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Enhancing Assembly Line Balancing Performance Using Simulation-Based Approach to Promote Sustainable Business Within Manufacturing

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Abstract

This research examines the integration of Lean Manufacturing (LM) principles with simulation-based methods to enhance line balancing (LB) within the automotive industry. It underscores the growing need for efficient and cost-effective production systems in response to intensifying global bisness competition. By employing simulation techniques, the research seeks to overcome the limitations of traditional line balancing approaches and broaden their applicability, particularly in sectors such as garment manufacturing. The findings emphasize the pivotal role of LM in elevating operational performance, identifying Lean principles as key enablers of improved customer satisfaction, reduced operational costs, and increased productivity. The primary objective of this research is to utilize simulation tools and LB methodologies as core LM instruments to address production system challenges. Through a suggested methodological framework, the project seeks to reduce bottlenecks, facilitate more informed decision-making, and systematically collect performance data through simulation. The scope includes using line balance and simulation to increase productivity up to 10.% and grow the business among automakers.

Keywords: Lean Manufacturing, Simulation, Line Balancing, Sustainable Bisness Strategies

Introduction

Lean Manufacturing (LM) is a systematic approach that is used in manufacturing organizations that competitive advantage in the global bisness (Deshmukh et al. 2010 ; Maware et al. 2022). According to Susanty et al.,(2022), the Japanese Toyota Motor Company pioneered his LM concept in the 1950s, which came to be known as the Toyota Production System (TPS) (Susanty et al. 2022). A primary goal of TPS was to reduce waste and non-value-added activities (NVA) to reduce costs and increase production. This is one of the business strategies Toyota adopted to compete in market sales. Over the past two decades, manufacturing companies operating in fast-changing and competitive markets have adopted the principles of LM thinking. In recent years, there has been an increasing interest in applying LM principles to service industries. According to the LM principle, waste is defined as everything that does not bring value to the willingness of customers to pay for it (Sanders et al. 2016 ; Womack & Jones 1996). LM seeks to generate the same amount of output with fewer inputs, such as less time, space, human labour, machinery, material, and cost (Dixit et al. 2015). LM is categorization through three distinct lenses: (1) philosophy, (2) principles, and (3) tools and procedures as shown in Figure 1.

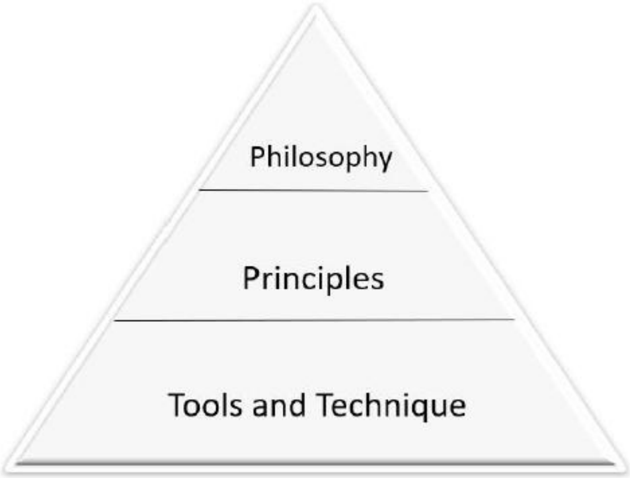
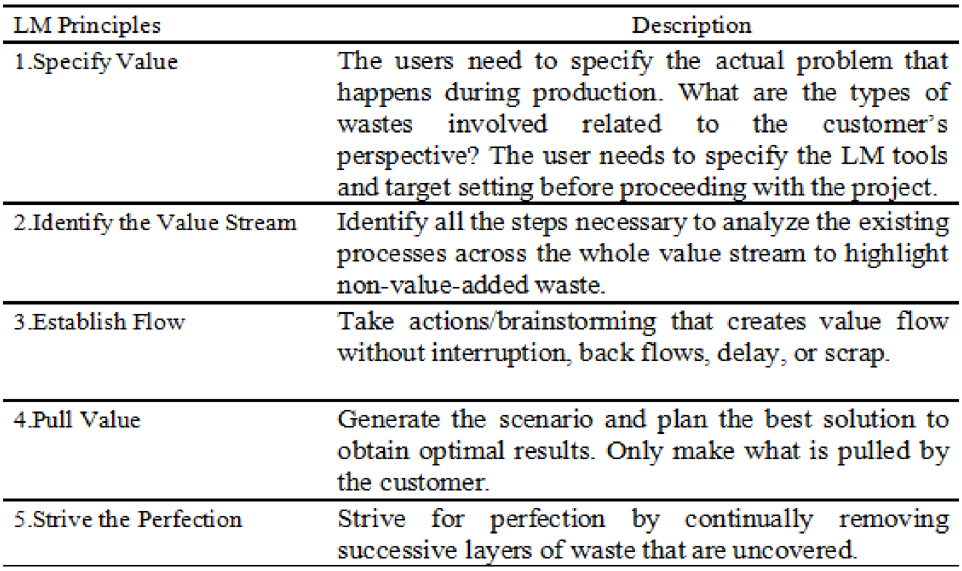


Figure 1 : Categorization of LM in Production

LM principles are considered in designing the simulation process flow. The guidelines of how the Five LM principles, namely 1) specify value, 2) identify the value stream, 3) establish flow, 4) pull value, and 5) strive perfection merged with the simulation process flow is presented in Table 1 (Kilpatrick 2003).

Table 1
LM Principles



LM Principles	Description
1.Specify Value	The users need to specify the actual problem that happens during production. What are the types of wastes involved related to the customer's perspective? The user needs to specify the LM tools and target setting before proceeding with the project.
2.Identify the Value Stream	Identify all the steps necessary to analyze the existing processes across the whole value stream to highlight non-value-added waste.
3.Establish Flow	Take actions/brainstorming that creates value flow without interruption, back flows, delay, or scrap.
4.Pull Value	Generate the scenario and plan the best solution to obtain optimal results. Only make what is pulled by the customer.
5.Strive the Perfection	Strive for perfection by continually removing successive layers of waste that are uncovered.

According to a study by Radnor (2016), lean thinking can be applied also to service industries such as healthcare, banking, and government to improve efficiency and reduce waste. Lean implementation in service industries comes with special challenges of the need for more flexibility and the difficulty of measuring performance (Gupta et al. 2016). Another area of interest in LM research is the use of technology to support lean initiatives. A study by Kusi-Sarpong et al. (2018) found that the use of digital technologies such as sensors and analytics can help companies monitor production processes in real time and identify opportunities for improvement. Therefor LM coupled with Industry 4.0 is believed to accelerate the bisness strategies (Nascimento et al.2019; Mofolasayo et al. 2022). In this fiercely competitive global market, manufacturers are finding it difficult to compete. Many businesses are looking for creative ways to boost the productivity and quality of their suppliers. Productivity development is always a top priority in business since it has a direct impact on a company's earnings. Total production costs are lowered when the LM technique is deployed to the manufacturing line.

The research is being carried out at automotive manufacturing plan. A few issues with the production system were found. Firstly, there is no standard time observation to validate the cycle time. The work station layout is fragmented and convoluted. However, the cycle time observation at kitting process station were not properly captured and the processing time for the kitting process takes more time consumption to split the parts into 30 set per to proceed for the next process in production line. The prior process cannot be finished when the workforce is idle or operating slowly. Next, another problem were revealed during the conversation at the company which is, there is there is no any simulation model for the manufacturing line that measures cycle time, process flow and efficiency. This corporation seeks to improve its manufacturing line using a new technique for dealing with product volatility. Line Balancing and Simulation is essential to analyse the LM waste in the production line to ensure the customer satisfaction and also to ensure the smooth process flow in the production line. By integrating simulation with line balancing as a Lean Manufacturing tool, this research demonstrates a practical and effective approach for evaluating alternative production scenarios, improving productivity, and enhancing the overall sustainability of manufacturing operations.

Therefore, this study aims to enhance assembly line balancing performance through a simulation-based Lean Manufacturing approach within an automotive manufacturing environment. By addressing real production constraints and validating improvements through simulation, the research contributes practical insights for improving operational efficiency, supporting sustainable business strategies, and strengthening competitiveness in modern manufacturing industries.

Case Study

Production Line 1 operates with two concurrent lines dedicated to assembling Frame Comp Rear RH and Frame Comp Rear LH. Each line is staffed by four operators, with an additional operator responsible for building and inspecting tasks at the inspection station. In contrast, both sides are served by five spot welding robots operating simultaneously. Operators 1, 2, 3, 4, 5, and 6 handle the loading and unloading of child parts from the jig after the spot welding process performed by the robots. Operators 1 and 2 manage workstations one and two, Operators 3 and 4 handle workstation 3, and Operators 5 and 6 operate workstation 4. Upon unloading from workstation 5, manual inspection is conducted by operators 7 and 8 at each quality control inspection gate.

Spot welding robots follow based on first-come, first-served system, with the initial station completing the loading of child parts initiating the welding process. The robot is triggered by the operator pressing the green button to commence the next task. For instance, Robot 1 weld the child parts S01, S02, S03, and S04 at workstation one, while Robot 2 weld the child parts S05 and S06 at workstation 2 by using CO2 MIG welding. Meanwhile, Robot 3 handles child parts A10 and A20 at workstation 3, and Robot 4 welds the child parts position A30 at workstation four. Robot 5 manages child parts A40 and A50 at workstation five without requiring manpower.

Figure 1 illustrates the layout of the existing production line model 3M in production 4. The Frame Comp Rear RH comprises 27 child parts sourced from 5 workstations (W1, W2, W3, W4, W5), including the QC Inspection station, and assembled using a spot-welding robot. Appendix D provides details on the child parts at each workstation for the Frame Comp Rear RH. Similarly, the Frame Comp Rear LH consists of 27 child parts obtained from 8 workstations (W1, W2, W3, W4, W5, W6, W7, W8) and the QC Inspection station, with assembly facilitated by a spot-welding robot.

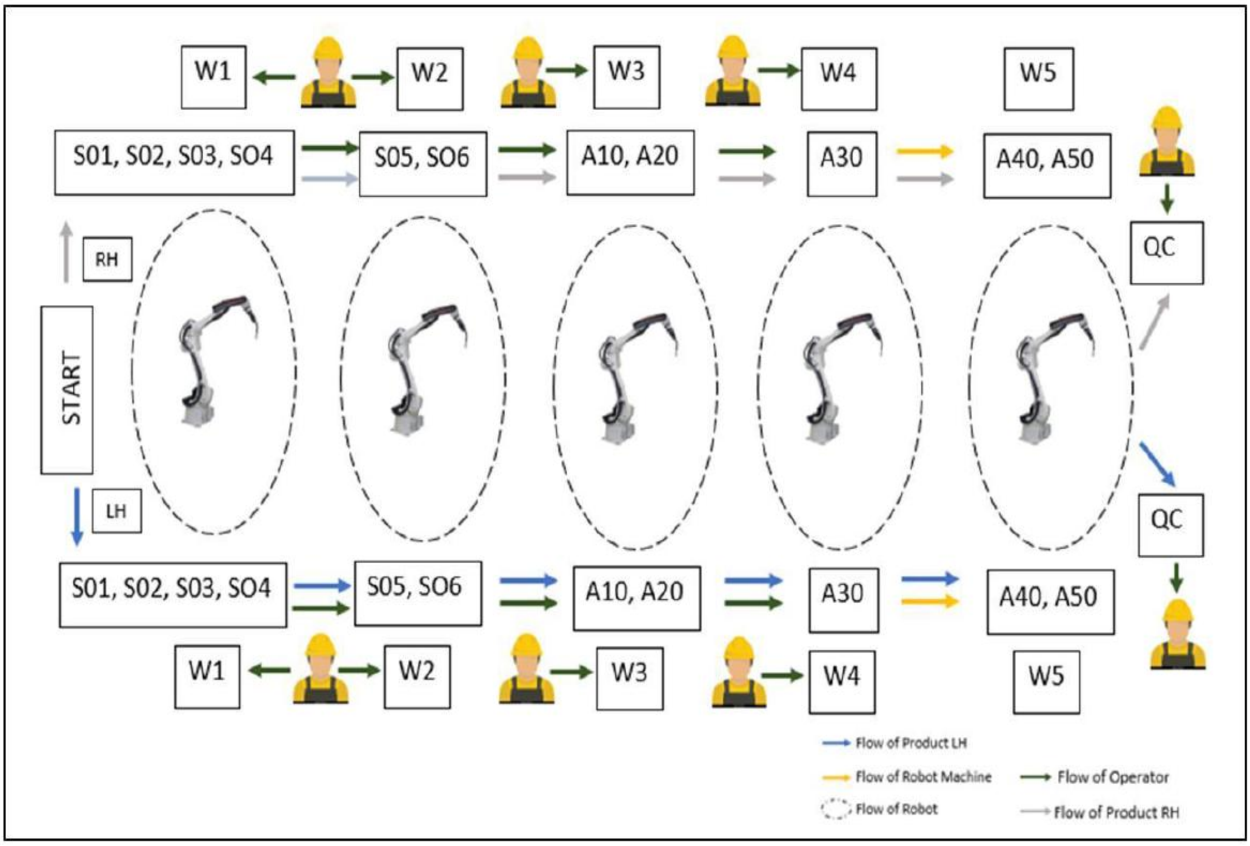


Figure 1 : Production Line 1

Methodology

Improvements were guided by the integration of LM principles. As shown in Figure 1, the process flow comprised data collecting, modelling, scenario testing, and analysis to find and suggest productivity improvements.

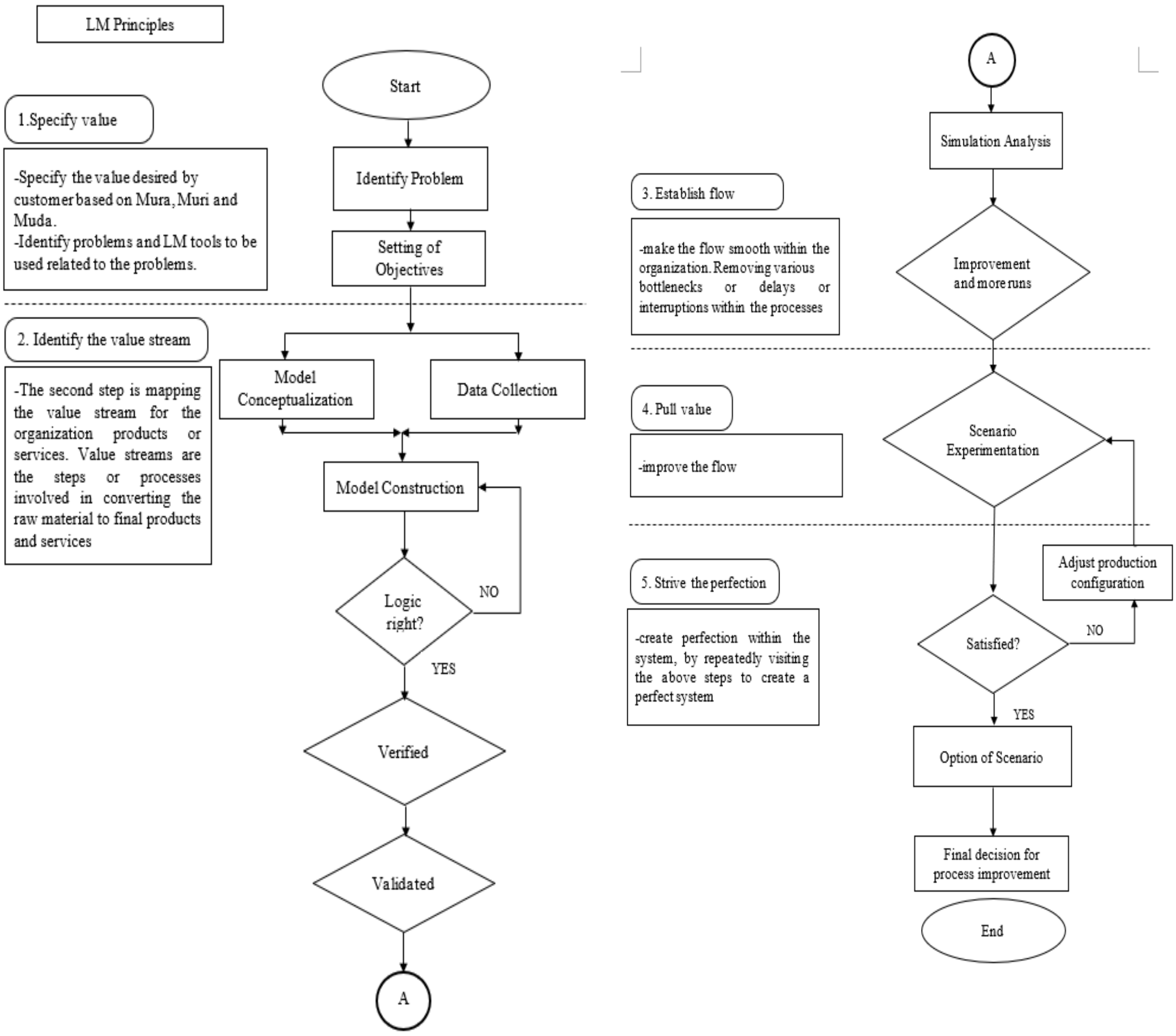


Figure 2 : Simulation process flow with LM Principles

LB is a technique used in production and manufacturing to optimize the efficiency of assembly lines by ensuring that the workload is evenly distributed among workstations (Rasib et al. 2025). The aim of this research is to minimize idle time, reduce bottlenecks, and provide a smooth workflow. An effective approach to analyzing and improving line conditioning is using simulation models. A simulation program, provides a robust platform for generating and testing assembly line models. This methodology's goal is to present line balancing using a simulation model. To attain the best possible balance and efficiency, understand the essential procedures in assembly line design, simulation, and analysis. Simulation approaches and builds a virtual model of the assembly line, mimic the manufacturing process, and collect vital data for performance evaluation.

The methodology employed in this research focuses on the utilization of line balancing, a technique crucial in production and manufacturing, to optimize assembly line efficiency by ensuring an even distribution of workload across workstations. The primary objectives are to minimize idle time, alleviate bottlenecks, and establish a seamless workflow. A key component of this methodology involves the use of simulation models, serving as a powerful platform for creating and evaluating assembly line models. The purpose of this methodology is to introduce the process of line balancing using simulation model, encompassing the key steps in assembly line design, simulation, and analysis to achieve optimal balance and efficiency. Through the simulation, a virtual representation of the assembly line is created, allowing for the simulation of the production process and the collection of valuable data for performance evaluation. This methodology forms the backbone of the research, providing a systematic approach to analyzing and improving line conditioning in the context of manufacturing and production. The simulation model for existing production line designed based on 95% similarity of the actual layout to make sure that the model used for improvement provides accurate data (Pajo 2022). The simulation model was proposed to tackle the bottlenecks in existing production line as Figure 3.

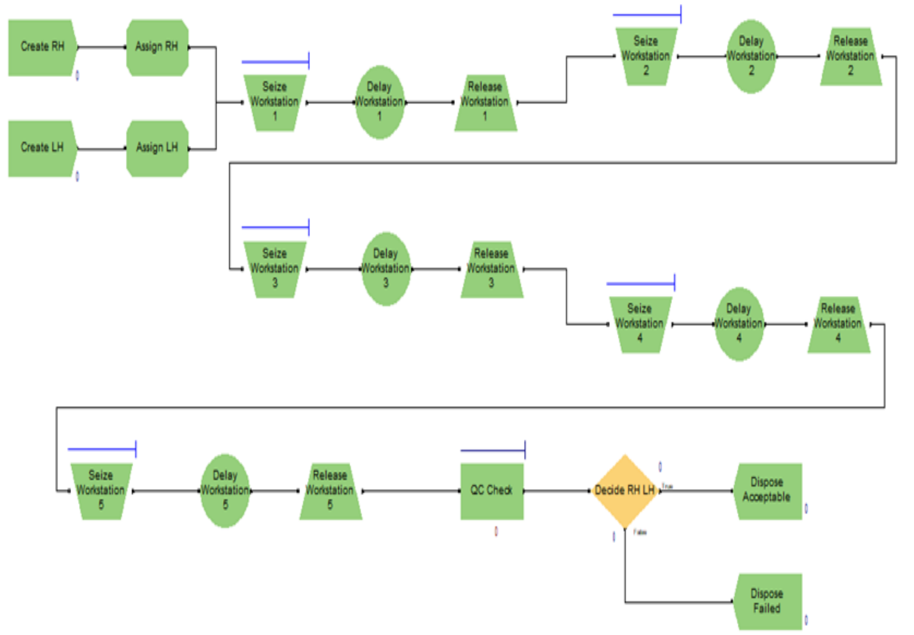


Figure 3 : Simulation Model of Existing Production Line 1

Results and Discussion

Solve Line Balancing Problem

First and foremost, the data collection, to enhance efficiency using simulation, crucial data points such as workstation details, the number of operators, process flow, standard time, process cycle time, operating hours, and customer demand will be gathered to calculate using Eq. (1), Eq. (2), Eq. (3), Eq. (4), and Eq. (5). The identification of the system's bottleneck will be a pivotal aspect, highlighting the operation with the longest cycle time. After the completion of data collection, the focus will shift to evaluating necessary improvements to streamline procedures. To boost the productivity of the production line, targeted methods will be implemented to address inefficiencies and optimize workflow dynamics. After the data collection, further steps involved conducting line balancing by attempting to create a simulation model using gathered data and if the results are accurate then, the study advances to the final steps of calculating the line balancing efficiency using Eq. (6). After the calculated data gathered, the bottlenecks in workstation is identify as illustrated in Figure 4.

Takt Time = $Total\ available\ working\ minutes\ per\ dayDaily\ Quantity\ Required$ (1)
Normal Time = Average time x Rating Factor (2)
Standard Time = Normal time x (1+ Allowance factor) (3)
Minimum Workstation = $Total\ Standard\ TimeTakt\ Time$ (4)
Productivity = $OutputSalary\ hour\ x\ number\ of\ workstation$ (5)
Line Balancing Efficiency = $Total\ Cycle\ TimeManpower\ X\ Takt\ Time$ x 100% (6)

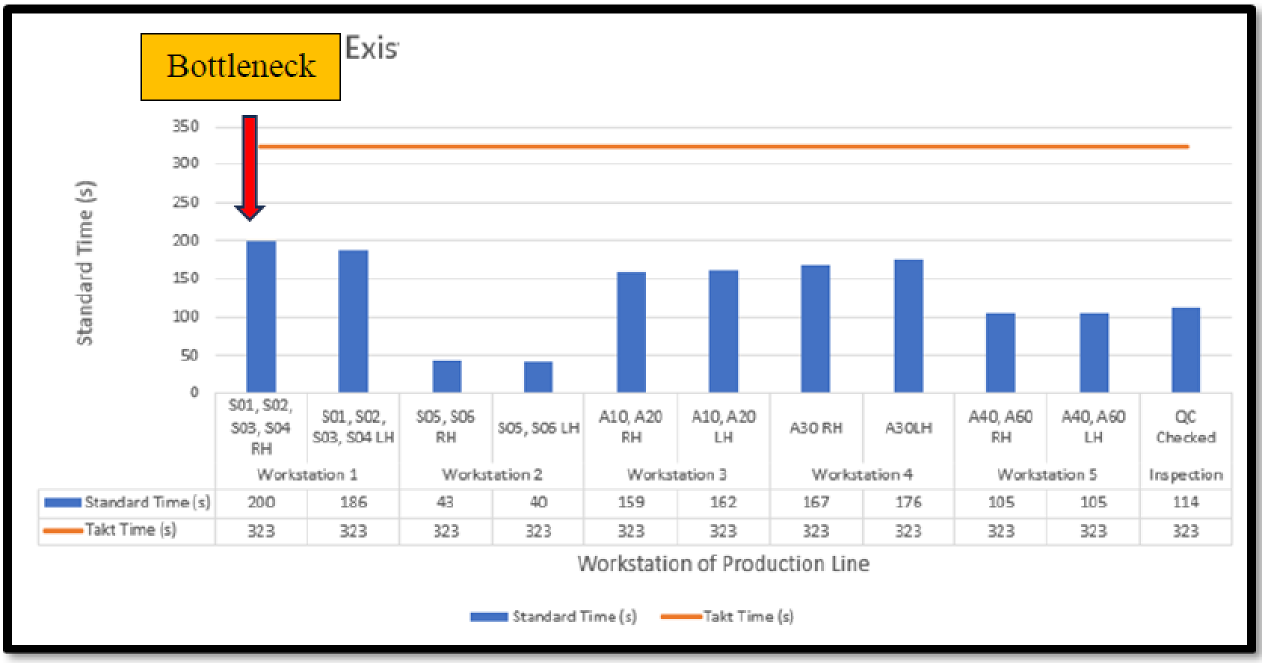


Figure 4 : Bottleneck in Existing Production Line 1

Using simulation, two suggestions for improvement were examined. The output from these simulation results was used to construct comparative data. When compared to other workstations, S05 and S06 RH LH have the shortest cycle times for improvement 1.The total number of workstations was reduced from five to four after it was consolidated. Figure 5 shows the new line balancing for improvement 1 , meanwhile the simulation model is show in Figure 6.

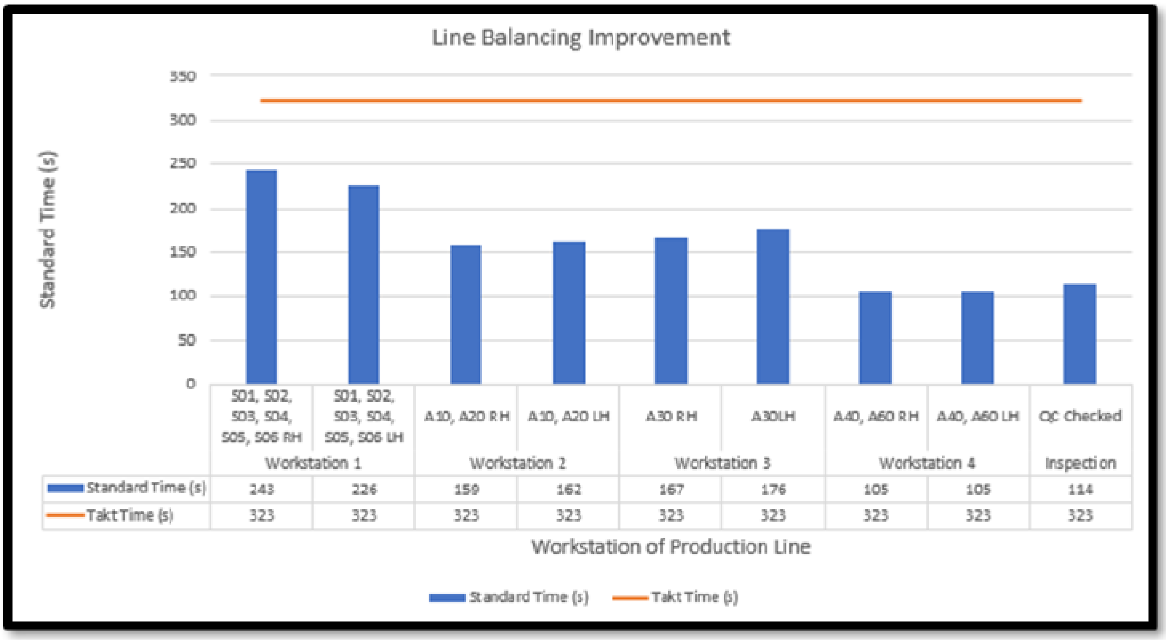


Figure 5 : Line Balancing for Improvement 1

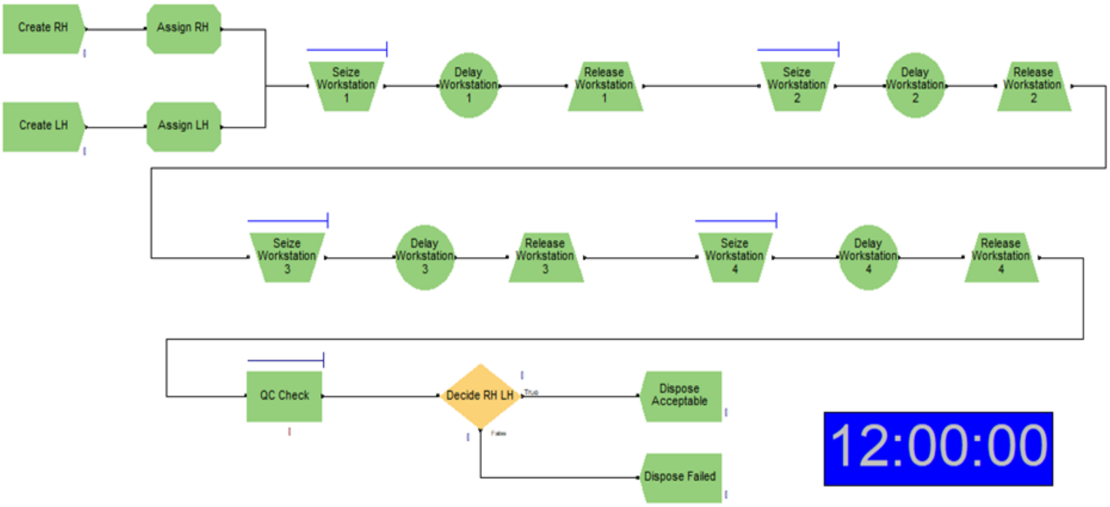


Figure 6 : Simulation Model for Improvement 1

In the meanwhile, Suggestion for Improvement 2 calls for moving the operators to workstation 2. On workstations 2 and 3, Operator 2 will take over and finish the suggested task. Figure 7 shows the new layout for Improvement 2.

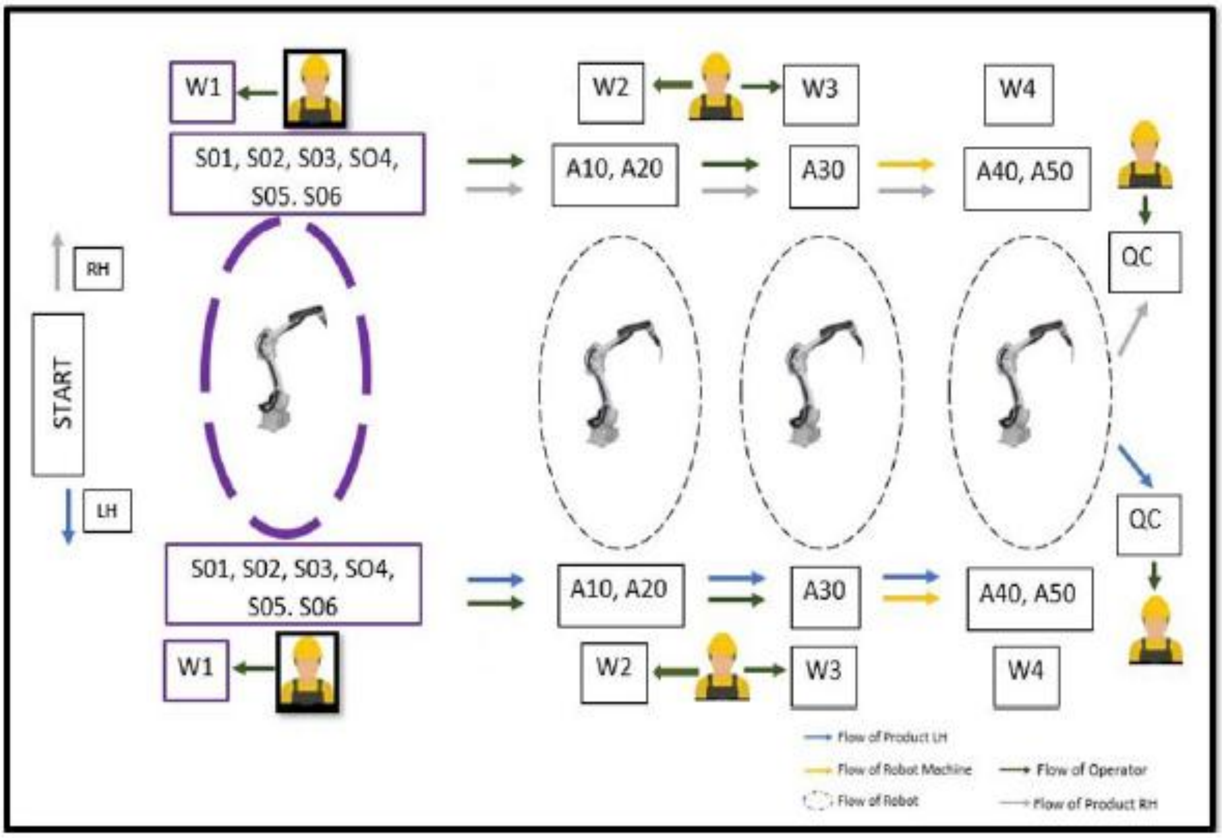


Figure 7 : New Layout Production Line After Change Operator Position (Improvement 2)

Comparison between the Actual and Improvement Output Rate

After reducing the number of workstations and changing operator positions, productivity increased by 10.8% and 3.33%, respectively. According to this study, the best solutions for attempting to deal with production line bottlenecks are simulation and line balancing. Since the percentage productivity of product manufacturing for first improvement is higher than the second option, the first improvement which was reducing the number of workstation is the suggested solution.

Table 2
Comparison between the actual and improvement output rate

Model	Productivity %	Efficiency %	Output	Productivity Cost (RM)	Decision- Making
Model 1 (Existing)	1	54.29	120	0.11 pcs	-
Model 2 (Improvement 1)	10.8	53.90	133	0.10 pcs	√
Model 3 (Improvement 2)	3.33	72.75	124	0.13 pcs	-

Improvement of Line Balancing Using Existing Simulation

They The data analysis reveals that the Model 3M production line comprises eleven stations. The histogram, serving as a diagnostic tool, illustrates the performance of the production line. Initial observations indicate that workstation two, encompassing stations S05 and S06 RH LH, exhibits the lowest cycle time among all workstations and stations. Consequently, in the pursuit of optimizing production line planning, it is proposed to focus on workstation two, specifically stations S05 and S06 RH LH. Figure 3 illustrates the production rate post-improvement. The graph highlights a reduction in the number of workstations from nine to five. Notably, workstation 1 (S01, S02, S03, S04, S05, S06 RH LH) now experiences an extended cycle time compared to other workstations, resulting in an imbalance. To address this, it is recommended to reduce the cycle time for workstation one, as depicted in Figure 4, showcasing line balancing post-improvement. The streamlined layout following enhanced line balance is illustrated in Figure 4. Moreover, a strategic suggestion involves modifying the operator arrangement. Initially, Operator 1 operates in workstation 2. The proposed adjustment entails Operator 2 taking over and completing tasks in both workstation 2 and workstation 3, as depicted in the revised layout of the manufacturing line post-operator repositioning. In summary, the proposed improvements involve optimizing cycle times at specific workstations, reducing the overall number of workstations, and strategically reassigning operators to enhance the efficiency of the Model 3M production line.

Conclusion

In conclusion, the meticulous planning process undertaken to achieve the set goals has proven successful in addressing the objectives outlined in this study. The researcher has gained a comprehensive understanding of the investigation, successfully resolving a challenge previously identified by another researcher. The study's methodology includes delineating the problem's scope and the complexity of the research. The recommended solution, comprising specific steps within the process, has been meticulously developed. The objectives related to reducing the bottleneck process, as informed by the gathered data, have been effectively realized. To validate the accuracy of the reported findings in this thesis, the simulation was conducted. The synergy of bottleneck analysis, line balancing, and the simulation played a pivotal role in the successful decision to enhance production line productivity.

In evaluating the best improvement decision, various factors such as production output, efficiency, and productivity percentage must be considered. The initial improvement, involving the reduction of workstations from 6 to 5, yielded a production output of 133 units per day. Conversely, the second improvement, which entailed changing the operator position from 8 to 6, resulted in a production output of 124 units per day. Based on this metric alone, the first improvement demonstrated a higher production output. However, the efficiency for the first improvement was calculated at 53.90%, while the second improvement achieved an efficiency of 72.75%. This indicates that the second improvement led to a 6 slightly higher efficiency in the manufacturing process. Furthermore, the productivity percentage for the first improvement was 10.8%, whereas for the second improvement, it was 3.33%. This substantial difference indicates that the first improvement resulted in a significantly higher increase in productivity compared to the second improvement. The analysis concludes that the first improvement, involving the reduction of workstations, is the superior choice in decision making. This is substantiated by the higher production output achieved with this improvement, coupled with the noteworthy increase in productivity compared to the second improvement. Despite the proximity of efficiency values for both improvements, the first improvement outperforms the second in terms of production output and overall productivity.

This study is significant as it addresses a critical industrial challenge—inefficient assembly line balancing—by integrating simulation techniques with Lean Manufacturing principles. The research is highly relevant to automotive manufacturing environments where productivity, cost efficiency, and sustainability are essential for competitiveness. The outcomes of this study directly benefit production engineers, manufacturing managers, and decision-makers by providing a practical simulation-based tool to evaluate and improve line performance. The practical implications include reduced bottlenecks, improved workflow balance, and enhanced productivity without physical trial-and-error on the shop floor, thereby supporting sustainable manufacturing practices.

Future Research

In order to produce more thorough performance insights, especially with regard to bottlenecks and workstation balancing, future research could expand this study by running the simulation model over a whole production day. Optimal workstation arrangements and the long-term effects of fewer workstations on overall productivity could be the subject of future research. Additionally, future studies might analyse the impact of enhancing equipment performance—such as raising the welding robot’s speed—on operator idle time and process efficiency. Decision-makers at the car manufacturing company would have more solid evidence to direct productivity increases if the model were expanded with real-time production data and various optimization tactics were tested.

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