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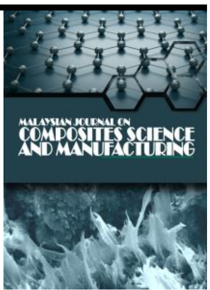

Work Standardization in Lean Manufacturing for Improvement of Production Line Performance in SME

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ABSTRACT

Lean manufacturing is a management philosophy and production system that provides all humanly conceived soft technology to remove waste in any production line. One of the requirements of lean is work standardization. Work standards impose a 'rule of law' in a production line by restricting operators to how long they should work on a single unit. The standards consist of the standard workflow, standard work time, and standard quantity that must be adhered to to meet the customers' demands. The main objectives of this study were to improve the performance of a production line, say SW660 x 600, in terms of weekly output, lead time, and work-in-process (WIP). By applying certain lean elements to the production line, this work indeed improved the performance of the production line. In this work, 5S, PDCA cycle, SPC, and VSM tools were used together to solve the production line problems systematically. It was noticed that the low weekly output and long cycle time at each workstation resulted in delays in the delivery of products to customers. The study managed to increase the weekly output from 61.75 per week to 128.75, an improvement of more than 108.50 percent. Next, in terms of lead time, with the help of a simulation exercise, this work also managed to reduce the lead time from 5 to 1 hour, a reduction of 80 percent. Lastly, the WIP also recorded a reduction from an average of 17 to 9 units weekly, which was an improvement of 47 percent on the weekly WIP. Therefore, this work showed that with the introduction of work standards on the production line, the organization could meet the customers' demands and deliver on time as promised. The study can also be used in other production lines of this and other organizations to help improve their production line performance in the long run.

1. Introduction

In this competitive world, most organizations are looking for a competitive edge over other organizations by introducing all sorts of improvement programs, as the ability of an organization to produce in time according to customers' demands is crucial to maintaining a good relationship with

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the customers. Lean production tries to align shop floor operations with the client's specific requirements, including reliable due dates, product quality, shorter lead times, and competitive prices [1]. Thus, it is essential to understand the cycle time of each workstation and carry out an improvement process to enhance the delivery time and operational process performance. Work standardization is the basic foundation of lean production. Standard work involves specifying standards for the production rate, the required inventory, and the sequence of the operator's actions [2]. The organization of the study, XYZ Manufacturing Company, produced aluminum windows (model SW660x600) in a make-to-order business environment according to their customer's specifications. They were facing difficulties in delivering their products on time to their customers, which they blamed on the low productivity in the production line, and this had been jeopardizing the relationship with their customers and causing monetary losses to the company. Therefore, this study was intended to conduct operational process improvement regarding the weekly output of SW660x600. This study applied the lean approach and statistical tools to investigate the existing problems. The root causes of the problems were identified, and the proposed solution, 'standard work, ' was studied to evaluate the changes it would bring to the production line. Standard work consists of a set of work procedures to establish the best method and sequence for each process and worker [3]. By solving the problem, this work would help the organization improve their weekly production and enhance their operational performance in terms of lead time, cycle time, and line efficiency. For production in the financial year 2020–21, the model SW660x600 was in high demand. However, they received complaints regarding on-time delivery and identified issues regarding the work-in-progress (WIP) and lead time. The production line of SW660x600 consists of nine workstations, from the 'testing and measurement' to the 'packaging' station. Accumulation of issues in the workstations leads to problems such as delayed delivery, low weekly productivity, long cycle time taken on the production line, and excessive usage of space for WIP.

The scope of this work has been centered on proposing a process improvement solution for the production line of SW660x600 after the root cause of the problems has been identified. The evaluation was derived from the simulation model, as the simulation model was able to quantify the changes made in the production line. The production line's performance will be reviewed in terms of weekly output, production efficiency, cycle time, and WIP. More specifically, the study's objectives were to increase the weekly output by 25 percent, reduce the lead time by 20 percent, and reduce the WIP by 20 percent.

2. Literature Review

Toyota has pioneered the concept of Toyota Production System (TPS), or lean manufacturing. The idea behind lean manufacturing is to eliminate waste. The goal of this management philosophy is to help improve the value stream in terms of efficiency and thus increase its ability to compete with other manufacturers. 'Lean' is defined as producing goods with minimal waste [4]. Lean manufacturing aims to produce end goods with minimal waste. Manufacturing activities can be grouped into two categories: value-adding activities (VAs) and non-value-adding activities (NVAs). Value-adding activities (VAs) refer to manufacturing activities that contribute value to the product's end value from the customer's perspective and non-value-adding activities (NVAs), which contribute nothing to the end value again from the perspective of the end users. This implies that some of the manufacturing activities in the production line have no value in the eyes of the customer, which can be deemed excessive processing that consumes the limited resources available. In other words, non-value-adding activities (NVAs) are producing waste.

Work standardization is the foundation of the Toyota Production System (TPS), as it is considered the most important technique of TPS and can be grouped into two types of standards in practice: managerial and operational [5]. The managerial standard was for managing administrative tasks such as company guidelines, working hours, etc. However, we were more interested in the operational standard, the second standard. This standard lays out the guidelines to complete the task best and safest. Work standardization was used in the Toyota Production System (TPS) to determine the best number of operators, machinery, and raw materials to provide their products. This standard seeks to maximize production productivity by eliminating non-value-adding activities (NVAs) and waste and defining the minimum level of WIP. Without operational standards, following up on the problems to ensure complete waste elimination is difficult.

With the standardization of the work, the production line will be at a steady pace, and continuous improvement on the production line can be made. It needs to include the task's time and sequence in the work standardization [6]. The data needed to draft the work standards were derived from work standard time studies and work measurement [7]. Work measurement is the time needed to complete a job; standard time is the total time for a qualified operator to do a certain task at a sustainable rate. The problem in a production line will be solved by first checking if the operators followed the standards [8]. Standardized work removes unnecessary motions and decreases variations in performance in the work steps, which leads to waste reduction, productivity enhancement, and ease of problem-solving [9].

Work standardization means joining the optimum machines, operators, materials, and operations level for a stable production line. Standardization is the act of setting, communicating, following, and improving existing standards. Standard work is the current best way to complete a task to the best outcome and quality possible. Strict standards must be followed by all operators involved in the work cell to ensure work standards are met. One of the standards is the flow of the operational processes involved in the work cell. This can be visualized by a standard work diagram [10]. The development of standards completes every improvement and change in the manufacturing process. Without standards, there is no improvement or management. The standards define best practices for implementing the work [11]. The combination of lean tools such as PDCA (Plan-Do-Check-Act), 5W2H (5Why's and 2How), and 5S (Seiri, Seiton, Seiso, Seiketsu, Shitsuke) can be implemented in view of standardization and continuous improvement, which adds critical value to the process. The results show a 10% increase in the useful available time [12].

Simulation has wide use in operation management. Simulation can generate statistics for operational process performances. Simulation models can manage inventory levels, lead times, and machine utility uncertainty. In this work, Rockwell Arena simulation software version 14 was used to quantify the changes in the production lines. Simulation has a huge application in operation management, ranging from simple to complex simulation models. Simulation, a descriptive tool, enables users to evaluate the behavior of the models under different constraints [13]. It is common in product design, facility layout, job design, etc. However, engineers are using simulation as a preferred approach as the optimizing technique does not answer more delicate questions regarding the changes. One should also remember that simulation is just a descriptive tool to provide answers to the system in question; therefore, it does not provide the solution to the problems.

Work standardization requires several tools of work methods and measurements, along with a change in personnel culture, to avoid implementation resistance. The assembly line of the case becomes more productive after using work standards to redesign the assembly process. This proved the efficiency and effectiveness of work standardization implementation [14]. By applying standard work, the variability in the processes could be reduced by eliminating the root causes of variability and permanently resolving the issue [15]. After finding out the root cause of not meeting customers' demand, value stream mapping (VSM) is used to identify the non-value-adding time and activities of the core process flow and to eliminate them through standardization-of-work (SW) procedures in a manufacturing company [16]. VSM enables the visualization, analysis, reduction, and complete waste elimination. This tool aims to enhance processes and eliminate or reduce operations that do not add value to the final product. For it to occur, the value stream mapping illustrating the current situation must be carried out, and afterwards, a future value stream mapping can be made [17]. PDCA (Plan, Do, Check and Act) is closely linked to planning, implementation, control, and improvement, thereby streamlining the relationship between the operator and the process based on efficient controls. It is emphasized that this methodology aids in executing tasks and is frequently used to determine improvement [18].

3. Methodology

During a lean production implementation at XYZ Manufacturing Company producing aluminum windows (model 660X600), the standard work tool was implemented following the action-research methodology as below:

(i) *Diagnosis:* We had the necessary visit (weekly) to study the production line. The window production line had nine (9) workstations. The current status of the company's production line was first analyzed, including the analysis of several documents, conversations with the workers, and video recordings of the assembly procedures. Some analysis and diagnosis tools were also used, such as a sequence diagram, a cause-and-effect diagram, value stream mapping, and a skills matrix. After this, some problems were identified, such as, for example, the lack of pre-defined work routines, the inexistence of a balanced work-in-process between workstations, etc.

(ii) *Planning for action:* An action plan was created using the 5W2H technique.

(iii) *Action taking:* The Standard Work tool was implemented with the creation of three distinct sheets: (a) the parts-production capacity worktable, (b) the standard operations combination chart, and (c) the standard operations chart. The study also developed a simulation model based on the existing production line.

(iv) *Evaluation:* The results obtained with the implementation of Standard Work were analyzed and discussed with the managers and workers involved in the study.

(v) *Learning specification:* Finally, standard work procedures were identified, and documentation was done.

However, the research methodology can also be expressed in Figure 1 as the framework for the study.

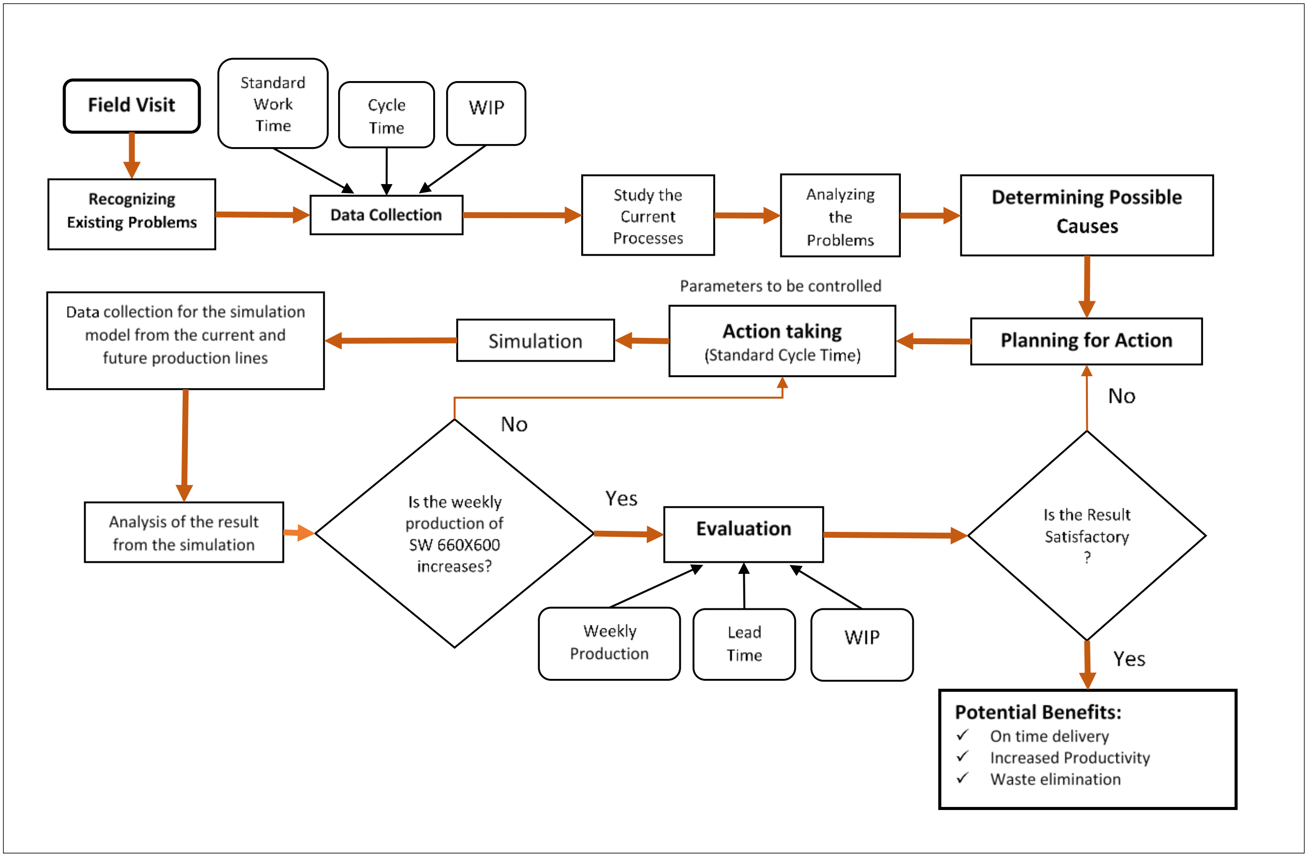


Fig. 1. Framework for the study

4. The Production System

Aluminum bars were retrieved from storage and sent to the production line. First, the aluminum bars were checked, tested, and measured to ensure that they were physically ready to be processed without any dents or anything below the desired standard. Ink tests were carried out to check the coating on the extruded bars. In addition to the ink test, the thickness of the coating was also measured to ensure the coating was well coated all along the bars and within the specification desired. Last, the bars were checked for their hardness using handheld Rockwell hardness testers.

The bars proceeded to the next station, a cutting station, where the bars were cut according to the required shape and length. Drilling took place after the cutting, followed by the insertion of the rubber strip. The cut bars were joined to form the main frame of the aluminum window. A tenon was inserted to hold the frame. Lastly, adhesive was applied to seal off the main frame.

This next section involved the construction of the sash section of the windows. Again, the bars were cut according to the desired dimensions. The sash was fixed with an enforcer to strengthen the structure. The sashes were merged with the help of adhesive. Before welding off the sash, the construction of the sash was checked for any irregularities in the joint or the structure. An air gun was blown on the sash to remove any residual dirt. The sash was welded after the above processes were done. However, Figure 2 shows the current process flow in the production of SW660x600.

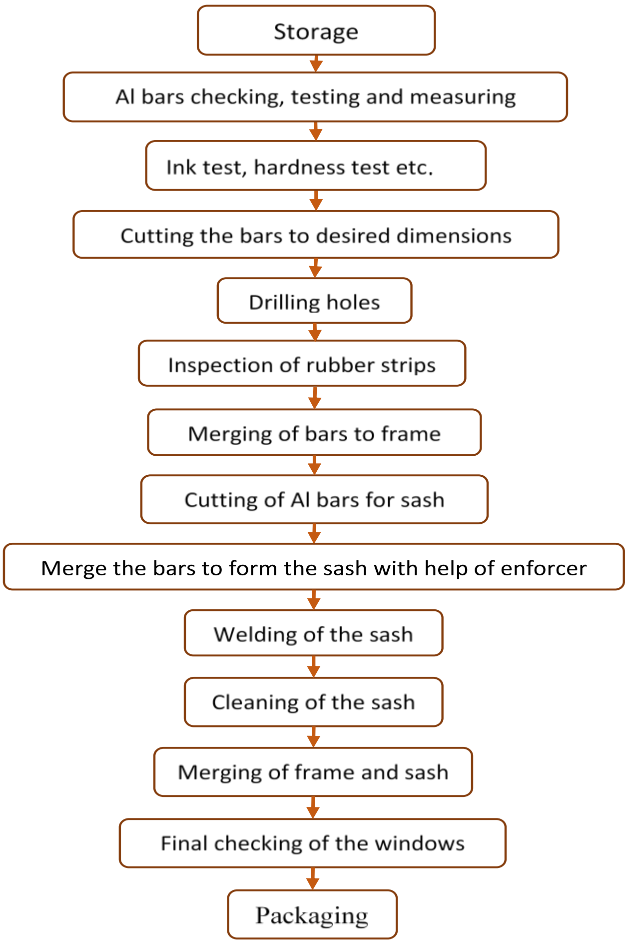


Fig. 2. The current process flow in the production of SW660x600

The frame and sash were merged, and a final inspection was made on the windows' dimensions, finishing, and any irregularities or imperfections. The final workstation on the production line was the packaging station. The windows were wrapped up to protect them from any damage while on the way to the customers.

To better understand the whole process, the following Figure 3 indicates the total workflow and workstations in the production line.

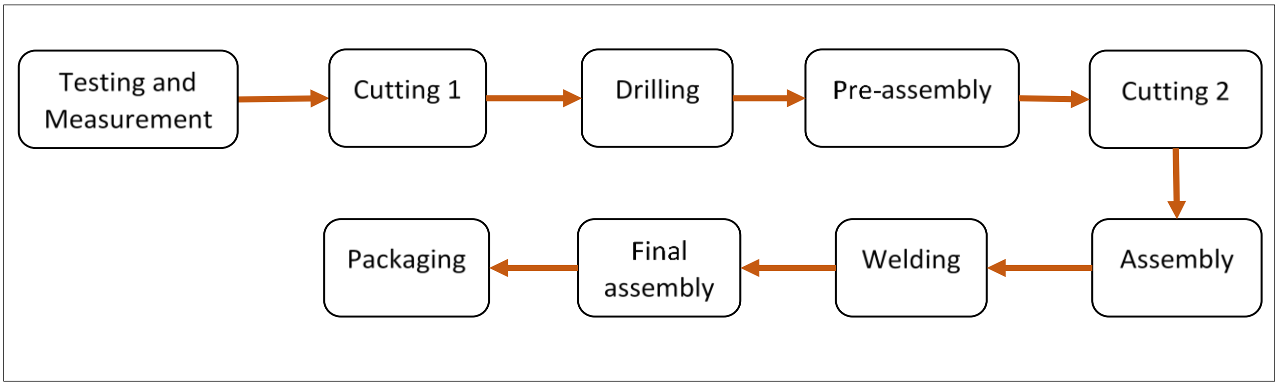


Fig. 3. The work flow and workstations in the production line

5. Standard Work Implementation

The workstations on the production line produced less than needed to match the customers' demands. Without any standards implemented in the production line, it was difficult to measure productivity performance. Therefore, the first thing before implementing any improvement process was that work standards must be well defined and understood by all the operators, including the administration staff. This standard would be the 'bible' related to the task at the workstation.

The management believes the productivity of the production line can be at a faster pace as most operators are well versed in tasks and lack discipline among the operators. Therefore, the senior operators experienced the 'BOHICA' syndrome during improvement initiatives. Thus, while developing the standard, the operators must be involved to ensure they have a sense of ownership of the standards they have developed. However, Figure 4 indicates the current state of the value stream mapping of the production line.

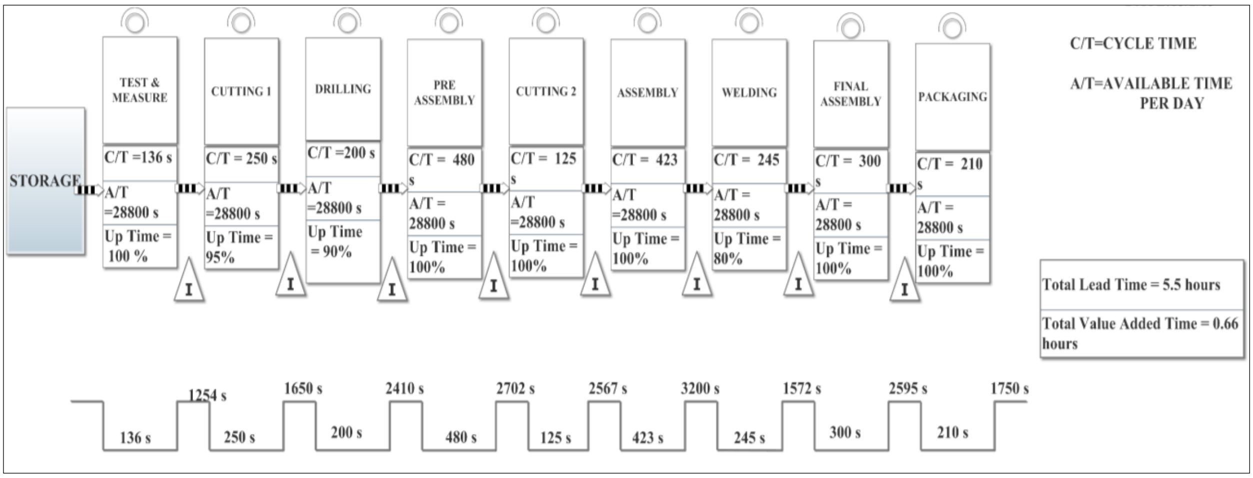


Fig. 4. Depicts the Value Stream Mapping (VSM) of the current production line

Certain steps were followed to implement standard work. Initially, efforts had been made to recognize the existing problems and the data collected. The existing process was studied, and problems were analyzed to determine the probable causes through root cause analysis. Ishikawa Diagram, an SPC tool for 'delay in workstation', 'low weekly output', and 'excess of WIP', was used to find out the relevant causes of the problems. 5S has been implemented to improve the overall workplace. Time and work studies were done, and PDCA was executed to determine the standard cycle time and necessary improvements.

Table 1 describes the solution proposed to management. The solutions encompassed the four elements in 'Pareto analysis': method, manpower, machines, and materials.

The standards developed were compared with the current activities on the production line. Any activities that fell below the standards were reviewed, and the changes were implemented as suggested by the standards. Therefore, the work standard and workflow diagrams were placed at each workstation to guide the operators and clear any doubts they had regarding the task.

The leaders must exert a strong sense of commitment to their operators to ensure they obey the standards. This standard promotes the best, safest, and most efficient task execution method. This standard will induce a steadier pace in the production line.

Table 1
Proposed Solutions

Element	Description
Method	1) Reducing the cycle time by proposing a better way of executing the task. 2) This 'new' way was developed with the help of the operators of the respective stations. 3) This new method would relieve the workers from overbending or overstretching, as it considers the operators' ergonomics. 4) This method laid out the process flow of materials and operators and clearly described how the task should be completed and how long it should take. 5) This new method would serve as a standard method. 6) Every task at each station had its own standard of process flow and method. 7) This standard consists of a standard workflow, a standard cycle time, and a standard quantity.
Manpower	1) The operators would be guided by those standards on how the task should be executed and how long it should take. 2) Since the operators were involved in developing the standard, this uprooted a sense of ownership towards it, which would oblige them to follow it.
Machine	1) As per the standard, the order of the machines used in each station was well recorded and shown.
Material	1) The WIP of each station would be organized and placed in the designated area. 2) The flow of material would follow the standard workflow.

As a result, operational performance was increased by reducing cycle time, lead time, and better weekly output. It had been identified that the delay in the production line was due to a lack of standardization in the work cell. There was no pacesetter for the operators to follow, and eventually, there was no consistency in the weekly output, leading to a delay in delivery to the customers. Operators would be accustomed to their willful way of completing their tasks without this standard. Collectively, this would result in a delay in delivering to their customers. The proposed standard cycle time would guide completing a piece of product at each workstation. The operators buckled up their pace to match the standard cycle time. One should remember that the cycle time was the pace at which the operators were comfortable executing the task. Finally, the future state production line's value stream mapping (VSM) was done, as shown in Figure 5.

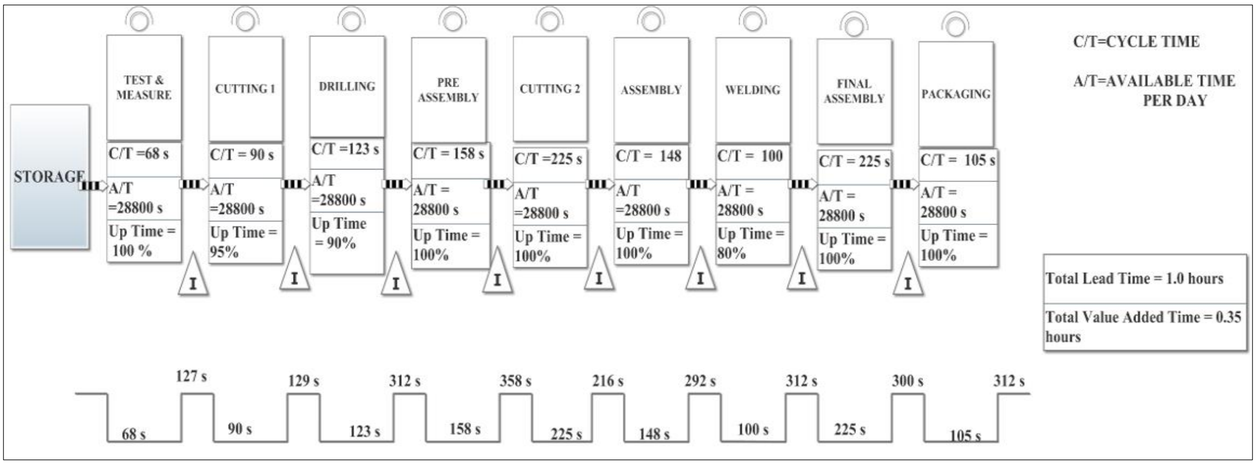


Fig. 5. Depicts the value stream mapping (VSM) of the future state production line

Five readings were taken for one operator to complete each task from the initial station, cutting, to packaging. The maximum and minimum values were eliminated, and the rest of the three readings were made average to become standard work time. This was done before, and improvements to the operation have been made. Table 2 shows the standard work time before and after the new standard work time. All the processes show an improvement in their standard time, apart from Station Cutting 2.

Table 2
Standard Work Time

Station	Testing and Measurement (1)	Cutting 1 (2)	Drilling (3)
Before (s)	136	250	200
After (s)	68	90	123
Station	Pre-Assembly (4)	Cutting 2 (5)	Assembly (6)
Before (s)	480	125	423
After (s)	158	225	148
Station	Welding (7)	Final Assembly (8)	Packaging (9)
Before (s)	245	300	210
After (s)	100	225	105

Most stations recorded improvements in the standard work time as a better way to complete the task had been drafted. With this standard, operators worked steadily to work within the standard time, not too fast or slow.

However, Station Cutting 2 had a longer standard time to relieve the operators from working in non-ergonomic conditions. A better way to complete the task without overbending or overstretching the body is to ensure a more productive operator without any health complications.

6. Simulation Setup

This study developed the simulation model based on the existing production line (Fig. 3). The simulation was built concerning the respective standard time derived from the standard work. The simulations were run for 365 days, and data were collected every week regarding weekly output, lead time, and work-in-progress WIP. The logic of the Arena simulation for the operational processes was seized, delayed, and released. Seize and release logics were to model contention of resources processing a capacity. When resource capacity is fully utilized, the entities in the queue must wait until the current resources are released. Seize acted like a gate between entities and resources. The delay function specifies the processing time. Figure 6 shows the Formal logic of the simulation model.

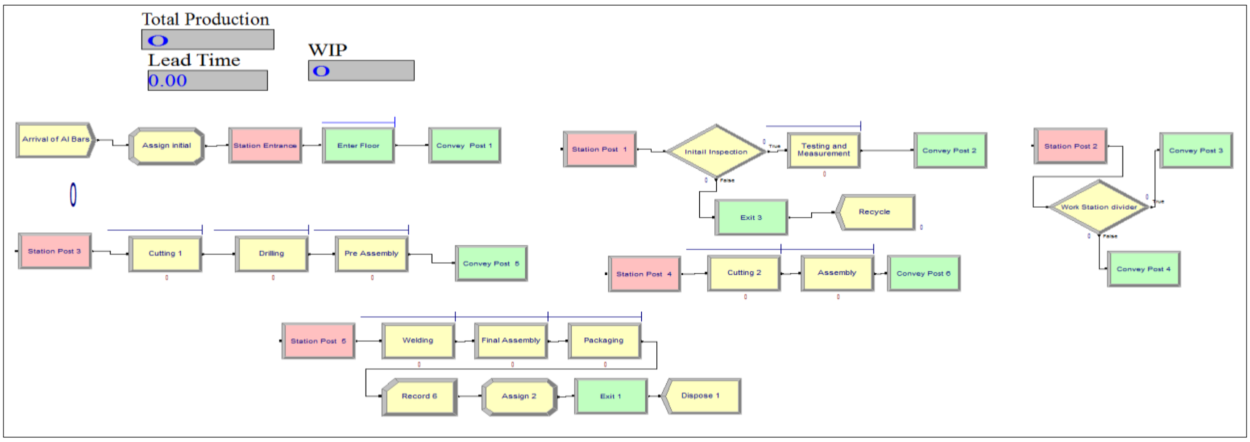


Fig. 6. The formal logic of the simulation model

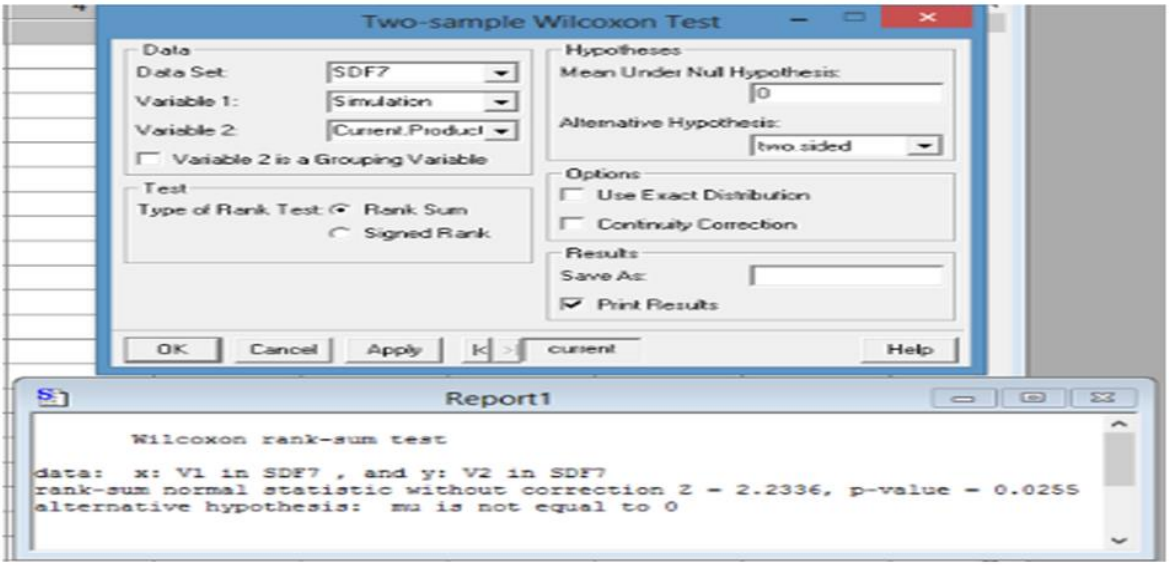
7. Collection and Validation of Data

Data were collected from the production line before the simulation was built, and the process parameters were determined. Before carrying out the simulation run, the model must be validated to test its similarity to the production line. A simple comparison of the production line and the simulation model's weekly output was made. Table 3 shows the data for weekly output for the production line and simulation model before improvement. A simple comparison was made, and the data was checked to see if it deviated 'how much' from the production line.

Table 3
Comparison of weekly output

Week	Simulation Model	Production line
1	62	57
2	61	65
3	63	58
4	68	63
5	64	59
6	61	71
7	65	60
8	69	61
9	66	61

The initial checking was done, and the result was satisfactory, as agreed by the management. Next, we proceeded with the Wilcoxon rank sum test. The Wilcoxon test can test two sets of data from different samples of their distribution. The Wilcoxon rank sum test is a nonparametric alternative to the two-sample t-test based on the order in which the observations from the two samples fall. This test was conducted using TIBCO Spotfire S+ software. Figure 7 shows the result of the rank-sum test.



Data Set: SDF7
Variable 1: Simulation
Variable 2: Current.Product
☐ Variable 2 is a Grouping Variable
Type of Rank Test: ● Rank Sum ○ Signed Rank
Mean Under Null Hypothesis: 0
Alternative Hypothesis: two.sided
☐ Use Exact Distribution
☐ Continuity Correction
Save As:
☑ Print Results

```
        Wilcoxon rank-sum test

data:  x: V1 in SDF7 , and y: V2 in SDF7
rank-sum normal statistic without correction Z = 2.2336, p-value = 0.0255
alternative hypothesis:  mu is not equal to 0
```

Fig. 7. S+ test result

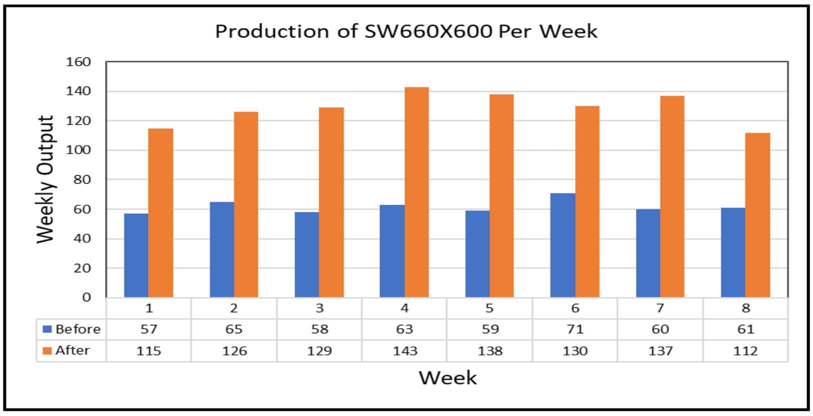
The test shows that both samples had a confidence level of 97 percent, which was very encouraging from the perspective of the organization and the weekly output. Therefore, with these two tests, we could conclude that the simulation model could mimic the production line to a great extent, as confirmed by the two tests.

8. Data Analysis (Results) and Discussions

We conducted the simulation model run for the current and future state production lines. The outcome of the run was observed and analyzed. The evaluation elements were weekly output, cycle time, lead time, WIP, and production efficiency, as requested by the organization.

8.1 Weekly Output

Figure 8 shows the weekly output of both productions collected from the simulation model and the organization. An improvement in the production of SW660x600 was found from an average of 61.75 to 128.75 per week, with an increase of 108.50 percent. This improvement could be attributed to the shorter cycle time at most workstations. With the elimination of the non-value-adding activities, the weekly productivity improved significantly.

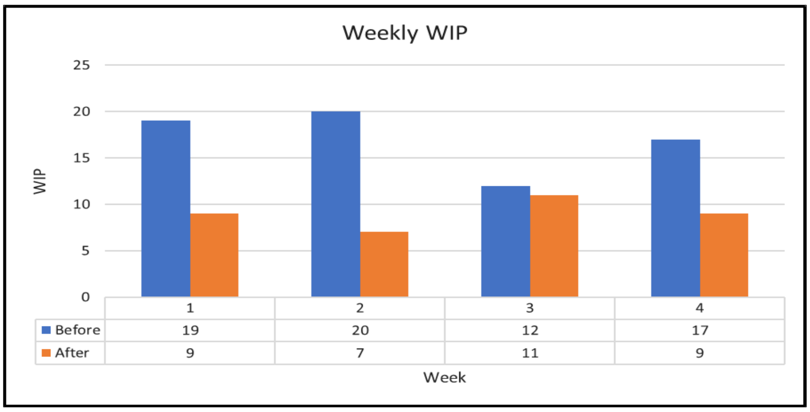


	1	2	3	4	5	6	7	8
Before	57	65	58	63	59	71	60	61
After	115	126	129	143	138	130	137	112

Fig. 8. Weekly output

8.2 Work-In-Progress (WIP)

Figure 9 shows the weekly WIP of both the organization and simulation models. The models showed an improvement, all the current (after) production produced less WIP.



	1	2	3	4
Before	19	20	12	17
After	9	7	11	9

Fig. 9. Weekly work in progress (WIP)

However, if we compare each model's output, we can see that the current production line produces one WIP for every 3.7 SW660x600 windows. The future production line will produce one WIP for every 12.5 windows daily. Therefore, the future production line can reduce WIP by an average of 17 to 9 WIP weekly, an improvement of 47.1% on the weekly WIP.

8.3 Lead Time

Figure 10 shows the lead time of both models. The proposed solution managed to reduce the lead time of SW660x600 from an average of 5 hours to 1 hour. This reduction in lead time could be attributed to the eliminating of non-value-adding activities in production, resulting in shorter cycle times at most stations.

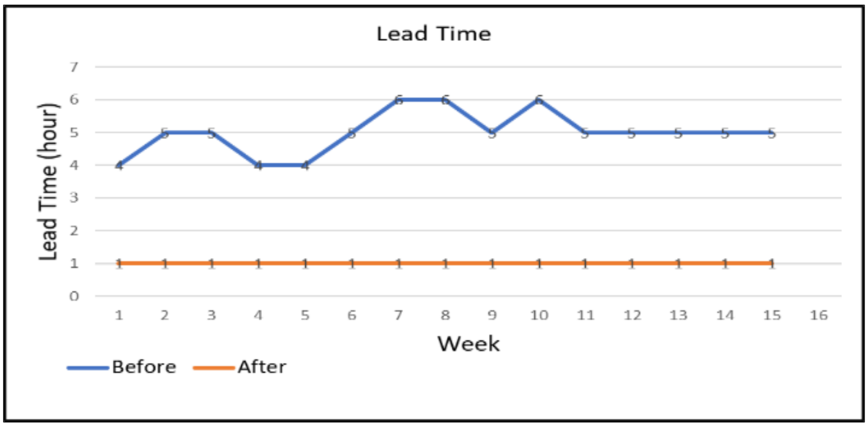


Fig. 10. Lead time of two models

8.4 Production Efficiency

Since the beginning of the study, the target production efficiency has been set at 50 percent. Figure 11 shows that after the implementation of the work standard, the production efficiency increased from an average of 41.47 percent to an average of 85.53 percent, which was an improvement of 106.25 percent over the previous efficiency. It recorded a major improvement overall from week one to week eight. Therefore, we managed to achieve the objective of this study.

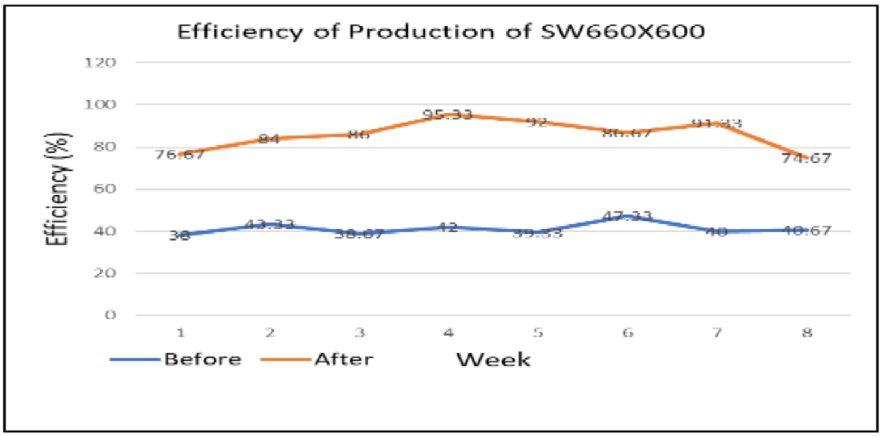


Fig. 11. Production efficiency over the weeks

Finally, the overall improvement in the production system is summarized in Table 4.

Table 4
Improvement Summary

	Before	After	Improvement (%)
Average weekly output	61.75	128.75	108.50
Weekly WIP	17	9	-47.1
Lead time (h)	5.0	1.0	80%
Ratio of output to WIP	3.7	12.50	-
Actual Cycle time (s)	480	225	53.13
Line efficiency (%)	54.84	62.77	14.50
Production efficiency (%)	41.47	85.53	106.2

9. Conclusions

The standardization of work procedures, through Standard Work and work instructions, gave the company a base for documenting manufacturing processes, components, and tools. These documents served to provide greater flexibility to the production line and to increase its productivity to the extent that they enabled the reduction of several wastes and manufacturing errors. This study managed to meet the objectives set earlier; more so, this work surpassed the management's expectations. The following conclusions can be drawn from the study:

1) Work standards can provide the 'rule of law' in the production, therefore resulting in a more 'disciplined' manner in the production as the operators need to meet certain expectations in a day's work, such as daily output, hourly output, allowable task time for a single unit, etc.
2) With this, a pacesetter was implemented at each workstation, and operators must adhere to the setter as closely as possible. Therefore, a pacesetter will impose a leaner production line as the number of outputs can be predicted accurately and excess production per day can be eliminated.
3) This work increased the weekly output by an average of 61.75 per week of SW660x600 to 128.75 per week, an increase of 108.5 percent. By eliminating unnecessary tasks in the process, the operators managed to produce more daily, increasing weekly output.
4) With the help of the simulation model, the lead time of a single product also improved from 5 hours to 1 hour, an improvement of 80 percent. This is a leap and bound from the previous production line.
5) Besides weekly output and lead time, WIP also recorded a major improvement.

Nevertheless, this work will help and guide other SMEs to improve their production line performance, leading to huge benefits. Improvement is a continuous process, and further study can be carried out to determine the scope of future development.

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