WITNESS SIMULATION MODELLING FOR PRODUCTION LINE EFFICIENCY IMPROVEMENT IN AEROSPACE MANUFACTURING COMPANY

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A thesis submitted in fulfilment of the requirements for the degree of Bachelor of Manufacturing Engineering Technology with Honours

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DECLARATION

I declare that this Choose an item. entitled "Witness Simulation Modelling for Production Line Efficiency Improvement in Aerospace Manufacturing Company" is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have checked this thesis, and, in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Manufacturing Engineering Technology with Honours.

Signature	:	
Supervisor Name	:	TS. DR. ROHANA BINTI ABDULLAH
Date	:	9 January 2024

DEDICATION

I dedicated this thesis for my beloved people who support from the beginning of this journey. My supervisor who helps me completed this study, my friends and family who give emotional support and remind me for who I am. Thank you.

ABSTRACT

In order to satisfy the rising demand for components, production line efficiency is crucial in aircraft manufacturing. Traditional manual analysis approaches are limited in their ability to capture the complex relationships that exist throughout production processes. However, simulation modelling appears to be a potential strategy for increasing efficiency. Using Witness simulation models, this study tries to improve production line efficiency in an aircraft manufacturing industry. The study's goal is to comprehend present processes, uncover inefficiencies, and investigate improvement solutions. Experiments based on simulation will be used to assess the impact of suggested modifications on key performance measures. The problem statement highlights the difficulties that aerospace manufacturing companies have in obtaining optimum efficiency, which leads to increasing costs and production delays. Productivity enhancement is hampered by a lack of full understanding of existing processes. The study goals include creating a simulation model, conducting a line balance analysis, and recommending changes. The scope of the study is limited to a single production line, with modelling and analysis performed using Witness Horizon software. However, the supply chain is not addressed. The findings will assist aerospace firms in identifying bottlenecks and implementing data-driven methods to improve production line efficiency.

ABSTRAK

Untuk memenuhi permintaan yang semakin meningkat untuk komponen, kecekapan barisan pengeluaran adalah penting dalam pembuatan pesawat. Pendekatan analisis manual tradisional adalah terhad dalam keupayaan mereka untuk menangkap hubungan kompleks yang wujud sepanjang proses pengeluaran. Walau bagaimanapun, pemodelan simulasi nampaknya merupakan strategi yang berpotensi untuk meningkatkan kecekapan. Menggunakan model simulasi Witness, kajian ini cuba meningkatkan kecekapan barisan pengeluaran dalam industri pembuatan pesawat. Matlamat kajian adalah untuk memahami proses semasa, mendedahkan ketidakcekapan, dan menyiasat penyelesaian penambahbaikan. Eksperimen berdasarkan simulasi akan digunakan untuk menilai kesan pengubahsuaian yang dicadangkan pada ukuran prestasi utama. Pernyataan masalah menyerlahkan kesukaran yang dihadapi oleh syarikat pembuatan aeroangkasa dalam mendapatkan kecekapan optimum, yang membawa kepada peningkatan kos dan kelewatan pengeluaran. Peningkatan produktiviti dihalang oleh kurangnya pemahaman penuh tentang proses sedia ada. Matlamat kajian termasuk mencipta model simulasi, menjalankan analisis keseimbangan garisan dan mengesyorkan perubahan. Skop kajian adalah terhad kepada satu barisan pengeluaran, dengan pemodelan dan analisis dilakukan menggunakan perisian Witness Horizon. Walau bagaimanapun, rantaian bekalan tidak ditangani. Penemuan ini akan membantu firma aeroangkasa dalam mengenal pasti kesesakan dan melaksanakan kaedah dipacu data untuk meningkatkan kecekapan barisan pengeluaran.

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CHAPTER 1

INTRODUCTION

The first component of the report is an overview of the study, which outlines what the research is about, the objective of the investigation, and the constraints or boundaries of the relevant study. The format of the study's report is also briefly discussed to guarantee a clearer visualization of the whole study's process.

1.1 Background

Production line efficiency is crucial in the aerospace manufacturing business to fulfil the rising demand for components. The complexity of aircraft production processes, as well as the necessity for exact coordination across multiple activities, make achieving maximum efficiency a substantial problem. Inadequate production line performance can lead to increased expenses, production delays, and decreased product quality.

Manual analysis has traditionally been used to improve production line efficiency, but it may be time-consuming, subjective, and restricted in its capacity to capture the complicated relationships between different elements. However, the development of powerful simulation modelling tools has opened a new path for improving production line efficiency. Simulation modelling enables the production of virtual representations of real-world systems, allowing for the study and analysis of complicated industrial processes in a controlled and flexible setting.

According to Caterino et al., (2020), several advantages for industries come by the implementation of new technologies that play a key role for improving production processes, focusing on working times, product quality, accuracy of operations and other important parameters of the production systems. They also said that in order to evaluate these parameters, simulation may be used as a tool to verify the improvement adopted on existing production lines or the design solutions adopted for a new line, optimizing the processes.

The goal of this project is to increase production line efficiency in an aerospace manufacturing firm by using Witness simulation models. This study is conducted to get a full understanding of the present production line operations, uncover inefficiencies, and investigate new optimisation options by using Witness's capabilities. In addition, this study will figure out the impact of proposed changes on key performance rates including throughput, cycle time, resource utilization, and overall productivity using simulation-based experiments and analyses.

1.2 Problem Statement

Manufacturing industries are constantly striving to improve the productivity of their processes (Schmenner, 1982). Productivity improvement is mainly centred around increasing throughput, which can be defined as the pace at which parts pass through a production line (Lai et al., 2021). The throughput of a production system is constrained by one or more resources, known as “throughput bottleneck(s)” (Possik et al., 2021).

In aerospace manufacturing organisations, the production line frequently confronts obstacles in reaching maximum efficiency, resulting in increased costs, production delays, and degraded product quality. Traditional techniques of enhancing aerospace manufacturing production line efficiency, which rely on manual analysis and subjective decision-making, are restricted in their capacity to capture the complex relationships and difficulty within the production system.

The absence of a complete understanding of existing production line processes restricts the identification of bottlenecks and inefficiencies, making it difficult for aerospace manufacturing businesses to improve their productivity. The necessity for precise operation coordination and synchronisation in aerospace manufacturing necessitates a more advanced and data-driven technique for analysing and improving production line efficiency, overcoming the constraints of old methodologies.

In contrary, simulation supposedly give precise operation coordination and synchronisation. Bottlenecks can be identified easily in a production line and many experimental situations can be made without increase any production cost such as labour, money and working space.

1.3 Research Objective

The main aim of this research is:

a) To develop the current state simulation state model.

b) To perform line balancing and analysis at the current state simulation model.

c) To recommend improvement based on line balancing and analysis.

1.4 Scope of Research

This research study focus is to improve productivity in a production line. Line balancing will be conducted to find the bottleneck in assembly line. Next, Witness Horizon simulation software will be used as the major tool for modelling and analysing production line operations in this study. Current state layout model of the production line will be simulated and being compared to manual calculation of line balancing to find the error percentage or validate it. Improvements model will be suggested and compared to current layout model.

Furthermore, there will be limitations to perform this study. The simulation of this study will only be covered one production line. Moreover, supply chain phase is not included in this line balancing performance. While supply chain management is critical to overall operations, this research will not cover supply chain-related issues such as procurement, shipping, or distribution.

1.5 Report Structure

This research report is divided into chapters, each with its own goal and contribution to the overall understanding of the study. The following offers a summary of each chapter's structure and content:

Table 1-1: Structural Report

Chapter	Topic	Description
Chapter 1	Introduction	The context and setting for the

		research study are provided in the introductory chapter. It describes the research topic, aims, and scope of the study. It also explains the report's structure, emphasising the substance of the ensuing chapters and their connection to the study objectives.
Chapter 2	Literature Review	The chapter on literature review provides a thorough examination and analysis of current scholarly publications, research papers, and important literature in the topic. It lays the theoretical groundwork for the research study and highlights gaps, disputes, and essential concepts concerning production line efficiency enhancement and simulation modelling in aerospace manufacturing.
Chapter 3	Methodology	The methodology chapter discusses

		the study's research design, data gathering methodologies, and simulation procedures. It explains in detail how the data was collected, analysed, and evaluated. This chapter also describes the Witness simulation modelling implementation procedure and the parameters used to increase manufacturing line performance.
Chapter 4	Preliminary Result	The preliminary results chapter provides an early overview of the findings generated from the analysis of the collected data and the initial simulation experiments. While these results are not yet final or conclusive, they offer valuable insights into the research topic and provide a foundation for further investigation.

Chapter 5	Conclusion	The conclusion chapter provides a summary of the research study, highlighting the main findings, contributions, and their implications especially on PSM I.

1.6 Summary

In summary, this chapter provides an overview of the study's main findings, focusing on the application of line balancing and simulation techniques in production systems. The problem statement highlights the specific issue that prompted this investigation. Meanwhile, the study objectives clearly outline the purpose and rationale behind conducting this research. Finally, the research scope outlines the investigation's purpose, limitations, and underlying assumptions.

CHAPTER 2

LITERATURE REVIEW

The literature review in this chapter examines research from numerous published sources as well as the studies' general themes. Journals, articles, books, and internet resources are employed as a guide for the project's following stages. This method of examining what has already been done and what needs to be done in research is beneficial. This section also indicates the research gap, allowing any gaps in earlier studies to be identified. This part can also be linked to current research that is currently being conducted as well as what is expected in the research plan. The domains and subjects related to line balance, as well as the vocabulary and concepts involved, will specifically be covered in this chapter. Additionally, the part will introduce the subtopic of simulation and other related themes.

2.1 Manufacturing

According to Kenton (2022), the term manufacturing refers to the processing of raw materials or parts into finished goods using tools, human labor, machinery, and chemical processing. Manufacturing allows businesses to sell finished products at a higher cost than the value of the raw materials used. Large-scale manufacturing allows for goods to be mass-produced using assembly line processes and advanced technologies as core assets. Manufacturing has evolved and become more automated, computerized, and complex, (Kusiak, 2018). Smart manufacturing is an emerging form of production integrating manufacturing assets of today and tomorrow with sensors, computing platforms, communication technology, control, simulation, data intensive modelling and predictive engineering. It utilizes the concepts of cyber-physical systems spearheaded by the internet of things, cloud computing, service-oriented computing, artificial intelligence, and data science.

2.2 Productivity

Productivity is a term used to describe the ratio of production or results obtained to the resources utilised to produce them. It is a crucial consideration when evaluating the efficacy and efficiency of people, groups, companies, or even entire economies. In determining competitiveness, profitability, and overall success, productivity is a key factor. According to (Rawat et al., 2018), to measure the firm efficiency, productivity is an important factor which is calculated by converting inputs to total outputs. The output (OT) by any manufacturing system is usually expressed in units of physical volume, such as pieces, tons, and any other measurable units. These physical units must be weighted in some manner so they can be added together. Good productivity means how much input is converted to output. For this work productivity is being calculated in terms of Labor productivity, Overhead productivity, Material productivity and Capital productivity.

2.2.1 Labour Productivity

A measure of output or results per unit of labour input is referred to as labour productivity. It measures the efficacy and efficiency of labour in the creation of goods or services. A crucial indicator for evaluating the effectiveness and performance of individuals, groups, departments, or entire organisations is labour productivity. According to Rawat et al., 2018, labour productivity calculates that how much labour performance is necessary to give maximum output. This productivity is useful in manned cellular manufacturing systems or labour-intensive industries.

Labour productivity can be affected by several factors such as:

i. The structure, arrangement, and assignment of duties can affect how productive the workforce is. Productivity levels may be increased using clear instructions, efficient coordination, and optimised work procedures.

ii. The availability and utilisation of cutting-edge tools, equipment, and technology may have a considerable influence on labour productivity by simplifying processes, lowering mistakes, and boosting effectiveness.

For businesses, labour productivity is a critical metric since it shows how effectively, and efficiently labour resources are used. More output may be produced with the same or less labour inputs thanks to higher labour productivity, which also means lower costs, more competitiveness, and better overall performance.

2.2.2 Capital Productivity

Based on Rawat et al., 2018, Capital Productivity measures the efficiency of capital that is invested on equipment and buildings that are used in producing the output. This productivity measure is especially useful in unmanned cellular manufacturing systems or capital-intensive sum of the annual values measured for every belonging on the basis of its productive life, base year cost, and the firm's cost of assets.

2.2.3 Material Productivity

According to Rawat et al., 2018), material productivity calculates the capacity of raw material use. This criterion is beneficial when material cost is a large scrap of the total cost. For a better understanding, depending on the precise context and desired level of information, multiple methods can be used to determine material productivity. The formula for measuring material productivity is as follows:

Material Productivity = Output / Material Input

The number, quality, or value of the commodities or services produced is represented by output. The quantity or cost of materials utilised in the production process is referred to as the "material input."

2.3 Capacity Management

The process of efficiently planning, regulating, and optimizing a manufacturing system's production capacity to satisfy customer demand is known as capacity management in the industry. To maintain effective operations and satisfy customer expectations, it involves achieving a balance between the production needs and the available resources, such as labour, machinery, and facilities.

Sabet et al., 2020, cited that large-scale multinational manufacturing firms often require a significant investment in production capacity and extensive management efforts in strategic planning in an uncertain business environment. Resource management is one of the most important management tasks in manufacturing and production capacity is the most strategic internal capability that manufacturing firms must create, sustain, and plan for. Capacity management aims to ensure that a manufacturer has the 'right' capacity to act within a complex structure and how best to utilise their internal capabilities.

2.3.1 Theory of Constraint: The Bottleneck Operation

A bottleneck in manufacturing is a stage in the production process where the capacity or output is constrained, impeding the production process' overall flow. It is a step or resource in the manufacturing system that slows down or caps the production rate, preventing the system from performing to its fullest capacity. Bottlenecks can happen for a number of reasons, including inadequate equipment, inefficient processes, a lack of resources, or an imbalance in workloads.

Generally, the bottleneck is defined as the resource limiting the production capacity. However, the definition of bottleneck is still a controversial issue on which there is no consensus among researchers (Mahmoodi et al., 2022). A bottleneck usually is a sub-process in the main process which delays the process. The performance of a process can be increased by eliminating the bottlenecks (Bemthuis et al., 2021).

According to Lai et al., 2021, to improve the overall throughput of the manufacturing systems, it is essential to identify effective methods to detect the throughput bottleneck. In the last two decades, significant work has been done in the area of bottleneck detection and can mainly be categorized into three groups: analytical methods, simulation-based methods, and data-driven methods.

Lai et al., 2021, agree using simulation-based methods to identify bottleneck by saying simulation-based method is the second category of work, which is effective in performing sensitivity-based throughput analytics. It has been implemented in industry such as automotive assembly systems. In the simulation methods, discrete event simulation models are often created for production line. The main advantage of the simulation-based throughput analysis and bottleneck detection method is that it can detect bottlenecks in complex production lines, (Lai et al., 2021).

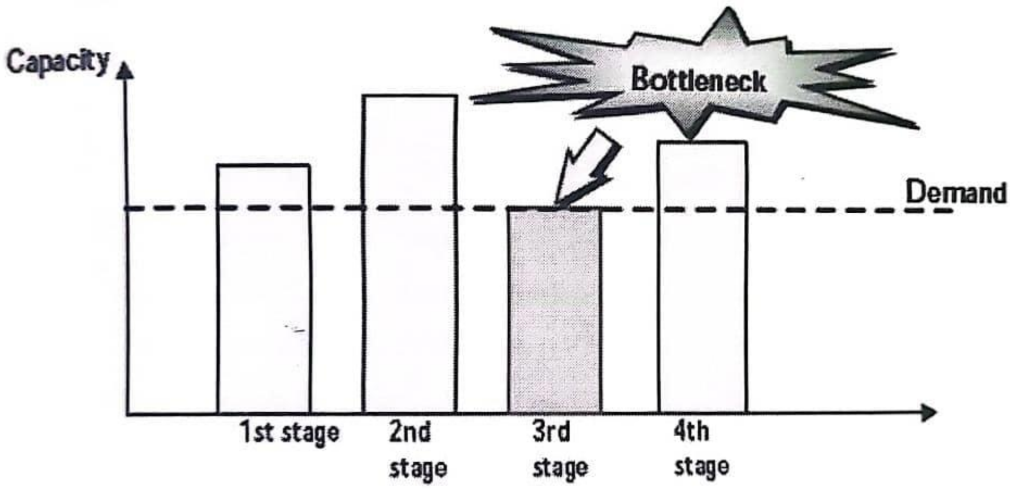


Figure 2-1: Example of Bottleneck According to Assembly Line Balancing Analysis.

2.3.2 Assembly Line Balancing

Reducing bottlenecks in line production can be achieved and one of the methods is assembly line balancing. First, what is an assembly line? According to (Lopes et al., 2022), assembly lines are product-oriented production layouts commonly employed in various industrial settings. The most classical optimization problem associated with them is the assembly line balancing problem, which consists in assigning tasks to stations. There are many improvements that assembly line balancing can bring to the production line. According to Fansuri et al., 2018:

A way to minimise imbalance workloads between workers as to achieve the desired output.

It provides a routine for consistency of an operation or a process and a basis for improvement.

2.3.2.1 Cycle Time

Cycle time is the time it takes to complete a unit of labour or manufacture a single item or product. It contains all the processes, activities, or tasks involved in the process, from start to finish. The time required at each station for the performance of the work is known as cycle time. The cycle time at a station is the time interval between the completion or the starting of the work on successive items and therefore includes both productive and non-productive work as well as any idle time, Karthick, 2019:

Cycle Time = Service Time + Idle Time

According to Goyal et al., 2022, cycle time is an important parameter in deciding productivity of a manufacturing process and flexibility of production line. In order to determine bottleneck on a production line, the study of cycle time provides important insights. Longer cycle time has always been seen as a problem, even in the age of Industry 4.0.

Goyal et al., 2022, also indicated that cycle time can be reduced using several techniques, which are well-adopted in industries and covered by numerous works in the literature through the past decades. One of the techniques is adding additional machines or tools in parallel with increasing manufacturing capacity and speed or adding any auxiliary equipment to reduce the process time. The formula to calculate cycle time in production line can be shown below:

$$\textit{Cycle Time} = \frac{\textbf{Production time available per day}}{\textbf{Unit required per day}}$$

2.3.2.2 Relationship Between Cycle Time, Takt Time and Task Time

Takt time is a phrase used in lean manufacturing and production systems. It reflects the maximum time permitted per unit to fulfil consumer demand, or the rate at which items must be produced to match the rate of customer demand. Takt time is computed by dividing the available manufacturing time by the customer demand for that period. For example, if the available manufacturing time is 480 minutes per day and the client demand is 240 units, the takt time would be 2 minutes per unit.

(Gardarsson et al., 2019) cited that takt is German for "beat" and refers to the manner takt time planning is carried out in production. Takt is a lean tool that has a goal to reduce waste and increase value by creating a stable environment for implementing Last Planner (Frandson et al., 2015). Takt was first used in traditional industry, like the automotive industry, where products move down an assembly line with a set takt time at each workstation. Each station must finish their work before the item is moved along to the next workstation.

$$\boldsymbol{Takt\ Time} = \frac{\textbf{Total time available}}{\textbf{Total customer demand}}$$

While the length necessary to execute a given job or activity inside a process or operation is referred to as task time. It denotes the real time spent on completing a certain activity or labour piece. Task time is commonly quantified in time units such as seconds, minutes, or hours. Task time is an essential component in many industrial engineering and time research methodologies, including job measurement and line balance. It is useful for calculating the time necessary to accomplish specific activities, assessing resource needs, and optimising workflow within a process.

The relationship that occurs between them are to satisfy customer demand effectively, the process cycle time should be equal to or less than the takt time. This guarantees that the rate of production corresponds to the rate of consumer demand, avoiding overproduction or underproduction. Next, the total cycle time is the sum of the task timings inside a cycle. Efficient task times aid in the achievement of a balanced production flow and the reduction of idle time or bottlenecks.

Individual task timeframes should be planned and optimised to meet the takt time to establish a balanced production flow. Task time balance ensures that workstations or resources are not overburdened or underutilised, resulting in a smooth production flow.
In summary, cycle time indicates the entire time for a process, takt time determines the rate of production to fulfil consumer demand, and task time adds to cycle time. Balancing and optimising task timings in relation to takt time assists organisations in achieving efficient production flow and efficiently meeting consumer demand.

2.3.2.3 Techniques in Assembly Line Balancing

Table 2-1: Techniques in Assembly Line Balancing

No.	Techniques	Description
1.	Precedence Diagramming	This approach entails drawing a precedence diagram to depict the sequence of jobs and their interdependence visually. Manufacturers can discover

		the sequence in which jobs should be completed and find the ideal task allocation by analysing dependencies.
2.	Analytical Methods	In assembly lines, mathematical approaches can be used to find the best balance. Creating mathematical formulae to reduce the workload disparity across workstations. Developing a mathematical model to optimise work allocation based on specified restrictions and goals.
3.	Work Element Analysis	This method involves breaking projects down into smaller work pieces and analysing their timings. Manufacturers can achieve a balanced line by analysing the job aspects and distributing them more evenly among workstations.
4.	Simulation	Manufacturers can use simulation software to generate virtual models of the assembly line and simulate various situations. Manufacturers may discover bottlenecks, optimise line balance, and make educated choices by altering work assignments and analysing the outcomes.

2.4 Simulation

The practise of generating a virtual version or model of a real-world system or process to analyse its behaviour, performance, or results is referred to as simulation. It entails simulating the dynamic interactions and behaviours of the system under various settings or scenarios using mathematical or computer-based methodologies. A model is created in simulation that represents the key components, laws, and interactions of the real system being researched. This model can be a mathematical equation, a collection of algorithms, or a computer program that replicates the system's behavior and reactions over time.

Durán, 2020, cited that there are many insightful discussions in the philosophical literature about the epistemology of computer simulations. Most of this literature, however, takes computer simulations to consist of the implementation of some kind of special model running on the physical computer. This leaves a conceptual vacuum regarding the specific nature of such special models and the philosophical implications in connection with them. He also said that to this end, the author examines the general architecture for simulation models with the objective of recognizing practices, structures, and relations commonly found in computational practice and which differ from other forms of modelling.

2.4.1 Simulation Based on Manufacturing

The use of computer-based models and techniques to simulate and analyse different elements of manufacturing systems, processes, and operations is referred to as simulation in manufacturing. It entails developing virtual models of industrial systems to comprehend their behaviour, analyse performance, and make intelligent decisions. Simulation widely used in Industry 4.0 to help boosting the production line or increase productivity in assembly line.

Table 2-2: Application of Simulation in Manufacturing

NO.	**Application Of Simulation in Manufacturing:**	
1.	Production Line Simulation	Simulation is used to simulate and assess the performance of assembly lines and manufacturing lines. It aids in the evaluation of production rates, workloads, and resource utilisation, as well as the identification of possibilities for line balance and optimisation.
2.	Process Simulation	Individual manufacturing processes such as machining, assembly, material handling, and quality control are represented and analysed using simulation models. Engineers can detect bottlenecks, optimise parameters, and enhance efficiency by modelling these processes.
3.	Factory Layout and Planning	Factory layouts, including the location of equipment, workstations, material flow pathways, and resources, are designed and optimised using simulation. It helps to analyse and improve the overall flow and efficiency of commodities, decreasing congestion and journey lengths.
4.	Supply Chain Simulation	Supply chain networks, comprising inventory management, order fulfilment, transportation, and distribution, are simulated and analysed using

		simulation. It aids in the evaluation of various situations, the optimisation of inventory levels, and the overall performance of the supply chain.

2.4.2 Simulation and Assembly Line Balancing

According to Yasir & Mohamed, 2018, simulation is one of the methods used to figure out assembly line balancing problem. Simulation is a scientific method to not separate study a system without actually disconcerting it, but also to assess ideas that have not been used in the real world. Simulation is used to predict assembly line performance among other machine layouts and scheduling rules, thus find the best performing layout.

In the era of Industry 4.0, several advantages for industries come by the implementation of new technologies that play a key role for improving production processes, focusing on working times, product quality, accuracy of operations and other important parameters of the production systems, (Caterino et al., 2020):

To evaluate these parameters, simulation may be used as a tool to verify:

i. The improvement adopted on existing production lines.

ii. The design solutions adopted for a new line, optimizing the processes.

Caterino et al., 2020, also cited that the introduction of these technologies in the factories allow to facilitate analysis and process measurement that were very complex to be performed in the past and then to use these measures to support the improvement of production systems and to evaluate the advantages of new production technologies, such as additive manufacturing, automation, and virtual simulations.

To achieve line balancing in production line, simulation-based model really helps to reduce bottleneck in assembly line by showing which workstation that increase the cycle time. According to Onofrejova et al., 2020, an efficient production with a significant impact on productivity of a manufacturing process may be enabled by retaining a mutual balance between the capacity of the workplace and the load of the workplace in terms of the volume and the timing of production.

The model simulations offer data about the process results, performance, and behaviour with diverse process structures. Mostly, a manufacturing approach is a set of manufacturing policies planned to maximise performance among trade-offs among profit standards to meet the manufacturing job determined by a corporate strategy, (Yasir & Mohamed, 2018).

2.4.2.1 Case Study

a) Simulation of Assembly Line Balancing in Automotive Component Manufacturing (Jamil & Razali, 2016)

The modelling of assembly line balance in an automobile component at a vendor manufacturing business is the topic of this research. A mixed-model assembly line of charcoal canister product that is utilised in an engine system as a fuel's vapour filter was examined, and it was discovered that the line's present production rate does not meet customer demand, despite the company's practise of buffer stock for two days in advance.

This research was conducted by conducting extensive process flow and time analyses along the line. To create a simulation of the line, real data was collected from the factory floor and checked for distribution fit. The collected data was then converted into a simulation model. After comparing the model to the actual system, it was discovered that the existing line efficiency is not at its peak owing to obstruction and idle time. To remove the reason, several what-if analyses were used.

The design suggested illustrates that the line is balanced by providing a buffer to avoid blocking. While labour is added to the stations to minimise process time and thereby idle time. ProModel software was used to conduct the simulation investigation.

For starters, the manufacturing pace falls short of meeting client demand by 8%. Second, the line has a poor level of efficiency. The system is clogged due to an imbalance in line production cycle time. It was discovered that the queue cycle time is shorter than the workstation cycle time. As a result, the corporation produces stock storage for two days to avoid a supply shortfall.

Objectives for this study:

i. To measure the throughput system using simulation.
ii. To keep track of the state of the manufacturing line in terms of resource utilisation, obstruction, and idle time.
iii. To determine the fundamental reason for any imbalance of the line.

iv. To provide numerous improvement ideas using simulation modelling, resulting in the most efficient production line with the lowest cost effect and providing the firm with improvement alternatives.

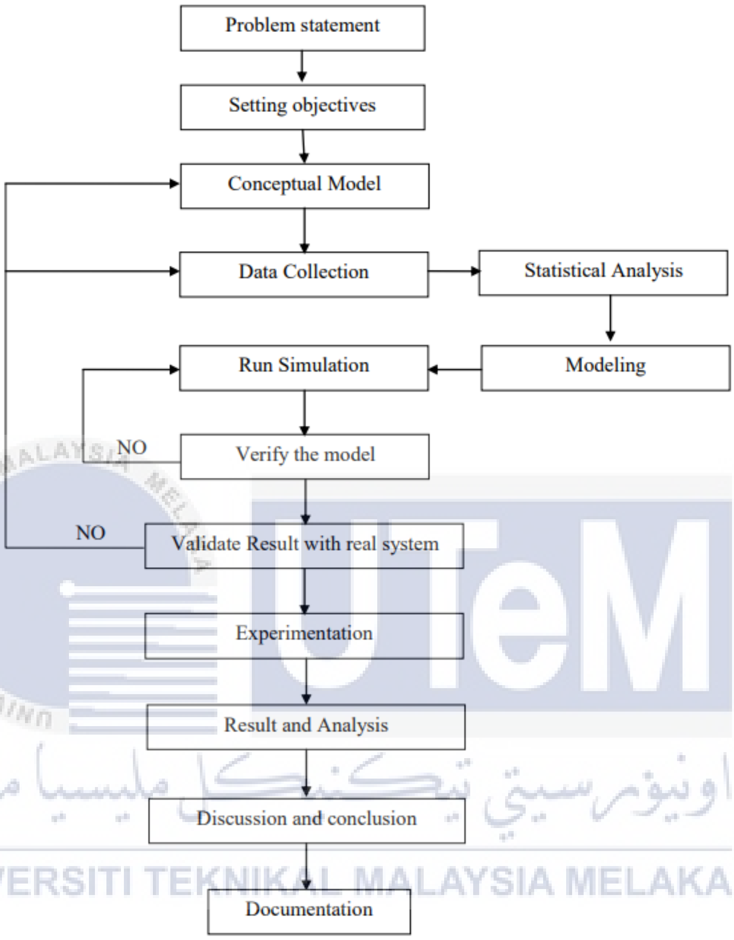


Figure 2-2.2: Methodology of simulation study

W/S	Process	Operation	Total entries (units)
	Arrival Area		1161
1	Assembly 1	Manual	1032
2	Paper Stamping	Semi-auto	1032
3	Spin Welding	Semi-auto	951
4	Assembly 2 & Carbon Filling	Manual	950
5	Vibration Welding	Semi-auto	950
6	Water Leak Test	Semi-auto	950
7	Valve Test & Laser Printing	Semi-auto	949
8	Vent Foam & Cap Assembly	Semi-auto	950
9	Packing, Tagging & Inspection	Manual	950

Figure 2-3: Charcoal Canister process

This manufacturing line is built on five core process characters: assembling, marking, sealing, testing, inspection, and packaging. The first workstation, Assembly 1, assembles the child pieces of the charcoal canister, which include the ball, spring, plug, and case. The assembly of these kid pieces is then delivered to the spin welding workstation for sealing. The second assembly step involves carbon loading and the installation of filter elements. The amount of carbon to be filled is regulated and determined by the machine based on the performance requirements of the item. Meanwhile, the filtering components are installed by hand. Vent foam and cap assembly is the final assembly operation on the production line.

According to Figure 2-4, the bottleneck of the production line occurs at the spin welding workstation, with only 951 parts capable of entering the workstation compared to 1032 components set to enter in the first place. It is also discovered that the spin welding technique has the longest processing time. As a result, this workstation is designated as the bottleneck workstation.

Name	% Operation	% Setup	% Idle	% Waiting	% Blocked	% Down	% Utilization
Arrival							10.54
Assy 1	58.72	0	16.43	0	24.85	0	84.06
Paper Stamping	27.99	0	16.6	0	55.41	0	83.81
Spin Welding	83.19	0	16.35	0	0.46	0	84.40
Assy 2	58.63	0	41.36	0	0.01	0	58.10
Vibrate Welding	28.49	0	70.29	0	1.22	0	29.94
Water Leak Test	59.91	0	40.09	0	0	0	59.63
Laser Print	27.04	0	72.96	0	0	0	26.14
Cap Assy	30.82	0	68.26	0.01	0.91	0	33.81
Pack Inspect	59.21	0	40.79	0	0	0	59.45

Figure 2-4: Output from the simulation for current layout (before improvement)

Figure 2.4 depicts a general report provided by the ProModel software, indicating that the spin welding technique is the most used workstation in this manufacturing line, accounting for 84.40% of all workstations. In the simulation model, two improvement plans were offered in order to eliminate blockage, enhance production rate, and line efficiency. The idea called for the installation of a buffer to prevent components from becoming blocked for the following workstation, which might cause the manufacturing line to stop. Another suggestion was to add resources (operators) who run the workstations or transport pieces from one to another. The manual workstation's resource augmentation balances the processing time.

Items	Detail	Line Efficiency (%)	Production Rate (unit/hour)	Line Utilization max (%)	Idle Time max (%)	Blockage max (%)
Current Production Line	9 workstation Semi-manual assembly line	81.1%	118	84.40%	73.86%	55.83%

Figure 2-5: Summary of simulation results after improvement

Items	Detail	Line Efficiency (%)	Production Rate (unit/hour)	Line Utilization max (%)	Idle Time max (%)	Blockage max (%)
Improvement 1	Add 5 buffer workstation and 1 resource with new machine	88.9%	129	65.44%	70.32%	0%
Improvement 2	Add arrival area, create stock in advance, 3 buffer	90.4%	131	83.69%	69.78%	0%

Figure 2-6: Summary of simulation results after improvement (cont.)

In summary, the data revealed that line balancing had a favourable influence on the production line with a few enhancements. It also demonstrates how simulation may save time in the process of simulating line balance. Line balancing not only reduces bottlenecks but also increases output.

b) <u>Concrete Mixture Assembly Line Improvement using ARENA Simulation (Tushar D. & Mukesh C., 2018).</u>

Arena is a piece of software that organisations use to design production lines, balance assembly lines, find bottlenecks in assembly lines, develop or alter plant layouts, and assist manage productive hours of manpower. Concrete mixes are available in a variety of forms for cement-related operations. Hand-feed concrete mixture is the most often used and oldest equipment.

Product mixup, priority change, and rush of work at any level of the production line or bottleneck, among other challenges, occur often in line production at Esquire machines. The highest issue generator in this complete bottleneck, and the bottleneck directly affects the efficiency of the plant or firm. In this study, we discovered and attempted to alleviate or remove bottlenecks in the manufacturing line of a hand feed concrete machine.

Figure 2-7: Flow of assembly product

Objectives for this study:

i. To reduce rush of work.

ii. To eliminate product mix ups.

iii. To reduce or eliminate bottleneck.

iv. To utilize man working hours.

Figure 2-8: Methodology of simulation study

To identify a bottleneck location in production, first understand the whole flow of the manufacturing line. In this case study, we are only interested in the primary assembly line for that one model, which is generated in ARENA Simulation software and is a model of the actual system, followed by the assembly shop to assemble different parts or sub-assemblies.

In the real system, three employees are required to run the assembly line. If the simulation runs for a day shift (eight hours), the run configuration will look like Figure 2.8. Workers practise in a batch manufacturing system, thus they take FIVE machine assembly pieces to work at the start of each shift/replication (cycle).

Figure 2-9: Run Setup for Simulation

Workers constructed three machines at the end of the day, with the remaining two in process at the drum fitting stage and the other waiting for in process assembly at the handle fitting stage, which is the final stage of the assembly line. As an upgrade in the assembly line, a few extra workstations are provided for those processes that take longer in the real assembly line, such as yoke fitting, engine cabin fitting and drum fitting.

	Actual model	Modified model
Cycle time	29340 sec	11736 sec
Number In	5	15
Number Out	3	10
Value added time	97.8045	71.635
Waiting time	371.3	121.37
TOTAL TIME	469.12	193
Work in process	2	5
Base frame queue	5.1928	5.2004
Angle frame queue	36.5008	36.5007
Yoke queue	30.167	-
Engine cabin queue	58.1307	-
Drum fitting queue	52.3432	-
Handle queue	9.9504	2.6501
Assembly line 1	-	35.3238
Assembly line 2	-	35.3192
TOTAL TIME	192.2839	114.9942

Figure 2-10: Comparison of actual model and modified model.

According to Figure 2-10, the cycle time for the original and modified models differs because the updated model includes a new assembly line for the yoke fitting, engine cabin fitting and drum fitting assembly processes. The value-added time and waiting time for entities are substantially greater in the original model than in the changed form. For all processes, queue time is compared, however in this case, queue time is higher in the changed model, but when compared to our output in the modified model, we have less queue time than the actual model. As a result, the improved model is more efficient than the actual assembly line.

A few recommendations were made to the firm to increase line efficiency and workforce utilisation:

i. Add another assembly workstation with only three processes: yoke fitting, engine cabin fitting, and drum fitting.

ii. ARENA simulation may also be performed on other products' data and the company's manufacturing process to gain a better knowledge of bottlenecks.

iii. Assembly line workers should have prior expertise in machine assembly.

The simulation results generated by ARENA are valuable for comparing the original system to the improved system. In the original method, only three machines can be constructed with three people, but in the improved system, ten machines can be assembled with six people in the same amount of time. These conclusions are reached without any training and using the same tool. As a result, ARENA may be used to improve plant efficiency without impacting the real system.

c) Simulation Modelling and Analysis of A Production Line (Heshmat et al., 2017).

A cement manufacturing process is investigated and tracked for a year in this article. Actual data is gathered for each workstation, including production capabilities, transfer times, and processing times. Furthermore, for each machine, one-year historical failure and repair data is filtered and analysed, including preventative and predictive maintenance, yearly shutdown, workstation blockage and hunger, and even worker strikes. The optimal probability distribution is then determined using statistical evidence. The simulation model is developed with AnyLogic software (AnyLogic, 2016), and each workstation is represented by the distribution of real processing time, failure time, repair time, and time between failures.

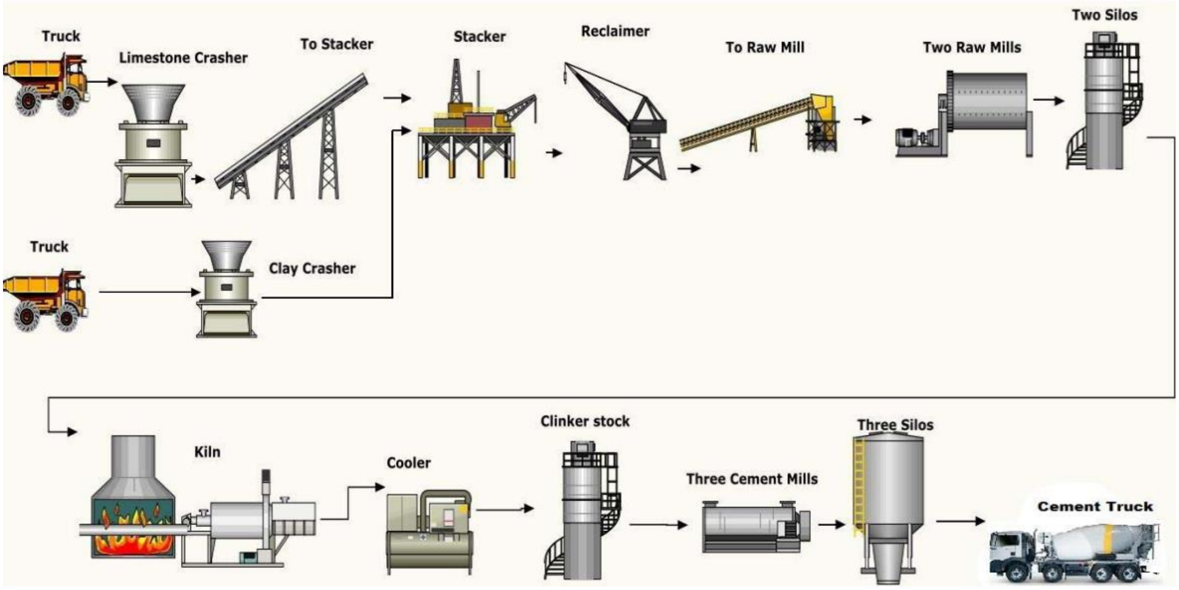


Figure 2-11: Schematic diagram of the cement production line.

First, the development line is thoroughly examined in the field, and data about each workstation is collected, including processing time, historical records for one year of failure, repair, and time between repeated failures. Second, we begin developing the simulation model with AnyLogic software. We contacted the cement manufacturing line engineers at this step to obtain any missing or required data. Third, we do a test run to confirm that the model's logic is met. Fourth, we use face validity to validate the model, which is dependent on model animation. Fifth, we validate the model with a walkthrough, comparing the model throughput to the actual throughput and utilising the test to see whether there is a substantial difference between the two means. When the model is validated, we examine bottlenecks in the production line and conduct the necessary tests to improve the KPIs and create any production plans. A manufacturing line simulation and analysis.

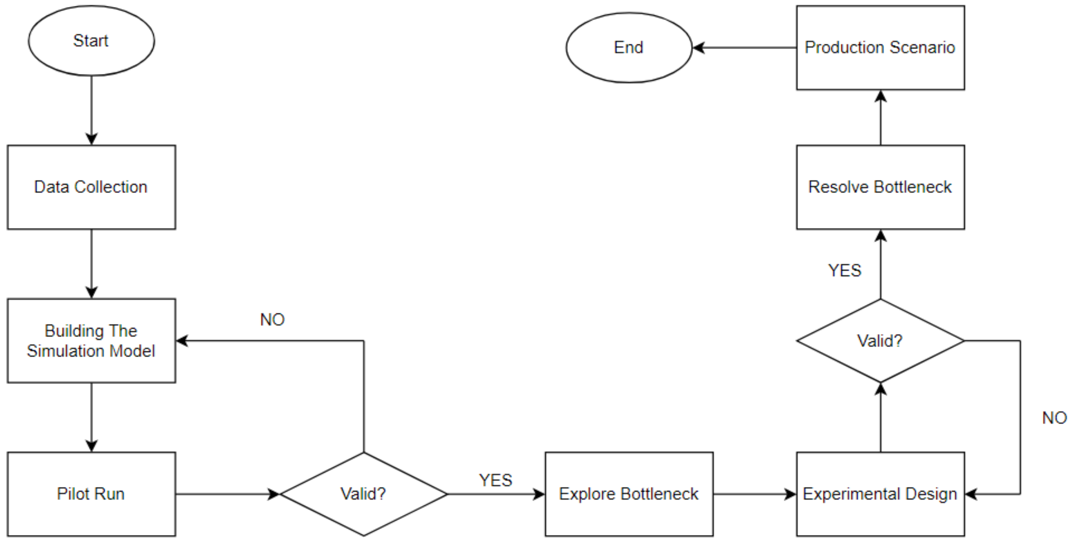


Figure 2-12: A flowchart represents the simulation methodology.

According to an examination of the production line machine utilisations, the kiln, cooler, and raw mills have the highest utilisation, as shown in Figure 2-13. This indicates that these regions are packed with work in progress, increasing the likelihood of a blockage. In this regard, we have received input from the manufacturing line's operations engineers that the kiln area is always clogged.

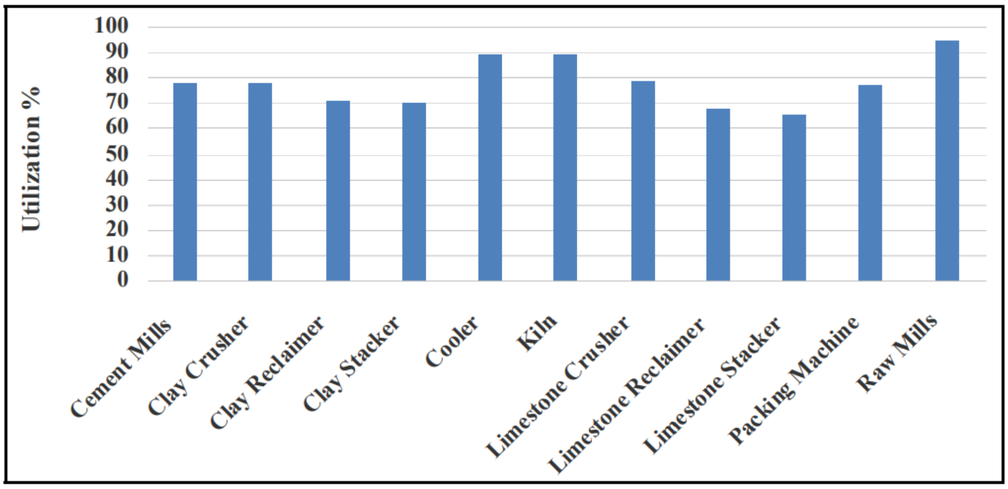


Figure 2-13: Utilisations of the production line's machinery

The buffer size is the second critical component. Except for the raw mill's silos, which have overstock difficulties in the simulation runs, the majority of the buffer sizes are seen to be below the maximum limit. Because of its restricted capacity, the kiln cannot handle all of the entering raw material, resulting in excess. Another KPI is that we run the simulation model without taking into account workstation breakdowns to determine the theoretical throughput of the production line, from which the production line efficiency can be evaluated. The throughput without breakdowns is 5,120 tonnes per day, whereas the throughput with breakdowns is 4,404.3 tonnes per day. As a result, the efficiency of the production line is 0.86. The simulation results and this rule indicate that there is a bottleneck in the clinker manufacturing sector. This is due to the highest kiln utilisation (95%) and the longest line before the kiln. This large wait causes obstructions before the kiln, increasing the kiln's average utilisation. Furthermore, the operations managers have advised us that owing to the high silo level, the raw mills must be stopped down for many hours. This input boosts our trust in the simulation model's outcomes. On the other hand, the latter phases, notably the cement mills and packaging equipment, have very poor utilisation. Because of this issue, operations managers are forced to run the workstations before the raw mills just two shifts (18 hours) rather of three shifts (24 hours).

To address the observed bottleneck in the kiln area, a 10% increase in kiln capacity is proposed. The model is then run with the updated proposal, and the bottleneck is overcome, resulting in an 8% improvement in overall production line throughput. Because there is enough room after the kiln area away from the clinker stocks, this modification might be applied in the real production line. Another option is to replace the kiln with a larger one that has a greater diameter but the same length.

Demand (tonne/day)	*Modifications*
500	No
600	Increasing the kiln capacity by 20% and operating the crusher, *stacker*, and *reclaimer* for 20 hours instead of 18 hours per day
700	Increasing the kiln capacity by 30 % and operating the crusher, *stacker*, and *reclaimer* for 24 hours instead of 18 hours per day
300	Working all the line for 18 hours instead of 24 hours per day

Figure 2-14: Demands and corresponding modifications in the production line.

The goal of this study was met by employing discrete event simulation to record, assess, and measure various key performance indicators (KPIs) for a cement manufacturing line. The manufacturing line was extensively examined, and bottlenecks were discovered, producing congestion in the kiln area. This bottleneck was evaluated and resolved using simulation. If the kiln capacity is raised by 10%, the manufacturing line throughput may be improved by 8%. Furthermore, the simulation model may be utilised to test production possibilities based on demand. The input from the production line operations managers validates the simulation model's believability.

d) <u>Assembly Line Efficiency Improvement by Using WITNESS Simulation Software (Yasir & Mohamed, 2018)</u>

This article provides a performance analysis of an existing production line. The actual cycle time seen and recorded while working. Witness simulation software was used to create and examine the existing arrangement. The productivity and efficacy of each individual operator are measured to define idle and busy time. To increase the performance of industrial tasks, two novel alternative layouts were developed and assessed using

Witness simulation software. This study contributed to a better knowledge of production effectiveness by modifying line balance.

After multiple selection procedures, the XYZ Company was chosen. The firm is chosen based on authorization requirements, which are needed by the premise before any further investigation on the company's problem is conducted. This research was carried out in the S-class automobile assembly plant on the premises of XYZ Company. The present assembly line has a line-balancing issue, which has reduced production productivity. On the S-class automobile production line, a total of ten workstations were engaged. This research will gather information about the existing design layout, the number of workstations, the number of operators, the time study, and the processing time.

Objectives for this study:

i. To locate the bottleneck in the manufacturing process.

ii. To provide fresh recommendations for improving the present plan-layout.

iii. To forecast assembly line performance in comparison to alternative machine configurations.

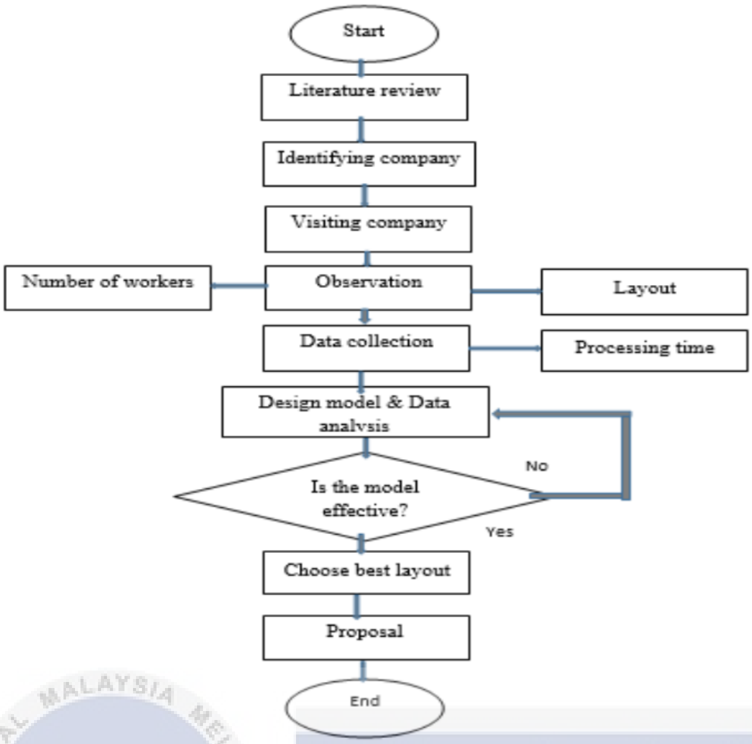


Figure 2-15: Research methodology flow chart.

According to the information gathered, there are several research on assembly line balance. As a result, various data points may be drawn to further this research. To do the study, an appropriate organisation must be found. The researcher will then visit the location to confirm that the company's status is known. The observation focuses on the processing time of the assembled product and the present layout design. The acquired data was then examined and transformed into a new layout design that will boost the assembly line's efficiency. The obtained data was evaluated to determine the standard time, current layout, workstation, number of operators, and material handling system utilised. Witness simulation software will be used to examine the collected data. The programme assesses the processes and makes the best decision in a short amount of time. The finest arrangement chosen from the new layouts will then be proposed to the organisation.

Workstation	Number of workers	Time (min)
Preparation	2	63.13
1	3	62.07
2	3	57.41
3	3	103.15
4	3	64.24
5	3	65.15
6	1	39.54
7	4	58.33
8	3	50.59
9	3	56.29
10	2	41.20

Figure 2-16: The summary of all cycle time for each workstation for current layout.

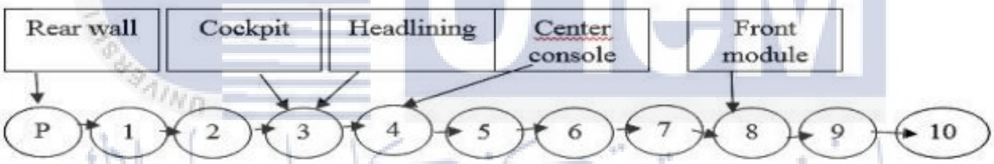


Figure 2-17: The precedence diagram for all workstation for S-class car.

The precedence graphs demonstrate how each workstation's work progresses, whilst the processing time reveals how much time it takes to finish the task. Figure 2-16 depicts a high-level overview of all workstations in an S-class automobile production line. Figure 2-17 depicts the precedence diagram for all workstations in an S-class vehicle. Witness Simulation reveals that with all needed inputs, the time required to finish manufacturing one automobile is 8165 minutes. The time was calculated from workstation preparation to workstation ten, including all sub-assemblies. The labour hour in a month is 13200 minutes since workers only work 22 days per month and 10 hours per day. After six months of simulation, the total number of cars produced is 51. Work hours were utilised as inputs to calculate productivity. The total labour hours for six months are 79200 minutes. The present layout's productivity for the next six months is assessed to serve as a baseline for the new designs.

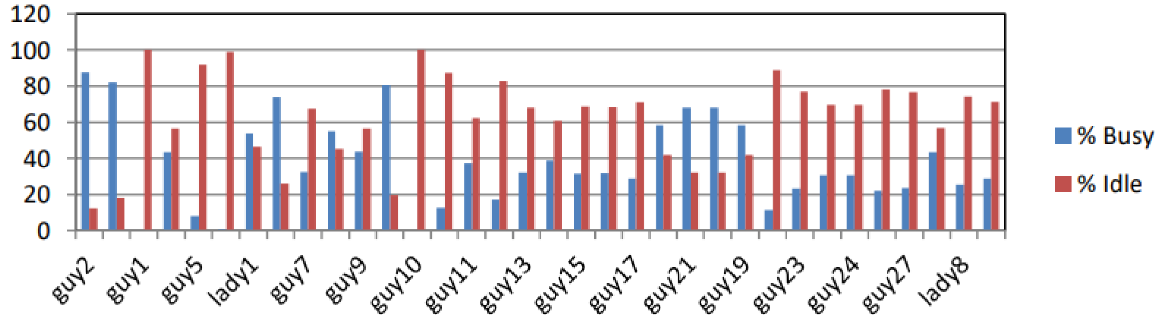


Figure 2-18: The graph of the effectiveness of each labour for current layout.

Witness simulation has resulted in two new layouts (1 and 2). According to the Witness simulation data, the time required to manufacture one automobile is 8119 minutes. The simulation is then extended for six months to assess the efficiency of the New Layout 1. The number of items grew by one, bringing total output to 52 pieces. To determine the success of the new design layout, productivity is assessed and compared to the present arrangement. The New Layout 1 productivity is 0.0006566 units per labour hour.

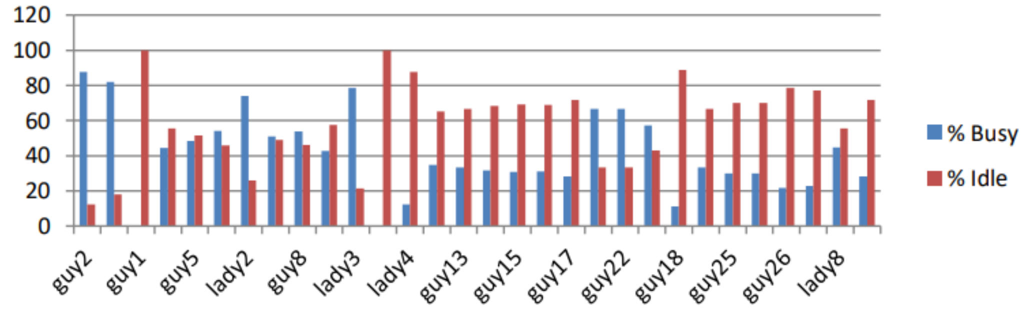


Figure 2-19: The graph of the effectiveness of each labour in the New Layout 1.

After the layout design is finalised, the analysis for New Layout 2 is simulated. The production time of an automobile is 8077 minutes. After six months of simulation, the number of automobile units produced is 53. The productivity is measured to determine the efficacy of the New Layout 2. According to the statistics, lady6 and guy28 have been sacked or reassigned to another department. The total number of employees in the new layout 2 is 32. The other two individuals that were eliminated in New Layout 1 were reallocated to the new workstation. Instead of having numerous idle intervals, they now have a new duty that can make them more efficient. The productivity for the New Layout 2 was 0.0006692 units per labour hour, which was 0.0000126 units greater than the productivity for the New Layout 1. The New Layout 2 had the greatest productivity of the three layouts, with 0.0006692 units per work hour. New Layout 2 also increased the present layout's efficiency by 3.93%.

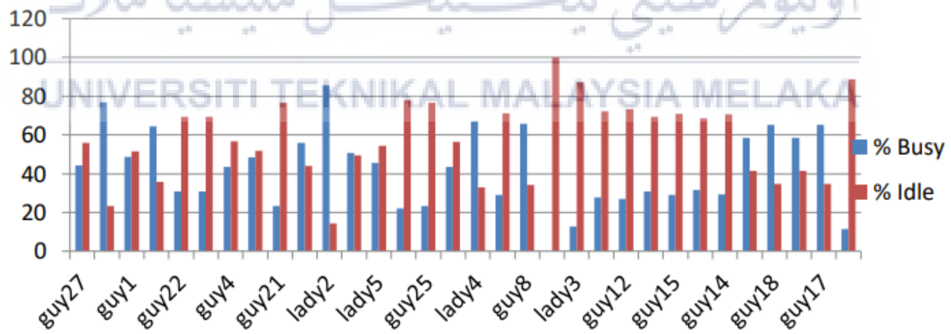


Figure 2-20: The graph of the effectiveness of each labour in the New Layout 2.

Table 2. Productivity and improved efficiency comparison

Layout	Productivity	Improved efficiency
Current layout	0.0006439 units / labour hour	-
New layout 1	0.0006566 units / labour hour	1.97%
New layout 2	0.0006692 units / labour hour	3.93%

Figure 2-21: Productivity and improved efficiency comparison.

The first goal was met when the data acquired about the time study, workstation arrangement, and number of workers was assessed using Witness software. According to the data analysis performed with Witness software, New Layout 2 outperforms New Layout 1 and the present corporate layout. The New Layout 2 has a greater production rate and efficacy than the New Layout 1. Layout 2 has a 3.93% efficiency, however New Layout 1 only has a 1.97% efficiency. The new Layout 2 production rate is 0.0006692 units per labour hour, which is higher than the present layout's rate of 0.0006439 units per labour hour.

In terms of increased efficacy, New Layout 2 is more efficient since it has a greater efficiency rate. As a result, it is preferable to use the New Layout 2 to boost product output. The results demonstrate that new arrangement 2 is superior than New Layout 1 and the current arrangement. The simulation was done using Witness software, which has been shown to be beneficial in studying assembly line difficulties since it helps enhance assembly line efficiency and operator productivity.

2.4.2.2 Reasons Simulation is a Powerful Tool for Addressing Line Balancing Problems

To identify line balancing problem such as bottleneck, simulation is one of the tools that can help you. Witness software is one of the best applications that give industry what they need. Based on the case studies above, we can conclude the reasonable steps to conduct simulation for production line. First, the objectives must be set for the simulation. Always set your target to line balancing problem because that's where production can increase its productivity.

According to Jamil & Razali, 2016, in line balancing application, there are two common issues to address. First, reducing the task time or processing time that have been assigned to all workstations to suit and not exceed the cycle time that has been given. Second is minimizing the highest workload assigned to a specific workstation when the number of workstation and line cycle time are fixed. Through simulation modelling, a company can save cost to improve the assembly line performance compared to the traditional way of trial-and-error on the actual production system. Simulation is defined as a powerful tool for the analysis of new system designs, retrofits to existing systems and proposes changes to operating rules (Jamil & Razali, 2016).

It is a tool that is preferable to use in large areas because it does not interrupt the current existing system. Plus, different scenarios can be tested to optimize and balance the line (Tushar D. & Mukesh C., 2018).

2.5 Summary

In the modern competitive industrial scene, improving production line efficiency is critical for corporations looking to boost productivity, save costs, and efficiently satisfy consumer needs. Simulation, as a strong tool, provides considerable benefits in reaching these objectives. Simulation gives significant insights and chances for optimisation by developing virtual models and analysing many areas of the manufacturing process.

Manufacturers may use simulation to test and evaluate various scenarios, discover bottlenecks, and optimize resource allocation. It enables the study of production rates, workloads, and material flows, resulting in enhanced line balance and overall efficiency. Manufacturers may obtain a better knowledge of their manufacturing processes, discover areas for development, and make educated decisions to increase performance by using simulation. With help from Witness software, productivity can be increased resulted of a balance in the production line.

CHAPTER 3

METHODOLOGY

This chapter emphasizes research methodologies that will be used in this study. In general, the expression "research methodology" simply refers to the "how" of a research investigation. It is primarily about how a researcher plans a study in a methodical manner to produce accurate and trustworthy results that answer the research aims, objectives, and research questions. This study will involve a variety of methodologies, from recording the cycle time, calculating the standard time, defining material handling, and defining bill of materials. This study will focus on using Witness Horizon software simulation so this chapter is going to tell what step will be used to conduct the simulation.

3.1 Planning Research

This undertaking can be divided into two main components. The initial phase (Projek Sarjana Muda 1) encompasses the introduction, literature review, and methodology sections. On the other hand, the subsequent part (Projek Sarjana Muda 2) entails creating the simulation model, presenting, and discussing the findings, and providing the conclusion and recommendations. Below this, the flowchart has been provided for the whole Projek Sarjana Muda (PSM).

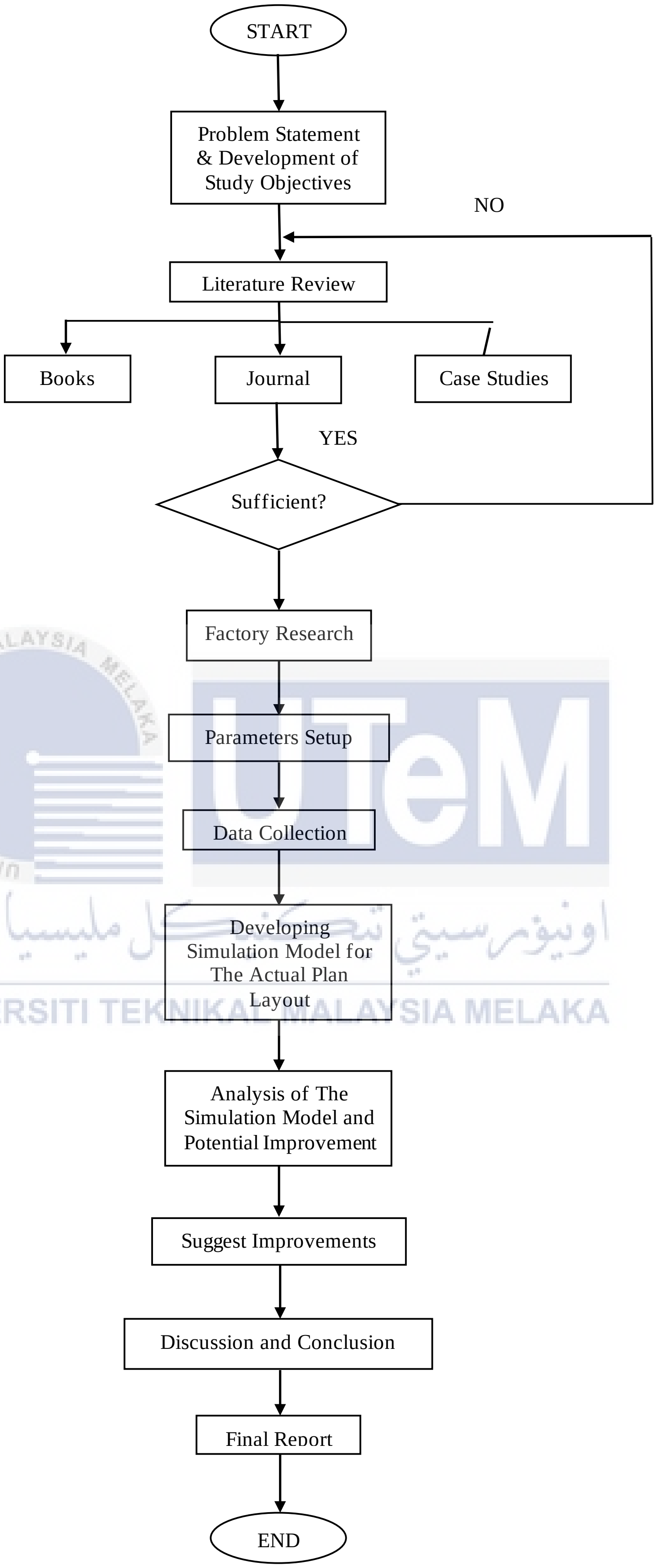


Figure 3-1: Methodology of Projek Sarjana Muda

3.2 Flowchart Clarification

This part will discuss more detail about every step in the methodology of PSM. Figure 3.1 above will be dissected and explored below.

3.2.1 Problem Statement & Development of Study Objectives

A problem statement is a brief and straightforward summary of the issue or difficulty that the research intends to address. It identifies the knowledge gap or the problem that must be solved. The problem statement should emphasise the importance and relevance of the study, describing why it is necessary to explore the topic. It should be detailed enough to steer the focus of the study and reduce the scope, yet wide enough to allow for useful investigation and analysis.

This study objectives explain the exact goals and outcomes that the study seeks to attain. They act as a guide for the whole investigation and give a clear path for the research. Objectives assist to concentrate the research and give a framework for assessing the study's success or failure. Multiple objectives are typical in a case study or research article, each addressing a different feature or angle of the issue statement. The goals should be written in a logical and hierarchical manner, with the primary goal being the most significant and the subsequent goals supporting it.

3.2.2 Literature Review

A literature review is a critical overview and assessment of previously published research and scholarly papers on a given topic. For this study, literature review mostly cover about simulation and assembly line balancing. It is an important part of a research paper or academic study since it provides a full overview of the current state of knowledge in the topic. The purposes of literature review are determining current knowledge and knowledge gaps. It assists researchers with determining what is currently known about the issue and any places where more study is required. Next, it determines important ideas, concepts, and approaches. It enables researchers to discover theoretical frameworks, concepts, and methodology employed in earlier studies, allowing them to expand on previous work. All the review has been obtained mostly from journal, books and case studies.

3.2.3 Factory Research

Factory research is a quick review for the student to know a little bit about scope of research or factory situation for this study. Questions have been asked to supervisor for this Projek Sarjana Muda.

3.2.4 Parameters Setup

Parameter setups are the exact settings and configurations chosen for the variables or parameters being researched or changed in the context of research or studies. Parameter settings are critical in assuring the validity and repeatability of research findings, as well as allowing for controlled testing and analysis. The simulation for this study will be conducted from Witness Horizon software.

First, we need to justify what data we need to collect to conduct assembly line balancing to the current layout of production line. This will help us compare the error percentage from manual calculations and simulation.

$$\textit{Takt time} = \frac{Total\ Available\ Work\ Time}{Actual\ Demand}$$

Table 3-1: Template Data Collection for ALB

Assembly Line	Process 1	Process 2	Process 3	Process 4	…
Available work time (sec/day)					
Cust. Demand rate (units/day)					
Takt time (sec/unit)					
Cycle time (sec/unit)					
Standard Time (sec)					

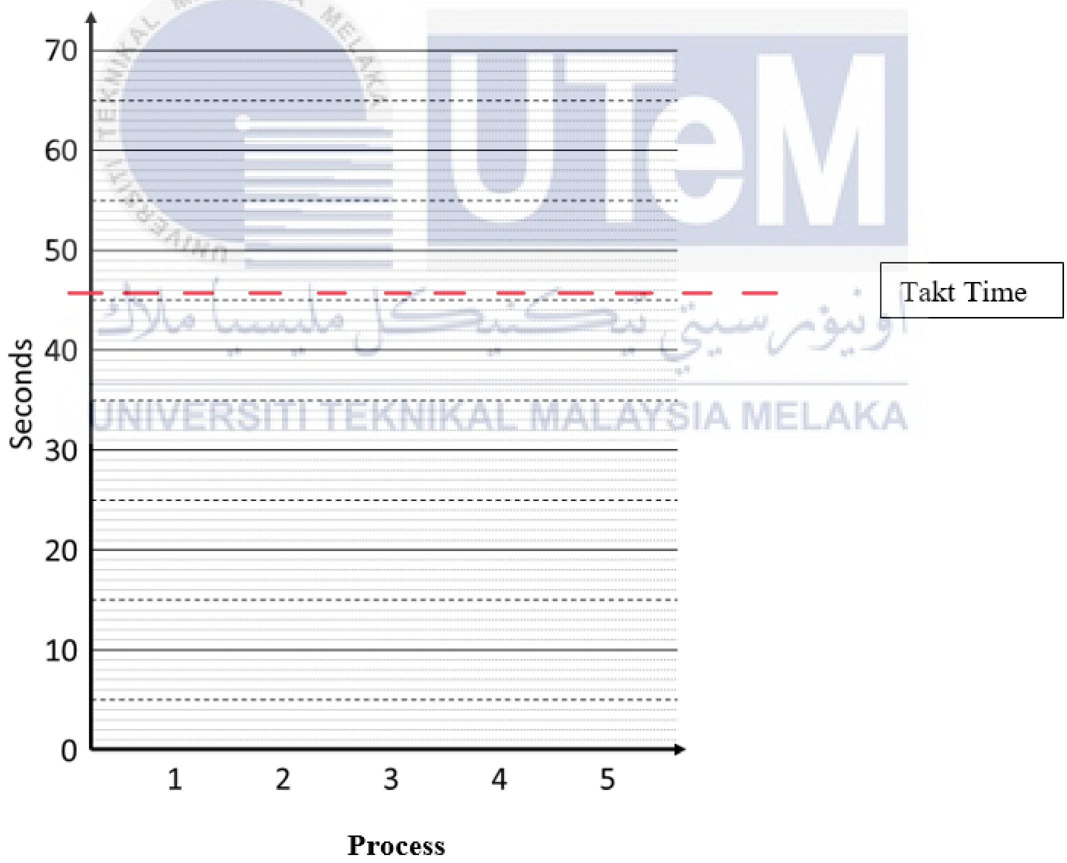


Figure 3-2: Example of blank line balancing graph

We can dissect based in what happened in line balancing graph. There are situations we can conclude:

- If process time taking much longer than takt time, overtime is most likely used to make up for lost output.
- Excess capacity can be supplied by absorbing part of the work from other processes when the Takt time is exceeded.
- Pretty near to meeting Takt time, not a focus area but possibly some best practices. These improvements might be utilised to spread burden from constraint processes.

Secondly, the parameters for simulation are also needed. To run a simulation with Witness software, you must normally specify and configure several parameters that characterise the features and behaviour of the system being modelled. The parameters required may differ based on the nature of your simulation and the specifics of your manufacturing process.

Table 3-2: Template Data Collection for Simulation

Parameters	**Remarks**
Arrivals Rates (minutes):	
Resource Capacities (unit):	No. of Machine: No. of Labor: No. of Equipment: No. of Workstation:
Routing Rules:	*The paths or sequences that things take as they travel through the production line are defined by routing rules.

Table 3-3: Template Data Collection for Simulation (cont.)

Process No.	**Processing Times (second)**	**Queue Capacities (unit)**	**Downtime or Failure Rates (second)**
Process 1			
Process 2			
Process 3			
Process 4			
Process …			

To analyse this simulation, we can use the performance measures below for indicators to evaluate the efficiency and effectiveness of the production line:

i. Throughput

ii. Cycle Time

iii. Work-In-Progress (WIP)

iv. Resource Utilization

Those performance measures can be used to comparison for manual calculations.

The parameters will be divided into 3 parts based on Input-Process-Output (IPO). The input-process-output (IPO) model shows the flow of information or resources through a system. It is widely used in a variety of industries, including computer science, business, and engineering, to comprehend and analyse how inputs are changed into outputs via a succession of processes. To make the simulation, this setup is important.

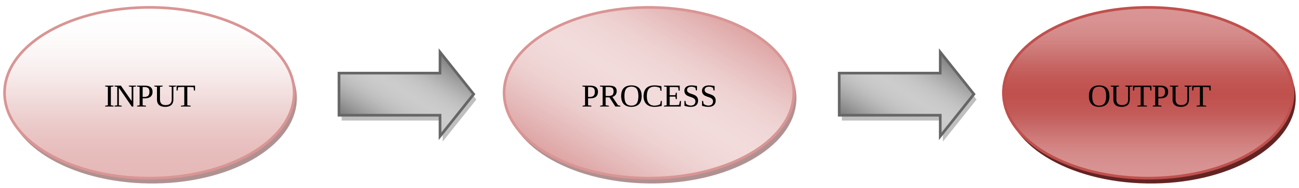


Figure 3-3: Input-Process-Output (IPO)

i. <u>Input</u>

Inputs are resources, data, or information entered into a system to start a process or action. Depending on the context and nature of the system, inputs might take several forms. In a manufacturing environment, for example, inputs might include raw materials, components, energy, product specifications information, or even human resources such as labour and knowledge. Inputs in software development might be user requirements, data collections, or computer code.

ii. <u>Process</u>

The process refers to the actions, operations, or transformations that take place inside the system to turn inputs into desired outputs. It denotes the acts or steps performed to modify, integrate, or change inputs in order to obtain a given result. Human activities, automated tasks, algorithms, or a mix of these are examples of processes. The value-adding actions or transformations occur in the process component, when inputs are transformed, organised, or utilised to generate the desired outputs.

iii. Output

Outputs are the outputs, goods, services, or outcomes produced by the system because of the inputs' processing. Outputs indicate the system's outcome or objective. Depending on the nature of the system, they might be physical or immaterial. Outputs might be finished items, reports, software programmes, customer services, or any other quantifiable or observable conclusion.

3.2.5 Data Collection

The practise of gathering information or data from multiple sources or participants to answer research questions or examine a specific phenomenon is known as data collection. It is an important phase in the research process that has a direct influence on the quality and dependability of the results. For this case, to make the simulation we need to collect some variables from the working space or site. Cycle time need to be recorded. Cycle time refers to the total time it takes to complete a process, task, or operation from start to finish. It means recording each machine time to produce a unit. From the cycle time then we can achieve the takt time and next we can detect the bottleneck from the production line. To make it productive, analysis from assembly line balancing can be made.

Next data that we can collect is number of machines and its position from the production line. From that, precedence diagram can be made. Number of workers, total shift time per day, demand from the client, breakout time of the machines or any variables in the production must be collected to produce the simulation.

3.2.6 Simulation

There is many software that can be used to do a simulation or analysis the productivity of the assembly line. This researcher chooses Witness Horizon software to conduct this research and achieved my objectives. The method for the simulation regarding this study has been made below based on the case studies that I review in the literature review:

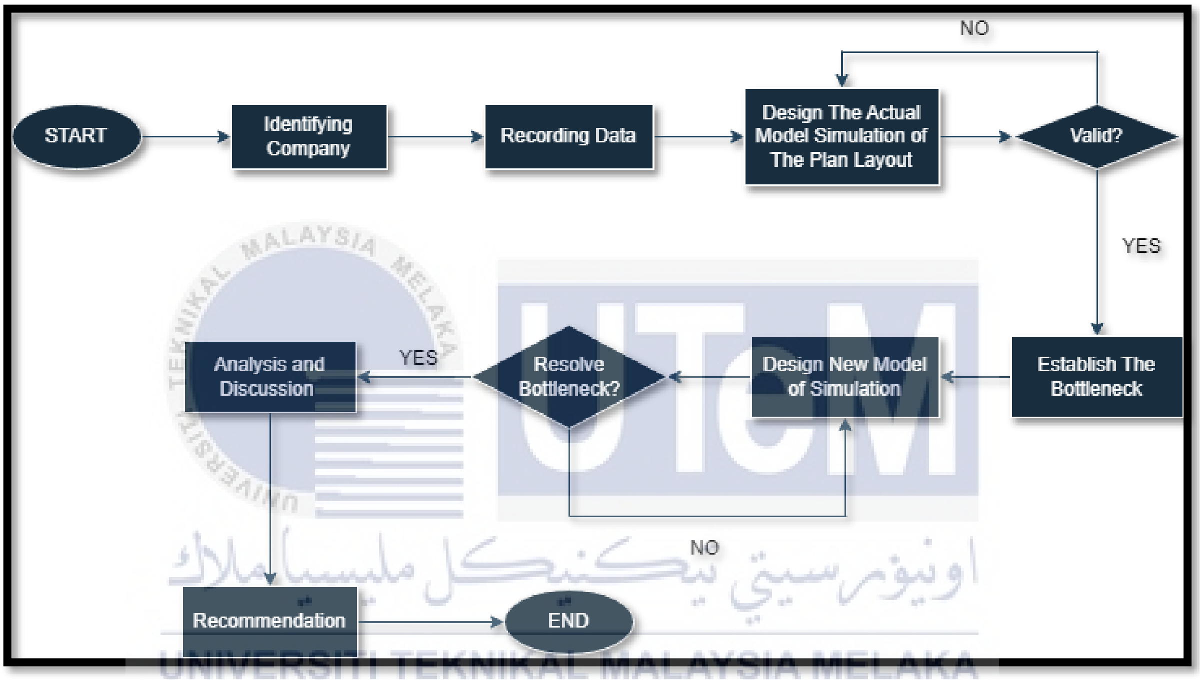


Figure 3-4: Methodology of Simulation Model (Yasir and Mohamed, 2018)

Table 3-4: Definition Simulation Methodology

Phase	Description
Identifying Company	Clarify the process of assembly line in the company.
Recording Data	Take all the variables data such as cycle time, total shift per day, capacity, number of operators, plan layout of production line,

	number of machines and breakout time or maintenance of the machines.
Design The Actual Model Simulation of The Plan Layout	Create the actual simulation model from the assembly line and verify it by give a brief comparison with manual calculation.
Establish The Bottleneck	Find the bottleneck in the system.
Design New Model of Simulation	Propose some model simulation that eradicate the bottleneck.
Analysis and Discussion	Make the comparison and suggestion to the production line.
Recommendation	Propose the best model layout.

3.2.7 Discussion and Conclusion

Discussion and conclusion let the researcher to evaluate and analyse the findings, relate them to prior knowledge, and make larger conclusions and suggestions based on the research. Comparison with previously published material. The discussion connects the findings to the field's current body of knowledge. It draws attention to any resemblance contrasts, or conflicts between the present study's findings and earlier research. This comparison describes the findings and adds to knowledge progress. In this case, the actual simulation model will be compared to new simulations model and will be analysed.

The conclusion covers any practical consequences or recommendations that the research may have. It discusses how the findings might be implemented in real-world situations, such as influencing decision-making or guiding practises.

3.3 Gantt Chart

Tasks are displayed as horizontal bars along a time axis in a Gantt chart. Each bar's length correlates to the task's duration, while its location denotes the task's start and finish dates. The chart also displays task dependencies, indicating the order in which they must be accomplished. Gantt chart for this study can be found at APPENDIX A.

3.4 Summary

Finally, this chapter discusses the flow of the study and the steps needed in carrying it out. It starts with generating a flowchart that summarises the PSM's flow method. The scope and objective are then developed based on this. The purpose is to accomplish the objectives that have been established. Moreover, all the simulation steps have been discussed in this chapter.

CHAPTER 4

RESULT AND DISCUSSION

The results of the witness simulation, which was created to increase production line efficiency in the aerospace industry, are presented in this chapter. It explores experimental data and simulation-derived information to provide strategic recommendations for optimisation as well as insights into the production line's existing condition. Following an examination of the simulation setup and data gathering techniques, the presentation presents the findings, highlighting trends, patterns, and performance indicators. These results are interpreted in the study that follows, providing connections to the wider aerospace manufacturing sector background. The chapter ends with a summary of implementation suggestions and possible directions for further research.

4.1 Company Background

The selected company for this project is SME Aerospace Sdn Bhd, situated in Sungai Buloh, Selangor. SME Aerospace (SMEA) Sdn. Bhd., a wholly owned subsidiary of National Aerospace & Defence Industries (NADI) Sdn. Bhd. was established in 1992 as part of the Offset Program. The initial products launched included Hawk Aircraft Pylons for BAE Systems and the Civil Certified MD3-160 Aircraft Aerostructural Parts and Components. These programs were initiated with technical assistance from BAE Systems under the Hawk Aircraft Offset Programme.

Following the success of the first offset program, SMEA independently secured various international tenders. These projects encompassed the manufacture of over 300 Hawk Aircraft Pylons, Hawk Fuselage Parts and Assemblies, Airbus A300 and A319/320/321 Civil Aircraft Parts, BAE Systems Regional Jet (RJ) Wing Leading Edges and Carriage Assemblies, Nimrod Aircraft Parts, and Parker Aerospace Turbine Engine Parts.

Since then, SMEA has evolved into a significant manufacturer of aircraft components for major players such as Boeing and Airbus. Providing a comprehensive solution, SMEA operates vertically integrated facilities offering high precision machining, fabrication, treatments, and assembly. Located just outside Kuala Lumpur, SMEA strategically serves both local and international customers, delivering over one million quality components annually. The company's procedures are certified by internationally accredited Quality Management Systems, including AS9100 Rev. D, NADCAP PRI for Heat Treating, Surface Enhancement, Non-Destructive Treatment, Chemical Processing, and Measurement & Inspection.

4.2 Data Collection

This section describes the data gathering procedure, including data sources, variables evaluated, facility layout, assembly procedures at assembly line and any data preparation procedures used. It outlines how the data was cleaned, organised, and turned into an analysis-ready format.

4.2.1 Facility Layout

SME Aerospace Sdn. Bhd. is a company that specializes in the production of aerospace components, particularly the 6C overwing beam section. The assembly department of their factory houses this production line that is exclusively meant for manufacturing aircraft overwing beams. This assembly line only poses 4 workstations. Certain workstation will do different jobs, or the beam will enter the workstation multiple times like Jig Station. Below is Figure 4-1, which show the plan layout of the assembly line.

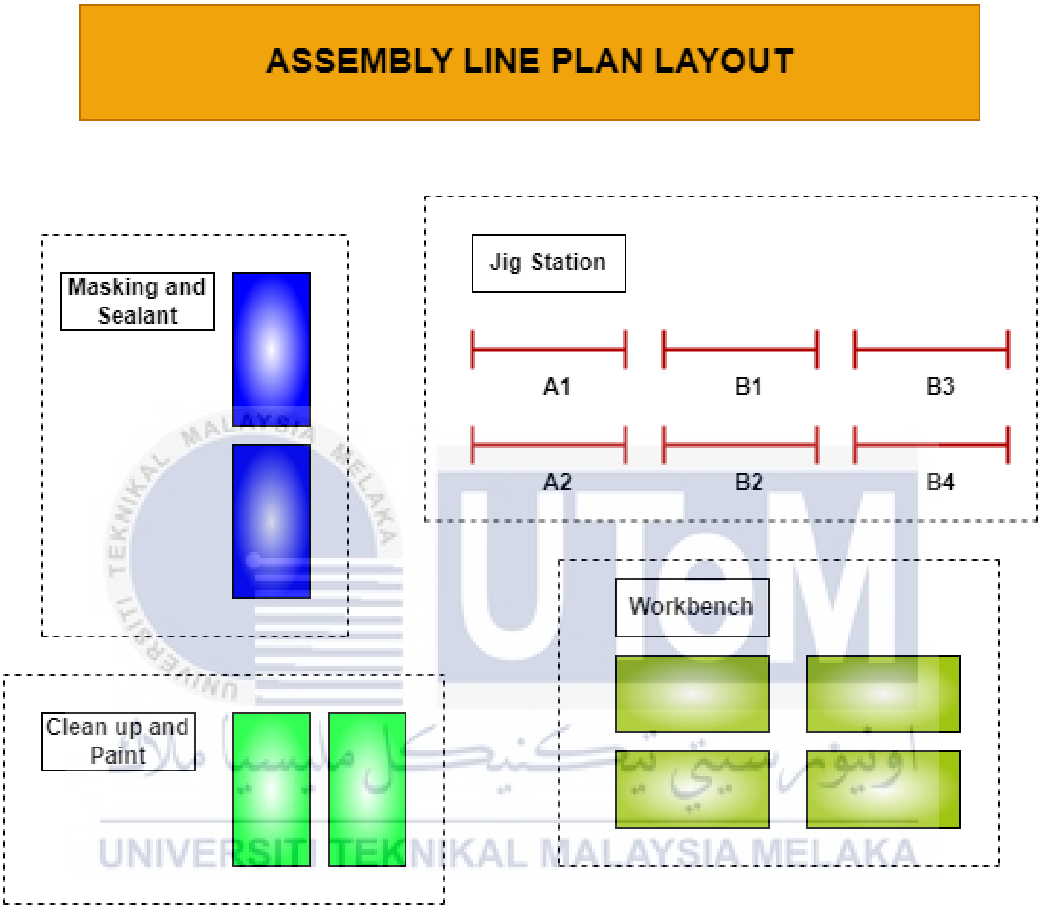


Figure 4-1 : Assembly Line Plan Layout

First, all the beams will be placed on their own Jig. This study classifies each beam using A1, A2, B1, B2, B3 and B4 because it keeps confidentiality issue between researcher and the company this research take place.

4.2.2 Work Process

The assembly line not only assemble one kind of beam but six. The six different types of overwing beams all go through the same four-stage production process, despite their differences. This approach helps to maintain uniformity and accuracy in the manufacture of these vital aerospace parts. In this study, our attention is directed specifically to the 6C overwing beam section production line. By focusing on this area, this research hope to give a full understanding of the procedures used in the manufacture of these vital aircraft parts. Examining the four stages that form the assembly process is part of this. Here is the work process according to 4 stages respectively:

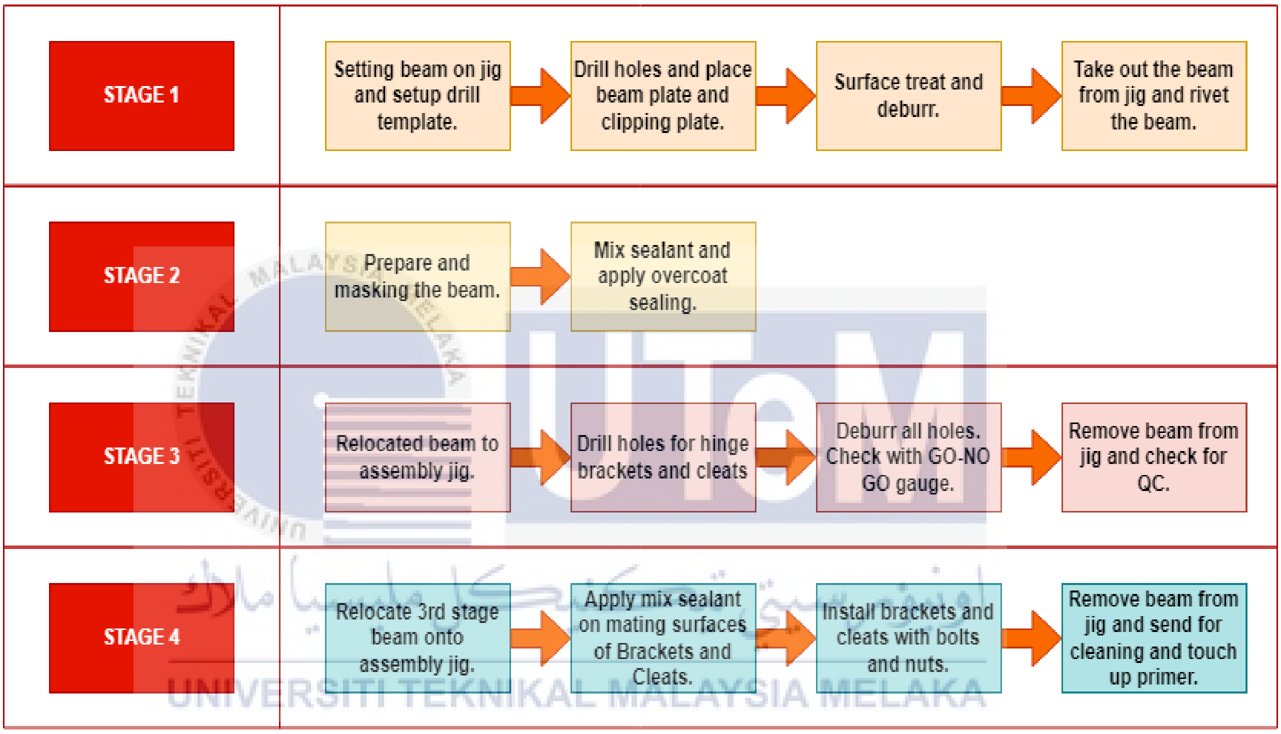


Figure 4-2 : Work Process Flow

To make it easy to understand, this study will develop a simple flowchart process. Cycle time also taken based on each work process below:

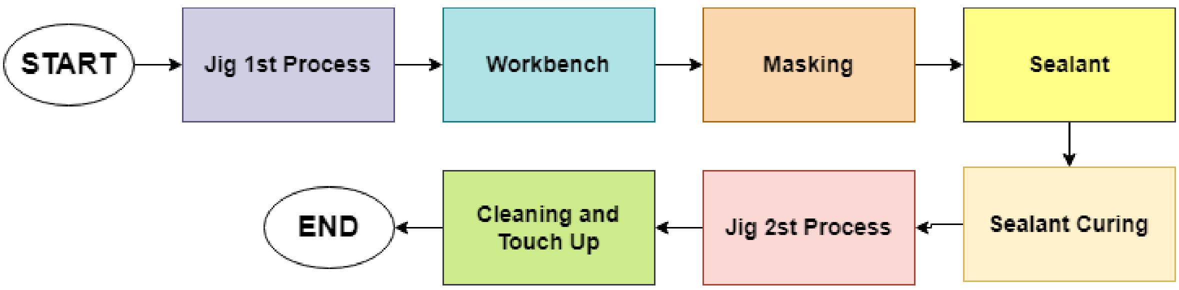


Figure 4-3 : Flowchart Work Process

4.2.3 Parameters

Key aspects to make line balancing graph have been collected. A key component of this attempt is the careful assessment of variables including cycle time, available work time, workstation count, and customer demand. According to Goyal et al., 2022, cycle time is an important parameter in deciding productivity of a manufacturing process and flexibility of production line. In order to optimise productivity by assigning duties evenly among workstations, line balancing is a strategic technique, and these factors are crucial to its success. The careful examination and coordination of these factors are necessary to guarantee that production rates are in perfect harmony with client demand, reduce bottlenecks, and optimise overall productivity.

Customer Demand for Week 26	13 units for each beam x 6 = 78 units
Total available working per week	1 shift = 9 hours Lunch break = 1 hour Total available working per day = 9-1 = 8 hours 8 x 60minutes x 5days = 2400 minutes

Takt is a lean tool that has a goal to reduce waste and increase value by creating a stable environment for implementing Last Planner (Frandson et al., 2015).

$$\boldsymbol{Takt\ time} = \frac{Total\ Available\ Working\ Minute\ per\ Week}{Customer\ Demand\ per\ Week}$$

For 6C Overwing Beam Assembly Line $= \frac{2400}{78} =$ **30.77 minutes per unit**

Table 4-1 : Work Process Data

Work Process	Cycle Time (min/unit)		Takt Time (min/unit)
Type of Beam	A1/A2	B1/B2/B3/B4	
Jig 1st Process	34.03	29.14	**30.77**
Workbench	16.53	16.53	**30.77**
Masking	25.2	25.2	**30.77**
Sealant	8.15	8.15	**30.77**
Sealant Curing	40	40	**30.77**
Jig 2nd Process	18.58	18.58	**30.77**
Cleaning and Touch Up	58.25	58.25	**30.77**

From this data that researcher got. Line balancing graph can be made. The graph will be divided into 2 because of different cycle time between beam A and beam B.

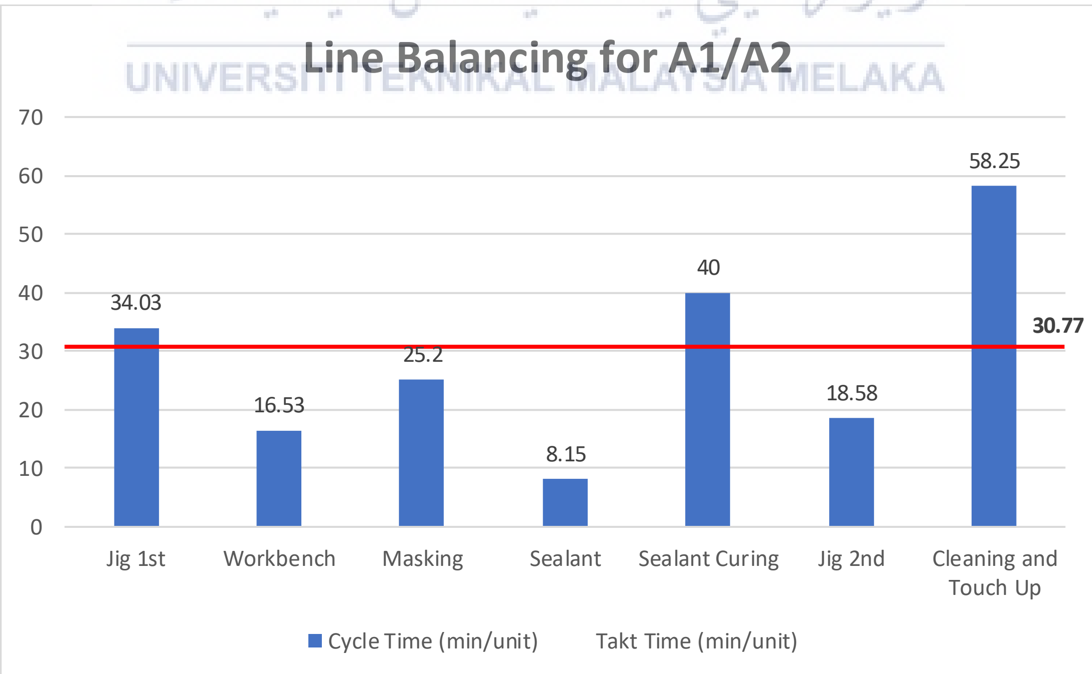


Figure 4-4 : Line Balancing for A1/A2

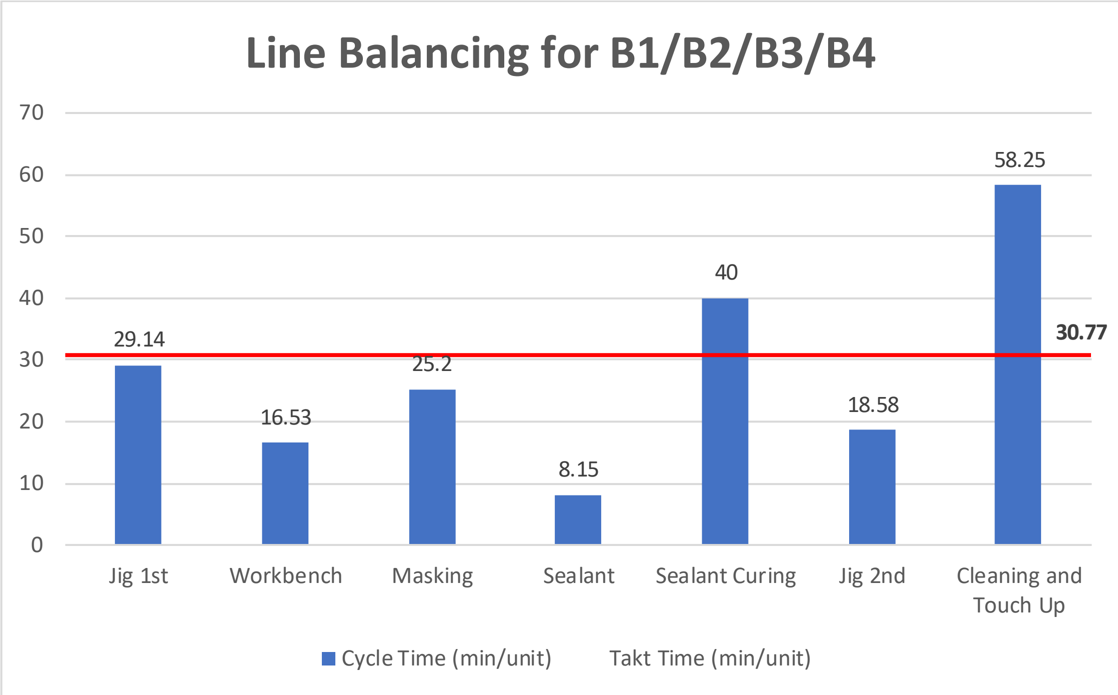


Figure 4-5 : Line Balancing for B1/B2/B3/B4

From both line balancing that this study gets, there are 3 work process that exceed takt time. Cleaning and touch up with most cycle time 58.25 minutes leave a huge gap with takt time. It can be considered as bottleneck for this assembly line. If process time taking much longer than takt time, overtime is most likely used to make up for lost output. Pretty near to exceed takt time, not a focus area but possibly have some restrictions that it holds for assembly line. Take an example from Jig 1st work process in Figure 4-3 with cycle time that 34.03 minutes.

A possible production bottleneck is indicated when a workstation in line balancing takes longer than the takt time. This imbalance suggests that the overall flow is being disrupted because the station's cycle time exceeds the predefined takt period. Inefficiencies, longer wait times, and possible delays in reaching production goals might result from this mismatch. A more synchronised and effective production line can be attained by distributing jobs or optimising the workstation's performance. Here are potential scenarios that can happened:

1. The production system may be inefficient, and resources such as labour and machinery may be underutilized.
2. The production line may accumulate excessive work-in-progress inventory as units take longer to complete than the customer demand requires.
3. Exceeding takt time increases the likelihood of delayed deliveries, as the production rate falls short of meeting the pace demanded by customers.

4.3 Simulation

After completing the line balancing process for the assembly line, the next step involves delving into the realm of simulation. A useful technique for evaluating and visualising the performance of our optimised manufacturing system is simulation. Through the development of a virtual assembly line model, this study can model different situations, examine possible modifications, and assess the effects on production and efficiency.

4.3.1 Model Assumption

Clearly stating the model assumptions is a crucial initial step before embarking on simulation modelling. This step sets the groundwork for the entire simulation process, defining the parameters and conditions that will guide the model. A well-defined declaration of assumptions ensures a more accurate and reliable simulation model, influencing its fidelity and relevance to real-world situations. This simulation model makes the following assumptions:

i. The simulation only focusses on 6C Overwing Beam assembly line.

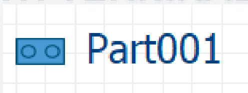
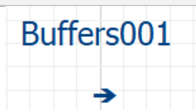
ii. The simulation only runs for 1 week that equal to 2400 minutes and does not include overtime hour.

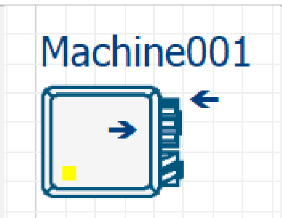
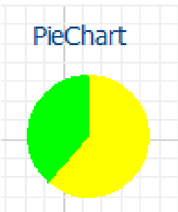
iii. The simulation tends to compare its throughput result with actual throughput result in week 26 at assembly line to seek for validation.

4.3.2 Elements of the Models

Examining the components of the simulation model especially the Witness Horizon tool offers insight into the many moving parts that create the system's virtual representation. For replicating and monitoring dynamic processes in a controlled setting, Witness Horizon is an effective tool. The main components of the Witness Horizon simulation are dissected in this subtopic, providing an overview of how these parts work together to provide a thorough knowledge of the system's behaviour.

Table 4-2: Elements in Witness Horizon

Elements	Elements Visual	Description
Parts (Entities)		Discrete objects that move within the model are represented by parts. It moves through the model and may stand in for tangible elements, a project moving through a big business, phone calls, or even shoppers going through a store.
Buffers (Queues)		Places where Parts (Entities) can be held.
Machines		Powerful Elements that are used to

(Activities)		represents anything that takes Parts (Entities) from somewhere, processes them and sends them on to their next destination.
Labour **(Resources)**		One resource that can be required for a task or process to be completed is labour. For example, loading, unloading, setting up, and recording model chores.
Variable		Variables are frequently used to store data that might change as the model runs, such as text, integers, and element names. Variables' values can be evaluated from any point in the model.
Graphical **Features**		The simulation results may be shown on the screen thanks to graphic elements like pie charts and histograms. The viewer can more easily see the model's goal thanks to the graphical elements.

4.3.3 Simulation Model using Witness Horizon

Continuing with this study, the researcher focused on making a simulation model that mimics how things are set up on the assembly line at SMEA Company. The main goal of this simulation is to copy the real assembly line system as closely as possible. This way, the study can run different trial simulations and look at how the assembly line might work in various situations. The simulation model is like a useful tool that helps the researcher figure out ways to make things better. It is about finding ways to improve how things are put together on the assembly line at SMEA, helping the company make better decisions based on this understanding.

4.3.4 Input Data

In constructing the simulation model for SMEA Company's assembly line, careful attention was given to the input data that drives the simulation process. The data used in the simulation encompasses a variety of sources and parameters critical to replicating real-world scenarios as accurately as possible.

Table 4-3 : Parameters for Simulation Model

Input Data	**Remarks**
Duration for simulation	2400 minutes
Size buffer (unit)	Minimum: 10 Maximum: 1000 *Depends on child's part that need to assemble.
Arrival rates for parts (unit/min)	1.0
Variables	6 for each beam to count production of beam. *Used for validation to real-world system.

Routing Rules:

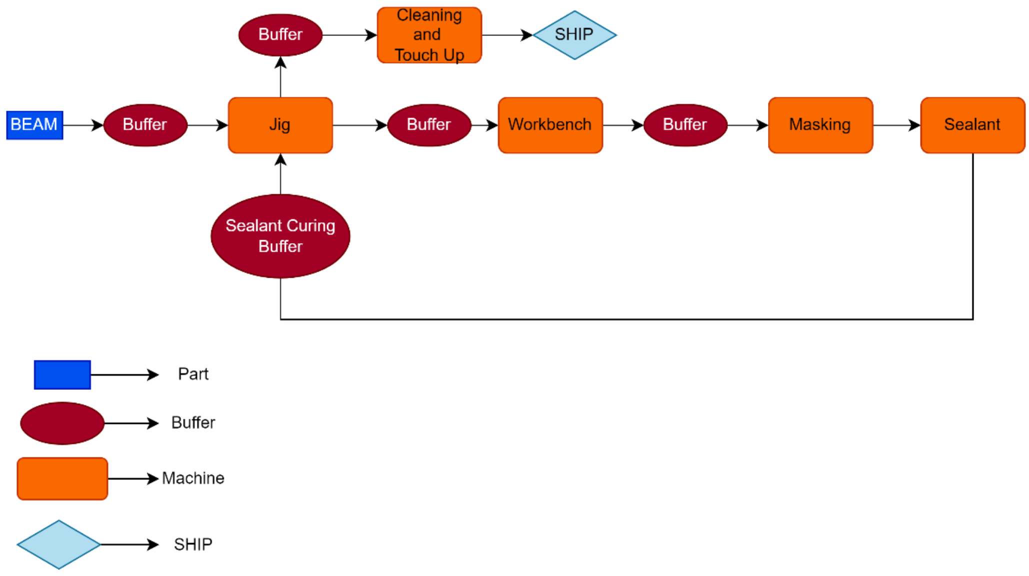


Table 4-4 : Parameters for Simulation Model (cont.)

Process	**Cycle Time (minutes)**	**Queue Capacity (units)**
Jig 1st	34.03	10
Workbench	16.53	10
Masking	25.2	-
Sealant	8.15	10
Sealant Curing	40	30
Jig 2nd	18.58	10
Cleaning and Touch Up	58.25	10

4.3.5 Simulation Model

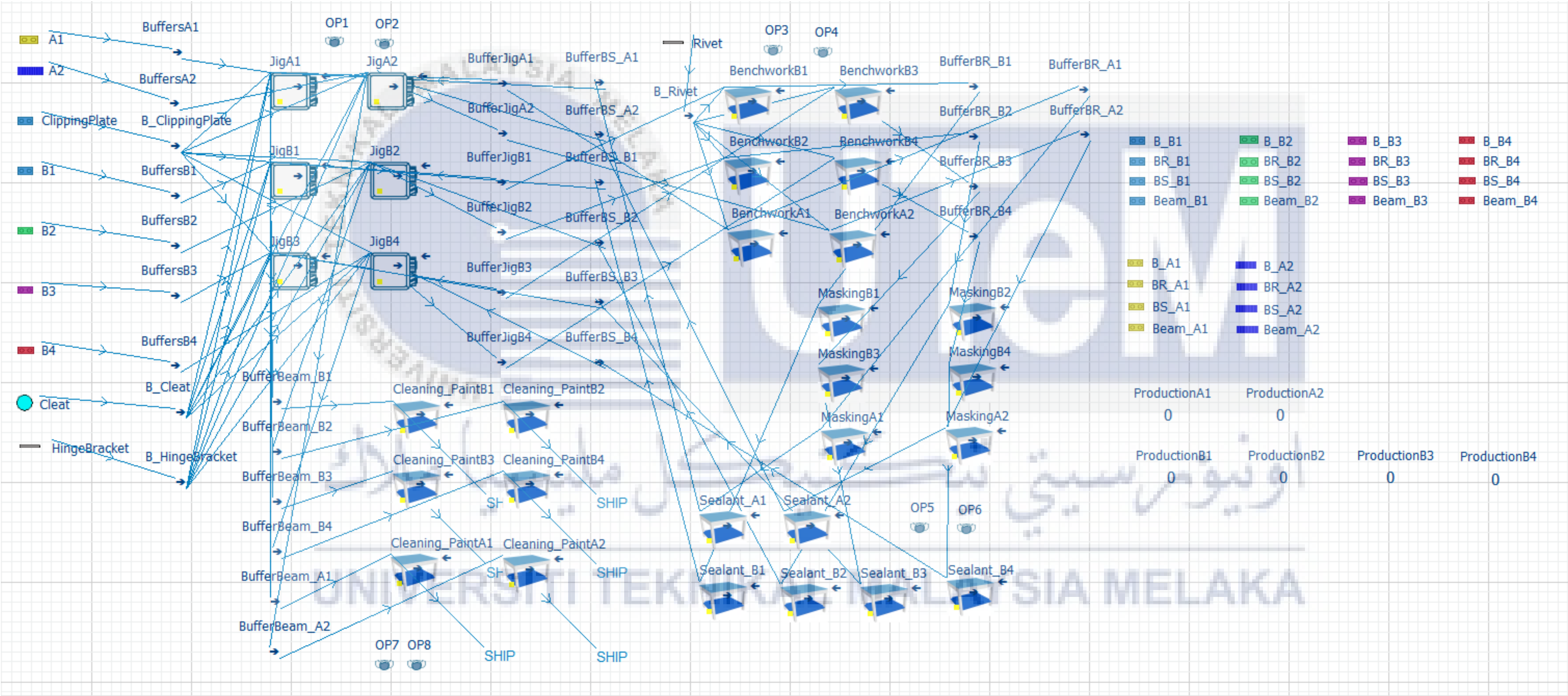


Figure 4-6 : Current Layout Simulation Model

4.3.6 Validation Simulation Model

Verification is concerned with building the model correctly. In model verification, it proceeds by the comparisons of the conceptual model to the computer representation that implements that conception. Meanwhile, validation is concerned with building the correct model. It attempts is to confirm that a model is an accurate representation of the real system (Banks et al., 2010).

In the context of our investigation into SMEA Company's assembly line, a crucial aspect is ensuring the accuracy of our simulation model. The reliability of our findings depends on the careful validation and verification of this model. This section outlines the procedures used to confirm the model's accuracy, emphasizing the need to align it closely with the actual operations on SMEA's assembly line. Through these systematic processes, we aim to provide dependable simulation results that form a solid foundation for decision-making within the organizational context.

In the process of validating my simulation model, real-world throughput data from SMEA's assembly line serves as a critical benchmark. Using week 26 throughput or production output in SMEA’s assembly line as a guidance, the simulation model can be validated. Throughout this validation process, I transparently document any assumptions made during the model's development, providing a comprehensive understanding of the simulation's alignment with SMEA's actual assembly line operations.

Total actual production for week 26 at SMEA: **78 units** of beam

While for simulation model that be made:

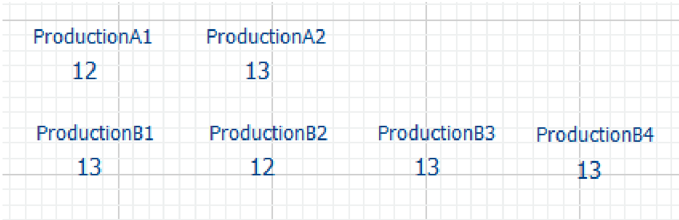


Figure 4-7 : Variables for Showing Production Output

It added up to **76 units** of beam.

$$Accuracy\ percentage = \frac{Simulation\ Output}{Actual\ Output}\ x\ 100\%$$

$$Accuracy\ percentage = \frac{76}{78}\ x\ 100\%$$

$$Accuracy\ percentage = 97.44\%$$

Achieving a validation accuracy exceeding 90% for my simulation model is a significant success. This outcome indicates a strong agreement between the simulated results and the real-world throughput data from SMEA's assembly line. The high level of accuracy reinforces the reliability of the simulation, showcasing its capability to closely replicate the actual system. While it not being 100% accurate to real-world systems, it can be considered for next experimental phase because the simulation did not count overtime hour.

4.3.7 Proposed Improvement Simulation Model

While the simulation model used in the study can be advanced, it is important to note that this section is about the improvements and modifications made on the simulation model to make it more accurate and effective. The major alterations and fine-tuning that were made to the simulation model are explored in this section, while addressing limitations noted previously and making use of knowledge gained during validation. To provide a sophisticated and dependable instrument for comprehension and optimization of assembly line processes within SMEA Company, this simulation architecture needs further development with every iteration.

Proposed alteration that will change the current simulation model is to cut Cleaning and Touch Up work process cycle time. In the line balancing analysis, figure 4-4 and figure 4-5, it shows 2 work process that exceed takt time. These can be considering bottlenecks for the assembly line. But sealant curing that take 40 minutes cannot be reduce. Proposed idea is to combine curing process of Cleaning and Touch Up with Sealant Curing process. Cleaning and Touch Up's cycle time long because 40 minutes of it also have sealant curing process. In other words, we change the arrangement of 4 stages work process flow from 1-2-3-4 to 1-3-4-2 in figure 4-2. Below is the proposed line balancing graph that be made:

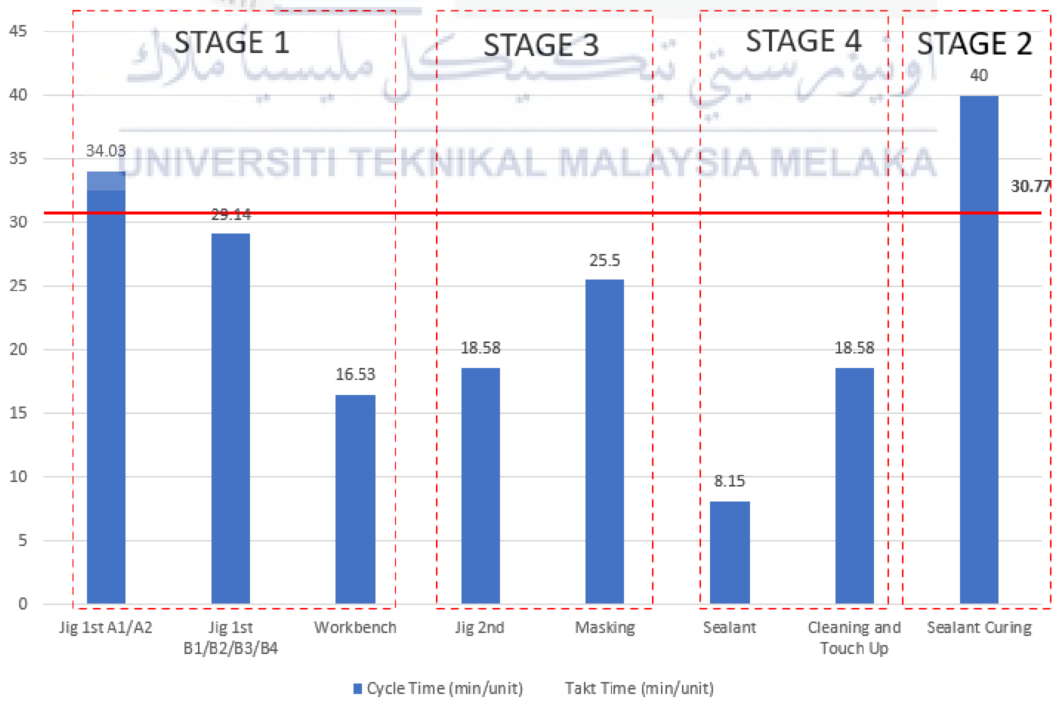
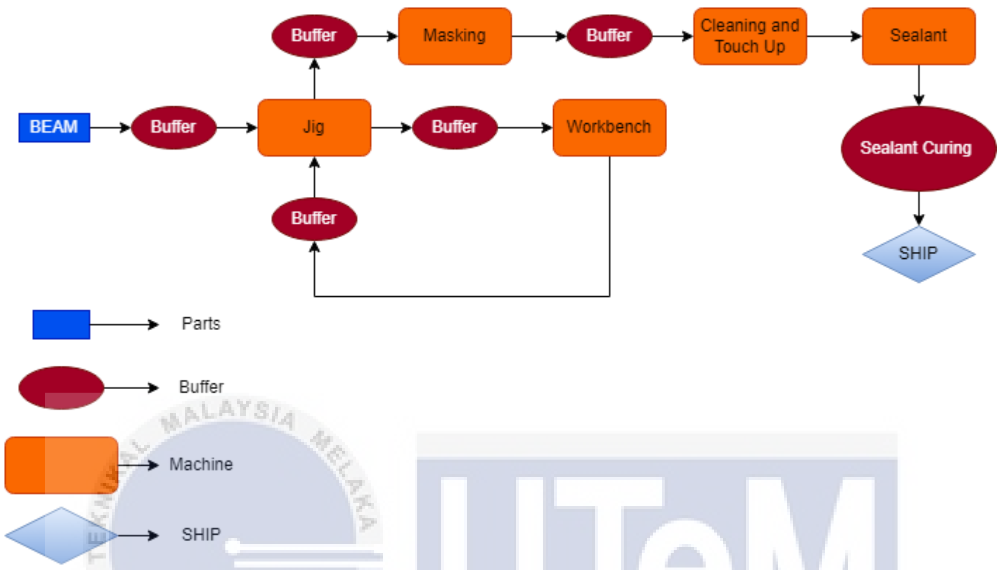


Figure 4-8 : Proposed Line Balancing

4.3.7.1 Alterations in Simulation Input Data

Cycle Time for Cleaning and Touch Up Process (minutes)	From 58.25 to 18.25. *40 minutes cut
Routing Rules: 	

Several key changes have been implemented in the existing simulation model, focusing on routing rules and cycle times for the Cleaning and Touch Up process. These adjustments significantly improve the model's representation of assembly line stages, ensuring a more accurate reflection of material movement. A bottleneck usually is a sub-process in the main process which delays the process. The performance of a process can be increased by eliminating the bottlenecks (Bemthuis et al., 2021). The reduced cycle time aligns the simulated production rate more closely with observed real-world efficiency.

These targeted modifications not only address identified shortcomings but also better capture the efficiency of SMEA Company's assembly line processes. Based on what we learned during validation, these changes are meant to make the model more reliable for making decisions and improving processes within organizations.

4.3.7.2 Proposed Simulation Model

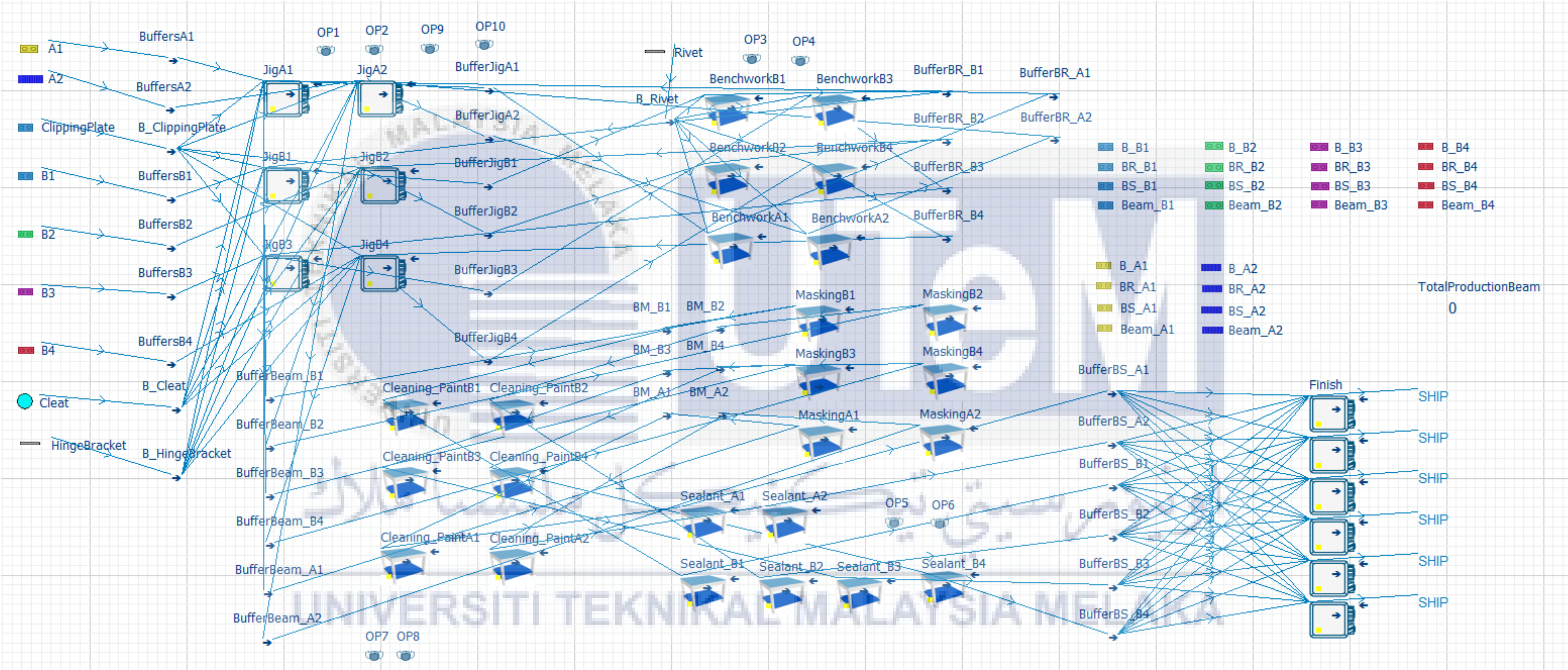


Figure 4-9 : Proposed Layout Simulation Model

4.3.7.3 Results from Proposed Simulation Model

From new simulation model, this research found that there has been increasing production number in assembly line.

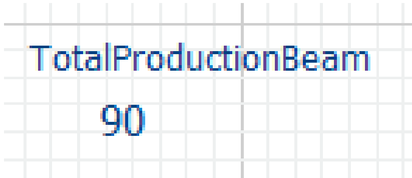


Figure 4-10 : Variable showcase output for total number of production beam

Productivity improvement is mainly centred around increasing throughput, which can be defined as the pace at which parts pass through a production line (Lai et al., 2021). The factual production on the assembly line resulted in the creation of 78 units of beams, whereas the simulation, which suggests an improved production process, indicates a potential output of 90 beam units. This signifies a notable increase of 12 units in the simulated production when compared to the real-world assembly line performance. The augmentation observed in the simulation output highlights the potential effectiveness of the proposed changes in enhancing production efficiency within the assembly line.

4.3.8 Discussion

A comparison is possible to observe the distinctions between the current simulation model and the suggested improvements in the proposed simulation model. This evaluation aims to illuminate and assess the differences and enhancements introduced, offering valuable insights into the potential impact of the proposed changes on the overall simulation performance.

Table 4-5 : Comparison Result

Simulation Model	Current Layout	Proposed Layout
Running Time (minute)	2400	2400
Actual Output (units)	78	78
Simulation Output (units)	76	90
Validated Accuracy (%)	97.44	-
Improvement (%)	-	15.38
Flow Process (stage phase) *** Figure 4 2 : Work Process Flow**	1-2-3-4	1-3-4-2

The proposed simulation model not only demonstrates a substantial advancement in production output, generating 90 units of beams compared to the baseline production of 78 units, but it also results in a noteworthy reduction in bottlenecks within the line balancing process. This signifies a significant improvement of 15.38% in simulated production, highlighting the positive impact of the proposed modifications.

The observed increase in output, coupled with the mitigation of bottlenecks, underscores the efficacy of the enhancements made to the simulation model, showcasing a more efficient and optimized assembly line process. These findings not only validate the effectiveness of the proposed changes but also suggest potential avenues for continued improvements in the pursuit of enhancing overall production efficiency within the assembly line.

4.4 Summary

In summary, this chapter has delved into the development and enhancement of the simulation model for SMEA Company's assembly line. The objectives, including the development of the current state simulation model, the performance of line balancing and analysis, and the recommendation of improvements based on these evaluations, have been effectively met. The proposed modifications not only refine the simulation model for a more accurate representation of the assembly line but also contribute to a comprehensive understanding of production processes through line balancing. The resulting recommendations are aligned with the overarching goal of enhancing efficiency and performance. The chapter concludes with a tangible indication of progress, marking a significant step forward in optimizing the assembly line system within the SMEA Company context.

CHAPTER 5

CONCLUSION

This study is summarized in Chapter 5. The research study flow provided an overview of how the Witness Horizon simulation programmed and line balancing may accomplish the three initial research study objectives. The results of the previous section are summarized in this chapter along with the steps that SME Aerospace may take to boost productivity. This chapter also includes a recommendation for the case company to improve the manufacturing process in the future.

5.1 Conclusion

The aim for this study is to enhance productivity at SMEA's assembly line, to be exact is 6C Overwing assembly line. By developing line balancing for this research, bottlenecks in assembly line can be found. Next steps were successfully made, simulation model layout using Witness Horizon really helpful in mimics the real-world system. Not to mention, problem statements in early of this study have been answered by 3 objectives. Methodology provides ways for researcher to commit in objectives. All the parameters setup from methodology have been used to complete simulations run and analysis line balancing in chapter 4 which are results and discussion. The proposed simulation improvements have been successfully implemented in this thesis.

This study pursued three main objectives. The initial goal, involving the development of the current state simulation model, proved successful with a 97.44% resemblance to the real-world system using Witness Horizon Simulation Software. The second objective centred on conducting line balancing and analysis within the current state simulation model. The findings identified the Cleaning and Touch Up process as a bottleneck due to its cycle time exceeding the takt time. This discovery set the stage for the third objective, which aimed to recommend improvements based on the line balancing and analysis outcomes. The proposed idea successfully reduced the bottleneck by decreasing the cycle time, resulting in a 15.38% enhancement in the simulated assembly line model. The actual output, initially 78 units of beams, increased to 90 units per week within the available 2400 minutes of work time. In essence, all three objectives have been accomplished, underscoring the success of this research.

5.2 Recommendations

Considering the limitations found in this study, here are some suggestions for future research and improvement. Firstly, it might be helpful to look at more than just one assembly line in the assembly department. This way, a broader view of the entire production system can be gained, giving a better understanding of how different processes connect and affect efficiency.

Secondly, because there was limited time for data collection (only six days of site visits) and validating old data, it could be beneficial for future researchers to find ways to spend more time collecting data or exploring alternative methods to ensure accuracy.

Since the study did not cover much about how labour is used due to time constraints, a future study could put more focus on understanding how workers are utilized. This could provide useful insights into productivity and areas that might need improvement.

Lastly, to address the fact that this thesis did not investigate cost efficiency, future research could take a closer look at the costs associated with the proposed improvements. This way, overall research can get a better overall view of how practical and cost-effective the suggested changes might be. These suggestions aim to help future studies tackle the limitations identified and lead to more in-depth and insightful research.

REFERENCES

Bemthuis, R., van Slooten, N., Arachchige, J. J., Piest, J. P. S., & Bukhsh, F. A. (2021). A classification of process mining bottleneck analysis techniques for operational support. *Proceedings of the 18th International Conference on E-Business, ICE-B 2021*, 127–135. https://doi.org/10.5220/0010578601270135

Caterino, M., Greco, A., D'Ambra, S., Manco, P., Fera, M., Macchiaroli, R., & Caputo, F. (2020). Simulation techniques for production lines performance control. *Procedia Manufacturing*, *42*, 91–96. https://doi.org/10.1016/j.promfg.2020.02.027

Durán, J. M. (2020). What is a Simulation Model? *Minds and Machines*, *30*(3). https://doi.org/10.1007/s11023-020-09520-z

Fansuri, A. F. H., Rose, A. N. M., Ab Rashid, M. F. F., Mohamed Nik, N. M. Z., & Ahmad, H. (2018). Productivity Improvement Through Line Balancing at Electronic Company - Case Study. *IOP Conference Series: Materials Science and Engineering*, *409*(1). https://doi.org/10.1088/1757-899X/409/1/012015

Frandson, A. G., Seppänen, O., & Tommelein, I. D. (2015). Comparison between location based management and takt time planning. *Proceedings of IGLC 23 - 23rd Annual Conference of the International Group for Lean Construction: Global Knowledge - Global Solutions*, *2015-January*.

Gardarsson, M. H., Lædre, O., & Svalestuen, F. (2019). Takt time planning in porsche consulting, the boldt company and veidekke. *27th Annual Conference of the International Group for Lean Construction, IGLC 2019*. https://doi.org/10.24928/2019/0232

Goyal, A., Vaish, D. C., Agrawal, R., Choudhary, S., & Nayak, R. (2022). Sustainable Manufacturing through Systematic Reduction in Cycle Time. *Sustainability (Switzerland)*, *14*(24). https://doi.org/10.3390/su142416473

Heshmat, M., El-Sharief, M., & El-Sebaie, M. (2017). Simulation modelling and analysis of a production line. *International Journal of Simulation and Process Modelling*, *12*(3–4), 369–376. https://doi.org/10.1504/ijspm.2017.085563

Jamil, M., & Razali, N. M. (2016). Simulation of Assembly Line Balancing in Automotive Component Manufacturing. *IOP Conference Series: Materials Science and Engineering*, *114*(1). https://doi.org/10.1088/1757-899X/114/1/012049

Karthick, R. (2019). Cycle Time Reduction in Manufacturing Processes. *International Journal for Research in Applied Science and Engineering Technology*, *7*(2), 728–730. https://doi.org/10.22214/ijraset.2019.2106

Kusiak, A. (2018). Smart manufacturing. *International Journal of Production Research*, *56*(1–2), 508–517. https://doi.org/10.1080/00207543.2017.1351644

Lai, X., Shui, H., Ding, D., & Ni, J. (2021). Data-driven dynamic bottleneck detection in complex manufacturing systems. *Journal of Manufacturing Systems*, *60*, 662–675. https://doi.org/10.1016/j.jmsy.2021.07.016

Lopes, T. C., Brauner, N., & Magatão, L. (2022). Assembly line balancing with fractional task allocations. *International Journal of Production Research*, *60*(5), 1569–1586. https://doi.org/10.1080/00207543.2020.1866224

Mahmoodi, E., Fathi, M., & Ghobakhloo, M. (2022). The impact of Industry 4.0 on bottleneck analysis in production and manufacturing: Current trends and future perspectives. *Computers and Industrial Engineering*, *174*. https://doi.org/10.1016/j.cie.2022.108801

Onofrejova, D., Janekova, J., Grincova, A., & Soltysova, Z. (2020). Simulation and evaluation of production factors in manufacturing of fireplaces. *International Journal of Simulation Modelling*, *19*(1), 77–88. https://doi.org/10.2507/IJSIMM19-1-504

Rawat, S., Gupta, A., & Juneja, C. (2018). Productivity Measurement of Manufacturing System. In *Materials Today: Proceedings* (Vol. 5). www.sciencedirect.comwww.materialstoday.com/proceedings2214-7853

Sabet, E., Yazdani, B., Kian, R., & Galanakis, K. (2020). A strategic and global manufacturing capacity management optimisation model: A Scenario-based multi-stage stochastic programming approach. *Omega (United Kingdom)*, *93*. https://doi.org/10.1016/j.omega.2019.01.004

Schmenner, R. W. (1982). Making business location decisions. *Journal of Economic Literature*, *20*(4).

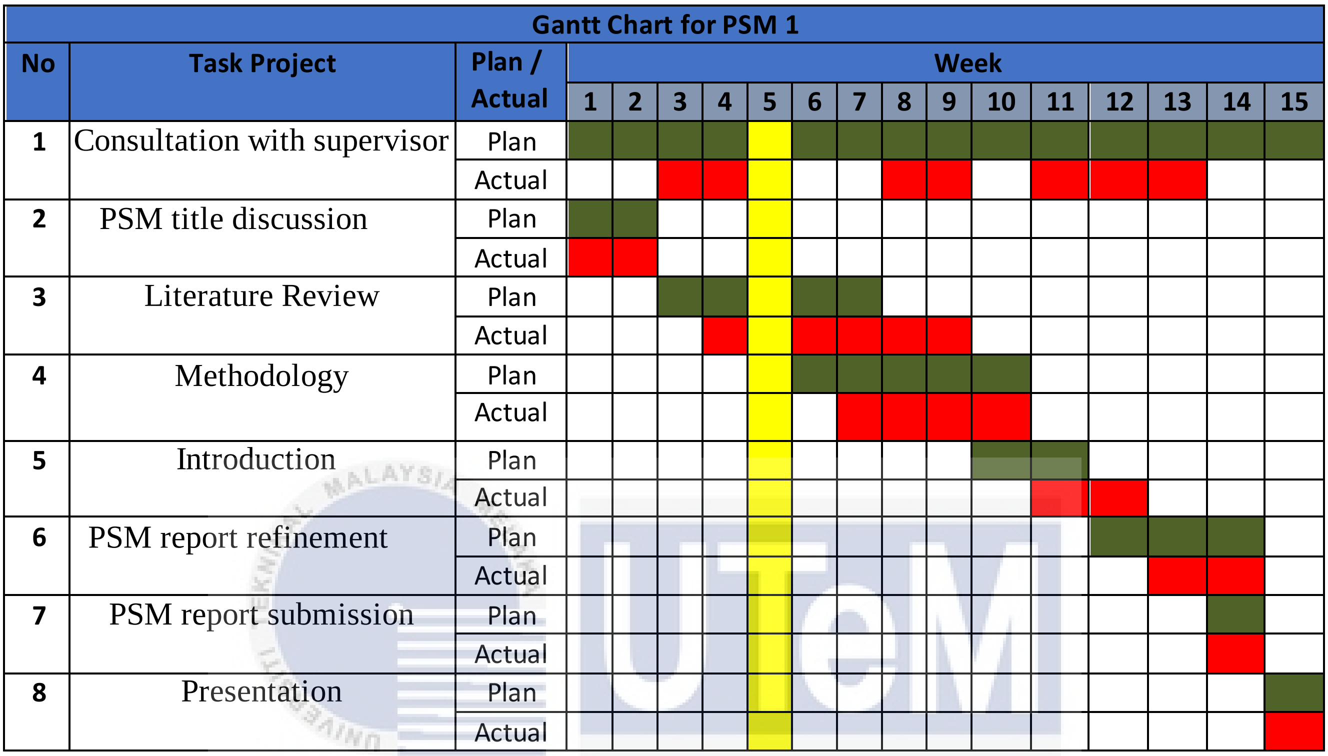
Tushar D., K., & Mukesh C., C. (2018). Concrete Mixture Assembly Line Improvement using ARENA Simulation - A Case Study. *International Journal of Trend in Scientific Research and Development*.

Yasir, A. S. H. M., & Mohamed, N. M. Z. N. (2018). Assembly Line Efficiency Improvement by Using WITNESS Simulation Software. *IOP Conference Series: Materials Science and Engineering*, *319*(1). https://doi.org/10.1088/1757-899X/319/1/012004

Banks, J., Carson II, J. S., Automation, B., Nelson, B. L., & Nicol, D. M. Discrete-Event System Simulation Fourth EDITION.

APPENDICES

APPENDIX A Gantt Chart for PSM 1



APPENDIX B Gantt Chart for PSM 2

Gantt Chart for PSM 2																	
No	**Task Project**	**Plan / Actual**	**Week**														
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	PSM 2 Briefing	Plan															
		Actual															
2	Data Collection	Plan															
		Actual															
3	Result & Discussion	Plan															
		Actual															
4	Conclusion	Plan															
		Actual															
5	Formatting & Grammar Checking	Plan															
		Actual															
6	Slide/Poster Preparation	Plan															
		Actual															
7	Final Improvement	Plan															
		Actual															
8	Report Submission	Plan															
		Actual															
9	Thesis Summary	Plan															
		Actual															
10	Final Presentation	Plan															
		Actual															

APPENDIX C Site Visit Picture

Figure 5-1 : Beam Installation on Jig

Figure 5-2 : Sealant Process

Figure 5-3 : Riveting Process at Workbench

Figure 5-4 : Site Visit at SMEA Sdn. Bhd.