Advanced and Sustainable Technologies
ASET
E-ISSN 2976-2294

Volume 4, No 2, December 2025 [163-175]

The Effectiveness of Lean Warehousing Towards Reducing Waste in Manufacturing Companies Using Siemens Tecnomatix Plant Simulation Software (STPSS)

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Received 9 June 2025, Revised 10 July 2025, Accepted 22 July 2025

ABSTRACT

Originally developed for Toyota's assembly line and vehicle manufacturing, lean manufacturing has become a widely adopted approach across various industries. However, most existing research primarily focuses on its application to production lines, often overlooking the unique challenges and opportunities within warehouse operations. Despite the crucial role warehouses play in the supply chain, there is a significant gap in the literature addressing the tailored application of lean methodologies in warehouse settings. This research aims to investigate the impact of implementing lean principles on warehouse processes in manufacturing companies, using Siemens Tecnomatix Plant Simulation Software (STPSS) for analysis. The study also seeks to evaluate the effectiveness of lean manufacturing tools in reducing waste and enhancing operational efficiency. A manufacturing company in Johor serves as the focal point for this research, aiming to guide the company towards lean warehousing. STPSS is employed as the primary method for this research, offering a 3D simulation model to visualize and analyse the proposed improvements. The outcomes of the simulation provide a comprehensive overview of the enhanced process flow layout. This study managed to reduce 30% of production time. These results clearly illustrate the positive impact of the modified layout on overall operations, emphasizing the effectiveness of the implemented changes.

Keywords: Lean Warehousing, Operational Efficiency, Plant Simulation, Warehouse Management, Waste Reduction.

1. INTRODUCTION

Competition among manufacturers has made it difficult for most firms to adopt contemporary production procedures and technologies. In order to assess their success, such businesses have sought to incorporate a portion or the entire range of lean manufacturing (LM) principles. Lean practices, such as cost and setup time reduction, Kaizen, and value stream mapping, have been a driving force for sustainable operations. However, many businesses struggle to implement lean systems owing to inconsistencies in implementation aspects. The lean practice is fraught with

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difficulties, most notably the methods for applying the idea, systematic thinking, and the suitability of lean philosophy throughout each manufacturing sector category.

The proper use of lean philosophy incorporates the notion of Industry 4.0 to improve current production systems. The lean method, which is distinguished by industry, focuses on continuous. As a result, lean is viewed as an Industry 4.0 project since it eliminates delays in production related to human resources, suppliers, customers, automation, and waste. Optimization and standardization of value streams through industrial digitalization. 4.0. However, adopting lean techniques is not a free ride; there are significant barriers and challenges. As a result, variables that give guidance to industrial sustainability must be established.

Lean manufacturing is described as a continuous improvement strategy that combines everyday labor in creating and delivering goods, services, and information in order to detect waste that impacts production flow, grace period, quality, and cost [1]. The most significant benefits of this include lower manufacturing costs, increased productivity, and shorter production lead times [2]. According to [3], lean manufacturing enables a firm to compete by removing non-value activities, and any company's sustainability should center on protecting its resources by avoiding waste. Lean performance and methods on knowledge generation have been examined in manufacturing strategies [4]. This technique aids management in developing explicit and implicit understanding of lean indicators. It was a crucial component of lean practice and a need for adopting lean. Furthermore, it was recommended that in order to raise performance levels, directors of the management should be more aware of the knowledge of each generation and its effectiveness. With the use of a mapping tool, a manufacturing industry has decided to talk about and evaluate the job being done in the production line [5].

As suggested by [6], enhancements in manufacturing practices involve the application of lean manufacturing principles to companies engaged in lean production. The proposed approach encompasses the evaluation of key factors such as process control and improvement, workflow optimization, workforce skill development, effective maintenance management, just-in-time practices, customer-centric focus, and the cultivation of robust supplier relationships. In manufacturing firms, lean manufacturing, also known as lean production, employs a complete system, flow system, setup times, and total productive maintenance [7].

Lean warehousing is a strategy that enhances resource efficiency without compromising quality and productivity. Lean warehouses aim to achieve more with fewer resources, thereby optimizing operational processes. This approach enables businesses to deliver goods more effectively. Lean warehousing involves improving the use of time, space, and resources in a warehouse through automation and proactive planning, which in turn boosts customer satisfaction. The effectiveness and efficiency of warehouse operations, as per lean principles, rely on well-thought-out layout planning, effective material handling methods, and appropriate transportation modes. This paper reviews current literature on the comprehensive methodology of lean warehouse structures and the associated tools that help reduce inefficiencies and enhance productivity, highlighting the importance of customer satisfaction as a key objective. A program that simulates a discrete event simulation tool called STPSS assists in building digital models of logistical systems, such as manufacturing, to evaluate and improve system performance [8].

This research gap is particularly evident in the absence of comprehensive frameworks for waste reduction within warehouses. The study aims to fill this void by extending the application of lean manufacturing to warehouse management and introducing an approach to simulation methods. The utilization of STPSS to create a 3D model for visualizing and optimizing lean processes in warehouses represents an innovative step forward. This approach addresses the need for practical tools to implement and visualize lean practices in warehouse environments. In essence, the research contributes to the broader understanding of lean principles by offering insights into their practical application in warehouse settings. This study aimed to address the following research objectives: to identify the impact of the implementation of lean principles on warehouse processes in manufacturing companies, to analyse the effect of lean manufacturing on lead time using Siemens STPSS, and to evaluate the reduction in the operation time of the company. Through this approach, viable solutions are given to address the identified waste and eliminate it, mostly to increase production effectiveness.

1.1 Lean Manufacturing

The Toyota Production System (TPS) originated in 1988 as a response to challenges faced by Toyota after World War II. Facing shortages in materials, finances, and human resources, TPS strategically focused on reducing shop floor waste. This initiative not only helped Toyota survive but also positioned it as a global leader in the automotive industry. TPS's emphasis on productivity and efficiency turned resource constraints into opportunities, enabling Toyota to thrive during challenging economic times [9]. The "Lean manufacturing" concept, pioneered by Taichi Ohno, gained widespread popularity through the Toyota Production System (TPS). Ohno, Toyota's principal production engineer, conducted continuous research under the guidance of Eiji Toyoda. Initially aiming to improve efficiency based on observations in Detroit, Ohno unintentionally developed a groundbreaking system that transformed production. This approach has since been adopted globally. Today, managing product innovation requires businesses to embrace modern technologies and methodologies for survival in the market [10].

1.2 Lean Warehousing

Lean warehousing is a management approach aimed at eliminating processes or activities within a warehouse that consume resources without adding value, thereby reducing waste and enhancing productivity. Originally developed by Toyota in the automotive industry, this method focuses on minimizing waste and improving efficiency. Manual picking, for example, requires warehouse operators to use pick lists and navigate pick locations manually, which is considered wasteful as it consumes time and labor without providing any added value to the customer [11]. To address this inefficiency, the lean warehousing approach would recommend implementing automated picking solutions.

1.3 Areas for Implementing Lean Warehousing

Improving the following areas is critical for the success of lean warehousing. Lean Warehousing can be applied across various crucial sectors to streamline operations and minimize waste. This involves designing a warehouse layout that promotes efficient material movement, managing inventory to avoid surplus stock, choosing the right material-handling equipment, utilizing resources effectively, improving stock visibility, eliminating outdated stock, addressing bottlenecks at pick locations, and adopting a robust Management Information System for informed decision-making. The overarching aim is to boost the movement of goods and information by refining layout designs, simplifying processes, and smartly employing technology [11].

1.4 Process Effectiveness

Effectiveness is defined as the percentage of anticipated outcomes as well as the planned activities that have been carried out. [12] claims that regions where achieving good outcomes ensures an organization's success are where the primary elements influencing the development of new products may be located. According to [13], costs, delivery efficiency, quality, adaptability, and innovation are the five main factors that determine how effective a production process is.
According to [14], an eight-part model for managing enterprise effectiveness encompasses innovation, competitive advantage, production output, customer-oriented outcomes, financial and market results, employee-driven outcomes, process efficiency results, and leadership

outcomes. The evaluation of process effectiveness involved gauging indicators of efficiency and efficacy, including cost savings, heightened productivity, emission reduction, and similar factors. This assessment also considered indicators of internal responsiveness, such as cycle time, production flexibility, delivery time, and adjustment time, as well as specific metrics for improving office work and administrative functions, like innovation levels and Six Sigma initiative outcomes. Additionally, the model incorporated indicators for assessing supplier–customer relationships.

1.5 Stimulation Modelling

Nowadays, the dominance of IT tools is incredibly crucial, and computer simulation is an excellent study strategy [15]. It is a mathematical model-based representation of the researched event or process in the form of a computer programmer, also known as a computer model. Building a simulation process model is a multi-stage procedure. In order to lower the chance of failure while implementing significant modifications to the current manufacturing systems, simulation models are used. After the model is created, a simulation study is carried out to identify specific steps in the process [16]. An investigated system's traits, features, and constraints are presented in a model along with how the process functions under various scenarios.

2. RESEARCH METHODOLOGY

The approach used in this research to analyze the data is the qualitative method. To determine the process flow of the operation at a manufacturing Company, the qualitative technique was employed to collect data through observation and interviews. The researcher must then suggest a new manufacturing process flow based on the data collected in the process flow. The simulation models incorporate internal and external supply networks, manufacturing resources, and business processes, allowing you to assess the impact of various production changes. Extensive data and charts may be used to aid in the dynamic study of performance characteristics such as line workload, breakdowns, idle and repair time, and unique critical performance indicators. Tecnomatix Plant Simulation supports the JT™ data format for 3D visualization, an ISO standard, as well as Siemens' direct model technology, which allows for rapid loading and accurate visualization of huge 3D simulation models. The interface of Tecnomatic Plant Simulation Software can be shown in Figure 1.

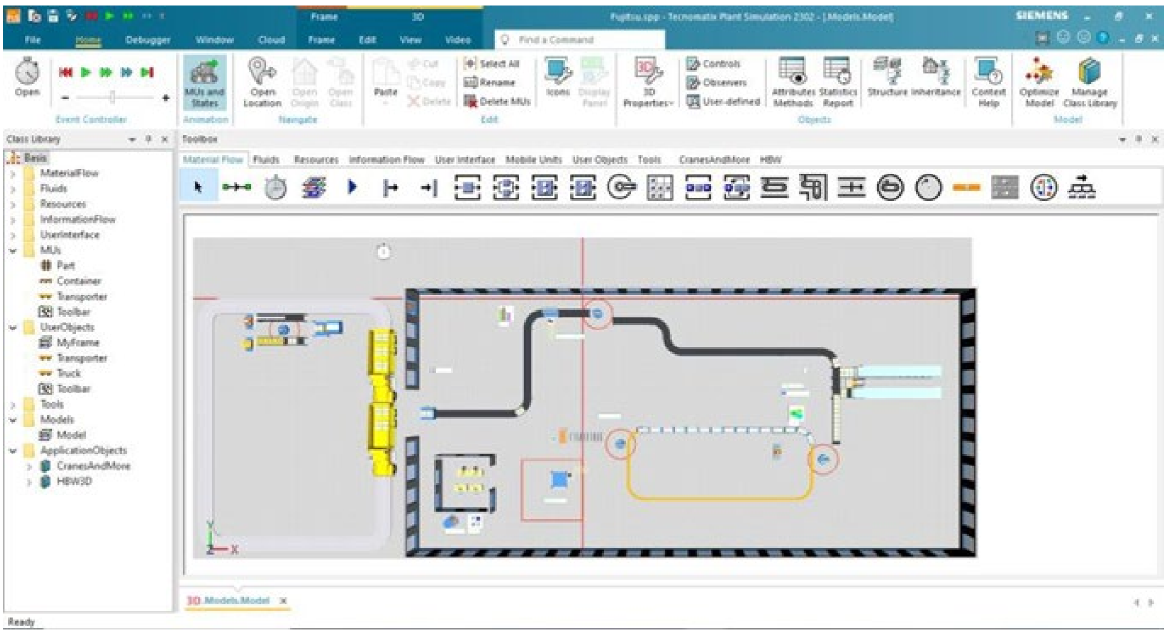

Figure 1: Interface of STPSS.

The research design refers to a problem-solving technique, which is an instrument and method that provides the researcher with a framework for collecting, measuring, and evaluating data. This strategy involves various decisions in determining the technique to apply in this study. As data gathering and analysis tools, this study used the description of analytical research, historical study, and simulation approach. The research methodologies chosen are determined by the difficulties or problems being addressed. This study was carried out in a manufacturing company located in Johor. The researcher gathered the data by observing the warehousing and procedures. It is critical to obtain more updated information and data from all relevant sources for data collection to guarantee that this research is based on solid facts. The data and information gathered were used to discover answers to the research's questions and to forward the research's objective. Primary data (interviews and observations) and secondary data (journals, books, internet articles, and other reference materials) were used in this study. The firm's warehouse was observed for this study, and interviews with company executives were undertaken. The time it takes to complete each step was measured during the observation. This study concentrated on the average cycle time for each process throughout the whole process. Finally, the information and data acquired from the observations and interviews were documented and analysed.

In this research, simulation analysis was employed to examine the qualitative data. This involved the use of Siemens Tecnomatix Plant Simulation (STPSS) to construct a virtual depiction of the system, commonly known as a model. This model is designed to represent long-term processes. The investigation carried out using the Siemens STPSS yielded practical solutions to the issues identified in the existing manufacturing processes. Prior to presenting the proposed solutions to the company, they were re-verified using the exact simulation.

3. RESULTS AND DISCUSSION

3.1 Data collection

Critical insights into the manufacturing company's warehouse operations were extracted through interviews with key personnel. The focus encompassed crucial aspects such as receiving procedures, warehouse layout, and operational systems. Complementing this, thorough observations were conducted to assess the existing warehouse design comprehensively. The visual representation of the receiving process flow is depicted in Figure 2, while the data collected for STPSS is systematically detailed in Table 1.

Table 1: Comparison before and after improvement.

Current Receiving Process in Warehouse					
Process	**Workstation**	**Operator**	**Process Time (seconds)**	**Waiting Time (seconds)**	**Lead Time (seconds)**
1	Transfer Station Process	2	364	153	420
2	Physical Check Process	1	147	120	267
3	Segregation Area	1	549	303	852
4	Transfer to the warehouse Process	1	300	30	330
5	Pick the part for the production Process	1	907	567	1474
Time for one cycle			2267	1173	3440

3.2 Current Process of a Manufacturing Company Warehouse Layout

Illustrated in Figure 2, the current receiving process flow elucidates the stepwise journey from transportation to warehouse systems. The depiction brings attention to the manual aspects involved, including material handling, inspection procedures, segregation, and manual transportation. Noteworthy challenges identified include the labor-intensive nature of manual processes, time consumption, and the potential for errors.

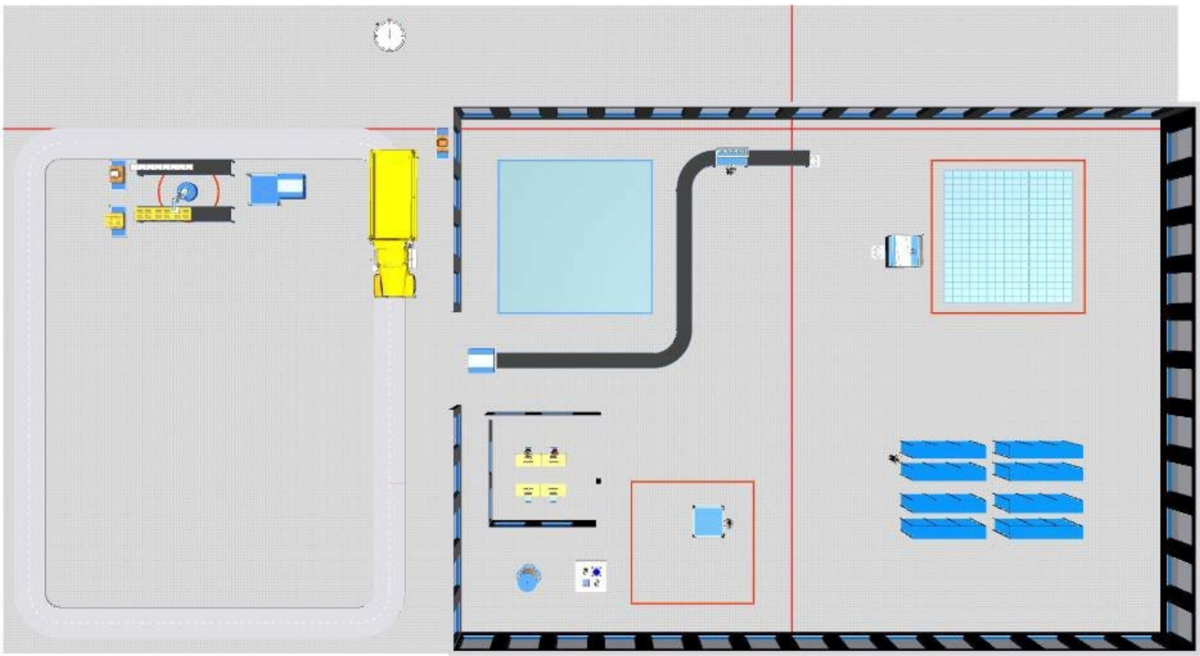

Figure 2: Current process flow of receiving in the warehouse.

3.3 Process Improvement

The current layout or design can be restructured to achieve a more systematic arrangement, thereby minimizing unnecessary movements and reducing waiting times. Moreover, the manual method currently employed is time-consuming, with each cycle requiring a significant amount of time. This approach aims to minimize wastage, optimize workflow, and ultimately enhance overall productivity in the warehouse.

3.3.1 Reorganize the Process Flow to Reduce Waste

Researchers have pinpointed various unnecessary motions within the current workflow, and the recommended course of action is to eliminate these inefficiencies. The overarching objective of these changes is to reduce the time, ensuring a smoother and more streamlined material flow from one station to another and ultimately to the storage area.

3.3.2 Implemented an Automated Machine to Reduce Waste

Recognizing the potential for improvement, the researchers suggest the implementation of automated equipment to streamline operations. This shift towards automation is anticipated to reduce the reliance on manual labor and expedite the transfer of materials between different locations.

3.3.3 Implement a conveyor to Reduce Waste

It is recommended that a conveyor system be integrated into the existing process flow to solve this issue and improve operational efficacy. The desired consequence is a large reduction in waiting times between procedures, resulting in smoother and efficient movement from one stage to the next. This strategic move aims to improve overall workflow and add to the operational efficiency of the organization.

3.3.4 Implement the Kanban System

Introducing a Kanban system into a warehouse with automated material handling machines requires a thoughtful integration strategy for optimal efficiency. This may involve the use of barcoding or RFID technology for streamlined communication. Establishing reorder points for materials utilized in automated processes is essential, and defining the optimal material flow path within the warehouse should align with both manual and automated workflows.

3.4 New proposed production process flow simulation model

Based on the data gathered from the existing condition of the receiving process in a manufacturing firm, the researcher proposed a new structure and process flow to boost the process's effectiveness while reducing all waste. The initial arrangement at a manufacturing company for the receiving process was characterized by a lack of systematic organization and heavy reliance on manual methods. However, following significant improvements, a new and more systematic arrangement has been implemented, leveraging STPSS. This updated system incorporates advanced technologies, such as conveyors and robotic arms, to enhance efficiency and streamline the workflow.

Table 2. New Proposed Receiving Process in Warehouse.

Process	Workstation	Operator	Process Time (seconds)	Waiting Time (seconds)	Lead Time (seconds)
1	Transfer Station Process	1	327	60	379
2	Physical Check Process	1	120	30	150
3	Segregation Area	-	432	12 2	554
4	Transfer to the warehouse Process	-	180	-	180
5	Pick the part for the production Process	-	615	11 2	727
	Time for one cycle		1674	224	1898

In the enhanced receiving process flow at a studied company, the integration of conveyors facilitates the smooth movement of materials, reducing manual handling and minimizing the potential for errors. The inclusion of automated robotic arms adds a level of precision and speed to the process, further reducing reliance on manual labour and enhancing overall efficiency.

Furthermore, the implementation of a Warehouse Management System (WMS) represents a significant advancement. The WMS incorporates a Kanban system, a visual management method aimed at optimizing workflow within the warehouse. This involves the use of visual cues, often in the form of cards or signals, to indicate the status of tasks and materials in the warehouse. The Kanban system, within the WMS, contributes to the improved organization and efficiency of the warehouse operations at a studied company by providing a clear and visual way to manage inventory, monitor processes, and ensure a more streamlined and responsive workflow.

Simultaneously, the allocation of workers for each process is adjusted, accompanied by a recalculation of process time, waiting time, and maximum time in seconds. The revised process flow for the warehousing system is illustrated in Figure 3.

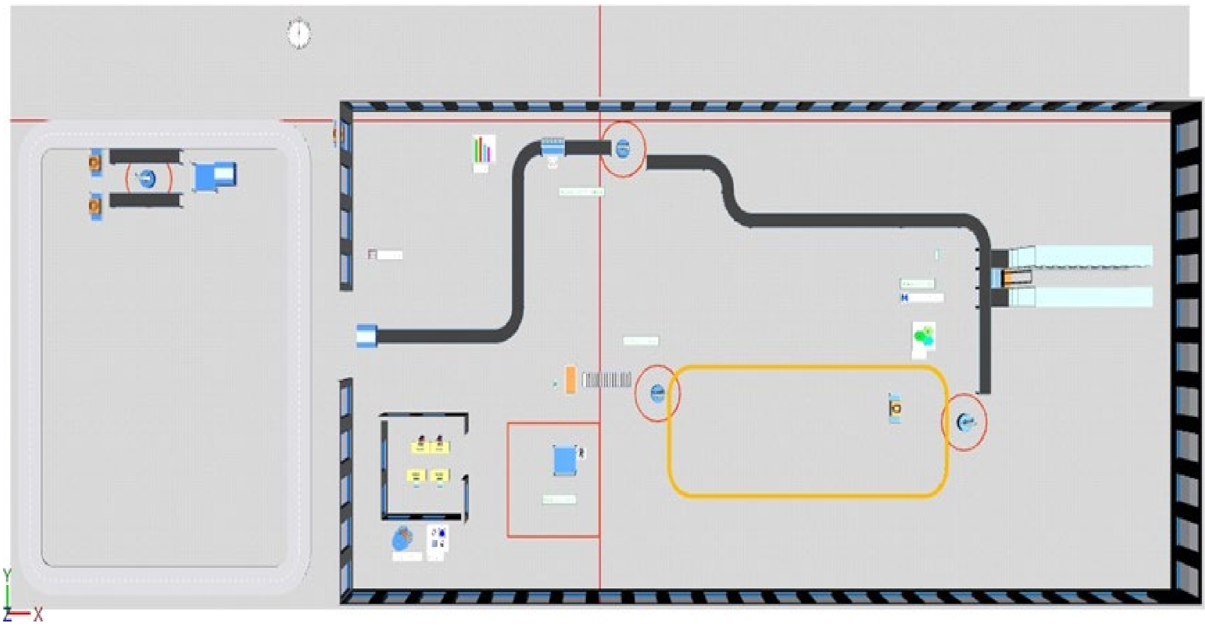

Figure 3: New proposed process flow of warehouse layout using STPSS.

The outcomes of the simulation run using STPSS provided a comprehensive and detailed summary of the enhanced process flow layout. The simulation results meticulously illustrated the improvements in the overall layout, offering a thorough examination of the refined processes. This analysis allowed for a detailed understanding of how the modified layout positively influenced the flow of operations, showcasing the effectiveness of the implemented changes.

3.5 Comparison of Current Process Flow and Proposed New Process Flow

Based on the present process flow structure, the researcher devised a new process flow layout to optimize the process and eliminate waste. Figure 4 shows the present process layout as well as the proposed replacement process layout. The findings and insights from this comparison are shown in Table 3, which provides a comprehensive overview by combining both the current process flow and the proposed new process flow. This comparison serves as a valuable reference point, allowing for a thorough evaluation of the improvements made and their impact on the overall efficiency of the process.

Table 3: Comparison before and after improvement.

No	Process	Current Process Lead Time (s)	New Proposed Process Lead Time (s)	Average Reduction (%)
1	Transfer Station Process	420	379	9.76
2	Physical Check Process	267	150	43.82
3	Segregation Area	852	554	34.98
4	Transfer to the warehouse Process	330	180	45.45
5	Pick the part for the production Process	1474	727	50.68
	Total	3343	1990	36.938

The findings from this comparison are shown in Figure 4, which provides a comprehensive overview by combining both the current process flow and the new proposed process flow. This comparison serves as a valuable reference point, allowing for a thorough evaluation of the improvements made and their impact on the overall efficiency of the process. Based on the present process flow structure, the researcher devised a new process flow layout to optimize the process and eliminate waste. Figure 4 shows the present process layout as well as the proposed replacement process layout.

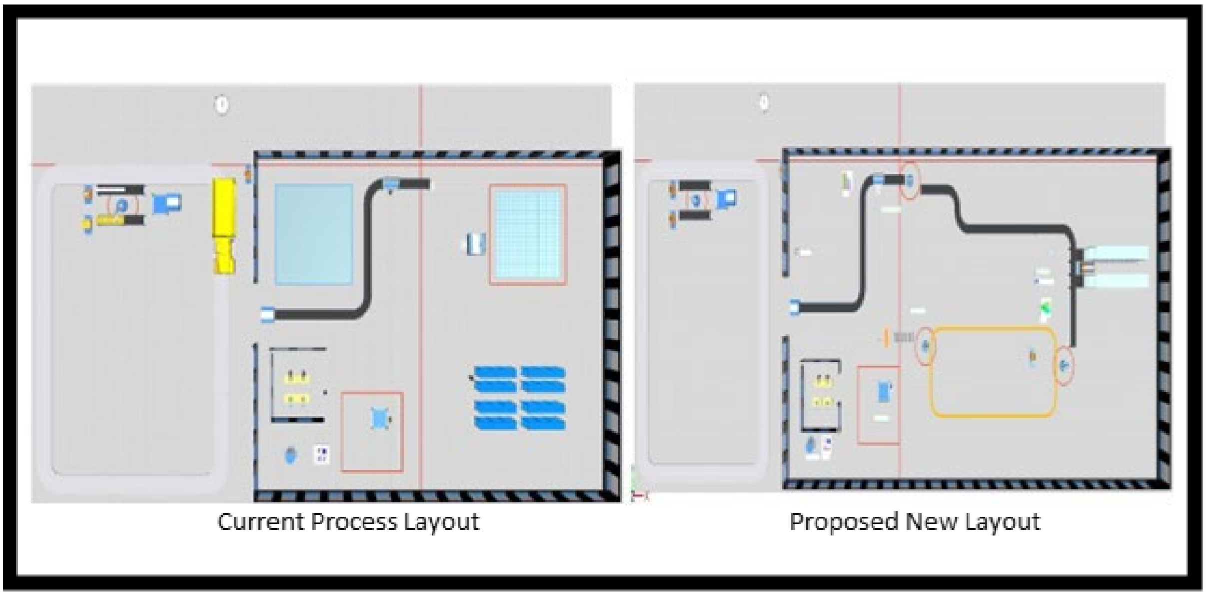

Figure 4: Comparison of the current process layout and the new proposed layout.

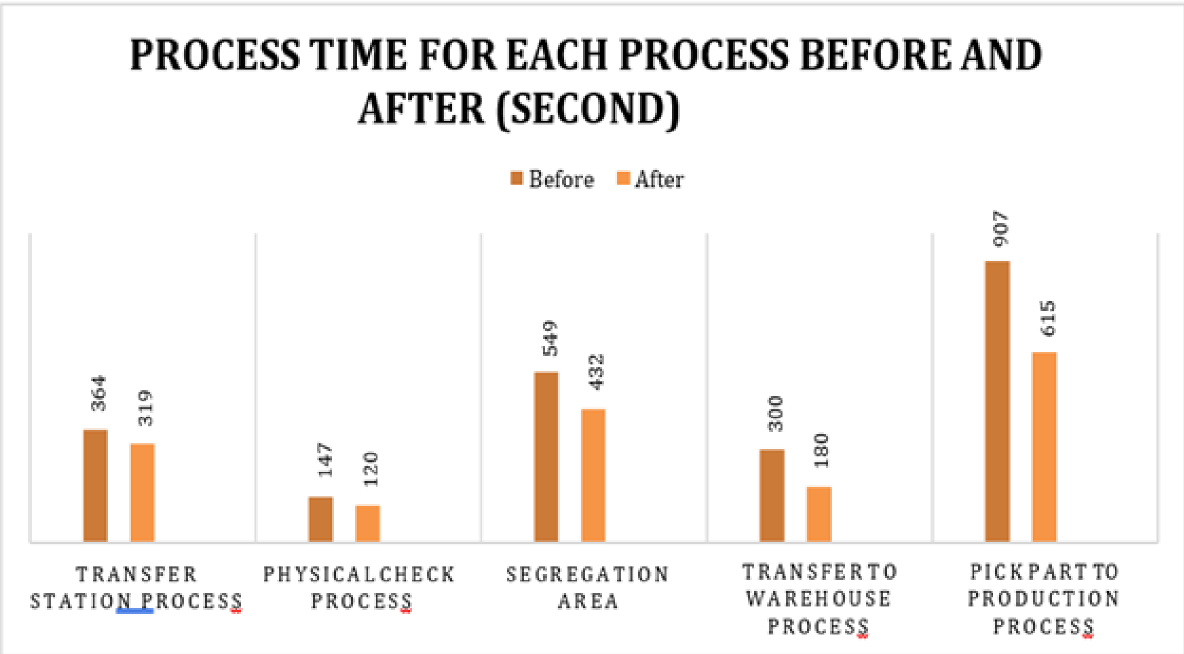

Figure 5: Processing time for each process before and after.

Figure 5 illustrates the processing time for each process before and after the simulation. By using Tecnomatix Plant Simulation Software, changes can be implemented to observe outcomes before actual application within a company's processes.

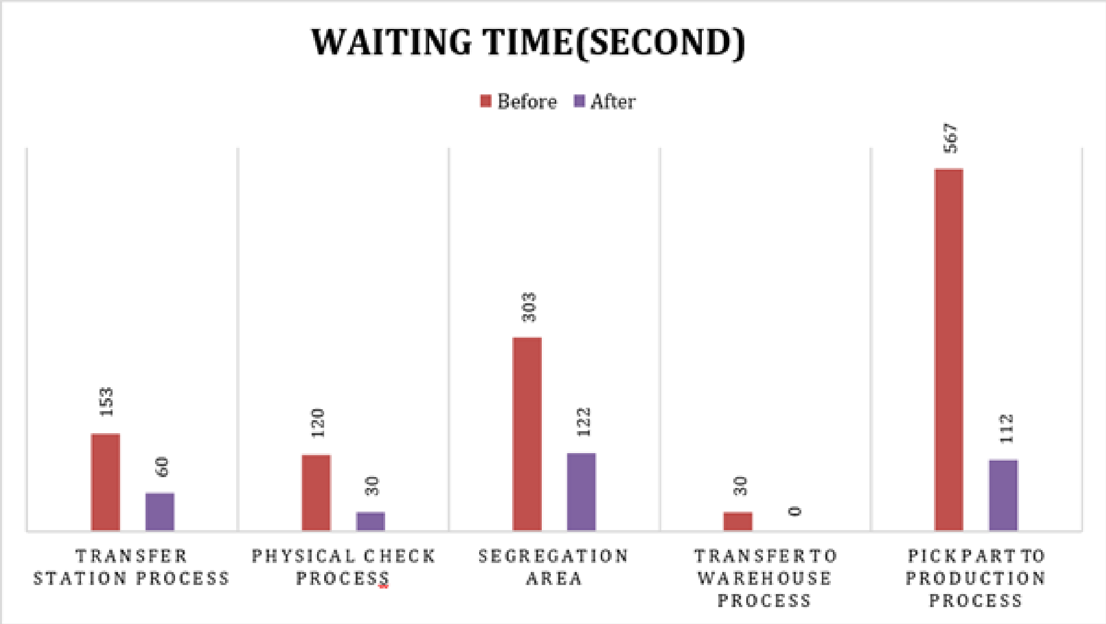

Figure 6: Waiting time for each process.

Figure 6 shows the waiting time for each process during the receiving process. Within the context of a process or system, waiting time refers to the amount of time that an entity, object, or task experiences a delay or is inactive before moving to the next step. This temporal interval can appear in a variety of settings, such as industrial procedures in which a product or component is awaiting transportation between stages of production. Referring to Table 3, the average total waiting time reduction is 36.93% of the total lead time.

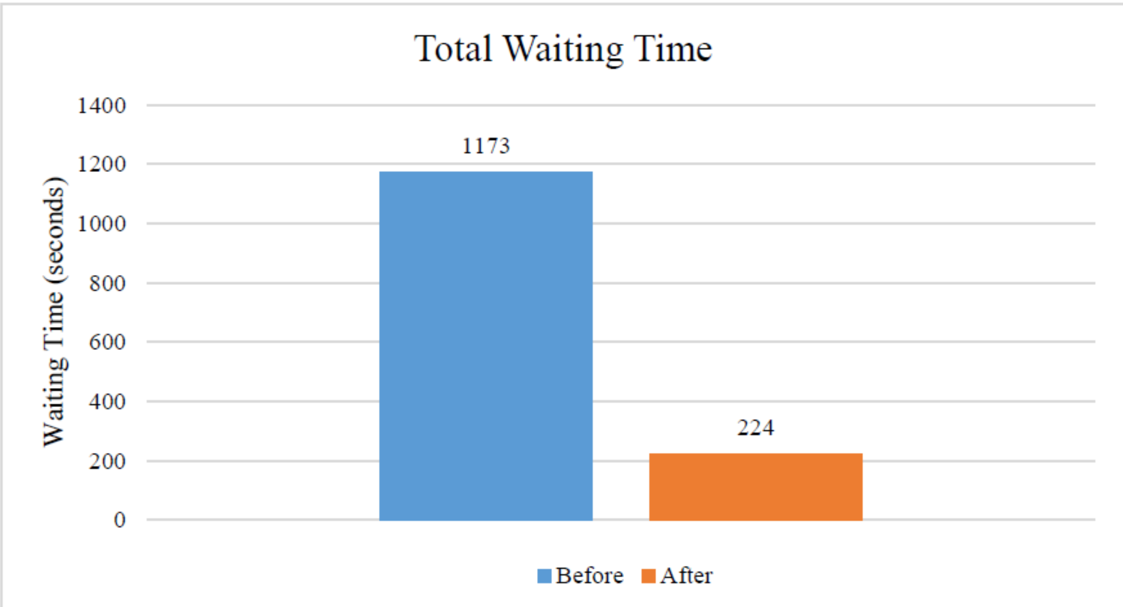

Figure 7: Total waiting time for the overall process.

Figure 7 shows the total waiting time of the production process. The current total waiting time is 1173 (seconds), and the new total waiting time is 224 (seconds). The total waiting time is decreased by 949 (seconds), which is 36.93%. The substantial reduction in waiting time can be attributed to the cumulative effect of improvements made across various processes. While the specific details of the changes are not provided, the extent of the improvement suggests comprehensive enhancements, potentially involving automation, process optimization, and efficient utilization of resources.

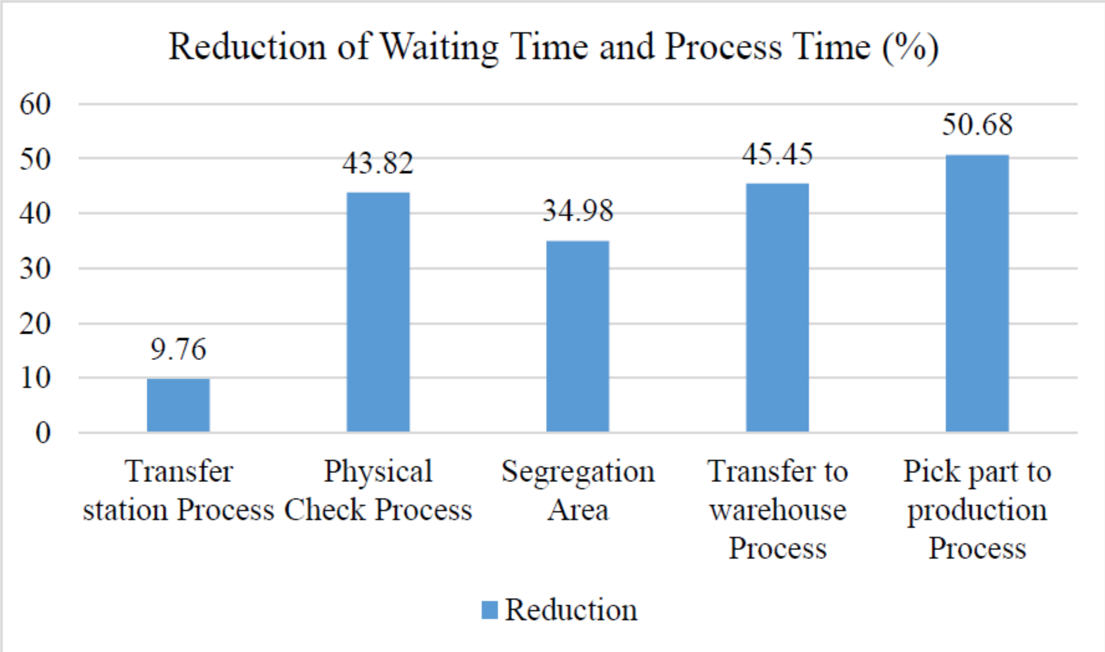

Figure 8: Total reduction of waiting time and process time (%).

The successful reduction of 36.93% in total waiting time, as shown in Figure 8, indicates a systemic improvement in operational efficiency. The changes implemented appear to address bottlenecks, streamline workflows, and minimize idle time across different stages of the processes. It's noteworthy that individual improvements in waiting times for specific processes, as discussed in earlier figures, may collectively contribute to this overall reduction. The integration of automated systems, the use of Kanban systems, and the deployment of conveyors and transporters, as seen in previous elaborations, could be part of the broader strategy leading to this substantial improvement in total waiting time.

3.6 Simulation model improvement and validation

Figure 9 demonstrates the outcomes of the simulation run using Tecnomatix Plant Simulation software, which provides a comprehensive and detailed summary of the enhanced process flow layout. The simulation results meticulously illustrated the improvements in the overall layout, offering a thorough examination of the refined processes. This analysis allowed for a detailed understanding of how the modified layout positively influenced the flow of operations, showcasing the effectiveness of the implemented changes.

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Conveyor1	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor2	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor3	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Source2	0.00%	0.00%	21.83%	78.17%	0.00%	0.00%	0.00%	0.00%	0.00%	
PickAndPlace2	4.29%	0.00%	95.71%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor4	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
ToProduction	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Track	2.92%	0.00%	97.08%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
TwoLaneTrack	1.27%	0.00%	98.73%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Source3	0.00%	0.00%	98.96%	1.04%	0.00%	0.00%	0.00%	0.00%	0.00%	
TransferStation	0.45%	0.00%	99.55%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Buffer	0.00%	0.00%	12.10%	87.90%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor5	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor6	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
PickAndPlace3	20.35%	0.00%	79.65%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Source4	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Source5	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
TransferStation1	98.14%	0.00%	1.86%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor7	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Inspection	48.57%	0.00%	43.42%	0.00%	0.00%	8.00%	0.00%	0.00%	0.00%	
PickAndPlace4	2.43%	0.00%	97.25%	0.32%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor8	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor10	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor11	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
TwoLaneTrack1	5.06%	0.00%	94.94%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Buffer1	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
PickAndPlace	3.56%	0.00%	96.44%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 9: Overall result of Tecnomatix plant simulation software.

4. CONCLUSION

The study's comparisons of the firm's present and projected waiting times allowed informative conversations, resulting in clear conclusions and practical suggestions for a manufacturing company in Johor. The study of the data revealed inefficiencies, notably in transportation, waiting, and movements inside the receiving area, underlining the existence of waste. To solve these issues, this research suggested redesigning the receiving process flow using lean management concepts. This strategic use of lean management appears as a feasible strategy for reducing or eliminating recognized waste, hence improving the overall efficacy of the receiving process each cycle. The research not only identifies current problems but also provides a realistic path for the studied company to optimize its receiving area and apply lean warehousing concepts for long-term process improvement. In total, there is a 30.93% reduction in total lead time for the production process in the particular studied company.

ACKNOWLEDGEMENTS

The authors would like to extend our sincere gratitude to Universiti Tun Hussein Onn Malaysia and the studied manufacturing company for their support of this study. Also, to those who made direct or indirect contributions.

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Conflict of interest statement: The authors declare no conflict of interest.

Author contributions statement: Conceptualization, Ahmad Nur Aizat Ahmad & Md Fauzi Ahmad; Methodology, Mohd Ali Selimin & Lee Tee Chuan; Software, Mohd Kamarul Irwan Abdul Rahim & Ahmad Zaki Mohmad Amin; Formal Analysis, Lee Tee Chuan & Mustaqqim Abdul Rahim; Investigation, Ahmad A.N.A & M A Selimin; Writing & Editing, Ahmad Nur Aizat Ahmad & Md Fauzi Ahmad.