IMPROVING THROUGHPUT OF A SEMI-AUTOMATED ASSEMBLY LINE SUBJECT TO OPERATOR SKILL-LEVEL CONSTRAINT

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Industrial Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **IMPROVING THROUGHPUT OF A SEMI-AUTOMATED ASSEMBLY LINE SUBJECT TO OPERATOR SKILL-LEVEL CONSTRAINT** was prepared by **SEE SHU XIN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Industrial Engineering at Universiti Tunku Abdul Rahman.

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ABSTRACT

Integrating humans into manufacturing systems has been considered a critical aspect in a semi-automated line as dynamic human characteristic constrains the throughput production and leading to the occurrence of manufacturing bottleneck. In the research, it is discovered that the manufacturing problems was incurred at the manual assembly workstation where the process has longest cycle time and lowest production output. With regards to this, this paper presents a methodology for analysis of the bottleneck in the manufacturing systems and aims to develop potential solutions that have direct impact toward throughput improvement. Results obtained are based on the research that was carried out in the Camfil Malaysia Sdn Bhd.

In this research, Root Cause Analysis was implemented as an analytical technique and preliminary step to identify the potential causes of the manufacturing problems. It was found out that poor arrangement of tasks, inconsistent performance of operators, imbalance in workload distribution, poor workflow and poor layout design were the main issues encountered in the manual bottleneck workstation. To tackle the relevant production issues, work standardization, 5s practices and redesign facility layout were adopted in the manufacturing line. Besides, Kaizen was applied in re-constructing the work sequence, working technique, equipment, work scheduling, workflow and the design layout.

With the application of work standardization and Kaizen, consistent production with optimal work practices was achieved in the bottleneck station, which leading to a high production outcomes and low operating time. Based on the result, there is about 38.69% decrement in production cycle time in the bottleneck workstation. Moreover, work standardization enables to tackle the problem of imbalance in workload distribution in which the utilization of workers has an apparent improvement for 49.37%. Poor workflow was being solved by setting a normative procedure and SOP with the purpose of eliminating the non-value-added activity. It is said that the average waiting time was reduced from 8.8 seconds to 5 seconds per unit.

Redesign facility layout was minimizing the unnecessary movement in the line and creating a comfy and ergonomic working condition. According to the result, the adjustment on facility layout allows time spent on motion to be reduce from 17.00 to 8.00 seconds which has a 52.94% improvement. Additionally, the practice of Set in Order and Sort that provide visual control and management had improved the efficiency and value toward the throughput production. In overall, the production throughput was obtained a 42.69% improvement with the aid of all the combined solutions.

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LIST OF ABBREVIATION

WIP	Work in Progress
VSM	Value Stream Mapping
SOP	Standard Operating Procedure
MTS	Make-to-stock
MTO	Make-to-order
MCO	Movement Control Order

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter will discuss the background, problem statement, objectives and scope of the study. Section 1.1 shows the background of the study. Section 1.2 explains the problem statement in this study. Section 1.3 shows the objectives of study.

1.2 Background

Manufacturing is a process of transformation of raw material into finished products. The process involved in manufacturing may include procurement, fabrication, assembly and bagging. Manufacturing processes may be varied in different industries which depend on the production processes and the nature of manufacturing operations. The three main types of manufacturing lines are manual manufacturing lines, semi-automated manufacturing lines and automated manufacturing lines. The nature of a manufacturing line is dependent on the complexity of the manufacturing volume, production cost and parts, restricted or hazardous manufacturing process and the sensitivity of the product. (Subramaniam et al., 2009).

A semi-automated production line is a production line that involves man and automated machines. The automation aspect in a semi-automated production line is the driving force in strengthening the efficiency and productivity, while a human operator is involved to handle machines and equipment, perform checking and inspection, verify the product quality, decision making and material handling (Oh et al., 2015). Semi-automatic systems are considered the widest part of the assembly system, and the level of human-intervention could be varied depending on the requirement of the systems. In a semi-automated production line, the optimal task allocation between man and machine is significant to control the combined systems efficiency of the dynamic human and machine interactions (Oh et al., 2015).

There are several types of semi-automated systems that could be involved in an industry such as shared control semi-automated and action support semi-automated. A shared control semi-automated manufacturing line involved actions being shared between the human and the machine in every stage of manufacturing (Kaber & Endsley, 2004). In other words, every automated machine along the production line required human-intervention. The involvement of the operator could be simple such as manually loading or unloading the entire system or it may implicate a high amount of labor on manually inspection and checking in every station to allow the production line run smoothly.

Moreover, some aspects of the production line that are too difficult to fully automate will implement an action support semi-automated production system (Kaber & Endsley, 2004). An action support semi-automated system will include some fully automated workstation and some fully manual workstation. In this scenario, human choices are required only at specific stages within the process for the optimal result.

Both skilled human workers and advanced technical machines are necessary to achieve flexible and efficient manufacturing.

In fact, choosing a right level and types of automation is significant and beneficial to a company as a correct system that works best for the manufacturing will be able to increase the production throughput which contributes to achieve the production goals. In engineering, production throughput is known as the amount of a product or service that an enterprise is able to produce and deliver to the customer in a specified time frame. It is a measure of a production flow rate and the overall performance of a production line which determines optimal quantity to be produced with limited resources. Since production resources such as operators, machines and workstations are usually scarce, finding effective ways to increase throughput will be able to help manufacturers to improve its effectiveness, internal efficiencies, adaptability and customer service levels (Oh et al., 2015).

In maximising throughput, it is essential to identify the bottleneck in a production system. A bottleneck is a point or workstation that will limit the capacity of a system. The presence of a bottleneck will increase the production cost and time which will then inhibit the system performance.

Improving throughput of a production line in the case of the bottleneck being the manual workstation instead of automated workstation is a major concern in many factories. This is because humans are heterogeneous; varying levels of skill of operators will behave differently over time and achieve varying results. For instance, a low skill level of an operator would take longer time to operate, which will lead to the production cycle time to increase. The level of skill in operator exists as the constraints throughout the whole process and it will limit the throughput to the optimal level of performance. Specifically, in the race for achieving set goals, human capital is the key concern in most companies while less emphasis was placed on automation bottleneck. This is because cycle time for automation machines is usually fixed, cycle time reduction may only be possible during machine change over and set up or with substantial investment in new technology.

Apart from throughput, there are also some useful parameters that are vital to the manufacturing company such as productivity, efficiency and utilization. Productivity is a measure of efficiency which is commonly used to calculate the amount of output over unit input. A highly efficient and productive workforce is imperative to generate high profit. Moreover, utilization refers to production capacity that is being utilized in a period of time. Using the capacity utilization, the company is able to determine the efficiency of the resources, which is good in eliminating the waste.

1.3 Problem Statement

In human-controlled operation systems, humans are represented as one of the most flexible system resources by executing an extensive variety of physical tasks ranging from material handling to complex tasks like assembly and inspections (Oh et al., 2015). However, integrating humans into manufacturing systems has been considered a critical aspect in a semi-automated line, as in the case of the bottleneck being the manual workstation instead of the automated workstation, the output rate could be unpredictable and fluctuate widely, which will result in high standard deviation of throughput. This is due to the fact that the human characteristics are dynamic and affected greatly by factors such as time, knowledge and most importantly operator's level of expertise (Oh et al., 2015). Developing a production planning system that incorporates human beings is challenging as the unstable conditions may lead to poor production planning, which results in inability to meet customer demand on time.

In addition, inventory management is one of the vital issues for the manufacturing industry during the pandemic. This is because manufacturers are facing difficulty when the forecasting future demand is overestimated and causing them to suffer from low sales and high WIP inventory.

1.4 Aim & Objectives

This research aims to improve throughput of a semi-automated assembly line by reducing the process cycle time and improving the efficiency of the manufacturing line. The objectives of the project are shown in the following:

1. To identify potential solutions that are able to improve the throughput of a semi-automated production line.
2. To develop solutions for a semi-automated production line that have direct impact to the improvement of the manufacturer.
3. To validate the selected solutions.

1.5 Project Scope

To prevent and reduce the transmission of the coronavirus, visitor restrictions during the COVID-19 pandemic caused limitations on conducting data collection in the factory. Therefore, there is only one case study involved in this research.

1.6 Outline of Thesis

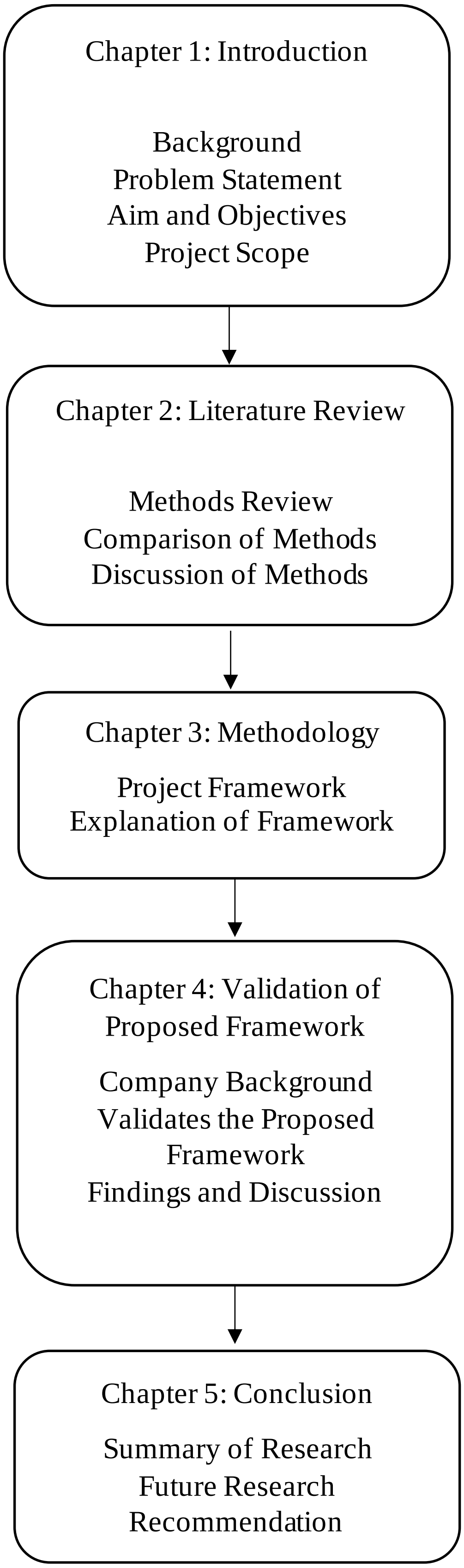


Figure 1.1: Outline of thesis

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This literature review focuses on finding appropriate strategies to increase the throughput and improve the productivity of the production line. Section 2.2 shows the literature review of Redesign Facility Layout. Section 2.3 shows the literature review of Value Stream Mapping (VSM). Section 2.4 shows the literature review of Root Cause Analysis. Section 2.5 shows the literature review of 5S Practice. Section 2.6 shows the literature review of Simulation. Section 2.7 shows the literature review of Kaizen. Section 2.8 shows the literature review of Six Sigma. Section 2.9 shows the literature review of Line Balancing & Work Standardization. Section 2.10 shows the comparison of methods. Section 2.11 shows the discussion on methods.

Table 2.1 List of section in chapter 2

Section 2.2	Redesign Facility Layout
Section 2.3	Value Stream Mapping (VSM)
Section 2.4	Root Cause Analysis
Section 2.5	5S Practice
Section 2.6	Simulation

Section 2.7	Kaizen
Section 2.8	Six Sigma
Section 2.9	Line Balancing & Work Standardization

2.2 Redesign Facility Layout

Redesign Facility Layout is redesigning the existing layout in the production line and finding an optimum arrangement of facility to improve the system performance. According to Kovács (2019), facility layout design is crucial and has a massive impact towards the system performance such as throughput, efficiency, productivity, and lead time. This is due to the fact that a well-designed facility layout is able to reduce up to 50% of operating cost, material handling cost and the time spent in the manufacturing system. In the research, lean tools are combined with the facility layout design to enhance process improvement. The availability of lean tools allows reduction of workstation, while optimum arrangement of workstation led to a high utilization of resources such as facilities, space and labour force. Besides, the result showed that transportation distance for material and goods have a significant decrease of 10.45% and 4.51% in the total material handling cost. Nevertheless, Kovács (2019) claimed that the arrangement of the facilities such as the machine, equipment and workstation have to be adjusted from time to time to fit the changing production plan and customer demands. This is because only an optimum layout design and facilities will improve the efficiency of materials flow, maintain the flexibility of the operation, shorten manufacturing time and create a comfortable and safe environment.

To support the idea, Radhwan et al. (2019) mentioned that feasible production planning on the process flow and facility layout are fundamental to achieve effective movement, high utilization of work area and improvement on production performance and throughput. Systematic layout Planning (SLP) is a good way to solve the facility issue by reducing the unnecessary movement of operators and inefficient flow of materials. In the research, process flow chart, data collection and relationship diagram are the significant components used to generate possible alternative layouts. The alternative layouts will then be evaluated by the Graph-Based Method and Efficiency Rate for the purpose of selection of optimum layout. Layout that obtained the highest arc score and level of efficiency will be chosen, as it's able to divide several paths for material flow and reduce the transportation distance between connected workstations. According to the result of the selected layout, the total processing time per batch is able to reduce for about 10% and 11% improvement in manufacturing productivity.

2.3 Value Stream Mapping (VSM)

Value Stream Mapping (VSM) is a lean tool that aims to enhance productivity by reducing the production waste and production lead time. Nowadays, many manufacturers are struggling with improving productivity, producing the right number of products and services at the right place and at the right time. In this situation, constructing the VSM allowed the manufacturer to visualize the flow of the process and it acted as a systematic starting point for process improvement. The system approach to create VSM was divided into five basic steps such as constructing a current VSM, assessing current VSM, determining the problems, generating future VSM and implementing the final plan. Constructing a VSM allows non-value added and value-added processes to be determined, which is good to facilitate the production and eliminating manufacturing wastes. Besides, a timeline will usually be included in the VSM to record the value-added and non-value-added time to allow better vision on every detail of the system.

According to a case study illustrated by Bhamu, Shailendra Kumar, and Sangwan (2012), the adoption of VSM in the Indian automotive company delineates the overall process precisely, which eases the teams on finding the bottom lines of the manufacturing processes. In the study, VSM depicts that unnecessary delay and storage, high WIP, long working distances and high change over period are all the main factors that create high lead time and defective products. To overcome the problem, reduction in production waste such as damage, cut out and sizing issues able to improve with assisting tools such as Root Cause Analysis and Kaizen. Besides, U shape layout design is able to tackle the problem of material movement and working distances, purchasing flat base probes can solve improper offset setting issues and etc. The future VSM proved that reduction in lead time was obtained with 21% improvement, 74% decrement in working distance, while reduction in WIP and production waste was taken by 29% and 59% respectively.

Shobha and Subramanya (2012) describe VSM as an effective tool in identifying four crucial management tasks such as design flow, production flow, material and information flow and the integration of design and production flow. Data analysis on current VSM allows the company to realize their manufacturing issues such as high lead time and WIP inventory. Other than that, Pareto Chart and Flow Process Chart were created to study each work element in the production line. Gap analysis between the current VSM and future VSM in food manufacturing allows the company to have some insights on future work such as emphasizing more on inventory management, scrap rate, and manpower requirement. According to the constructed future VSM, the manpower that is required for several production lines can be reduced, the dough scrap rate and packing scrap will slightly decrement for about 0.4% and 0.2% respectively if the future VSM is able to change to current VSM. They also predicted that the goal of lead time reduction would be able to be fulfilled if they are successfully converting the future VSM into the current VSM.

Pambhar and Pambhar (2017) implies VSM in a MCCB (molded case circuit breaker) manufacturing to determine the non-value-added activities in the process. The data obtained from current VSM demonstrate that the non-value-added activities in the production line were particularly high and lead to a low VSM ratio. To overcome the issue, the company proposed a Kaizen approach to handle by carrying out a brainstorming session among operators and supervisors. The sufficient data available allow delay analysis to be conducted via VSM. As a result, the case study successfully eliminated the excessive non-value-added activities by 6.3% and improved the VSM ratio from 3.71% to 10.51%. Future VSM also reveals a throughput time improvement for about 37%.

2.4 Root cause analysis

Root Cause Analysis is an analytical technique used to identify the contributory factors and resolving problems by conducting a comprehensive, corrective and system-based review of critical incidents.

According to Mahto and Kumar (2008), it is significant to first understand and recognize what are the root causes of a problem. This is because understanding the problem helps in determining risk minimization approaches and allows development of action plans with measurement strategies to assess the feasibility of the plans. Important tools and techniques that involve root cause analysis are Causes-and-Effect Diagram, Current Reality Tree (CRT), Interrelationship Diagram (ID) and etc. On the other hand, Events and Causal Factor Analysis, Barrier Analysis and Change Analysis are some of the examples for root cause analysis methods. In the case study, Management Oversight and Risk Tree methodology was first adopted where to identify the hazards, potential conflicts, potential contacts and to determine the strategy for minimization of consequences. Lack of lubrication and knowledge of setting machine parameters were some of the reasons that caused item defects. Later on, Cause and Effect Diagram and Why-Why Analysis was further implemented to visualise the interrelated activities and find solutions for improvement. The observation of the result proved that the implementation of root cause analysis allows reduction of defection rate for about 83.82% and increment in utilization and productivity for 18% and 5% respectively.

Moreover, Ghatorha, Sharma, and Singh (2020) also describes root cause analysis as one of the useful strategies to identify the variables of variation in the system. The initial step in the study was done by direct observation and feedback from workers and supervisors. After that, data collected will be used to construct a fishbone diagram in order to figure out the root causes of the problem. The issues that are encountered in the manufacturing are small depth of cut, high finishing cuts, low feed rate and rpm. Detailed analysis on the fishbone diagram allows the company to have some ideas such as installing a flange fixture on the plunger bush to provide extra support and a modified machining process of flange fixture. The solution was successfully enhancing the feed rate, depth of cut and rpm of the system with low finishing cuts. This outstanding result enabled improvement on the material removal rate by 100% and economized the machining cost by approximately RM1000 with improvement in productivity.

2.5 5s Practice

5s technique is a non-costly and simple method that is able to reduce non-value-added time, improve productivity and quality of product. The term 5s represents the acronym of five important steps in the manufacturing workplace which are shine, sustain, set in order, standardize and sort.

a) Shine- Keep it clean and shining
b) Sustain- Maintain and review standard
c) Set in order- Items should be labelled clearly and kept in the right place.
d) Standardize- Work practices should be consistent.
e) Sort- Separate the needed from the Not-Needed

Omogbai and Salonitis (2017) integrated 5s method in a manufacturing plant. They develop 5s practice such as how items should be arranged for sorting led to a dramatic improvement in the throughput. For instance, they separate every item to different sections and implement visual control in all the storage rack and location. They found out that workers are able to search and grab the item easily with labelling. Besides, the system dynamic simulation result showed that the throughput produced rises by 40% when the normal sorting time is shortened by about 80%.

Meanwhile, the exploratory study that was carried out by Rojasra and Qureshi (2013) emphasizes every single element in 5s practice. In the study, rating criterion on system contents such as operating condition, information and guidelines, waste elimination, material arrangement, cleanliness and etc are implemented to determine how well 5s practice was adopted in a plastic manufacturing company. From the result, it is obvious that awareness of workers towards 5s practice promotes better rating results and higher efficiency. The 5s rating result of each S was improved from average 3.35 to 4.44 marks, and efficiency was increased from 67% to 88.80% in a10 weeks period. Besides, the author mentioned that the adoption of 5s in the company leads to a safer working environment and condition, proper arrangement of material and tools, and efficient use of resources.

Al Aomar (2011) illustrates 5s method could revise the production workflow and working conditions in a case study. This is due to the fact that the Prefab factory encountered an increment in customer demand causing them to suffer from indistinct workflow, poor working environment, disorderly workstation, production delay, continuous layout changes, excessive production and effort waste. The 5s methodology was begun by conducting observation in several aspects such as shop floor, labor, machine set up and utilization of resources. After understanding the issue in the plant, they started to concentrate more on improving worker awareness towards 5s through seminars and meetings. As a result, culture changes that involve the plant allow continuous improvement such as proper dividing the plant to ease layout identification and material flow, emphasis on cleaning and safety measures, reduction in production waste by proper labelling and arranging the material and etc. According to the author, successful implementation of 5s in the project allows overall plant operation to be improved in 3 month, and tangible changes in operators such as worker morale and productivity.

2.6 Simulation

Simulation is one of the useful methods used to study a complex production system in a virtual world. It allows visualisation of dynamic effects and supports decision-making of various commercial tasks. The model simulations provide useful data for process behaviour, result and performance with diverse process structures. However, adequate quality of the input data is essential for the actual simulation and to draw legitimate conclusions from the simulation model.

Kamble and Telsang (2019) describe how model simulation could visualise the redesign system in the manufacturing company. The case study was first conducted through the application of Maynard Operation Sequence Technique (MOST) to capture the workflow and figure out the non-value-added activities. It is obvious that the adoption of MOST enables them to determine low productivity operators, make changes on operation sequences and work assignment, and set conveyors as a solution to remove unnecessary movement. The data that concluded in MOST will then be validated with simulation and the statistics results obtained from simulation allow analysis, graphical results and tables be created. From the result of analysis, it is shown that the takt time was able to be reduced for about 2 minutes and a 20% increment of throughput was obtained.

Besides, the study of Yasir and Mohamed (2018) proved that the simulation that is run by Witness simulation software is useful in analysing the manufacturing lines issue as it manages to improve the productivity of the workers and the efficiency of the manufacturing line. In the study, the strength and weakness of every workstation was determined by analysing the current layout through simulation. The effectiveness of alternative future layouts and the productivity of operators able to compare by referring to the statistics result provided by simulation. From the result, the new ideal layout showed that the manufacturing efficiency was able to improve by 3.93%. Although improvement is obtained, the increment in efficiency for new design layout was yet to fulfil the company goal. Sufficient information offered by simulation allows the company to make the conclusion that layout redesign method is not appropriate to implement in their production line but reassigning the operator instead.

2.7 Kaizen

Kaizen is a Japanese philosophy that encourages people to make continuous improvement. The adoption of Kaizen philosophy in numerous industries across the globe promotes innovation and creativity among workers. Workers feel satisfaction and have a sense of accomplishment when their efforts regarding Kaizen strategies led to a non-value-added reduction. Meanwhile, team efforts and awareness in workers play a prominent role in implementation of Kaizen manufacturing philosophy.

Chikwendu et al. (2020) through an exploratory study of a tissue manufacturing company found out that kaizen production techniques are able to improve production throughput and quality of product. They provide some insight about the implementation of Kaizen along with the challenges and success factors. Communication, organization structure, training, skill and expertise are all the vital factors for successful Kaizen Implementation. Besides, Chikwendu et al. (2020) emphasize on using the Kaizen umbrella that consists of several improvement activities such as workplace discipline, quality improvement and development, productive maintenance, etc. The author also encourages to use Plan-Do-Check-Action (PDCA) technique which involves three stages which are planning stage, setting goal and follow up for continuous improvement in the company. The commencement of Kaizen implementation in the tissue manufacturing company led to an increment in production volume per day by 60%, with 31% lesser defective products and 51% improvement in product quality.

Kumar, Dhingra, and Singh (2018) explored the advantage of Lean-Kaizen implementation through the study in India organization. Lean-Kaizen is a manufacturing strategy that combines both Lean and Kaizen approaches to reduce the non-value-added activities and eliminate inefficiencies in the organizations. In the study, VSM is constructed to visualize the workflow, 5 why method was implemented for root cause identification while Kaizen employed for continuous improvement. Two different types of Kaizen were adopted in the production line which are poka-yoke technique and brainstorming technique. Poka-yoke approach is applied to manage the occurrence of variation due to the machine while brainstorming employs to produce ideas on fixing product variations. The combination of Lean and Kaizen showed an excellent result on reduction of lead time (69.47%), inventory level, rework and manpower (40%). Besides, the significant improvement on productivity and quality of products encourages the organization to apply Lean-Kaizen technique in different processes and products.

The study of Al Janahi (2019) reveals the company introduced Lean RACE (Reduce, Accelerate, Consolidate, Enhance) as a Kaizen approach to determine the improvement opportunities. In their opinion, RACE provides information on waste reduction and encourages further development in different aspects which enable continuous improvement to be achieved. In the study, unnecessary movement and transportation, high WIP inventory and poor working environment is the main concern of the company. With the successful implementation of Lean RACE, the company was able to increase the throughput and reduce the wastage. For example, they found out that rearranging the gates on the conveyor belt could reduce the transportation distances by 13 meters, changing the task sequence can make the worker perform efficiently, and implementing robotic arm can lead to decrement in unsafe and disergonomic risk. From the result of simulation, 18.41% decrement in waiting time with 42% improvement in transportation distances was obtained. Besides, 26.32% throughput improvement was achieved as the cycle time and unnecessary waste is reduced.

2.8 Six Sigma

Six-Sigma is a statistical tool that focuses on process variation reduction and productivity improvement. It provides systematic structure and basis for problem solving and decision making based on its powerful statistics. The Six Sigma composed both people power and process power in quality improving processes such as reduction of defects and improving capabilities.

The application of Six-Sigma in the study of Kabir et al. (2013) shows that it offers the company a performance benchmark on which it could base its future performance enhancement programs. The six-sigma framework provides insight on a new management approach on improving efficiency and consistent quality customer service. In the research, assisting tools such as Root Cause Analysis, 5s and Line Balancing approach helps Six Sigma to become more beneficial to the organization for all types and sizes. The result of data displays an improvement in the line efficiency by 29% with 30% reduction in production defective. Thus, the company concludes that Six-Sigma is considered as a useful tool to implement for the long run.

Van den Bos, Kemper, and de Waal (2014) combine both Six Sigma approach and lean philosophy to tackle the problem in a construction company. According to them, Lean Six Sigma creates a wide view on the process performance in terms of throughput time. The valuable and potential information that generated with Lean Six Sigma project execution enables the author to identify the causes for delay easily. This is beneficial to the company as it allows them to generate more ideas for improvement. As a result, the implementation of suggested ideas yields a significant reduction in throughput time of 52.88% as unnecessary delays decrease.

2.9 Line Balancing & Work Standardization

Line balancing is a manufacturing tool that involves equally distributed tasks to the workers and workstation to ensure that the production rate is able to match the production takt time. Meanwhile, work standardization refers to establish a best work sequence and procedure for efficient manufacturing operations.

Mulugeta (2021) through his exploratory study in an Ethiopian garment manufacturing company showed how a detailed work of time-study or work measurement techniques was able to improve productivity in terms of system and workers. High motion and movement in transportation and unbalanced task assignment of workers creating an unbalanced cycle time and high WIP inventory in the production line. To overcome the problem, sequential relationships among tasks using a precedence diagram provide an overview of the actual processing sequence of the line and it then helps in determining the workstation cycle time and minimum workstation that is required in each line according to the actual customer demand. The result showed significant improvement in worker efficiency by 65.44% and production efficiency from 6 trouser per day per machine to 10 trouser per day per machine when the assigned task follows the workstation cycle time as the line becomes balanced.

In addition, line balancing practices that are applied in a small-scale manufacturer show that balancing the workforce is essential for lead time reduction purposes. According to Nallusamy and Saravanan (2016a), balance the operation time is able to achieve constant processing time among workstations, which is beneficial for process improvement. In the study, the bottleneck workstation such as cylinder boring and boring motor side must reduce its cycle time to fit the balanced processing time. To solve the problem, the company suggested that cylinder boring could adjust to in-house operation to reduce the cycle time, setting of valves promote bottleneck reduction in boring motor side, while splitting of workstation allows the cycle time to fit the takt time. Indeed, the future VSM concluded that lead time and cycle time were shortened by 47.83% and 17.65% respectively after implementing the proposed solution.

Nallusamy and Saravanan (2016b) proposed lean manufacturing in a small-scale industry and emphasized on line balancing and work standardization with the objective of shortening the cycle time, lead time and set up time, and enhancing the overall output. In the research, line balancing was introduced to arrange the manpower effectively, while work standardization works as a sequential method to identify the best work practices and encourage workers to strictly follow the standard operating procedure. With the assistance of several lean manufacturing tools such as VSM, kaizen and 5s, improvement on cycle time reduction created significant impact toward overall output and customer satisfaction. It is obvious that overall lead time is able to decrease for about 32% with a total 1850 seconds reduction in setup and cycle time through line balancing and work standardization.

2.10 Comparison of Methods

Table 2.2: Methods for throughput improvement

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
COST	Low Cost		√		√														√	√	√
	Medium Cost	√				√		√	√	√	√	√					√				
	High Cost			√			√						√	√	√	√		√			
METHOD	Redesign Facility Layout	√	√																		
	Value Stream Mapping (VSM)			√	√	√									√					√	√
	Root Cause Analysis						√	√							√						
	5S								√	√	√										
	Simulation								√			√	√								
	Kaizen					√								√	√	√					√
	Six Sigma																√	√			
	Line Balancing																		√	√	√
	Work standardization																		√		√

References: 1) Kovács (2019); 2) Radhwan et al. (2019); 3) Bhamu, Shailendra Kumar, and Sangwan (2012); 4) Shobha and Subramanya (2012); 5) Pambhar and Pambhar (2017); 6) Mahto and Kumar (2008); 7) Ghatorha, Sharma, and Singh (2020); 8) Omogbai and Salon itis (2017); 9) Rojasra and Qureshi (2013); 10) Al Aomar (2011); 11) Kamble and Telsang (2019); 12) Yasir and Mohamed (2018); 13) Chikwendu et al. (2020); 14) Kumar, Dhingra, and Singh (2018) 15) Al Janahi (2019); 16) Kabir et al. (2013); 17) Van den Bos, Kemper, and de Waal (2014); 18) Mulugeta (2021); 19) Nallusamy and Saravanan (2016a); 20) Nallusamy and Saravanan (2016b).

2.11 Discussion of Methods

In the semi-automated production line, humans are the most concerned resources and have a massive impact toward system performance. Redesign facility layout is crucial for manufacturing lines that involve human factors because an efficient layout will be able to reduce movement of workers, materials and goods. In fact, minimizing unnecessary movement in the line means non-value-added activities will be reduced, more time is saved to run the production, higher outcome could be produced and led to a significant improvement in the throughput. Besides, an optimum facility layout will create a safe and comfortable working environment for the workers. This is because a comfy and ergonomic working condition provides an opportunity to improve workers productivity and efficiency. According to the research of Kovács (2019) and Radhwan et al. (2019) both authors provided insight on different methods to redesign the facility layout such as Lean with Redesign System and Systematic Layout Planning (SLP). However, since every company has different layouts and produces different types of products, the implementation of redesign facility layout method in the semi-automated manufacturing line in this case study requires consideration of constraints within the facility. A best layout will be chosen from the alternative layouts after evaluation and optimum selected design layout validation will be required to ensure it is able to incorporate with the real situation in the semi-automated company.

Moreover, Value Stream Mapping and Root Cause Analysis are the popular tools that are suitable to utilize by all types of companies. This is due to the fact that both methods attempt to figure out the reason for a developed problem which is an essential part of the problem-solving process. However, Root Cause Analysis will be preferred in this case study. This is due to the reason that VSM involves large scale and constructing a Value Stream Map is time consuming and requires a lot of input data, while Root Cause Analysis is more directly toward analysis of potential causes from personnel to production element such as material, machine, method and measurement. Thus, Root Cause Analysis will be selected as an initiative for problem solving in this case study.

Taking into consideration human factors, 5s practice recommended by Omogbai and Salonitis (2017) is used with the purpose of reduction of processing time. More emphasis will be placed in the Set in Order and Sort technique compared with other three main practices such as Shine, Sustain and Standardize. To improve the throughput of a semi-automated line that involves human-intervention, reduction in processing time could be significant as humans that used shorter time to process an item will be more efficient and have the opportunity to produce more output. The practice of Set in Order and Sort that provide visual control and management will create efficiency and value toward the process which is beneficial for throughput production.

Furthermore, Lean-Kaizen implementation in the study of Kumar et al. (2018) shows a systematic way in which the company solves their production problem with a step-by-step sequence involving tools such as VSM, Root Cause Analysis and Kaizen. Both VSM and Root Cause Analysis were used to assist Kaizen events which allow proper actions to be performed towards selected problems. Likewise, the successful implementation of Six Sigma in the study of Kabir et al was unable to disregard the contribution of the assisting tools such as Root Cause Analysis, 5s and Line Balancing as well. However, the comparison between Kaizen and Six Sigma approach showed that Kaizen is more widely used in any manufacturing company while Six Sigma is more concentrated on improving the throughput by minimizing the defective instead of by improving the productivity of the operator. In this situation, Kaizen will be better to employ in the semi-automated production line in this case study.

In the research of Kamble and Telsang (2019), Maynard Operation Sequence Technique (MOST) and Discrete Event Simulation was implemented. However, most focus was placed in the simulation because MOST is a predetermined motion time system which is used to set standard time for the worker to perform a task. This is particularly hard and sophisticated as the level of skill in operator exists as the constraints in this case study; the company cannot expect a low skill level of an operator to perform effectively as an experienced operator. Nevertheless, Discrete Event Simulation implemented by the study of Yasir and Mohamed (2018), and

Kamble and Tealsang (2019) offer visualisation of dynamic effects according to the data provided by the company which is very useful for a complex production system.

In addition, the exploratory study of Mulugeta (2021) and Nallusamy and Saravanan (2016) emphasize on creating line balancing and work standardization in the manufacturing company. Line balancing provides insight on maximizing the utilization of human resources to produce a high output rate. This is imperative to a semi-automated manufacturing line especially for the production that involves manual bottleneck workstation as improvement on human workforce through line balancing provide opportunity to increase productivity and efficiency of workers. However, line balancing will be inappropriate to tackle the production where the bottleneck is appeal in a particular workstation only. This is because line balancing emphasizes on monitoring the production line that involved several workstations to achieve a balanced circumstance. Conversely, work standardization that allows consistent production by using optimal work practices will be recommended for bottleneck that appeal in a particular workstation only as it is able to standardize the optimal work sequence in that station which enable high production outcome and demand fulfilment rate.

In short, Root Cause Analysis will be chosen as the preliminary step in figuring out the potential causes of the manufacturing problem. Meanwhile, 5s practice, Kaizen and Work Standardization will then be implemented to tackle the manufacturing issues in the human-intervention production line. Additionally, redesign facility layout will be employed after considering the constraints within the facility.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the methodology of study. Section 3.2 shows the project framework. Section 3.3 explains the method and tools used in different phases of the framework.

3.2 Project Framework

In this subchapter, a comprehensive framework is developed to clarify the direction on how implementation should be carried out in a chronological order. The framework encompasses several phases, and each phase consists of different actions and decisions related to the project. The steps within a phase are grouped in sequence and connected to each other to offer a clear direction on the project flow. These steps are intended to guide the engineer systematically from the beginning phase until the final phase. The phases of the framework are established as shown in figure 3.1.

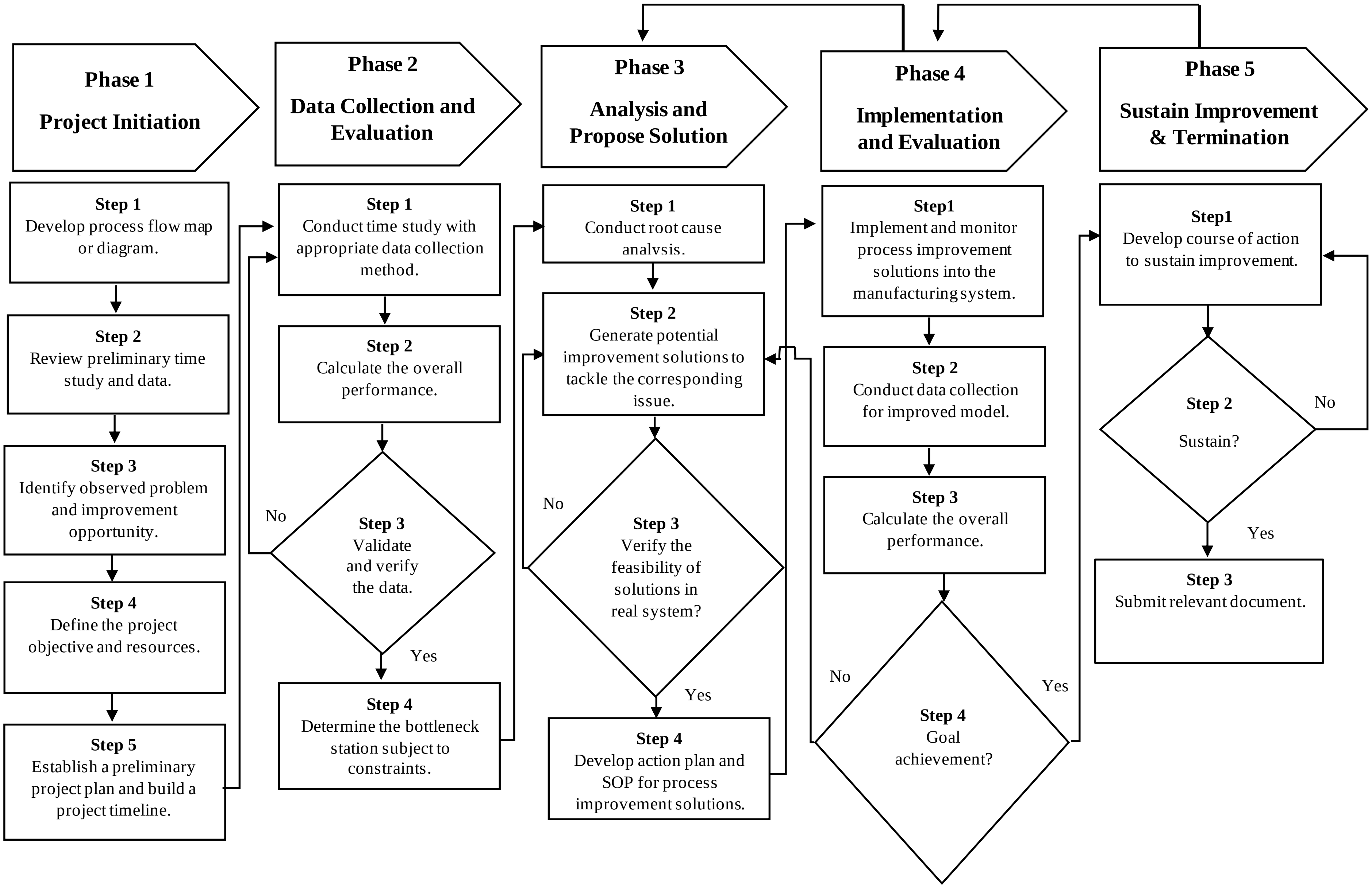


Figure 3.1: Project framework

3.3 Explanation of Framework

This subchapter explains the content in each phase of the framework.

3.3.1 Phase 1: Project Initiation

The development of a project has to begin from an initial idea and concept. Establish a process flow map or diagram promotes study and exploration on how the manufacturing process is operated and the sequences of material flow. Next, review preliminary time study and data allow further comprehension of the process performance in previous projects and the manufacturer's concern. The example of preliminary time study or data could be recording videos or information from past projects such as data, analysis, and performance results. Study on preliminary time study and data is extremely crucial during project initiation to ascertain the process direction on how to tackle the manufacturing issue directly and serve as a database for validation.

Through the proper understanding of the information provided from preliminary time study and data, engineers can identify observed problems and improvement opportunities. This is because capturing the important information can enhance the visibility of problems and allow the team to highlight the area of improvement. For instance, if the area of improvement is time, knowing the current time baseline will help to track the actual time used in the manufacturing against what the manufacturer expected.

In addition, project objectives involve understanding the aims of the project and it will only be defined after having some idea and foresight on the manufacturing operation. The objective of the project should be specific, realistic, time-bound, attainable, and measurable. Clarifying the project objective is integral for successful project execution and helps to monitor the project element in order to align with the target of the manufacturer.

Once engineers understand the project objective, a plan can be devised. Establishing a project plan provides structure and foresight for the execution stage, which help to guide everyone to perform the task toward success. Besides, a project timeline that builds along with the plan allows the tasks to be conducted chronologically and aid in progress tracking. The combination of project plan and timeline drives communication among the team which is significant in project management. Gantt chart is one of the popular tools used to illustrate the project schedule and useful in progress tracking and project management.

3.3.2 Phase 2: Data Collection and Evaluation

The second phase introduces data collection and time study. In this phase, engineers should understand what data should be collected, data collection procedure and method of collecting. This is because data is valuable for process improvement; collecting accurate data helps in maintaining the integrity of the research, while collecting wrong data or excessive data may be useless and time consuming. In this project, time study will be carried out as part of data collection. Time will be the variable, where machine cycle time, labor processing time, machine set up, turn over and breakdown time will be important for a semi-automated production line. Besides, data could be qualitative or quantitative. Adopting appropriate data collecting procedure and method is the key to ease understanding and deliver accurate information to everyone.

Additionally, the most vital objective of data collection is to ensure reliable data and sufficient information is collected for process analysis in order to promote data-driven decision making. Hence, the data collected will be used to calculate and measure the overall process performance for the current system. Some of the significant parameters to determine the process performance are throughput, utilization and productivity. Model verification will come after data collection to determine whether the system meets the requirements and specifications. Besides, validation is conducted subsequently which aims to inspect the accuracy of the data collected to the actual system. Only systems that are verified and validated are considered an accurate representation of the situation at hand.

3.3.3 Phase 3: Analysis and Propose Solution

The whole process can be broken down into several key areas in Phase 3. The main processes that included are determination of manufacturing problems, generation of potential solutions and development of future action plans.

Validated and verified data will first be investigated to identify the bottleneck process or workstation along the production line subject to constraints. This is because bottleneck stations are the obstacles that may slow down or delay the work flow. More attention should be placed in the bottleneck to reduce the non-value-added activities. If the bottleneck station is an automated production line, further improvement may be limited, whereas determining the task or process that contributes to failure or setback in the manufacturing line will be easier to identify the bottleneck in a manual workstation.

Besides, root cause analysis will be the subsequent investigation process on bottleneck stations in order to determine the factors that contribute to the non-value-added activities. A detailed root cause analysis will include the investigation on several aspects and elements in the manufacturing line such as man, material, method, machine and measurement. This is valuable and vital for engineers to have an idea on generating potential improvement solutions. The potential solutions proposed by the engineer must be logic, workable, and tally with the real system. To avoid uncertainty, engineers should conduct a discussion among the team to determine the feasibility of solutions in the real system. If the solution generated is attainable, an action plan and standard operating procedure will be required to provide a comprehensive instruction in order to monitor the process. While, an impractical solution will be rejected and a brainstorming session will be needed for the engineer and the team to turn their vision into reality.

3.3.4 Phase 4: Implementation and Evaluation

In phase 4, the implementation of the proposed solution is able to proceed when all the in-charge workers fully understand the action plan and standard operating procedure for the chosen solution. Engineers are responsible to monitor and control the manufacturing system by continuously performing checks on the states to ensure everything is tally with the plan. To maintain a data-driven result, data collection must be carried out for the improvement model. Similar data collection steps and methods will be executed to ensure sufficient and appropriate data is collected. Furthermore, the overall result for the improvement model will be summarised and compared to the current model. Engineers are required to perform calculations on overall performance and determine the improvement obtained toward goal achievement. Only models that meet the objective of the project and the goal of the company are considered successful. While, a failed model will be rejected and required to rectify by generating attainable solutions to achieve project objectives.

3.3.5 Phase 5: Sustain Improvement & Termination

To achieve an excellence manufacturing operation, the engineer and the team should develop a course of action to sustain continuous improvement in the manufacturing line. Successive controlling, monitoring and inspection is a must; as the only system that strictly adhered with the SOP and guidelines could maintain a high efficiency operating process and producing throughput that meet company expectation over the long run.

CHAPTER 4

VALIDATION OF PROPOSED FRAMEWORK

4.1 Introduction

This chapter discusses the application of framework into the study. Section 4.2 explains the information of the research company. Section 4.3 validates the proposed framework.

4.2 Information of Research Company

This research is conducted in an air filter manufacturing company located in Batu Gajah, Perak. The company is an industrial filtration specialist that focuses on the development and production of air filters and clean air solutions. They are currently experiencing low throughput production for a semi-automated production line and the product that focused on this production line is Product X.

The managerial action of product X was followed by a make-to-stock (MTS) system to save the production cost and the company did hold inventory for forecasted demands. In 2020, the manufacturing line of the company was able to produce 202 units of product in a year. Exponential increment on customer demands in the following year leading to an increasing manufacturing operation and they were successfully producing 1426 units of products. The company has forecasted that demand will increase by 30% compared to the actual demand in the year 2021.

According to the company, the factory is operated with a three-shift system and each shift takes 8 hours. An employee is entitled for 2 breaks in a shift with 30 minutes each.

4.3 Validates the Proposed Framework

This subchapter explains validation of each phase of the framework.

4.3.1 Phase 1: Project Initiation

Project initiation was developed by involving selection of manufacturing line and product type. The lead engineer took major responsibility to determine which production lines were worth to be improved. Based on the forecasting from the company, Product X was considered one of the product types that have high possibility to capitalize on profit. This is due to the fact that it is an eco-friendly product which every component is able to reuse as long as it is still functionable. This promotes lesser waste and aids in cost savings. Therefore, product X was selected as the product type in this project.

The production of product X involves a semi-automated production where a combined system of automated and manual workstation is prominent. In the study, the exploration of the manufacturing process was carried out with a process flow map shown in Figure 4.1. The cycle time for each process shown in the figure was obtained from the company.

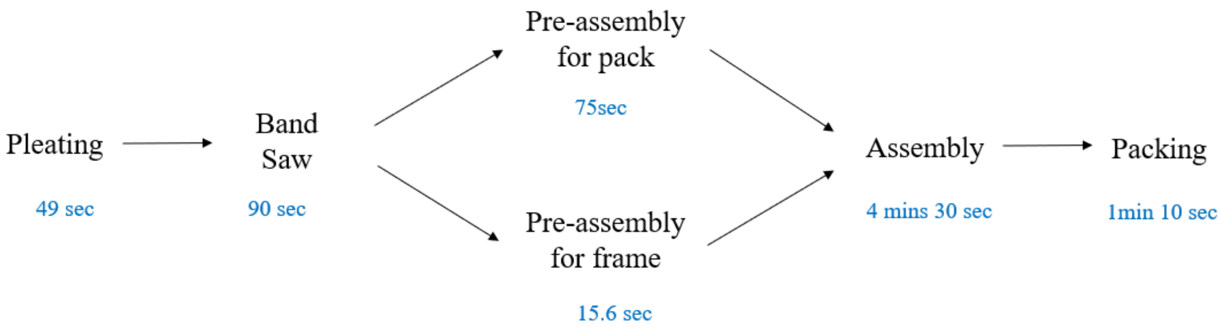


Figure 4.1 Process flow map for product X.

The first step of the production is involved in an automated machine to pleat the filter media. A row of filter media will be input to the machine to produce 62 pieces of 40 x 478 mm pleated media. Average machine cycle time is mean 49 seconds per piece with machine breakdown time and set up time included. Next, the aluminum pieces will be cut into desired shape using a bandsaw machine in order to fix into the filter media. An operator is required to control the bandsaw machine and the average cycle time is 90 seconds. Pre-assembly of the media pack and frame will come after the filter media is ready. Both of the pre-assembly processes are conducted manually with cycle time of 75 seconds and 15.6 seconds respectively. Subsequent assembly work will be executed after the media pack and frame are well-prepared. Two workers are in-charge with the tasks and the average cycle time is 4 minutes 30 seconds. Finally, the finished goods will be sent to pack. Bagging process is handled by an operator and finished goods are packed in 5 units per box. From the flow map, the bottleneck occurs in a manual workstation where the assembly process is conducted. This is because the workstation contributes lowest output and longest cycle time.

To allow further comprehension of the process performance, the lead engineer chose to interpret their concern by using videos to transmit the information. All the manufacturing processes were recorded and displayed for open discussion. During the meeting, the data and performance results were reviewed and examined according to the goal of the company, the expectation of the engineers toward the production line, and their observation on manufacturing issues. For this case, the company's goal is to improve the production throughput by 30% higher than the actual demand in 2021. However, existing work practice inhibited fulfillment of the need as several manufacturing issues were discerned.

Reviewing the data and performance results encourage assessment with the intention of making amendments if necessary. Since production throughput is known as the amount of a product that the manufacturer is able to produce in a specified time frame. Therefore, strong interrelation between production throughput and time allows changes to be instituted by focusing mainly on cycle time reduction and productivity improvement. Increasing the amount of output is an alternative approach if reduction of cycle time is difficult to measure. Additionally, the lead engineer expressed his preference to ameliorate the production layout and materials allocation. They found out that labours are experiencing difficulty during material searching and leading to time loss. To remedy the issue, they are expecting solutions that could minimize the impacts due to the weaknesses of the production line such as restricted movement in the working area.

With regards to this, preliminary analysis of the project was performed by identifying observed problems based on perspective. A few highlights about the key element of the manufacturing system are described as follows. First of all, since time is one of the factors that brings massive impacts toward the process, therefore any events that are idle or non-value-added will be considered as an issue that need to be solved. Based on the observation from preliminary time study, high visibility of problems could be found in the assembly workstation where low utilization of labour created waste and increased time spent on non-value-added activities. For example, W2 was spending much of the time waiting for W1 to complete his tasks. Low awareness of W2 toward work cooperation leading to imbalance workload distribution and time waste.

Project review and problem identification on preliminary time study was explicitly depicted the project direction and it is discovered that time will be the main factor where any process that may prolong the cycle time is wished to solve. Moreover, improvement opportunities could be generated by considering several aspects such as labour, workload distribution, production layout and material allocation.

Valuable information from preliminary time study and unambiguous project direction offers foresight to achieve the company goal. Since tangible target was defined, project objectives will follow the company goal as it is fulfilling the criteria in SMART which are specific, measurable, attainable, relevant and time-bound (Ogbeiwi, 2017). Meanwhile, production resources such as operators, machines, and workstations were remained.

To provide a structural approach for execution, a six-month plan was created. Figure 4.2 illustrates a gantt chart for projected time for tasks in the early stage. In regards, several objectives were instituted into the plan to ensure the decision-making outcome met the overall project objectives. The first objective is to determine the root causes of the production issues. Secondly, to generate feasible solutions that are able to tackle the corresponding production issues. Thirdly, to implement the solution into the production line.

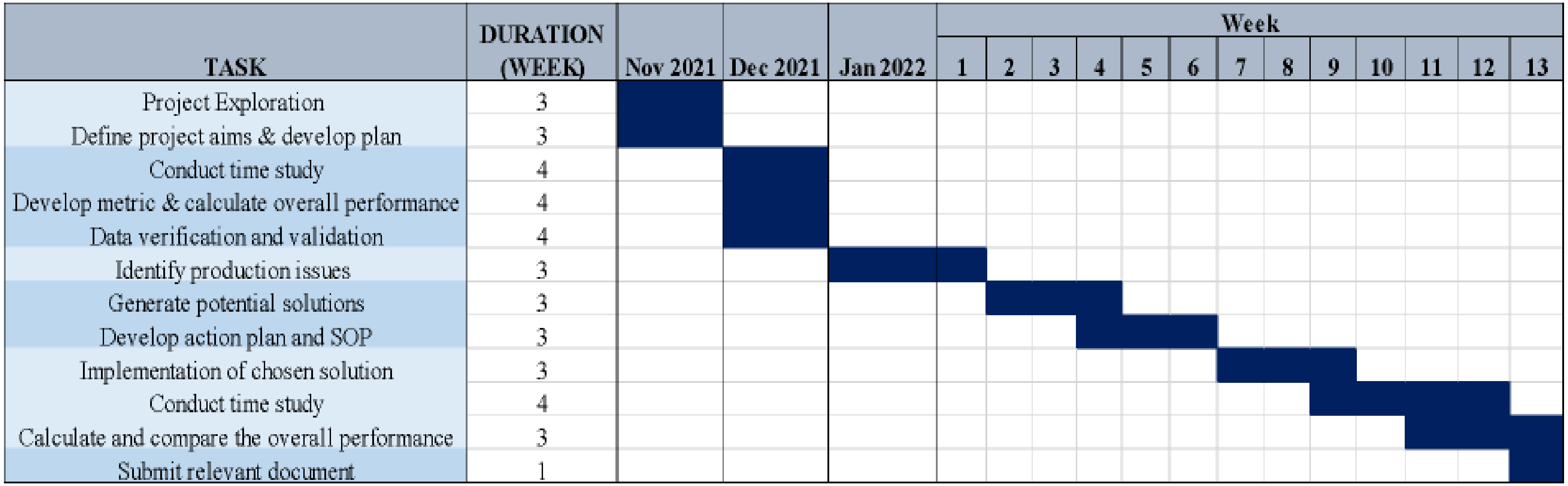


Figure 4.2 Projected time for tasks in the early stage.

4.3.2 Phase 2: Data Collection and Evaluation

A time study is a work measurement activity that requires proper planning and well preparation. In such a context, a general meeting that involved discussion on arrangement of production schedule, working shift and allocation of manpower was conducted with the lead engineer to foster the data collection process and aid in time saving. Besides, the time study took place only during the period that accurately represents the company's typical work environment. For instance, the lead engineer will arrange the production schedule based on the availability of operators. Time study will be postponed to a regular period with normal operating conditions if insufficient personnel occurred.

The main objective of conducting time study is to ensure reliable data and sufficient information for process analysis. Hence, to set a standard to control performance, it is essential to measure data on every single manufacturing process along the production line. A general time studies were conducted in the manufacturing line to collect the cycle time of each station. Also, detailed time studies that consisted of the processing time of each task was taken for only the bottleneck station. In this research, the manufacturing bottleneck arose in the manual workstation, detailed data collection in this particular workstation was much significant for data-driven decision making. Whilst, time studies for other workstations were accomplished with the purpose of clarifying this fact.

To be able to gather useful data, the time study was handled with the aid of equipment such as stopwatch and video camera. Time recorded data was then inserted into Microsoft Excel for ease of documentation. Figure 4.3 shows the template for data collection. The results can be obtained in Table 4.1 and Table 4.2.

Product Type	Date	Time	Number of Worker	Workers' Name

Sample / Task		Time(s)									
		1		2		3		4		5	
W1	W2	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2
Total											

Figure 4.3: Template for data collection in bottleneck station.

Data Collection 1 was conducted on 02/12/2021 with 2 low skilled operators. 10 sets of data were collected as the production schedule was planned to output 10 units of product on that particular day.

Table 4.1: Time study result for data collection 1.

Product Type	Date	Time	Number of	Worker's Name
X	2/12/2021	10.00-12.00PM	2	Muhammad Ismail Raja Wahil

Task		Time(s)																				AVG
		1		2		3		4		5		6		7		8		9		10		
W1	W2	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2	
Open the packaging seal		31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	31
Asking for unsure		65	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	65
	Take and Check the U-frame	8	-	-	3	-	5	28	-	-	3	-	3	-	4	-	6	-	5	-	5	7
Wear Glove		-	-	-	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	6
Idle/ Waiting - Looking Around	Idle/ Waiting - Waiting for W1	-	-	-	-	-	-	-	-	5		-	3	-	-	-	14	-	-	-	5	6.8
Clean the workstation		-	-	-	-	-	-	31	-	-	-	-	-	-	-	-	-	-	-	-	-	31
Take and Insert the Face Guard		16	-	40	-	39		22	-	17	-	18	-	23		17		21	-	25	-	23.8
Waiting for the Media		-	-	-	-	-	-	-	-	15		-	-	-	-	-	-	-	-	-	-	15
Check and Put the Media		52	-	46	-	55	-	88	-	52	-	53	-	15	-	40	-	39	-	35	-	47.5
Take and Insert the Media Clamp		48	-	25		45		41	-	31		47		28		32		30		36		36.3
Idle/ Waiting - Adjusting the tool that producing the PU which blocking the workers to perform their task.		-	-	-	-	-	-	22	-	-	-	-	-	-	-	-	-	-	-	-	-	22
Open the packaging seal		45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	45
Take and Insert the Face Guard		30	-	30	-	24	-	12	-	13	-	18	-	8	-	12	-	19	-	17	-	18.3
Open the packaging seal of Middle Bar		50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	50
	Adjustment - The face guard is not in a proper position	-	-	-	-	-	-	-	-	-	-			-	-	-	8	-	-	-	-	8
Take and Insert Middle Bar		36	-	75	-	53		55		54		22		54		22		42		37		45
Asking for unsure		32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32
Insert Middle Bar		10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
Adjustment - The face guard is not in a proper position		-	-	-	-	-	-	-	-	-	-	50	-	-	-	-	-	-	-	-	-	50
Find another worker		66	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	66
Put the Top Cover		26	-	99		40		44		24		17		31		25		29		25		36
Asking for unsure		-	-	-	-	-	-	11	-	-	-	-	-	-	-	-	-	-	-	-	-	11
Screw	Hold	35		56		89		72		42		55		89		62		55		47		60.2
	Take and Insert the Middle Rib	25	-	-	21	-	27	-	16	-	14	-	18	-	12	-	12	-	13	-	10	16.8
Preparing the screw		-	-	-	-	-	-	-	18	-	-	-	-	-	-	-	-	-	-	-	-	18
Screw	Hold	10		52		62		17		15		13		64		34		29		20		31.6
Change to another side		3		-	5	-	6	7		-	3	-	6	6	-	3	-	-	3	-	3	4.50
Idle/ Waiting - Waiting for W2		-	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
	Take and Insert the Middle Rib	12	-	-	33	-	33	-	13	-	15	-	6	-	8	-	9	-	10	-	10	14.9
Screw	Hold	20		132		94		22		14		15		30		28		15		21		39.1
Rescrew		-	-	-	-	-	-	-	-	-	-	-	-	-		30	-	-	-	-	-	30
Inspection + QAQC		26	-	27		35		27		25		27		26		22		28		28		27.1
Place the Panel to the Rack		17	-	5	-	8	-	17	-	12	-	11	-	16	-	16	-	18	-	20	-	14
Total		663		649		621		569		354		382		414		392		356		344		474.4
																				Total Time, Tx	4744	

Data Collection 2 was carried out on 25/12/2021 with 2 high skilled operators. Only 3 sets of data were taken as the current inventory was able to support the customer demand.

Table 4.2: Time study result for data collection 2.

Product Type	Date	Time	Number of Worker	Worker's Name			
x	25/12/2022	10.00-10.20AM	2	Ishaq Abdullah Ahmad Zaki			
Task		Time(s)					
		1		2		3	
W1	W2	W1	W2	W1	W2	W1	W2
	Take and Check the U-frame	-	5	6	-	12	-
Take and Insert the Face Guard		16	-	18	-	23	-
Check and Put the Media		32		28		20	
Take and Insert the Media Clamp		30		15		14	
Take and Insert the Face Guard		22	-	30	-	31	-
Take and Insert Middle Bar		32		23		24	
Put the Top Cover	Hold	37		40		25	
Screw	Hold	63		45		50	
Preparing Screw	Take and Insert the Middle Rib	17		13		15	
Screw	Hold	24		20		18	
	Change to another side	-	6	-	3	-	3
Preparing Screw	Take and Insert the Middle Rib	11		9		13	
Screw	Hold	20		14		22	
	Inspection + QAQC	-	30	-	13	-	20
	Place the Panel to the Rack	-	9	-	9	-	12
Total		354		286		302	
					Total Time, Tx		942

In manual bottleneck station, the amount of time taken by the operators to complete a particular task was measured and the standard time was defined. In engineering, standard time is the average time taken by an operator to complete a given task taking into account the occasional allowances to prevent operator fatigue and it is a useful metric that was applied to determine the production throughput. The standard time and production throughput was calculated using the formula below and the result can be obtained in Table 4.3.

$$Standard\ Time\ per\ sample = \frac{Total\ Cycle\ Time\ for\ n\ sample}{Number\ of\ sample, n} \tag{4.1}$$

$$Throughput\ per\ hour = \frac{3600 \text{ sec } per\ hour}{Average\ Cycle\ Time} \tag{4.2}$$

Table 4.3: The performance results for the current system.

Standard Time per sample (sec)	**Average Cycle Time (sec)**	**Throughput (unit/hour)**
374	344	10.47
314		

Since there were two workers involved in the bottleneck manual workstation, the utilization of both workers was determined with the formula:

$$Utilization = \frac{Total\ working\ time\ for\ particular\ worker}{Total\ cycle\ time\ for\ particular\ unit}\ X\ 100\% \tag{4.3}$$

Table 4.4: The utilization result for both workers in data collection 1.

Data Collection 1				
Sample	**Total working time / unit (sec)**		**Utilization (%)**	
	W1	**W2**	**W1**	**W2**
1	663	68	100	10.26
2	587	453	90.44	69.80
3	550	528	88.57	85.02
4	522	291	91.79	51.14
5	319	229	90.11	64.69
6	346	232	90.58	60.73
7	390	369	94.20	89.13
8	343	369	87.5	94.13
9	325	259	91.29	72.75
10	311	247	90.41	71.80
Average			91.49	66.95

Table 4.5: The utilization result for both workers in data collection 2.

Data Collection 2				
Sample	**Total working time / unit (sec)**		**Utilization (%)**	
	W1	**W2**	**W1**	**W2**
1	304	316	85.88	89.27
2	261	232	91.26	81.12
3	273	236	90.40	78.16
Average			89.18	82.85

For data to be accurate and representative, the time studies were taken from different operators to ensure that the sample is truly random. However, high inventory of finished goods that accumulated before the Movement Control Order (MCO) was problematic for the company as a consequence they operate under a make-to-stock (MTS) system. As a result, the production was unable to run as usual, even though the demand of customers was increasing after the COVID-19 pandemic. Low manufacturing operation and production output affected the study leading to low sample size of data was able to be collected. It is undesirable as low sample size of time studies data could be hard to determine a precise and accurate value of worker efficiency and production throughput.

To remedy the situation, a learning curve was applied to reveal the relationship between the forecasted production output and the time and it will be beneficial in assisting the calculation process of production throughput after that. Based on Chatzimichali and Tourassis (2008), a learning curve is significant to work as a planning tool to understand and identify how quickly a task could be done over a period of time as the worker on that particular task gains proficiency. Besides, the learning curve provides measurement for repetitive tasks of an operator and it is said that human performance usually improves when a task is repeated. (Chatzimichali and Tourassis, 2008).

After consulting the engineer, it was suggested that the forecasted production output was set based on the mean production volume before the COVID-19 pandemic, which is 20 units per day. The learning curve calculations was then applied with the formula:

$$T_x = K \sum_{u=1}^{x} (u^n) \qquad (4.4)$$

Where,

$u = the\ output\ unit\ number$

$T_x = total\ time\ needed\ to\ complete\ x\ units\ of\ output$

$K = time\ needed\ to\ produced\ first\ output\ unit$

$s = learning\ curve$

$n = \frac{\log s}{\log 2} = the\ learning\ curve\ exponent$

However, inadequate supporting information from previous project creates a dilemma when solving this equation. This is due to the learning curve, s appeal as an imponderable unknown in this study and a finite number of possible values could exist. To cope with this uncertainty, Yang, Meng and Lee (2004) argued that trial-and-error technique enable multiple attempts to be made, and therefore beneficial in determining the learning rate of the operators. Table 4.6 (a) shows the result of the calculation with a learning rate of 90%, which is s=0.9.

Table 4.6 (a): The calculation results for product X using a learning curve with actual production output.

Data Collection	K	x	s	$\sum_{u=1}^{x}(u^n)$	Total completion time, T_x (sec)		Percentage Error (%)
					Theoretical	Calculation	
1	663	10	0.9	7.12	4744	4717	0.57%
2	354	3		8.95	942	928	1.49%

Since the percentage errors obtained were critically low (less than 2%), it can be deduced that the operators in data collection 1 and data collection 2 have a similar learning rate, which is s=0.9. The learning rate was then applied into the formula again and calculated the total completion time, T_x for 20 sets of forecasted output as the mean production volume before the COVID-19 pandemic is 20 units per day (refer Table 4.6(b)).

Table 4.6 (b): The calculation results for product X using a learning curve with forecasted production output.

Data Collection	K	x	s	$\sum_{u=1}^{x}(u^n)$	T_x (sec)	$\overline{T_x}$ (sec)	$\overline{\overline{T_x}}$ (sec)
1	663	20	0.9	14.61	9685.04	484.25	371.41
2	354				5171.20	258.56	

Standard time and production throughput were measured subsequently and shown in Table 4.7. Besides, the percentage differences in throughput were calculated using the formula:

$$Percentage\ Difference\ (\%) = \frac{|V_2 - V_1|}{V_1}\ X\ 100\% \qquad (4.5)$$

Table 4.7: The calculation result for actual production output and forecasted production output.

	Actual production output	**Forecasted production output (20 sets)**
Average Cycle Time/ Standard Time (sec)	344	371.41
Average Idle/ Waiting Time (sec)	8.80	-
Average Time Spent on Motion (sec)	17	-
Throughput (Unit/hr)	10.47	9.70
Percentage Difference (%)	7.45	

Based on Table 4.7, the result of the percentage difference in actual production output and forecasted production output displayed a minor discrepancy in production throughput which is 7.45%. Since, the percentage error is low, it could be deduced that even if more sample size was collected, the production throughput was still maintained with 10 units per hour in a daily production.

Ultimately, model verification and validation were implemented by having a model checked with the lead engineer to insure the process matches the requirements and specifications. In this research, project verification and validation supplied evidence that support the credibility of the claims: the process bottleneck was incurred in the manual assembly workstation and it significantly slowed down the production. Plus, it is discovered that different levels of human skill appeal as a limiting factor in the project. High skilled operators (Data Collection 2) took a shorter time to complete a part, whereas junior operators (Data Collection 1) spent a longer period to assemble one unit in the manual bottleneck station.

4.3.3 Phase 3: Analysis and Propose Solution

To manage the bottleneck, a fishbone diagram was drawn to determine the factors that contribute to the non-value-added activities. Different aspects were studied such as material, man and method as illustrated in Figure 4.4. It is found out that poor arrangement of tasks, inconsistent performance, imbalance workload distribution, poor workflow and poor layout design were the main issues encountered in the production line.

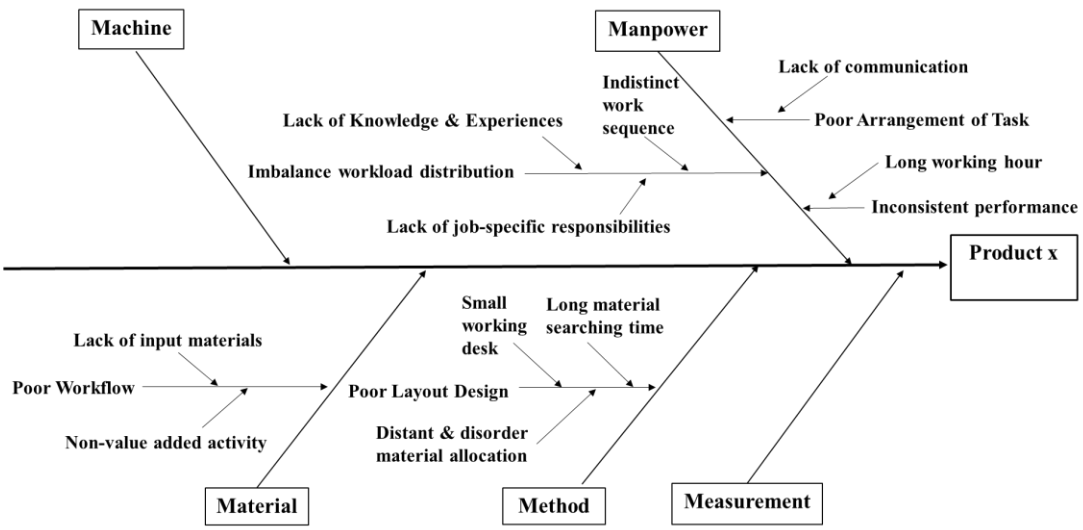


Figure 4.4: Fishbone diagram

According to Table 4.4, there is an imbalance in workload distribution incurred, where W1 was responsible for more tasks, while W2 was underutilized. This undesirable circumstance was non-value-added to the production and resulted in creating more idle time. The major factor that contributed to this was the lack of knowledge and experience of workers in particular tasks. This can be shown as the workers were lacking expertise and skills in problem solving, having inadequate information about the latest model and thus led to time wasting for verifying.

Moreover, uneven task allotment was induced on account of absence in job-specific responsibilities and indistinct work sequence. It is noticed that there was a jumbled task procedure and varying working steps were involved in the production where tasks handled by each operator were inconsistent in every production cycle as shown in Table 4.1 and Table 4.2. Absence of normative procedure and proper task allocation will affect the standard cycle time especially when the operator skilled level appeals as the constraint in the production (Puvanasvaran, Hamid, and MNH, 2018). In consequences, workers were unable to perform in pace, and lead to imbalance workforce.

Undoubtedly, deficient or muddle communication of operators was observed and it is considered one of the influential causes that inhibited the operators to structure their task integrally before the operation and resulting in inequity levels of contribution and poor arrangement.

The erratic utilization results of W2 from Table 4.4 embodied an inconsistent performance of an operator in the manufacturing line. This may be due to human performance may vary from time to time depending on their capability and duration of work (Brolin, 2016). In such a context, successive night shifts that associated with the particular worker was the factor that affected individual performance. Worker was underperforming as heavy workload and long working hours contributed to high fatigue level on personnel.

Furthermore, poor workflow was manifested in the production line as material unavailability was encountered in the bottleneck station. The system is said to be starved as the upstream pre-assembly process was unable to support the input materials for downstream assembly workstation on time and created a delay (Conway et al. 1988). The situation worsens when non-value-added activity was found on servicing, cleaning and adjusting. According to Table 4.1, it is observed that workers were spending time on opening the packaging of materials, wearing gloves, cleaning and adjusting the workstation which elicited temporary cessation of production. As a result, potential production capacity was lost due to the occurrence of work stoppage.

Apart from that, adjustment and rearrangement were taking place due to the reason workers were finding ways to make work more comfortable. This is due to the fact that the small working desk was confined to physical activity and the accumulation of materials restricted the workspace. Besides, distant material allocation in current layout impedes direct and rapid material processing as unnecessary movement of personnel was incurred. In fact, excessive motion may take attention off work, generate wastes and loss in productivity. This is because the workplace environment is the most critical factor for the personnel to perform. The physical aspects of a workplace environment have a direct impact on the employees' productivity, performance, health and safety, comfort, concentration and job satisfaction (Roelofsen, 2002). Ideal workspaces are those where people feel free to move around and don't feel tied to their desks which are able to create more opportunities for collaboration.

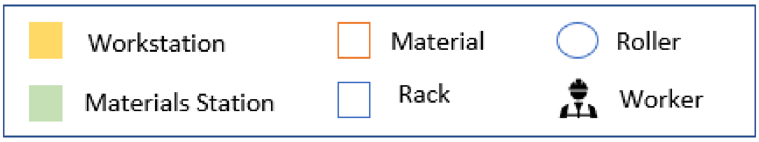
Additionally, long material searching time was observed by the lead engineer as workers were experiencing difficulty in distinguishing similar product components and materials. In an ideal condition, orderly managed and well-organized material allocation is essential to allow effective searching and reduce time loss.

In summary, there are 2 wastes identified in the bottleneck station under the lean manufacturing system which are waiting and motion. To improve the current system, potential solutions were generated. Grouping the information from desk research employing a single modified system in the bottleneck station with the aid of 5s practice, Kaizen and Work Standardization as shown in Table 4.8.

Table 4.8: Description of possible solutions to solve corresponding root causes.

No	Aspect	Root Causes	Solutions
1	Method	Poor Layout Design	5s principle and redesign facility layout
2	Manpower	Imbalance Workload Distribution	Kaizen - Work standardization
3	Manpower	Poor Arrangement of Task	Kaizen - Work standardization
4	Material	Poor Workflow	Kaizen - Standard operating procedure
5	Manpower	Inconsistent Performance	Kaizen - Provide training

Time wasted due to poor layout design was suggested to address using 5s principles. More emphasis was placed in the Set in Order and Sort technique compared with other three main practices such as Shine, Sustain and Standardize. Organized and sufficient allocation areas for materials and tools was set with proper labelling and colour coding to offer convenience and reduce the searching time of materials as shown in Figure 4.5(b). Similar material such as inlet face guard and outlet face guard were labelled with different background colour and placed in area A. The placement of the face guards was set to be oriented closer to the personnel in-charge to ease the process. For example, the outlet face guard was set in the position beside W2. This is because W2 was assigned to handle the outlet face guard whereas W1 was responsible for inlet face guard and media as referring to Table 4.9. Moreover, operators easily get confused between middle bar and middle rib. To remedy the issue, both materials were positioned with a gap, which was then occupied with the media clamp. Media clamp is one of the materials that are easy to recognize, so it was beneficial to improve visual identifications and facilitate the searching of materials.



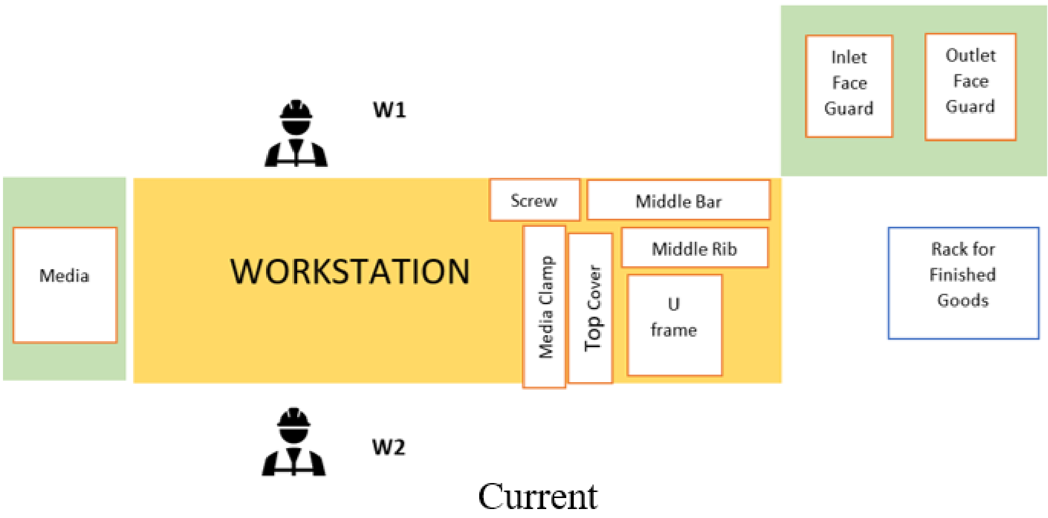


Figure 4.5(a): Current workstation layout design.

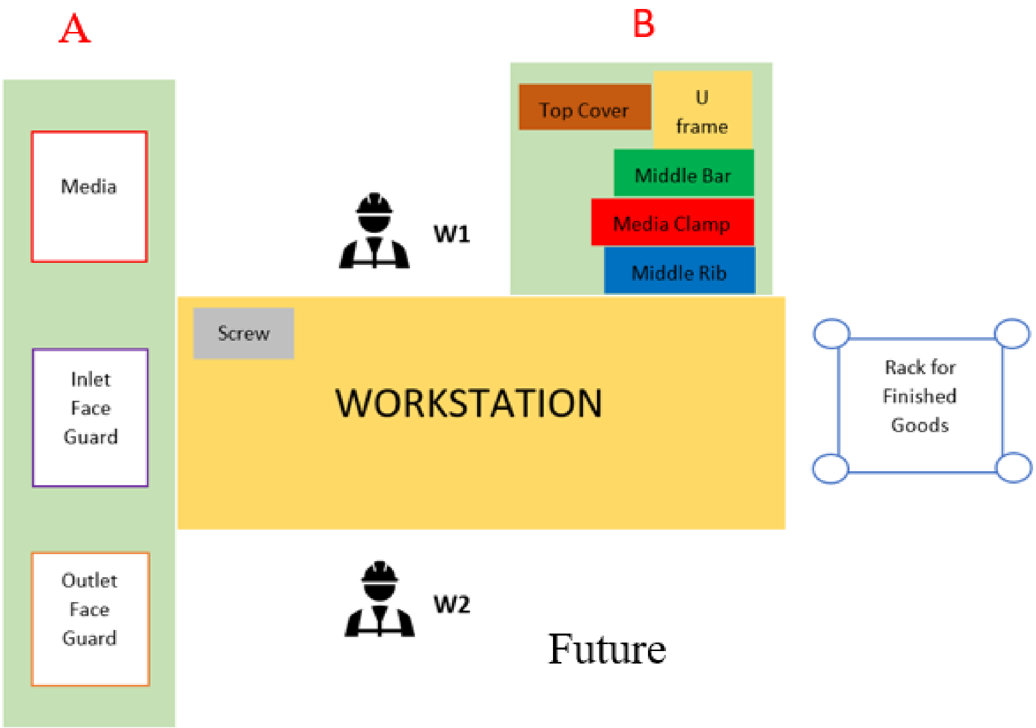


Figure 4.5(b): Future workstation layout design.

Meanwhile, redesign facility layout was recommended after considering the constraints within the facility. Since the working area was restricted, adjustment on the area for material allocation could be done to provide sufficient working area for the workers to assemble the products as shown in Figure 4.5(b). It is also prominent to minimize the unnecessary movement of workers, materials and goods by redesigning the material allocation area nearer to the workers. For instance, area A was allocated with materials that are bigger in size, while small size feedstocks were filling the area in B. To avoid defects when handling the finished goods, a rack with rollers was planned to be installed to smoothen the transportation process.

Furthermore, practice work standardization in the manufacturing line alters dominant system characteristics to influence performance. To tackle the issue of imbalance in workload distribution and poor arrangement of tasks, the assignment of the task in the manual workstation was planned to modify and adjust to achieve equalized workload distribution. No waiting was available for the labors as all the task was assigned to be done parallelly and simultaneously as shown in Table 4.9.

Table 4.9: Modified task assignment in bottleneck station.

<table>
<tr><th colspan="2">Task</th><th rowspan="2">W1</th><th rowspan="2">W2</th></tr>
<tr><th>W1</th><th>W2</th></tr>
<tr><td>*</td><td>Take and Check the U-frame</td><td>/</td><td>/</td></tr>
<tr><td>*</td><td>Take and Insert the Outlet Face Guard</td><td>/</td><td>/</td></tr>
<tr><td colspan="2">Check and Insert the Media</td><td>/</td><td>/</td></tr>
<tr><td>Take the Inlet Face Guard</td><td>Take and Insert the Media Clamp</td><td>/</td><td>/</td></tr>
<tr><td>Insert the Inlet Face Guard</td><td>Take and prepare the Middle Bar</td><td>/</td><td>/</td></tr>
<tr><td colspan="2">Insert Middle Bar</td><td>/</td><td>/</td></tr>
<tr><td>Take and Insert the Top Cover</td><td>Hold</td><td>/</td><td>/</td></tr>
<tr><td colspan="2">Screw</td><td>/</td><td>/</td></tr>
<tr><td>Prepare screw</td><td>Insert the Jig
Insert the Middle Rib</td><td>/</td><td>/</td></tr>
<tr><td>Screw</td><td>Hold</td><td>/</td><td>/</td></tr>
<tr><td></td><td>Change to another side</td><td></td><td>/</td></tr>
<tr><td>Prepare screw</td><td>Insert the Jig
Insert the Middle Rib</td><td>/</td><td>/</td></tr>
<tr><td>Screw</td><td>Hold</td><td>/</td><td>/</td></tr>
<tr><td>Inspection</td><td>*</td><td>/</td><td>/</td></tr>
<tr><td>Place the panel to the rack</td><td>*</td><td>/</td><td>/</td></tr>
<tr><td colspan="2">Total Time (s)</td><td></td><td></td></tr>
</table>

To minimize the impact of operator's technical skill level towards the production cycle time, rivets were recommended to replace the use of screws. This is because installation of rivets is fast, rapid and requires low technical skill. Plus, it is able to hold and secure the material better, which may reduce the chances of getting loose. On the other hand, the screw is particularly small and tiny, holding, adjusting or driving the screw will be troublesome to the operator and will prolong the cycle time. This could be noticed as the average cycle time spent on driving the screws on the top cover took a mean value of 1.0 minute per unit based on Table 4.1. In such a context, rivets were suggested to replace the screw to shorten the processing time. Nevertheless, if the company persisted in using screws to assemble the parts, a jig was recommended as shown in Table 4.9 to hold and fix the part for the purpose to ease the screw driving process.

Subsequently, the decision of selection for potential improvement solutions was relied upon the engineer team. According to the engineer team, the modified system was considered as an attainable and feasible solution to achieve as it does not involve high cost and complicated procedures, hence it was encouraged to be implemented. The only exception was incurred for the application of rivets as it is unable to reuse, and rivet cut out process may be sophisticated and will spoil the material.

To monitor the modified system, an action plan and standard operating procedure was created to hand out new guidelines to the workers. The criteria of the proposed solution were followed:

- Pre-assembly should be done before the assembly process. For instance, the pre-assembly of the pack must be completed before the assembly process to avoid starvation.
- All the materials should be well-prepared and undergo inspection before the assembly process. For example, the media should be checked before the assembly process, in order to reduce time spent on checking the media during assembly. Besides, the packaging seal of all the materials should be removed and arranged properly in its position which follows the labelling or colour-coding.
- Workers should not wait for others. Workers can start their task immediately even if another worker is busy with the previous task.
- Workers should standby for their job and be well-trained before they undergo the assembly process.
- Add one more screwdriver and jig.
- All the material should arrive Just-in-Time, and the worker in-charge for material handling should load up the material to maintain a smooth workflow.
- Increase group training sessions and ongoing professional development to enhance team members' skill sets.

Besides, the comprehensive action plan also encompassed the diagram of new layout design and unambiguous task procedures and workflow as shown in Figure 4.5 and Table 4.8. Time allocation for workers to clearly go through the plan and trials run was conducted in a two weeks period before getting ready for implementation. To ensure the trail run was able to run smoothly, all the operators that are in-charge for this particular production were involved to encourage information sharing and open discussion to accelerate the adoption of the new system. Meanwhile, the engineer team was supervised along the trials section to ensure everything was tallied to the plan and they were responsible to identify the greatest need and help of the operators.

4.3.4 Phase 4: Implementation and Evaluation

Implementation of the new modified system was put into practice after the workers recognized the changes and steps for improvement. To ensure the processes continuously uninterrupted and were completed on a prescribed schedule, regular checking, overseeing and controlling all the aspects of the modified system, from conception to completion was executed by the engineers. Actions that an engineer were carried out involved:

- Assist and support implementation of process according to the production plan and SOP.
- Observe and supervise the execution of a modified system.
- Help and resolve sudden issues that are keen to fix.
- Gather information that is significant for future study.

Time studied was then resumed when the production was stable. Data collection procedure and method of collecting was constant as mentioned in phase 2. Table 4.10 and Table 4.11 shows the time studies result for the proposed solution.

New data collection 1 was conducted on 11/03/2022 with 2 low skilled operators. 4 sets of data were collected as the remaining production units to be produced on that particular day is only 4.

Table 4.10 Time study result for new data collection 1.

Product Type	Date	Time	Number of	Time	Worker's Name
X	11/3/2022	1300-1320	2	1300-1320	Muhammad Ismail Raja Wahil

Task		Time(s)			
		1	2	3	4
W1	W2	W1 W2	W1 W2	W1 W2	W1 W2
*	Take and Check the U-frame	13	7	8	9
*	Take and Insert the Outlet Face Guard	15	13	20	20
Check and Insert the Media		17	21	15	13
Take the Inlet Face Guard	Take and Insert the Media Clamp	16	17	15	14
Insert the Inlet Face Guard	Take and prepare the Middle Bar	13	12	16	21
Insert Middle Bar		11	16	17	21
Take and Insert the Top Cover	Hold	15	18	16	11
Screw		25	31	40	31
Prepare screw		10	11	10	11
Screw	Hold	37	26	18	20
	Change to another side	2	3	4	5
Prepare screw	Insert the Jig Insert the Middle Rib	9	9	8	10
Screw	Hold	16	16	10	15
Inspection	*	28	20	16	14
Place the panel to the rack	*	10	8	9	6
Total Time (s)		237	228	222	221
				Total Time, Tx	908

New data collection 2 was conducted on 15/03/2022 with 2 high skilled operators. 10 sets of data were collected as the production schedule was planned to output 10 units of product on that particular day.

Table 4.11 Time study result for new data collection 2.

Product Type	Date	Time	Number of Worker	Worker's Name
x	15/3/2022	1050-1136	2	Ishaq Abdullah Ahmad Zaki

Task		Time(s)																			
		1		2		3		4		5		6		7		8		9		10	
W1	W2	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2
-	Take and Check the U-frame	2		2		2		4		5		3		5		4		5		4	
-	Take and Insert the Outlet Face Guard	20		19		17		15		18		8		10		13		22		14	
Check and Insert the Media		28		13		23		21		17		20		24		17		16		17	
Idle		-	-	-	5	3	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-
Take the Inlet Face Guard	Take and Insert the Media Clamp	14		10		15		15		13		16		16		23		16		14	
Idle		-	-	5	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-
Insert the Inlet Face Guard	Take and prepare the Middle Bar	13		8		10		20		7		6		7		8		9		10	
Insert Middle Bar		20		12		13		20		10		10		12		10		9		11	
Take and Insert the Top Cover	Hold	24		17		15		26		22		22		18		17		20		18	
Screw		19		45		20		17		30		27		14		24		16		24	
Prepare screw	Insert the Jig Insert the Middle Rib	13		15		15		13		15		8		11		9		12		19	
Screw	Hold	12		20		18		12		20		32		10		17		11		14	
	Change to another side	6		3		5		6		5		3		4		4		6		6	
Prepare screw	Insert the Jig Insert the Middle Rib	8		12		11		6		10		8		6		7		10		8	
Screw	Hold	17		15		12		8		13		16		9		10		10		15	
Inspection	-	14		6		9		7		7		9		6		8		11		7	
Idle		-	-	-	-	7	-	-	-	-	-	-	-	10		-	-	-	-	-	-
Place the panel to the rack	-	8		6		14		8		7		5		5		5		6		5	
Total Time (s)		218		213		209		198		199		193		177		176		179		186	
																			Total Time, Tx	1948	

To determine the performance result for the new system, identical metric as shown in phase 2 was applied, where the table was interpreted to organize the result of standard time and production throughput.

Table 4.12: The performance results for the future system.

Standard Time per sample (sec)	**Average Cycle Time (sec)**	**Throughput (unit/hour)**
227.00	210.90	17.06
194.80		

In the next section, the performance results of the current system and improvement system were compared as shown in Table 4.13. The percentage improvement was calculated using the formula as manifested below and the result was recorded in Table 4.13.

$$Percentage\ Improvement(\%) = \frac{(T_F - T_i)}{T_i}\ x\ 100\% \qquad (4.6)$$

Table 4.13: The result of standard time and production throughput for future system.

	Current System	**Improvement System**	**Improvement System (w/v 30 sec allowance)**
Average Cycle Time/ Standard Time (sec)	344.00	210.90	241.00
Average Idle/ Waiting Time (sec)	8.80	5.00	-
Average Time Spent on Motion (sec)	17.00	8.00	-
Throughput, T (Unit/hr)	10.47	17.06	14.94
Percentage Improvement (%)		63.11	42.69

According to Table 4.13, the calculation included an improvement system with an extra 30 seconds' allowance. These allowances are considered or provided to compensate the operator for the production interruptions that may occur due to personnel legitimate needs or the factors that beyond controls.

In contrast, the calculation results seem to have a great improvement on the standard time and the production throughput. High percentage improvement obtained in the manufacturing line was able to attain the goal of the organization which is improving the throughput by 30% higher than current throughput. Besides, several objectives that were instituted into the production plan were fulfilled and therefore the overall objectives of the project were achieved.

4.3.5 Phase 5: Sustain Improvement & Termination

To sustain improvement, optimized resources and standardized processes are essential. For repetitive production, it is advised that the production team should strictly adhere with the SOP, guidelines and standardized working procedure as to maintain a consistent and high efficiency production. To achieve an excellent manufacturing operation, continuously assessing and adjusting is integral in order to keep abreast of the developments and optimize the operations. The monitoring process was suggested to carry out every day during the first week of implementation, while alternate days for the following weeks as shown in Table 4.14. Once the modified system is stable for 3 consecutive weeks, the production line could resume as normal production. If the system fails to achieve a stabilized result, the monitoring process should keep going on every day until a stabilized result is obtained in 3 consecutive weeks. In addition, quality assurance is a major concern to be taken care of during the system monitoring to ensure high quality and low defective products are produced over the long run.

Week	1	2	3	4	5
Production units (units)	20	20	20	20	20
Number of days with monitoring (days)	7	4	4	4	4
Average Cycle Time (sec)	280	253	220	225	223
Stable? (Y/N)	-	-	-	N	Y

Table 4.14: Recording table for monitoring process in a month with dummy data.

Project termination is the final step of the project where project deliverables and relevant documents were handed over to the engineer team. The documents consisted of recording videos for current and future systems, data collected for time studies, calculation results, standard operating procedure for improvement model, perspective, feedback and advice.

4.4 Findings and Discussion

In the research, it was discovered that only manual bottleneck station was eligible for a detailed time study while the remaining workstations were deployed for a general time study to determine the cycle time. This can be explained as detailed data collection is costly and time consuming; implementation on other stations may cause waste in resources which is not worth to be carried out (Uusitalo and Engström, 2016). Plus, improving the performance in other workstations are unable to address the main factor that contributes to the inefficiency in the line and incapable to improve the production throughput as well. Instead of fighting for a detailed and statistical record for each station, placing more attention on the bottleneck will be much beneficial to the production and aids in time saving. Indeed, managing the bottleneck was optimizing the performance of the assembly station and there is a 42.69% improvement in production throughput.

From the previous report, the annual demand for product X is 1426 units in 2021. Although the company was expecting and predicted that the demand will improve in the future, the manufacturing line is still maintaining a low production volume after the MCO. In consequence, the production was forced to change their managerial action from make-to-stock system to make-to-order system to prevent the accumulation of WIP inventory. Dealing with low production manufacturing systems, recording videos will be an excellent approach used to implement in the production for data collecting. This is because video recording is an effective method that helps in capturing the contextual data in a comprehensive way which is beneficial in data presenting and team discussion.

Conversely, collecting a large sample size of real time data will be a good choice if the demand of production volume is increasing in the future. With increasing demand, more operation and production output will be required to fulfill the needs of the customer. In such a case, more data could be collected with large sample sizes which enable the data to have more accurate mean values and precise results (Tripathi et al., 2021). Additionally, improvement solutions are able to be interpreted with the aid of graphs to show more statistically and powerful data and results to encourage the production teams to adapt the new modified system in the production line.

Furthermore, a systematic improvement framework that provides detailed guiding steps on execution is much imperative towards coping with the production issue and generating effective solutions. This is because the existing problem-solving method in the company is still under a rudimentary stage. It could be discovered when the team was planning to improve their production only based on bare eyes observation, while details data collecting and root cause analysis are usually scarce. However, correcting only an immediate cause may eliminate a symptom of a problem, but not the problem itself. Production issues will still remain if proper action is omitted. This happened may probably due to inadequate worker expertise and time lacking on conducting a systematic way of methods in tackling the production issue. In such a context, a comprehensive framework is advocated and plays an essential role to discover the relevant underlying reasons for determining the causes of an issue and providing a systematic guiding step for execution.

In the research, the proposed solutions followed the concept of Kaizen and numerous benefits were gained. Firstly, standardized work provides a basis for Kaizen. This can be explained as the work sequence was changed and improved to a better structure. In regards, an organized and standardized method of work enables the variations in cycle time to be reduced even with the presence of human skilled level constraint. This is due to the fact that the work has become predictable with a normative procedure and the processing time for a unit product could be anticipated easily (Puvanasvaran, Hamid, and MNH, 2018). Besides, standardized work also helps the operators to structure their work which is beneficial in creating balancing workload distribution and establishing a distinct work sequence. Tasks could be divided equally and conducted simultaneously which allow the workers to be better engaged in their roles with best possible efficiency.

Plus, the sense of responsibility and good attitude toward the work will be induced when the utilization and contribution of human resources is improving through work standardization (Mor et al., 2018). In essence, wasted human energy can cost staggering amounts of capital each year when aggregated across your workforce. Meanwhile, standardized work makes training much easier. This can be explained as the results showed that a junior operator could perform nearly the same as an experienced operator when they are provided a correct way to perform the task through work standardization.

Apart from standardizing the work, Kaizen also apt in coping with the delay that contributed due to system starvation and reducing the occurrence of non-value-activity. Eliminating unnecessary activities, waste and having lesser idle time is significant to encourage continuous improvement and will help the production system to be more efficient. Typically, all of these will translate to cost savings and could turn potential losses into profits (Kucerova et al., 2015). Furthermore, Kaizen approach that emphasizes betterment of tooling such as implementation of jig in the process assembly brings a positive effect on reducing human fatigue and increasing productivity in the workforce.

The application of Kaizen was also adopted in the design of the facility layout. In the research, redesign of the facility layout equips the necessary needs of humans by creating an ergonomic working space for the workers to perform their role with best possible efficiency. Undeniably, time reduction on non-value-added activities such as material searching and excessive movement fostered the entire system after the facility layout was improved. More time is saved to run the production, higher outcome could be produced and led to a significant improvement in the throughput.

Nevertheless, human factors such as lack of knowledge and experience and inconsistent performance on workers (refer fishbone diagram in figure 4.4 in page 46) are still the issues that are keen to fix in the production. Workers should practice to be more interactive, be adaptable and increase in the knowledge base or sophistication.

This is vital and considered as the area to be focused by the organization over the long run. To mitigate the issue, training sessions must be organized frequently for the workers to cultivate their technical skills, knowledge and expertise so as to foster their effectiveness on production and problem solving. Besides, the production leader should keep track of the workers' behaviour and performance regularly to ensure the effectiveness of training sessions as well as enable the workers to be better engaged in their roles with best possible efficiency.

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter discusses the summary of the study and the future research that could be implemented. Section 5.1 summarizes the findings of this research by highlighting the essence of previous chapters. Section 5.2 lists out the potential research opportunities that could be carried out in future time.

5.2 Summary of research

Integrating humans into manufacturing systems has been considered a critical aspect in a semi-automated line as dynamic human characteristic constrains the throughput production and leading to the occurrence of manufacturing bottleneck. In such a case, reducing the process cycle time and improving the efficiency of the manufacturing line will be the effective technique that aims to improve the production throughput by reducing the negative impacts that come from human constraints.

The project gained insight from the data obtained in the preliminary and detailed time studies and it is discovered that the manufacturing problems incurred at the manual assembly workstation where the process has longest cycle time and lowest production output. With regards to this, literature review was carried out to gain an understanding on previous research and focused on finding appropriate strategies to tackle the manufacturing problem. In the meantime, a comprehensive framework was constructed to clarify the direction on how the implementation should be carried out in a chronological order.

Dealing with critical production issues, identifying the contributory factors was the initial steps to be carried out. Root Cause Analysis was implemented as an analytical technique and preliminary step to identify the potential causes of the manufacturing problems. Indeed, the detailed analysis of Root Cause Analysis enables several manufacturing aspects such as material, man and method to be investigated. In this research, it was found out that poor arrangement of tasks, inconsistent performance, imbalance workload distribution, poor workflow and poor layout design were the main issues encountered in the production line.

To tackle the relevant production issues, Root Cause Analysis was used to assist Kaizen events which allow proper actions to be performed towards selected problems. It is discovered that Kaizen was applied in re-constructing the work sequence, working technique, equipment, work scheduling, workflow and the design layout. In this research, work standardization provides a basis for Kaizen. It allows consistent production with optimal work practices which enable high production outcomes to be produced with low operating time. Based on the result, there is about 38.69% decrement in production cycle time in the bottleneck workstation. Besides, work standardization enables to tackle the problem of imbalance in workload distribution in which the utilization of workers has an apparent improvement for 49.37%. Poor workflow was being solved by setting a normative procedure and SOP with the purpose of eliminating the non-value-added activity. It is said that the average waiting time was reduced from 8.8 seconds to 5 sec per unit.

In the semi-automated production line, redesign facility layout is crucial for manufacturing that involve human factors because an efficient layout design will be able to minimize the unnecessary movement, reduce wastes, create a comfy and ergonomic working condition. According to the result, the adjustment on facility layout allows time spending on motion to be reduce from 17.00 to 8.00 seconds which has a 52.94% improvement. Additionally, the practice of Set in Order and Sort that provide visual control and management had improved the efficiency and value toward the throughput production.

Ultimately, the production throughput was obtained with a 42.69% improvement with the aid of all the combined solutions and it is said that the first and second objectives of the research were achieved. Apart from that, the implementation of the solutions was carried out in the production to validate the selected solutions. Successful implementation of the modified system and the excellent improvement results proved that the solution is feasible to the real system, and it is claimed that the final objective of the project was achieved.

5.3 Recommendation for future research

Since the demand for product X was increasing after MCO, it will have a high possibility that the company's forecasted demand will be turned into the actual demand. In such a context, high production demand may create more manufacturing issues, therefore several recommendations will be provided for future research.

- Apply VSM to analyze complex problems.
  Increasing demand in the manufacturing line may cause the bottleneck to occur in several workstations which creates a more complex production issue. To resolve the problem, it is advised to construct a Value Stream Map to visualize

the overall production and it is beneficial to determine the developed problem in different workstations. However, more detailed data will be required to collect to serve as the input data for VSM.

- Collect large sample sizes of real time data.

  Increasing demand means that more operations will be conducted. This will create an opportunity for the engineer team to obtain more data as the confidence level will be increased for large sample sizes. In fact, the average result from a large sample size will be the better representative for current or the actual system and this is more accurate for analysis. Besides, graph analytics could help in revealing the relationships between the data which enable discovery of new information to tackle the situation in hand.

- Adopt a comprehensive framework for project direction.

  Comprehensive framework is always a must for a proper project direction. In this case, a new framework could be constructed to tackle the next bottleneck that develops in the production.

- Organize more training sessions.

  To maintain a consistent performance, workers' technical skills and expertise is crucial over a long production run. Training sessions should be organized frequently for the workers to cultivate their technical skills, knowledge and expertise so as to foster their effectiveness on production and problem solving. Besides, the production leader should keep track of the workers' behaviour and performance regularly to ensure the effectiveness of training sessions as well as enable the workers to be better engaged in their roles with best possible efficiency.

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