enabled these improvements to be evaluated under realistic operating conditions before physical implementation. This integration reduced implementation uncertainty supported objective comparison between alternative logistics configurations, and provided quantitative evidence to support engineering decision-making. Consequently, the proposed framework extends previous research by demonstrating how multiple Lean practices can be combined within a single industrial improvement project and validated through simulation in a real manufacturing environment.

From a practical perspective, the proposed methodology offers manufacturing companies a structured and replicable approach for improving warehouse performance. The study demonstrates that optimizing warehouse layout, aligning storage locations with product rotation, revising inventory parameters, implementing digital Kanban systems, and standardizing logistics procedures can substantially improve operational efficiency while maintaining service levels. Because these improvements rely primarily on process redesign rather than additional

equipment, the proposed framework represents a cost-effective strategy that may be adapted to other industrial sectors with similar logistics characteristics.

This research is subject to several limitations. The study was conducted within a single manufacturing facility operating in the construction materials sector; therefore, the numerical results should not be generalized directly to other industrial contexts without considering differences in production processes, warehouse configurations, product characteristics, and demand patterns. Furthermore, the simulation model focused primarily on operational performance indicators and did not explicitly evaluate economic measures such as investment costs, maintenance requirements, energy consumption, or environmental impacts. Incorporating these dimensions could provide a more comprehensive assessment of logistics improvement projects.

Future research may extend the proposed framework by integrating digital twins, real-time warehouse monitoring systems, Internet of Things (IoT) technologies, autonomous guided vehicles (AGVs), machine learning algorithms, and reinforcement learning techniques to support adaptive warehouse optimization. Additional case studies involving different manufacturing sectors would also contribute to validating the broader applicability of the methodology and further strengthen the evidence supporting the integration of Lean engineering principles with simulation-based decision support.

Overall, the results confirm that combining Lean logistics practices with discrete-event simulation provides a robust engineering methodology for warehouse redesign and logistics optimization. The proposed approach enables organizations to evaluate improvement alternatives before implementation, reduce operational risk, and support data-driven decision-making, thereby contributing to more efficient, flexible, and sustainable industrial logistics systems.

Scientific Ethics Declaration

* The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the author.

Conflict of Interest

* The author declares that there is no conflict of interest.

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