# LAYOUT OPTIMIZATION FOR PRODUCTION LINE USING PRODUCT LIFECYCLE MANAGEMENT

Submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Hons.)

by

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# DECLARATION

I hereby, declared this report entitled “Layout Optimization for Production Line using Product Life Cycle Management” is the result of my own research except as cited in references.

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Date : 13 September 2021

# APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

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# ABSTRACT

Plant layout or facility layout is the process of designing and constructing workforce, material handling, and equipment systems. It encompasses determining the locations, sizes, and configurations of many tasks throughout the facility. It exemplifies a strategy for arranging, developing, or visualizing the desirable machinery and equipment in the most efficiently. Layout optimization comprises arranging items in the proper locations to facilitate future expansions in order to provide efficient material handling, ensure optimal space utilization, and an excellent work environment. Optimizing layout can increase productivity, product quality, and safety. This project is conducted in Prym Consumer Malaysia Sdn. Bhd. and Teaching Factory University Technical Malaysia Melaka (UTeM). By considering the current layout of the production line, the problem is that the total output of the circular knitting needle does not achieve the target. The aims of this research are to investigate the production line layout of the circular knitting needle packaging process, to simulate, and to propose the most optimum layouts using Product Lifecycle Management (PLM). PLM is broadly and widely used in modern manufacturing systems due to it can effectively manage a product across its lifecycles, from the very first idea until the disposal of the product. This project begins with record and analyze the packaging process of circular knitting needles by conducting time study. Then, analyze the initial layout of the production line for circular knitting needles packaging process. Following that, plan new layouts and simulate it. Tecnomatix Plant Simulation is used to create and simulate the layout. The most optimal layouts are proposed based on the simulation results. The optimal layouts have the highest daily throughput of 2602.01 and 6308.61. It is showed that optimal layout could increase the productivity of a company.

# ABSTRAK

Susun atur kilang atau susun atur fasiliti adalah proses merancang dan membina tenaga kerja, pengendalian bahan, dan sistem peralatan. Ini termasuk menentukan lokasi, ukuran, dan yang melibatkan konfigurasi pelbagai tugas dalam semua fasiliti yang terlibat. Ini menunjukkan strategi untuk mengatur, membangun atau membayangkan posisi mesin dan peralatan yang diperlukan dengan cara yang lebih efisien. Pengoptimuman susun atur merangkumi mengatur barang di lokasi dengan tepat untuk memudahkan pembangunan pada masa depan untuk memberikan pengendalian bahan yang efisien, memastikan penggunaan ruang yang optimum, dan lingkungan kerja yang terbaik. Mengoptimumkan susun atur mampu meningkatkan produktiviti, kualiti produk, dan keselamatan. Projek ini dijalankan di Prym Consumer Malaysia Sdn. Bhd. dan Kilang Pengajaran Universiti Teknikal Malaysia Melaka (UTeM). Dengan mengambilkira faktor susun atur barisan pengeluaran semasa, masalah yang dihadapi adalah kadar jumlah keluaran jarum kait tidak mencapai sasaran yang ditetapkan. Tujuan penyelidikan ini adalah untuk mengkaji susun atur pengeluaran proses pembungkusan jarum rajut bulat dan mencadangkan susun atur yang paling optimum menggunakan Product Lifecycle Management (PLM). PLM digunakan secara meluas dalam sistem pembuatan moden kerana ia mampu menguruskan produk dengan lebih berkesan sepanjang kitaran hayatnya, dari idea hingga kepada pelupusan produk. Projek ini dimulakan dengan merekod dan menganalisis proses pembungkusan jarum kait dengan melakukan kajian masa. Analisa susun atur barisan pengeluaran yang digunakan oleh kilang untuk proses pembungkusan jarum kait. Kemudian, rancang susur atur yang baharu dan lakukan simulasi. Tecnomatix Plant Simulation digunakan untuk membangun dan mensimulasikan susun atur. Susun atur yang paling optimum dicadangkan berdasarkan hasil simulasi tersebut. Susun atur optimum mempunyai nilai harian tertinggi, 2602.01 dan 6308.61. Ini menunjukkan bahawa susun atur yang optimum dapat meningkatkan produktiviti syarikat.

# DEDICATION

This thesis is dedicated to my mother and my late father. I hope that this achievement will complete the dream that you had for me all those many years ago when you choose to give the best education you could.

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**By the Name of Allah, the Most Merciful and Gracious**

First of all, with the highest to Allah, I manage to complete my Bachelor's Degree Project in time with a great manner, although during this rough time because of the Covid-19 situation. Without His blessing, this study would not be possibly completed.

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| | | |
|---|---|---|
| VSM | - | Value Stream Mapping |
| JIT | - | Just-In-Time |
| PLM | - | Product Lifecycle Management |
| UTeM | - | Universiti Teknikal Malaysia Melaka |
| Sdn. Bhd. | - | Sendirian Berhad |
| SLP | - | Systematic Layout Planning |
| 3D | - | 3-Dimension |
| 2D | - | 2-Dimension |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| % | - | Percentage |
| s | - | Second |
| cm | - | Centimeter |
| mm | - | Millimeter |

# CHAPTER 1

## INTRODUCTION

This chapter addressed the background of study and problem statement that is identified in the industry. This is accompanied by the objectives that need to be accomplished throughout the study and the scope that narrows down the area of the study. The significance of the study is also discussed in this chapter.

### 1.1 Background Study

Modern manufacturing encompasses all intervention processes necessary for the production and integration of the components of a product. Optimizing facility layout is a critical issue for modern manufacturing systems, as it plays a critical role in process and material flow design. Manufacturing facility design is the physical assets of a business that promote efficient resource utilization such as labour, material, time, equipment, and cost. The design of facilities encompasses the location of the plant, the process flow, layout of the plant, and material handling systems. Only a well-designed process flow and layout can ensure the smooth and rapid flow of material from the initial stage to the final stage of the process. Optimizing the flow layout can also significantly minimize waste or non-value added activities in production lines, thereby increasing overall production effectiveness (Guoliang Fan et al., 2017).

Furthermore, there are two major problems that need to be considered in the manufacturing industry. The first problem is a quantitative approach based on a distance function that aims to minimize the total material handling cost between workstations. The second problem is an approach that aims to minimize non-value-added activities. Material handling and process flow are inextricably linked in manufacturing. Material handling costs a substantial portion of the total manufacturing cost. Waste of time and energy can occur when workers and materials move long distances in the manufacturing process. The process of material handling operations can be minimized or removed utilizing efficient plant layout analysis and design (Azevedo et al., 2017). Additionally, by optimizing the process flow, it will increase the proximity of workstations and significantly reduce cross-flow caused by workers on production lines (Radhwan et al., 2019).

Plant layout can be explained as the method of locating and arranging physical facilities such as machines, equipment, and tools in order to maximize material flow at the lowest possible cost and with the least amount of handling during the processing of the product from raw material receipt to final product delivery. Besides, plant layout would involve allocating space and arranging equipment in such a way that total operating costs are minimized. The term plant layout refers to both new layouts and improvements to existing layouts (Naik & Kallurkar, 2016). There are four types of layouts are product, process, fixed-position, and cellular layout (William, 2020).

Next, implementing lean manufacturing principles has become a prerequisite for global competitiveness. Lean manufacturing is the most frequently associated with the elimination of waste that is typically retained by companies as surplus inventory. Excess capacity is the capacity of machines and human capacity to improve the impact of fluctuations in supply, processing time, or demand. Lean manufacturing tools are fundamental to the design of the layout. For instance, the concept of 5S, Kanban, Kaizen, Value Stream Mapping (VSM), and Just-In-Time (JIT) (Mojib, 2016). Time study analysis is one of the crucial methods for evaluating work in lean manufacturing. The purpose of the time study is to establish the motion study and time standard. Shorter cycle time has become crucial in nowadays manufacturing systems (Cury & Saraiva, 2018).

There are numerous tools and techniques to optimize the layout. Product lifecycle management (PLM) is the tool used in this study to optimize the layout for the production line. PLM is broadly and widely used in modern manufacturing systems due to it can effectively manage a product across its lifecycles, from the very first idea until the disposal of the product. The imagination phase, definition phase, realization phase, use phase and disposal phase are the five phases in the lifecycle of a product (John, 2016).

Prym Consumer Malaysia Sdn. Bhd and Teaching Factory Universiti Teknikal Malaysia Melaka (UTeM) has been selected to modify and improve the existing production line layout. This company, a leading supplier of sewing and handicraft accessories company. It has been established in Malacca for over 44 years. Prym Consumer Malaysia Sdn. Bhd. vision is to initiate the choice that customers' preferred for haberdashery products based on cost efficiency, excellent operational, quality of products, and services. Examples of the products that are produced by the company are straight pins, safety pins, ball pins, sew-on press fasteners, pearl headed pins, Concorde pins, braided elastics, snap fasteners tape, and knitting accessories. UTeM Teaching Factory is a university authority center operating under UTeM cater to students' attachment with industry-related projects. Circular knitting needles are the product that has been chosen in this study.

## 1.2 Problem Statement

By considering the current layout of the production line in Prym Consumer Malaysia Sdn. Bhd. and Teaching Factory UTeM, the current problem is that the total output of circular knitting needles does not achieve the targeted output. Circular knitting needles are a seasonal product. The high demand from customers is during winter season because at that season, there are many people who started to knit due to the cold weather.



Therefore, this study is conducted to investigate the cause of the problem specifically in terms of layout and apply some tools and techniques to solve the problem also obtained optimum layout. Moreover, this research can be essential as a reference in a layout problem since there is less attention in layout optimization study. Figure 1.1 shows the chart of output data of circular knitting needles from the past six months. There are five sizes of circular knitting needles: 40 cm, 60 cm, 80 cm, 100 cm, and 120 cm. The chart shows the highest demand for circular knitting needle size is 80 cm.

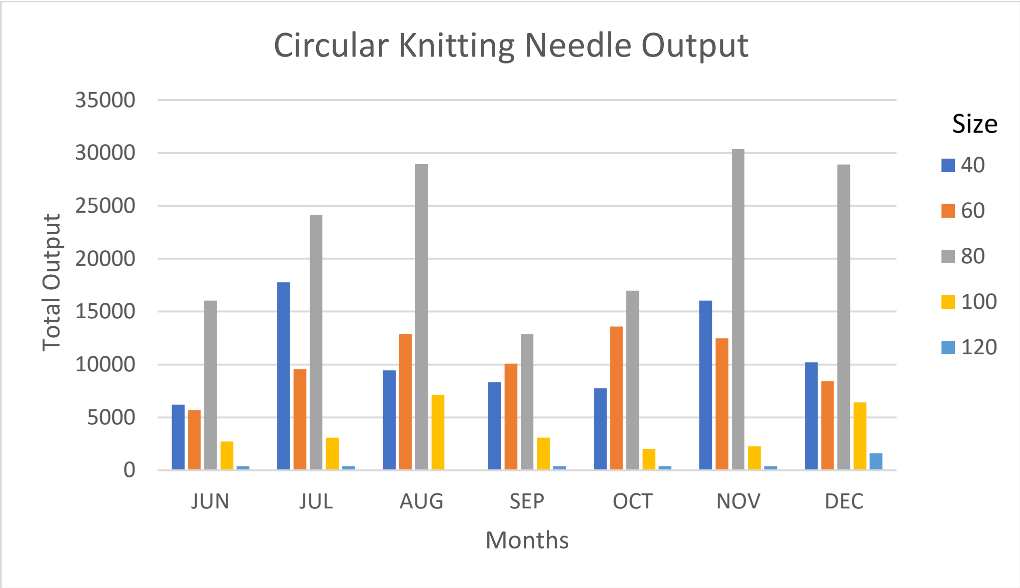



Figure 1.1: Circular Knitting Needles Output Chart of Prym Consumer Malaysia Sdn. Bhd.

## 1.3 Objective

To perform this project smoothly, several objectives are aimed to achieve its goals. The objectives are:

i. To investigate the production line layout of the circular needle packaging process.
ii. To identify the optimum layouts of the packaging process.
iii. To simulate the proposed layout using product lifecycle management.



## 1.4 Research Scope

The scope of this research is to investigate and analyze the problem at the production line of the circular knitting needles packaging process in Prym Consumer Malaysia Sdn. Bhd. and Teaching Factory UTeM. A time study analysis is conducted for the circular knitting needle packaging process. This study focuses on improving the existing production line of the circular knitting needles packaging process by redesigning or re-layout. Product Lifecycle Management (PLM) is proposed as a solution to the current layout problem in this research work. The current layout includes four workstations and implemented cellular layout. Tecnomatix Plant Simulation is the software that will be used in this study. With the help of PLM, a comparison between the existing layout and proposed layouts will evaluate.

## 1.5 Significant Study

The present study provides comprehensive information on the layout optimization for production lines using Product Lifecycle Management (PLM). There is currently scant information on optimizing layout using PLM. Hence, this study may indispensably contribute industrial guidelines to solve layout problems by performing simulation using PLM. In addition to this, this study can identify the most optimum layout of a production line. Therefore, this study can aid manufacturing industry to improve production efficiency and meet the delivery time requirements.

# CHAPTER 2

## LITERATURE REVIEW

The chapter consists of a review regarding the objectives and scope of the project. This chapter will describe and discuss the literature reviews that concentrate on previous research relevant to the title of this project. References are focused on journals, previous research, review papers, textbooks, conference and websites. This chapter also discussed the method used to gain information about the study. Each source and information shall be focused on the relationship within the scope of this study.

### 2.1 Company Background

#### 2.1.1 Prym Consumer Malaysia Sdn. Bhd.



Prym group of companies is a world-leading suppliers of revolutionary and various quality goods in the manufacture haberdashery products. Prym is the oldest family business in Germany owned by Johann Prym. In order to sew, craft, quilt, knitting and household clothing accessories, the Prym Consumer global network offers a single-stop solution. The company has over 400 years of experience providing excellent, precise, and sustainable sewing and craftsmanship accessories worldwide. Prym Consumer Malaysia Sdn. Bhd. is superintendent in Asia and Australasia for the production and distribution of hard and soft haberdashery. It produces and distributes notions of sewing and specialized clothing and accessories in the clothing and household industries, handicrafts and hobbies in high volume. The Prym Consumer Malaysia Sdn. Bhd. logo is shown in Figure 2.1.

Figure 2.1: Company Logo of Prym Consumer Malaysia Sdn. Bhd. (Prym, 2018)

Figure 2.2 below shows the example of products manufactured by Prym Consumer Malaysia Sdn. Bhd. The products are circular knitting pin, circular knitting needle, needle twister, and cable stitch.

(a) (b)

Figure 2.2: (a) Circular Knitting Pin (b) Circular Knitting Needle (c) Needle Twister (d) Cable Stitch (Prym, 2018)

### 2.1.2 Universiti Teknikal Malaysia Melaka (UTeM) Teaching Factory

Teaching Factory is structured under Deputy Vice-Chancellor's Office for Academic and International, developed and established in Universiti Teknikal Malaysia Melaka (UTeM) to provide real-life environment simulation of productions and services everyday industrial practices. The objectives of the teaching factory are to provide engineering, technology, education, and promotion services in the field of Advanced Manufacturing and Computing Technology to industry and society. It also offers a training platform and excellent reference centre in Advanced Manufacturing and Computing Technology in the country and region. Teaching factory also functions like planning and organizing business activities through services provided to the industry.

## 2.2 Lean Manufacturing Tools

Lean manufacturing attempts to find methods and approaches to reduce production costs, eliminate waste, improve product quality, increase productivity, and improve customer satisfaction in manufacturing industries (Mojib, 2016). The purpose of developing lean manufacturing tools is to facilitate manufacturing production systems and intensify quality and productivity in organizations. Lean manufacturing tools have been envisioned primarily for applications in the manufacturing industry. The tools that can be employed to encourage lean manufacturing implementation are:



i. 5S
ii. Kanban
iii. KAIZEN
iv. Value Stream Mapping (VSM)
v. Just-In-Time (JIT)
vi. Cellular Manufacturing

### 2.2.1 5S

In the late 1960s, Japan developed and implemented the 5S philosophy. Organizational values, cleanliness, standardization, and discipline are all incorporated into 5S practice in the workplace (Osada, 1991). It is a Japanese concept for a well-organized workplace that eliminates waste and streamlines equipment searches. According to Ahuja (2017), 5S systematically achieves the overall organization's cleanliness and standardization in an inspiring and satisfying workplace for all workers in the organization. Besides, 5S is also intended to reshape the workplace and provide a basis for substantial changes in the workplace (Ahuja, 2017). Based on Veres *et al.* (2018), implementing 5S has made the planet a cleaner place, increased workplace safety and product quality, easy detection and prevention of problems, reduced waste and cost, the product or service meets the customer requirements the most efficiently (Veres *et al.*, 2018).

The first 1S in 5S is seiri which means sort. A study from Jain (2015) showed that unwanted items, broken tools and cabinets, unused parts, and scrap materials were removed during sorting (Jain, 2015). A previous study from Agrahari *et al.* (2015) reported that sort resulted in eliminating all of the unnecessary items, and the reason for the sparse accumulation was discovered (Agrahari *et al*., 2015).

The second 2S in 5S is seiton which means set in order. The previous study has shown that set in order resulted in several changes in the workplace organization. Each workstation was equipped with its collection of equipment. All the tools were colour-coded to each workstation, and every piece of equipment had certain locations (Jain, 2015). The findings can be compared to another study which found that set in order can eliminate waste in production and ensure that all materials, tools, and equipment are stored in easily accessible locations (Agrahari *et al*., 2015).

Next, the 3S in 5S stands for seiso, which means sweep. Previous research has shown that sweep resulted in the removing scrap, dust, and other undesirable products from each workstation. The initial clean-up made it easier to see other problems (Jain, 2015). A study by Agrahari in 2015 stated that sweep emphasises cleanliness because it provides a comfortable and safe workplace, as well as improved visibility, which reduces retrieval times and ensures high-quality work, product, or service (Agrahari *et al*., 2015).

The fourth 4S in 5S is seiketsu which means standardize. Jain (2015) stated that standardize resulted in the development of standard operating procedure (SOP) for the assembly area employees (Jain, 2015) and Agrahari *et al.* (2015) stated that standardize include the development of procedures and simply checklists that are visible at all workplace (Agrahari *et al*., 2015).

The last element in 5S is shitsuke which means sustain. A previous study has shown that sustain led to periodic audits of assembly workers to monitor 5S changes in the assembly area (Jain, 2015). In addition, a study by Agrahari *et al.* (2015) showed that sustain which necessitates self-discipline in order to maintain consistent standards of quality, safety, and cleanliness (Agrahari *et al.*, 2015). Table 2.1 below shows the 5S elements.

Table 2.1: 5S Elements

| **Japanese Words** | **English Meaning** | **Meaning** | **Features** |
|---|---|---|---|
| Seiri | Sort | Organization | Discarding unnecessary equipment and material |
| Seiton | Set in Order | Neatness | Necessary items are arranged properly |
| Seiso | Sweep | Cleaning | Clean and routine maintenance |
| Seiketsu | Standardize | Standardization | Perpetuate excellence standard and adhere to it through regular audits |
| Shitsuke | Sustain | Discipline | 5S initiatives can be implemented by incorporating 5S into standard operating procedures and making 5S a part of daily life |

### 2.2.2 Kanban

Wakode *et al.* (2015) described the Kanban method as a useful technique for enhancing productivity. It optimizes the process, reduces idle time, and increases the plant's efficiency and productivity. Kanban's framework focuses on the reduction of waste in all details over-production, excessive motion, errors, over-processing and waiting. Kanban cards are crucial components that signal the need to transfer material inside a manufacturing or production facility. The card shows the signal that there is a depletion of goods, parts, and others. The theory of Kanban in conjunction with pull system production mode (Wakode *et al.*, 2015).

Based on Papalexi *et al.* (2016), implementing the Kanban system should result in a continuous flow of material throughout the manufacturing process. The implementation of the Kanban system can benefit an organization by increasing service quality. Additionally, the Kanban system minimized waste in terms of time, products, storage space and lower cost (Papalexi *et al.*, 2016). According to Al-Baik and Miller (2015), the following are the benefits of implementing Kanban (Al-Baik & Miller, 2015):

i. Improving visual control to facilitate and support decision-making.
ii. Facilitating cross-functional teamwork coordination and imposing self-organization.
iii. Decreased cycle and lead times.
iv. Enhanced customer satisfaction and realization of high value.
v. Developing strategies for continuous improvement.
vi. Improving the predictability of final product delivery under the constraint of changing customer requirements.

### 2.2.3 KAIZEN

A study by Marin-Garcia *et al.* (2018) described that Kaizen is the Japanese word for enhancement, bearing the industry's connotation of all uncontracted and partially contracted Japanese workplace activities to improve its operations (Marin-Garcia *et al.*, 2018). Garcia-Alcaraz *et al.* (2017) indicated that Kaizen refers to the process of continuous improvement for all human resources, managers, and employees. Kaizen eliminates waste and consequently improves work performance, resulting in a spiral of increased innovation within the organization (García-Alcaraz *et al.*, 2017). Kaizen assists in identifying hidden wastes in manufacturing processes, identifying the root causes and resolving them (Arya & Choudhary, 2015). According to Helmold (2020), the primary objective of Kaizen is to continuously improve work areas, processes, and products through the integration of affected areas' residents.The benefits implementation of Kaizen are as follows (Helmold, 2020):

i. Improved teamwork among the workers.
ii. Enhanced efficiency.
iii. Increase the elimination of waste.
iv. Enhance standard working paper.
v. Increased safety at workplace.



### 2.2.4 Value Stream Mapping (VSM)

Antonelli and Stadnicka described Value Stream Mapping (VSM) analysis results in process improvement by eliminating non added steps. VSM is widely used in industry, particularly in high volume manufacturing. VSM aims to classify activities of the production flow into three categories which are non-value added, necessary but non-value added, and value-added (Antonelli & Stadnicka, 2018). Masuti and Dabade indicated that VSM is a lean technique for determining the current state of a business and its information flow, which aids in resolving problems associated with the current state and assisting in future states. VSM encompasses the entire process, beginning with the customer order and ending with the product's delivery to the customer that enables anyone to view the processing system or information flow and easily identify bottlenecks (Masuti & Dabade, 2019).

Lacerda *et al.* posited that VSM is a highly effective tool for visualizing and comprehending the flow of materials and information throughout the value chain. It is used to provide a holistic view of the activities involved in the manufacturing process, enabling the source identification of wastes. Reduction production costs, increased customer response time, and improved product quality are all outcomes that can be expected when applying VSM to a manufacturing process (Lacerda *et al.*, 2016). According to Rohani and Zahraee, VSM encompasses all value-added and non-value added activities that are necessary to move a product through primary flows, beginning with raw materials and ending with the customer. The primary objective of VSM is to identify various types of waste and attempt to eliminate the waste. The steps to construct VSM are as follows (Rohani & Zahraee, 2015).

i. Identify a specific product to improve.
ii. Create a current state map, which is essentially a snapshot of how processes are currently being carried out.
iii. Create a future state map that depicts how the manufacturing process should be carried out once waste and inefficiencies have been eliminated. The future state map is developed by responding to a series of questions about efficiency-related topics and implementing technical issues associated with the application of lean techniques.
iv. The proposed map is used as a basis for implementing critical system changes.



### 2.2.5 Just-In-Time (JIT)

Just-In-Time (JIT) is focused primarily on waste reduction as well as enhancement and preservation of quality excellence in goods or services. JIT reduces waste by simplifying manufacturing procedures, reducing set-up times, managing the material flow and ensuring preventive maintenance of machinery and equipment. The inventory and resources can then be minimized and more effectively used (García-Alcaraz & Maldonado-Macías, 2016). According to Lyu *et al.*, JIT aims to minimize inventory by eliminating waste. It also can be characterized as the process of continuously reducing and eliminating inventory in manufacturing (Lyu *et al.*, 2020). In addition, JIT operations are widely used in manufacturing with the primary goal of controlling the timeliness of product production and delivery while maintaining or improving product quality. It requires manufacturers to complete tasks in concise time frames, which significantly impacts on the production schedule (Xu & Chen, 2016).

### 2.3 Seven Types of Waste

Sutrisno *et al*. proposed that anything that does not add value to the customer is defined as waste. The presence of waste may increase the cost and time required to meet customer demands (Sutrisno *et al*., 2018). Yeen Gavin Lai *et al.* described waste as anything in production that does not add value to the finished product (Yeen Gavin Lai *et al.*, 2019). Mostafa and Dumrak indicated that waste is defined as the activity within a process that increases costs and time but does not add value to the product from the view of the customer (Mostafa & Dumrak, 2015).



#### 2.3.1 Overproduction

Overproduction is regarded as the most severe type of waste, as it translates into high costs. It is also defined as the production of products in advance, and in more significant quantities than the customer requires (Rewers *et al.*, 2016). According to Yeen Gavin Lai *et al.* (2019), overproduction refers to producing excessive quantities, producing when they are not required, or producing without actual orders (Yeen Gavin Lai *et al.*, 2019). Overproduction entails producing more than required, which requires time, money, additional effort from employees, and additional inventory (Chahal & Narwal, 2017). It leads to unnecessary lead time and storage times. Also, it contributes to unnecessary work-in-progress inventories, resulting in physical isolation of operations.

### 2.3.2 Waiting

Waiting is a waste that is inefficient and time-consuming during processes. It comes in a variety of forms, including job plans, orders, and machine parts (Chahal & Narwal, 2017). Based on Yeen Gavin Lai *et al.* (2019), it is a waste of time, as it results in delays, idle time, or inability to process due to unforeseen circumstances (Yeen Gavin Lai *et al.*, 2019). Rewers *et al.* (2016) proposed the waiting for a product is the time lost due to unmet expectations regarding people, material, information, or a tool that adds no value to the manufacturing process (Rewers *et al.*, 2016).

### 2.3.3 Transportation

Material transport in the factory is a waste that cannot be disposed of but should be constantly reduced. Transportation is a wasteful movement of products or materials that are not required for the production process (Yeen Gavin Lai *et al.*, 2019). Chahal and Narwal (2017) described it as the movement of workstations equipped with different machine tools, components, and other items, regarded as non-value-added work (Chahal & Narwal, 2017). Excess transport refers to the unnecessary movement of materials, semi-finished products, and finished products. This results in increased production costs, and the risk of product damage is also increased (Rewers *et al.*, 2016).



### 2.3.4 Over-processing

Over-processing is performing tasks that provide no added value to the customer (Dixit, 2015). Yeen Gavin Lai *et al.* (2019) found that over-processing is unnecessary steps taken in manufacturing process, producing items that are not valued or required by the customer (Yeen Gavin Lai *et al.*, 2019). According to Chahal and Narwal (2017), when additional work is performed on a workpiece or machine to avoid rejection or ensure proper operation, it is referred to as over-processing. Additionally, it is time and money consuming (Chahal & Narwal, 2017).

### 2.3.5 Unnecessary Inventory

Unnecessary inventory includes all parts, work-in-progress, and finished goods that are not currently being processed (Dixit, 2015). Chahal and Narwal (2017) indicated that when a push system operates without regard for order, waste occurs in the form of excessive inventory (Chahal & Narwal, 2017). This waste occurs as a result of an excess of work-in-progress, stocks or materials finished or unfinished (Yeen Gavin Lai *et al.*, 2019). Therefore, unnecessary inventory increases lead time, prevents issues from being easily identified and increases room to discourage contact.

### 2.3.6 Unnecessary motions

Individuals or equipment moving or walking more than necessary is considered as unnecessary motion (Dixit, 2015). Yeen Gavin Lai *et al.* (2019) proposed that unnecessary motion is a waste that occurs due to movements that add no value to the product (Yeen Gavin Lai *et al.*, 2019). Essentially, it is a part of ergonomics, which is concerned with the relationship between man and machine. This occurs when employees are required to twist, movement from one workstation to another (Chahal & Narwal, 2017).



### 2.3.7 Defects

Defects are defined as a waste associated with producing defective products, poor quality, or requiring corrective rework to be accepted by the customer (Yeen Gavin Lai *et al.*, 2019). According to Chahal and Narwal (2017), defects are non-value-added work that occurs for different reasons. For example, less concentration of workers, substandard tool quality, and inadequate inspection. This contributes to the poor quality of the workpiece, which results in dissatisfied customers (Chahal & Narwal, 2017). Additionally, defects cost both immediate and longer-term money. The malfunction or defect types are internal defects in quality costing, such as scrapping, re-work, and delay.

## 2.4 Line Balancing

According to Lam *et al.,* line balancing is a technique for minimizing imbalances in worker and workload distribution in order to maintain the required run rate. As a result, the assembly process, workstation layout, and cycle time of individual workstations should be analyzed (Lam et al., 2016). A previous study by Adeppa (2015) described the line balancing technique is used to achieve the reduction of cycle time, minimize the number of workstations, maximize the workloads smoothness, and maximize work-relatedness. The primary objective of line balancing is to distribute tasks evenly across workstations to obtain an efficient balance of the capacities and flows of the production or assembly process (Adeppa, 2015). A study by Ariyanti *et al.* discovered that line balancing is concerned with increasing line efficiency in order to boost productivity. Line balancing reduces the number of workstations and the total idle time at all stations by balancing the work elements for the production line to the workstation (Ariyanti *et al.*, 2020).

## 2.5 Motion and Time Study

The motion and time study enables detailed techniques in analyzing an operation or task, determining which activities add value and minimize and eliminate those that do not value or are considered waste. Additionally, it is possible to calculate the capacity of the manufacturing process and increase its efficiency and productivity through time and motion study (Cury & Saraiva, 2018). According to Nallusamy and Muthamizhmaran, motion and time studies will examine work processes and identify non-productive processes. This will result in a decrease in the number of processes, space utilization, production, and operation time. Moreover, motion and time study is a scientific method for determining the optimal way to perform a repetitive task and measuring the time required for a worker to complete a given task in a fixed workplace (Nallusamy & Muthamizhmaran, 2015). Duran *et al.* indicated that time and motion study is primarily concerned with devising more efficient methods of accomplishing tasks. It adds value and improves efficiency by removing inefficient operations, avoidable delays, and other forms of waste (Duran *et al.*, 2015).

### 2.5.1 Cycle Time

According to Adnan *et al.*, cycle time is defined as the amount of time required to complete a process. It encompasses the time period from when an operator initiates a process until the work is ready to be transferred (Adnan *et al.*, 2016). Ariyanti *et al.* posited that cycle time is the amount of time required to manufacture a single product unit at a single workstation (Ariyanti *et al.*, 2020).

## 2.6 Plant Layout

The term plant layout is used in a general sense to include the layout of the factory and the layout of the machine. According to Ali Naqvi *et al.*, plant layout is the arrangement of operations, machinery, and spaces, including the relationship between them (Ali Naqvi *et al.*, 2016). It refers to the physical arrangement of equipment and facilities within a plant. For example, the grouping of equipment and operation in a factory to maximize efficiency. All work areas, production lines, and material storage areas should be designed to operate at the highest possible rate and with the shortest cycle time. Optimizing plant layout can increase productivity, safety and product quality (Kadane & Bhatwadekar, 2011).

A previous study by Jung posited that plant layout should be designed to facilitate production by minimizing material handling and operating costs and maximizing labour utilization. Plant layout optimization is concerned with the location of facilities within a plant area and is generally regarded as critical for work in progress, manufacturing costs, lead times, and productivity (Jung, 2016).

Plant layout optimization entails items in the proper locations to facilitate future expansions, ensure adequate material handling in terms of cost and time, ensure proper space utilization, excellent work environment, effective equipment use, better compensation, and profitability (Goyal & Verma, 2019).

## 2.7 Facility Layout Planning

Based on Naik and Kallurkar (2016), facility layout is the physical configuration of departments, workstations, machines, equipment, materials, and common areas within an industry (Naik & Kallurkar, 2016). According to Sharma and Singhal (2017), the layout planning of the facility includes the arrangements of the available facilities on the production line to maximize utilization and output (Sharma & Singhal, 2017).

Facility planning is critical in manufacturing processes because it impacts the ability to achieve an efficient product flow. Proper facility layout analysis can help improve the performance of the production line by reducing bottlenecks, lowering material handling costs, decreasing idle time, and increasing the efficiency and utilization of labour, equipment, and space (Barnwal & Dharmadhikari, 2016). According to Deshpande *et al.* (2016), facility layout planning is essential in the manufacturing process. It provides the optimal space to produce the maximum output with the least amount of effort on the floor area and reduces the total cost of manufacturing acitvity. The facility layout planning objective is to minimize work-in-process, inventory, material handling, manufacturing costs (Deshpande *et al.*, 2016). Shaker Abualsaud *et al.* (2019) posited that the purpose of facility planning is to increase worker and machine productivity by facilitating the workflow, information, and material throughout the system (Shaker Abualsaud *et al.*, 2019).



In general, the layout design depends on the variety of the product and the volume of output. Process layout, product layout, fixed-position layout and cellular layout are the four types of layouts.

### 2.7.1 Production Line

The layout of the production line is the arrangement of equipment, operations, and transportation routes. The primary objective of production line layout planning is to determine the optimal layout of the line with the highest possible delivery efficiency, minimize manufacturing cost, and the fewest possible distribution errors (Guoliang Fan *et al.*, 2017)

### 2.7.2 Factors Affecting Facilities Layout

In order to maximize benefits, facility layout solutions must take into account the balance between the characteristics and all other factors affecting plant layout. The factors that influence the layout of a plant can be classified into five categories:

i. Material Handling
ii. Materials
iii. Labor
iv. Machinery
v. Waiting Time

#### 2.7.2.1 Material Handling

According to Varinder Khurana (2015), material handling adds no value to the product. It is a waste of time and resources (Varinder Khurana, 2015). The aim is to reduce material handling by combining it with other operations to eliminate costly and unnecessary movements (Okpala et al., 2016).



#### 2.7.2.2 Materials

A previous study by Varinder Khurana (2015) indicated that the productive equipment layout would be determined by the characteristics of the product that will be managed at the facility, and the various components and materials that will be used. The size, shape, volume, weight, and physical-chemical properties should be considered as they affect manufacturing processes, and material handling processes and storage (Varinder Khurana, 2015). The sequence and order of operations will affect the layout of the plant, depending on the variety and quantity of products to be produced (Okpala et al., 2016).

#### 2.7.2.3 Labor

Based on Varinder Khurana (2015), in the production process, labour must be organized into three categories which are direct labour, auxiliary, and supervision. The environment takes into account employee safety, lighting, ventilation, temperature, and noise levels. Personnel qualifications, adaptability, the number of workers required at any given time, and the type of work to be performed by them are process considerations (Varinder Khurana, 2015).

#### 2.7.2.4 Machinery

A previous study by Varinder Khurana (2015) stated that it is critical to have knowledge of the processes, machinery, tools, and necessary equipment, as well as the intended use and requirements, to design a proper layout. The time studies and methods used to improve processes are inextricably linked to the layout of the plant. When it comes to machinery, one must take into account the type, total amount available for each type, including the type and quantity of tools and equipment (Varinder Khurana, 2015). Moreover, it is critical to understand the amount of space required, the shape, height, and weight of the workers, the quantity and type of workers required, the risks to the personnel, and requirements for auxiliary services (Okpala *et al.*, 2016).



#### 2.7.2.5 Waiting Time

Varinder Khurana (2015) described the material awaiting flow through the facility as not always an unnecessary expense. Thus, when designing the layout of the facility, it is necessary to account for the required stock space (Varinder Khurana, 2015). The objective is to maintain continuous material flow through the facility and avoiding the costs associated with waiting time (Okpala *et al.*, 2016).

### 2.8 Types of Facilities Layout

Previous studies have stressed that there are typically four types of facility layout that are deemed suitable for manufacturing facility. The types of facility layout are shown below:

i. Process Layout
ii. Product Layout
iii. Fixed Position Layout
iv. Cellular Layout

#### 2.8.1 Process Layout

According to Bennett (2015), process layout denotes similar production processes within a single department area. This method of facility layout is applicable to component production or assembly. In component manufacturing, the term processes refer to a variety of manufacturing operations such as milling, drilling, and turning. In assembly, process layout may include distinct areas for the production of various subassemblies, final assembly, testing, and packing (Bennett, 2015). A previous study by Tarigan *et al.* (2021) indicated that in process layout, all operations of the exact nature are grouped together in the same department. Machines and equipment that perform the same function are grouped. For instance, drilling machines are manufactured in one department, and mills are manufactured in one department (Tarigan *et al.*, 2021).

Based on Tanutomo and Octavia (2016), a process layout is a layout in which machines and production facilities are grouped in a department. Additionally, this layout is frequently used in plants that produce small production volumes of unstandardized products (Tanutomo & Octavia, 2016). Process layout is showed the arrangement of elements running a particular process cycle in a particular sequence (Siregar *et al.*, 2019). Furthermore, process layout is frequently used in a job shop production of small volumes of customized products (Kovács & Kot, 2017). The example of diagram of the process layout is shown in Figure 2.3 below.

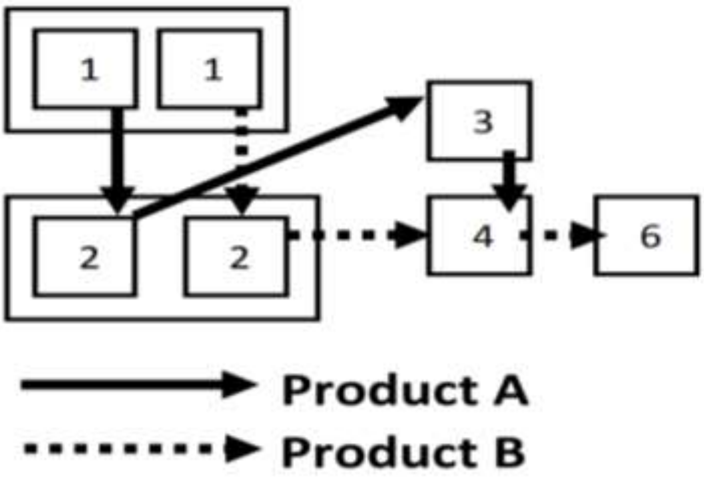


Figure 2.3: Process Layout Diagram (Tanutomo & Octavia, 2016)

In summary, the advantages and disadvantages of process layout are indicated in Table 2.2 below.

Table 2.2: Advantages and Disadvantages of Process Layout (William, 2020)

| **Advantages of Process Layout** | **Disadvantages of Process Layout** |
|---|---|
| • The system is capable of dealing with a wide range of processing requirements.<br>• The systems are relatively impervious to equipment failures.<br>• Individual incentive systems are possible.<br>• General-purpose equipment is frequently low cost compared to the specialized equipment required for product layouts. It is easier to maintain and low cost. | • The utilization rate of equipment is poor.<br>• Routing and schedule continue to be a source of contention.<br>• The handling of the material is inefficient and expensive per unit compared to product layouts.<br>• Costs associated with in-process inventory can be significant when batch processing is used in manufacturing systems. |

### 2.8.2 Product Layout

According to Tarigan et al. (2021), product layout can be defined as a method or technique for organizing and locating all necessary production facilities within specific department. A product can be manufactured within the department (Tarigan et al., 2021). Bennet (2015) described product layout is determined by the design of the product. It is the arrangement of machines, equipment, and workstations in accordance with the sequence of operations required to produce a specified product. There two types of product layout as follows (Bennett, 2015).

- **Assembly –** Materials and resources are added at each workstation in order to create discrete end products.
- **Disassembly** – A single raw input is divided into parts and then processed.

Previous study by Tanutomo and Octavia (2016) indicated machines and workstations are arranged in product layout according to the product's operation sequence. All production facilities which are necessary are arranged in a department. Products will be manufactured in a department with minimal movement from raw material to finished good. This layout is appropriate for plants that produce one or more standard products in large volume over an extended period of time (Tanutomo & Octavia, 2016). Product layout is used in flow shop production, which involves the mass production of standard products (Kovács & Kot, 2017). Moreover, machinery and materials are positioned in accordance the product path (Varinder Khurana, 2015). The product layout diagram is shown in Figure 2.4 below.

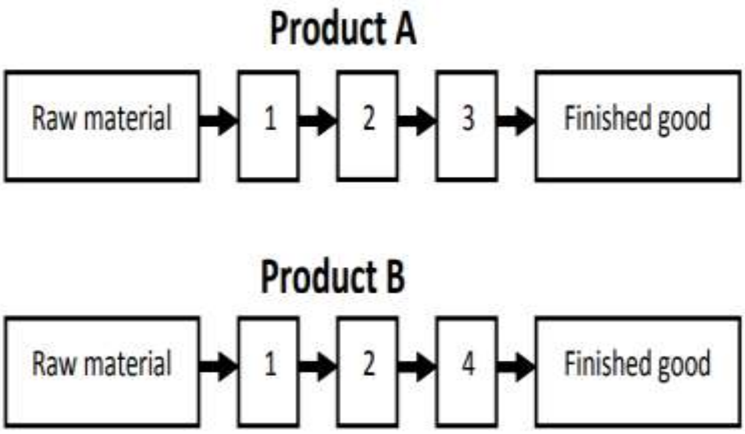



Figure 2.4: Product Layout Diagram (Tanutomo & Octavia, 2016)

The advantages and disadvantages of product layout stated in Table 2.3 below.

Table 2.3: Advantages and Disadvantages of Product Layout (William, 2020)

| Advantages of Product Layout | Disadvantages of Product Layout |
|---|---|
| • High labour and equipment utilization.<br>• High production rate.<br>• Labour specialization results in lower training costs and time, as well as a broad range of supervision.<br>• Due to the high volume, the unit cost is low. The high cost is that specialized equipment is distributed across many units.<br>• The cost of material handling per unit is low and material handling is often automated. | • The intensive division of labour frequently creates dull, repetitive jobs with little opportunity for advancement, resulting in low morale and repetitive stress injuries.<br>• Unskilled workers may pay less attention to equipment maintenance or product quality.<br>• The system is relatively inflexible in its response to changes in output volume or product or process design.<br>• Due to the interdependence of workstations, the systems are highly susceptible to shutdowns caused by equipment failures or excessive absenteeism. |

### 2.8.3 Fixed-Position Layout

Fixed-position layouts are not appropriate for small projects or products because it is the type of plant layout in which machines, equipment, and labour are transported to the location of the major product to be manufactured. This layout is used in the construction of a large or fragile structures such as bridges, ships, aircraft, space rockets, dams, road construction, and flyovers (Okpala et al., 2016). According to Tanutomo and Octavia (2016), the machines and facilities necessary to manufacture the product are brought to the location of the product in a fixed-position layout. This layout is appropriate for a large, difficult-to-transport product (Tanutomo & Octavia, 2016). Besides, product stays and resources move to it in fixed-position layout (Varinder Khurana, 2015). An example of a fixed position layout diagram is shown in Figure 2.5 below.

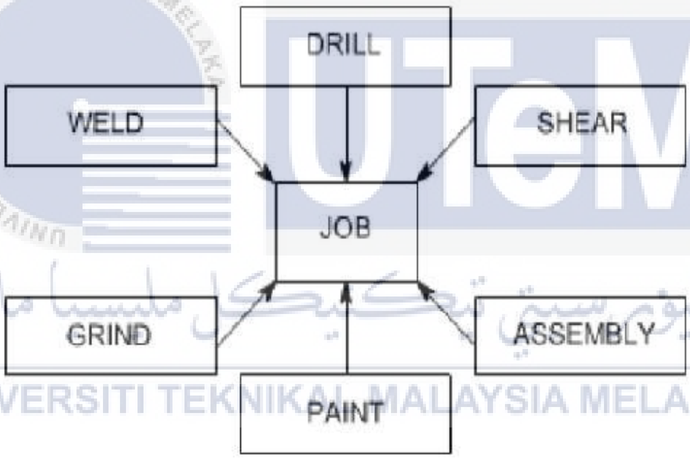





Figure 2.5: Fixed- Position Layout Diagram (Okpala et al., 2016)

The advantages and disadvantages of fixed-position layout are shown in Table 2.4 below.

Table 2.4: Advantages and Disadvantages of Fixed-Position Layout (Okpala et al., 2016)

| Advantages of Fixed-Position Layout | Disadvantages of Fixed-Position Layout |
|---|---|
| • High in flexibility and ability to accommodate changes in design and manufacturing process.<br>• Cost and time savings are associated with the constant movement of work from one location to another.<br>• It is highly cost-effective because jobs at various stages of completion can be produced concurrently. | • General supervision is required.<br>• Low equipment utilization.<br>• The positioning of material and machinery are cumbersome and costly.<br>• More operations involved make higher skill requirements for personnel. |



### 2.8.4 Cellular Layout

In the previous study by Bennett (2015), the cellular layout is a hybrid facility arrangement that incorporates elements or fixed-position and product layouts. This layout is a method of grouping different machines or processes in accordance with the product design being manufactured or the operations required to manufacture it. The operation sequence and direction of flow can be altered in cellular layout, and workers usually are multi-skilled and capable of operating multiple machines or processes (Bennett, 2015). Okpala *et al.* (2016) described cellular layout is defined as a type of layout in which machines and equipment are arranged in order to facilitate the continuous and uninterrupted movement of materials and tools through the manufacturing process without causing stoppages or waste of time (Okpala *et al.*, 2016). In addition, this layout is suitable for producing a variety of finished products in medium volume (Kovács & Kot, 2017). The example of cellular layout diagram is shown in Figure 2.6 below.

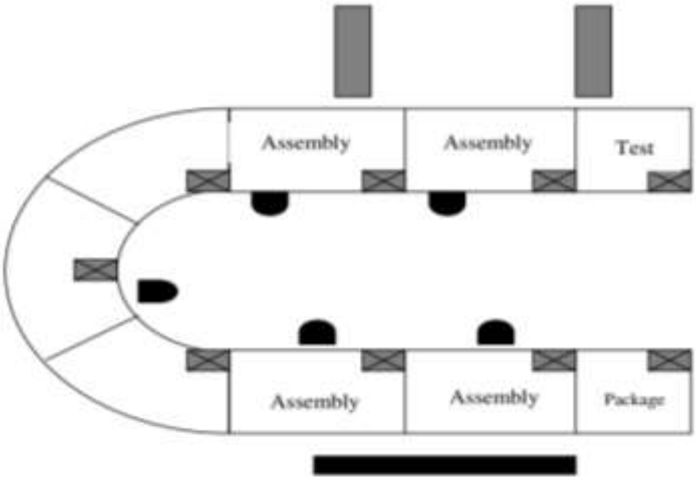



Figure 2.6: Cellular Layout Diagram (Sakran et al., 2017)

The advantages and disadvantages of cellular layout are stated in Table 2.5 below.

Table 2.5: Advantages and Disadvantages of Cellular Layout (Okpala et al., 2016)

| Advantages of Cellular Layout | Disadvantages of Cellular Layout |
|---|---|
| • Reduced lead time.<br>• Reduced setup time.<br>• Reduction in the inventory of work in progress.<br>• Reduction in the inventory of handling process.<br>• Reduced the amount of space wasted on the shop floor. | • Higher efficiency of the unit.<br>• Decreased versatility in the store.<br>• General administration is needed.<br>• Higher skills are needed of employees than for product layout.<br>• It relies on the synchronized flow of material among product layout and process layout. Otherwise, buffers and process storage work are required. |

## 2.9 Ergonomics Workstation

The height of the work area should always be between 800 mm and 1500 mm, and the work surface area dimension should always be 700 mm x 900 mm. The rules are as follows (Company, 2012).

i. **Avoid work above the heart (greater than 1500 mm)** – Reduced blood circulation and oxygen supply to the muscles, resulting in a decrease in performance. Work that requires bending, which is less than 800 mm, places an undue burden on workers and must be avoided.

ii. **Encourage dynamic activities** – Static holding inhibits blood circulation and oxygen supply to the muscles. This can result in a decrease in performance and the quality of processing.

iii. **Allow for varying levels of physical exertion** – Utilizing sit down or stand-up workstations or rotation of jobs. Varying physical exertion reduces worker stress and enhances performance.

iv. **Reduce exertion** – This can be accomplished by utilizing manual roller sections or lifting aids and selecting lighter-weight materials.



The reach zone is optimal for working with both hands because both hands easily to reach and in the worker's visual field, use smaller muscle groups, and allows for pure lower arm movements (Company, 2012). Anthropometry is a field of study within ergonomics that focuses on the measurement of human body dimensions and specify physical characteristics. The physical dimension of workstations, equipment, workspaces, and product design can be specify using anthropometric data (Woo et al., 2016). Figure 2.7 is showed the ergonomics standard of workstation.

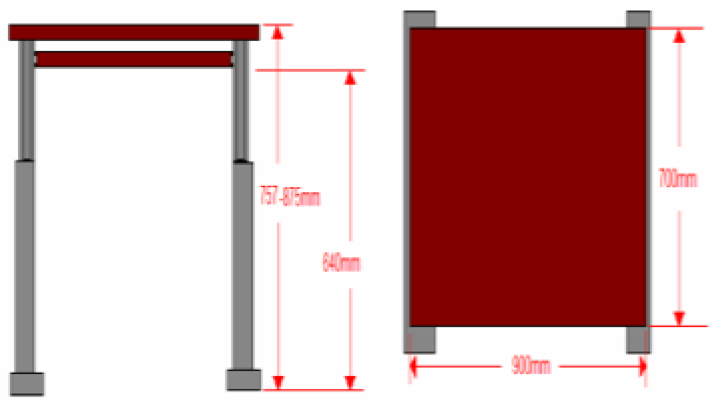



Figure 2.7: Ergonomics Standards of Workstation (Company, 2012)

## 2.10 Layout Optimization Tools and Techniques

The trends and history of previous layout optimization tools and techniques is reviewed. Table 2.6 below shows a summary of layout optimization tools and techniques from several previous researchers.



Table 2.6: Summary of Layout Optimization Tools and Techniques

| No. | Title and Author | Tools and Techniques | Finding |
|---|---|---|---|
| 1. | Optimization of Plant Layout Using Simulation Software (Anurag et al., 2016) | Simulation | With the aid of simulation software, it is possible to generate multiple what-if scenarios without affecting the actual operating process, choose the best possible outcome for the process, apply the optimal choice to the actual operating process, and obtain the desired results. |
| 2. | Improvement of Facility Layout Using Systematic Layout | Systematic Layout Planning (SLP) | The authors used Muther's SLP procedure to solve a facility layout problem. Despite the fact |

| | | | |
|---|---|---|---|
| | Planning (Maina et al., 2018) | | that SLP is a well-established procedure for designing new facility layouts, it also can be used to improve the existing layouts. |
| 3. | Wind Turbine Layout Optimization Using Multi-Population Genetic Algorithm and A Case Study in Hong Kong Offshore (Gao et al., 2015) | Multi-Population Genetic Algorithm | The results obtained in this study demonstrate that the algorithm always finds a better solution when optimizing wind turbine layouts in three cases varying wind scenarios, and comparisons to other previous studies are made. |
| 4. | A Simulation-Based Optimization Methodology for Facility Layout Design in Manufacturing (Zúñiga et al., 2020) | Simulation | The facility layout problem is analyzed in this paper. To resolve the problem, a simulation-based optimization methodology for designing facility layouts that take production and logistics constraints into account was proposed. The application was demonstrated through a case study in industry. |
| 5. | Layout Optimization of A Wind Farm to Maximize the Power Output Using Enhanced Teaching Learning Based Optimization Technique (Patel et al., 2017) | Teaching Learning Based | Two distinct variants of a fundamental teaching learning-based optimization algorithm are proposed and investigated for the complex layout optimization problem. The results indicate that the proposed algorithm produces a better solution. |

## 2.11 Product Lifecycle Management (PLM)

According to John (2016), the business practice of handling the company's product most productively during its lifecycles is referred as Product Lifecycle Management (PLM). PLM is the management framework for the goods of the organization. It is not only managing one of the products of the company but manages all the parts and products of the company and the product portfolio in an integrated manner. PLM monitors goods during its life cycle and maximizes product value throughout its lifespan (John, 2016). A previous study by Lutz (2015) is a critical component of state-of-the-art manufacturing for large companies, particularly in the automotive, aerospace, and increasing consumer electronics industries. Furthermore, PLM is concerned with the generation, storage, and retrieval of data, information, and ideally, knowledge throughout the lifecycle of a product, from conception to disposal (Lutz, 2015). There are five phases in the product lifecycle as stated in Table 2.7 below.

Table 2.7: Product Lifecycle (John, 2016)

| No. | Phase | Features |
|---|---|---|
| 1. | Imagination | The product is straightforwardly a concept and an idea |
| 2. | Definition | The concepts are expressed into detailed outline. |
| 3. | Realization | The commodity can be used by customer in its final form. |
| 4. | Use/Support | Product with the customer who uses it. |
| 5. | Dispose/Retire | Product is no longer useful. |

Figure 2.8 below shows the illustrated phases in product lifecycle.


Figure 2.8: Illustrated 5 Phases Product Lifecycle (John, 2016)

In addition, PLM increases the activity of product development and helps the organization to raise sales by enhancing creativity, minimizing time-to-market for new products, and offering outstanding support and new services for an existing product (Lutz, 2015).

### 2.11.1 Simulation

Anurag (2016) indicated that simulation has developed into a critical tool for effectively simulating the operation of any production system, whether continuous or discrete. Simulation optimization is a highly valuable technique for analyzing the behaviour of a variety of business processes, ranging from manufacturing layouts to supply chain management (Anurag, 2016).

A previous study by Vieira et al. (2019) described that manufacturing simulation enables the resolution of issues such as how to work with product mix required to achieve lower investment and operating costs, how to allocate resources in such a way that production targets are met while achieving excellent financial results, and how to improve the flow of production in terms of the total cost for cycle time limits (Vieira et al., 2019). Table 2.6 below shows the comparison of six simulation software: ARENA, FlexSim, AnyLogic, Simul8, and Product Lifecycle Management.



From Table 2.8, it can be concluded that Product Lifecycle Management (PLM) is the most beneficial software for layout optimization among the six simulation software. The manufacturing industry widely uses Product Lifecycle Management because it manages the product from the very first idea until the product is disposed of.

Table 2.8: Comparison of Simulation Software

| Benefit \ Software | ARENA | Flex Sim | Any Logic | Simul8 | Product Lifecycle Management |
|---|---|---|---|---|---|
| Accelerate the whole process: Process running more quickly. | ✗ | ✗ | ✗ | ✗ | ✓ |
| Diagnose and fix problem: Find the source of problem and find solution | ✓ | ✗ | ✗ | ✗ | ✓ |
| Realistic 3D visualization: Showing sensible and practical visual | ✓ | ✗ | ✓ | ✓ | ✓ |
| Product output increase: Surge of output and output target achieve | ✓ | ✗ | ✗ | ✗ | ✓ |
| Improve quality of product: Upgrade product's capability to meet user standards | ✗ | ✗ | ✗ | ✗ | ✓ |
| Increase revenue: Escalate sales | ✓ | ✓ | ✓ | ✓ | ✓ |
| Centralized data management: Store at a single location, e.g.: mainframe computer | ✗ | ✗ | ✗ | ✗ | ✓ |

## 2.13 Summary

Current research, theory, and establish methods that can be implemented and used for conducting this study are reviewed in this chapter. The main topics include the philosophy of plant layout, types of facility layouts, lean manufacturing tools that can be implemented in planning the layout, previous layout optimization tools and techniques and comparison between the existing simulation software.

There are numerous layout optimization tools and techniques by previous researchers. The literature review revealed that simulation is a tool to optimize layout widely used as it can predict the complex production systems behaviour by assessing the gesticulation and interaction of system components. For example, involving specifications that allow the user to alter the number of workers at a workstation, machine or vehicle speed, and conveyor control system's timing characteristic. A comparison among existing simulation software has been studied, and it shows that Product Lifecycle Management (PLM) has fulfilled all the requirements to generate the most optimum layout. PLM is the only software that manages a product across its lifecycle.

All in all, based on the literature review, there is a lack of information regarding optimization layout using product lifecycle management. Therefore, it is crucial and beneficial to study on this research topic, and this study can be a guideline for the manufacturing industry in solving layout problem that occurs in a production line.

# CHAPTER 3

## METHODOLOGY

This chapter provides a comprehensive overview of the methods used in this research, which focuses on optimizing the production line through the use of Product Lifecycle Management (PLM). This chapter comprises of descriptive method discussed about procedures and practices throughout the project. The approach discussion of methodology begins with the first stage of the research and continues until the end of the research process.



### 3.1 Project Planning

Project planning is an integral part of project management because it ensures that everything is completed on time and in the proper manner. The procedures and methods are developed in accordance with the scopes of the objectives to be accomplished. To ensure that the task is completed successfully, documentation is generated to ensure that everything is in order. The process flow of the project is depicted using a flowchart, which provides insight into the overall process of obtaining an acceptable result, beginning with data extraction, project methodology, and data analysis. Additionally, this chapter discussed methods for optimizing the production line using Product Lifecycle Management (PLM).

## 3.2 Flowchart

The process flow is frequently depicted in a flowchart to help visualize the steps involved in conducting the start from start to end. Each step of the procedure is represented with a symbol. The methodology for this research is summarized in Figure 3.1.

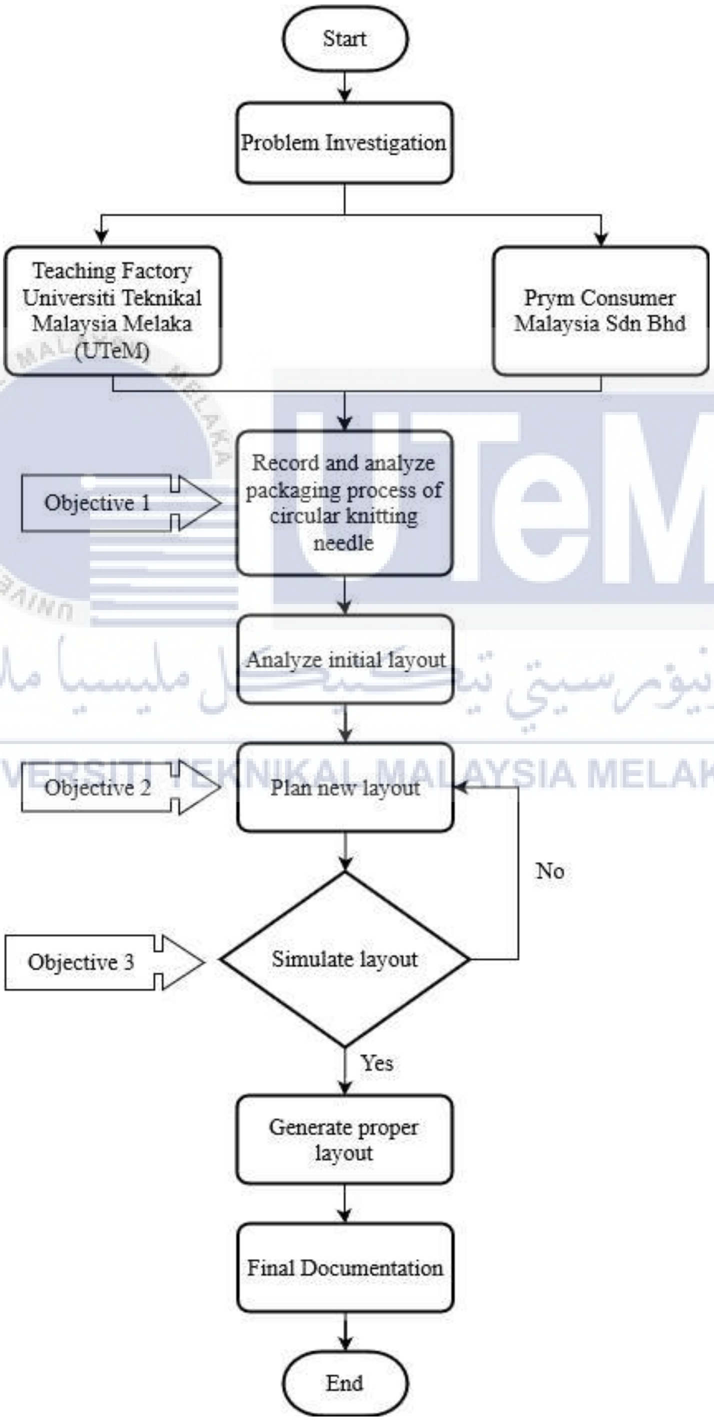



Figure 3.1: Flowchart

### 3.2.1 Problem Investigation

The project began with an investigation into a problem that occurred at Prym Consumer Malaysia Sdn. Bhd. and Teaching Factory UTeM. The primary issue is that the output of the circular knitting needles does not meet the target. The problem is stated and explained in detail in the problem statement.

### 3.2.2 Record and Analyze Packaging Process of Circular Knitting Needle

The following step is to record each step of the circular knitting needle packaging process. The purpose of this step is to thoroughly study and comprehend the method of the processes. Three operators included at the packaging production line, and there are three processes that are involved in assembling the circular knitting needle packages.



#### 3.2.2.1 Time Study

The first method of conducting a time study is to capture cycle time. A stopwatch is used to record the duration of each cycle. The purpose of capturing cycle time is to determine how long it takes each of the three operators to complete one process in assembling each component of the circular knitting needle packages. Table 3.1 below shows the time study sheet that is used to conduct the time study analysis. The time study sheet specifies the size of the circular knitting needles to be analyzed, the number of cycles to be captured, and a detailed description of the steps of the processes. Average observed time is also included in the time study sheet.

Table 3.1: Time Study Table

| TIME STUDY SHEET | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Size:<br>No. of Cycles: | | | | | | | | | | | | |
| Seq. | Description of Steps | Observed Time Process | | | | | | | | | | Average Observed Time (sec) |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |

**3.2.2.2 Data Analysis**

All the data collected during the time study and the output data from the circular knitting needles will be analyzed. The maximum cycle time of the operator will be determined during this stage. The purpose of data analysis is to correlate the reason why the output of the circular knitting needle does not meet the target with the data obtained.



**3.2.3 Analyze Current Layout**

The current layout of the production line is analyzed by finding the cause of the problem. The current layout may be poorly designed, resulting in the circular knitting needles output falling short of the target. Next, the layout is analyzed in terms of seven different types of waste that could occur. Overproduction, unnecessary motion, over-processing, unnecessary inventory, transportation, waiting, and defects are all possible wastes. A detailed explanation about the wastes has been discussed in the literature review. Besides, the dimensions of the workstations are considered when analyzing the current layout. The dimensions of the current workstations are analyzed whether it comply with the ergonomics standards. If the dimensions of the workstations do not comply with the ergonomics standards, therefore the layout is poorly designed. The workstation is designed using CATIA V5 software. The interface of the software is illustrated in Figure 3.2.

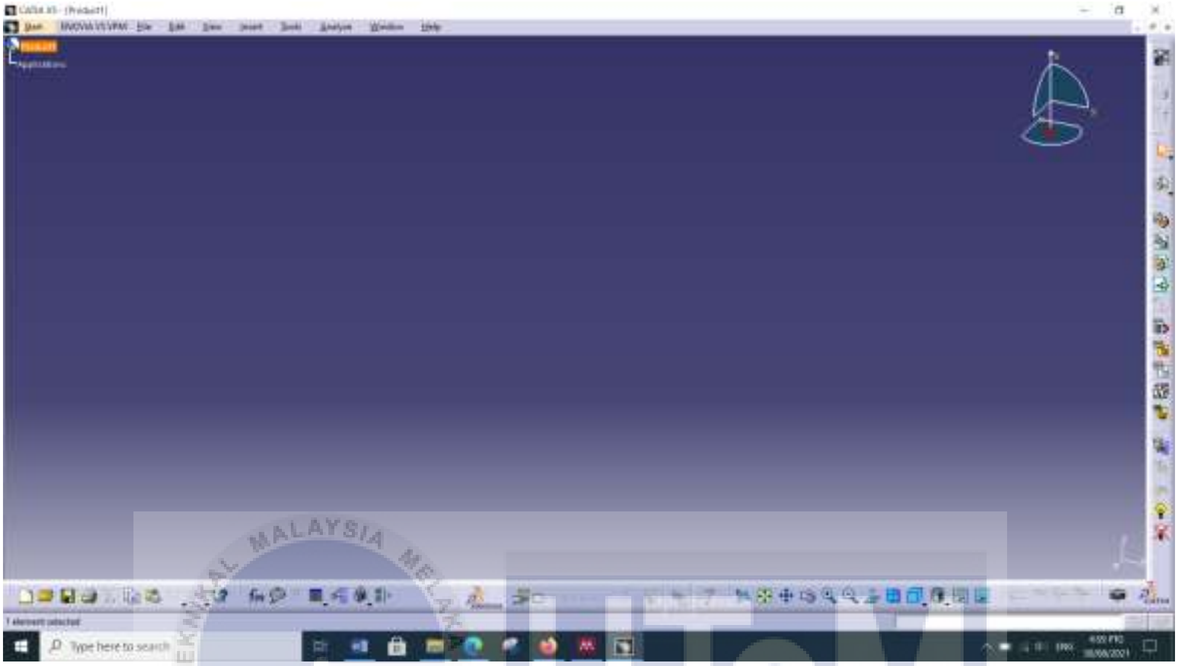


Figure 3.2: Interface of CATIA V5

Additionally, the method of the workers when performing the processes is considered when analyzing layout. This is because the current layout can be re-layout or redesign to make it easier for the workers to complete their tasks.

### 3.2.4 Proposed New Layout

After analyzing of the current layout, begin planning the new layout in order to optimize the production line. Consider incorporating lean manufacturing techniques into the new layout. 5S, Kanban, KAIZEN, Value Stream Mapping (VSM), and Just-In-Time (JIT) are all the lean tools that can be implemented in order to plan the new layout. These tools can help in reducing waste and increasing the efficiency of the production line. Additionally, these tools can assist in properly planning the new layout. The literature review discusses the lean tools in detail.

Following that, when designing a new layout, ergonomics standards for workstations must be considered. This is because ergonomics standards are correlated to the body posture of a worker when performing assigned tasks. For instance, a well-designed workstation does not require workers to stand if they are unable to reach the products. They are capable of efficiently completing the assigned tasks.

The new layout is designed using the Product Lifecycle Management (PLM) simulation software as it is a tool to optimize the layout of production line. Product Lifecycle Management (PLM) has managed the lifecycle of the circular knitting needle. Tecnomatix Plant Simulation is the software used for product lifecycle management. This software enables the virtual connection model of the plant to actual plant control in to simulate actual production. Then, simulate new layouts using the software. If the layout does not fulfill the requirements, the process will return to propose a new layout to correct and improve the layout design. If testing the new layout and the result obtained is fulfilled the requirements, then the process continues to generate a proper layout. Figure 3.3 shows the interface of the Tecnomatix Plant Simulation software.




Figure 3.3: Interface of Tecnomatix Plant Simulation

Figure 3.4 shows the interface of the 2D Frame in the Tecnomatix Plant Simulation.

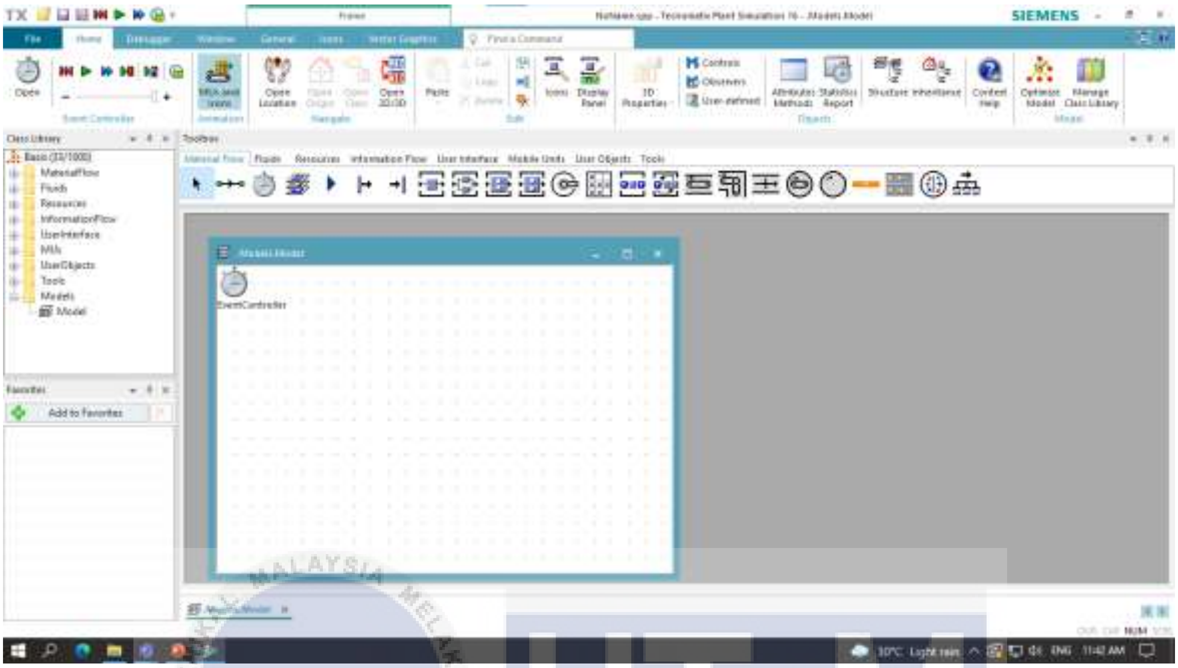


Figure 3.4: Interface of 2D Frame in Tecnomatix Plant Simulation

Figure 3.5 shows the interface of the 3D Frame in the Tecnomatix Plant Simulation.

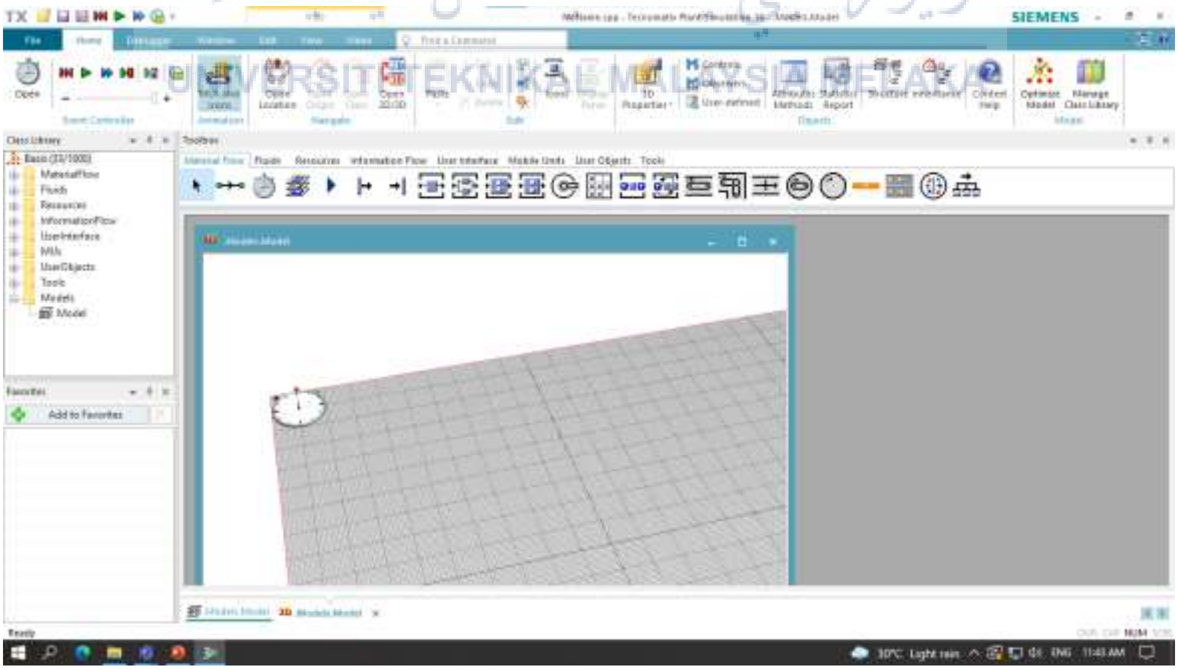


Figure 3.5: Interface of 3D Frame in Tecnomatix Plant Simulation

### 3.2.5 Generate Proper Layout

After the simulation process is successfully completed, a proper layout is obtained. The proper layout can be applied and implemented at the production line, rather than just virtually in the software. At this stage, the optimal layout is achieved, and the production line of the circular knitting needle packaging process has proven to be optimized.

### 3.2.6 Final Documentation

The final documentation stage is to explain the improvement that has been conducted in the packaging process of the circular knitting needle throughout this research. The enhancement was accomplished through the use of Tecnomatix Plant Simulation software. It depicts that the software has optimized the production line layout.



## 3.3 Summary

This chapter details the methodology used to complete the scopes in this research. A detailed description of the methods used to optimize the production line layout and Product Lifecycle Management (PLM) which the software used is Tecnomatix Plant Simulation, were discussed to acquire the necessary data for accomplishing the research objective. The results of the analysis and simulation can be used for optimizing the production line layout that is presented in Chapter 4.

# CHAPTER 4

## RESULT AND DISCUSSION

In this chapter, the result obtained regarding the improvement in the production line layout are presented and discussed according the objective of the study. The result is obtained by analyzing the problem that occurred at the production line. Then, the layout is optimized using Tecnomatix Product Lifecycle Management (PLM) to get the most optimum layout.

### 4.1 Standard Operating Procedure (SOP)



Standard Operating Procedure (SOP) of the circular knitting needle packaging process is presented in Appendix A. The proposed SOP for the packaging process can be used to train the workers by providing all the necessary detailed information to ensure that the process is carried out properly. If the other process is out of balance, workers can cover the process in order to balance it. Proposing SOP should result in a multi-skilled worker. SOP serves as an explanation of steps in a process. As a result, it assists in ensuring that workers will perform the procedures correctly and consistently. Additionally, the SOP instructs the workers to accomplish their assigned tasks effectively and efficiently (Singh, 2019). The materials that are required for every process are also included in the SOP.

## 4.2 Time Study for Circular Knitting Needle

Time study analysis enables the improvement and performance optimization of production lines and workers. Increase efficiency and reduce fatigue among workers are the result of improved working methods (Cury & Saraiva, 2018). Tables 4.1, 4.2, and 4.3 show the result of the time study of the workers at the production line of the packaging process circular knitting needle. The time study is conducted for sizes 60 cm, 80 cm, and 100 cm. The cycle time for one process is taken ten times as it is the relevant number to get one operator's accurate cycle time (Taifa & Vhora, 2019). Based on the result of the time study, the longer the size of the circular knitting needle, the higher the cycle time of the worker.

Table 4.1 is shown the time study result for 60 cm of the circular knitting needle. The time taken for process 1 at cycle 9 is the highest. The duration is increased from 7.3 s to 18.8 s. This is because the worker was struggling with the polybag, as shown in Figure 4.1. The polybag is crumpled, and the worker took a while to reposition it properly.



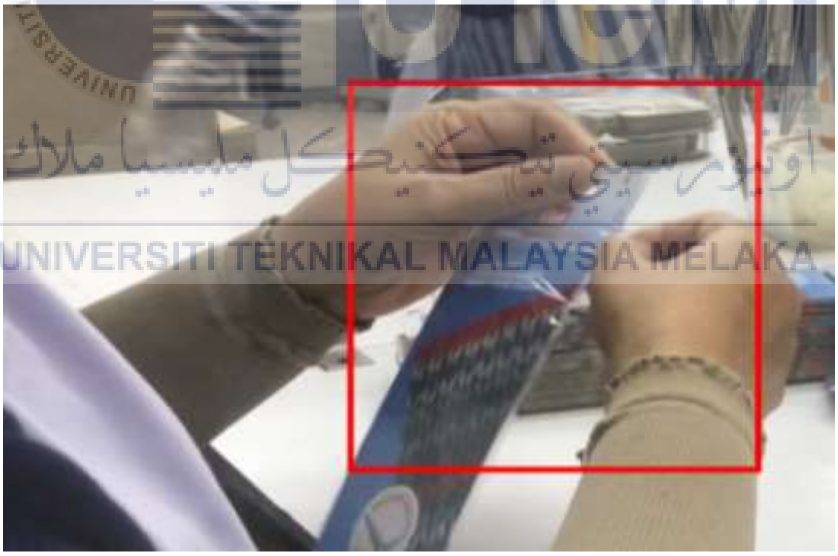


Figure 4.1: Cycle 9 of Process 1 with 60 cm Circular Knitting Needle

Process 1 takes 11.3s during cycle 1, 10s during cycle 2, 7.3s during cycle 3, 10.3s during cycle 4, 13.6s during cycle 5, 10s during cycle 6, and 8.8s during cycle 7. There is the time taken that are faster and slower. Therefore, the duration from cycles 1 to 7 is inconsistent. This is due to the way in which the worker completes the process for one cycle. The worker is used both hands to fold the bottom part of the card while holding the polybag as shown in the Figure 4.2. The worker then encounters difficulties when attempting to open the polybag.

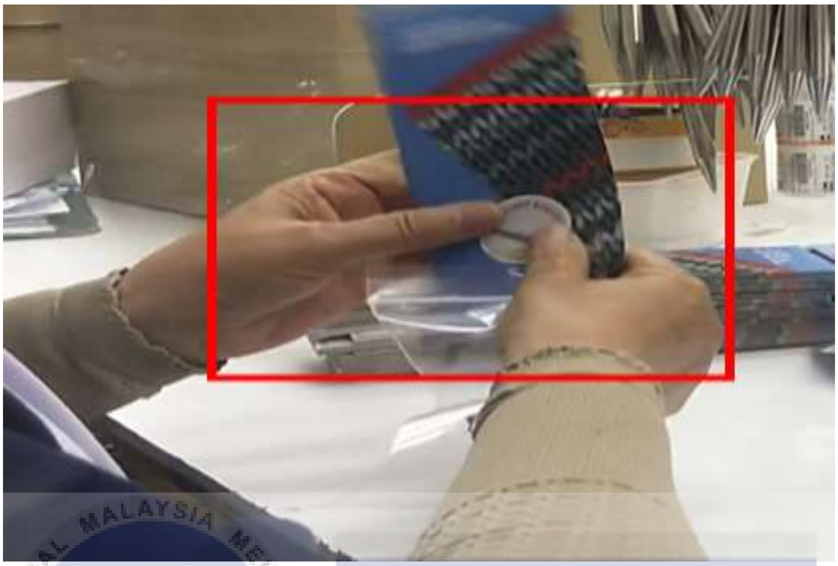


Figure 4.2: Cycle 1 to Cycle 7 of Process 1 with 60 cm Circular Knitting Needle

The highest time taken in process 2 is 16.3 s during cycle 2. During this cycle, the circular knitting needle seems to have a defect. Therefore, the worker takes some time carefully checking the circular knitting needle, as shown in Figure 4.3.



Figure 4.3: Cycle 2 of Process 2 with 60 cm Circular Knitting Needle

Then, cycle 3 takes 11.7s, cycle 4 takes 10.4s, and cycle 5 takes 13.2s. All of the duration of the cycles are inconsistent, and the difference is quite significant. This occurred due to the method of the worker to complete the process for one cycle. The worker frequently shakes the polybag to ensure the circular knitting needle is properly positioned, as presented in Figure 4.4. The faster the circular knitting needle can be correctly positioned at the bottom of the polybag, the shorter the duration of one cycle. However, if the worker encounters difficulties, such as the circular knitting needle stuck at the middle of the polybag, then the duration of a cycle will be longer.

Figure 4.4: Cycle 3 to Cycle 5 of Process 2 with 60 cm Circular Knitting Needle

Table 4.1: Time Study of 60 cm Circular Knitting Needle

| TIME STUDY SHEET | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Size: 60 cm<br>No. of Cycles: 10 | | | | | | | | | | | | |
| Process | Description of Steps | Observed Time Process | | | | | | | | | | Average Observed Time (sec) |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| 1 | i. Fold card and insert into polybag. | 11.3 | 10.0 | 7.3 | 10.3 | 13.6 | 10.0 | 8.8 | 7.3 | 18.8 | 12.0 | 10.9 |
| 2 | i. Roll the circular knitting needle one round and insert into polybag.<br>ii. Seal the polybag. | 15.0 | 16.3 | 11.7 | 10.4 | 13.2 | 13.0 | 15.2 | 12.2 | 11.5 | 10.5 | 12.9 |
| 3 | i. Fold outer box.<br>ii. Insert five circular knitting needle in outer box and close the lid.<br>iii. Stick a outer sticker to the outer box and arrange inside carton. | 22.4 | 24.8 | 22.6 | 21.5 | 22.6 | 22.1 | 21.9 | 23.0 | 21.8 | 21.2 | 22.4 |

The time study result for the 80 cm circular knitting needle is shown in Table 4.2. Process 1 takes 8.2 s during cycle 2, 6.8 s during cycle 3, and 8.1 s during cycle 4. The duration is inconsistent despite the method in which the worker performs the process, as shown in Figure 4.5. The worker uses left hand to hold the card and right hand to fold the bottom part of the card. Then, the worker uses the right hand again to open the polybag. This method requires a longer time to complete one cycle. The duration can be faster if the worker has no difficulty when attempting to open the polybag.

Figure 4.5: Cycle 2 to Cycle 4 of Process 1 with 80 cm Circular Knitting Needle



Cycle 5 of process 1 has the highest time taken of 9.5 s. This is because the worker accidentally took two cards, as shown in the Figure 4.6. The worker has to put the card back in its original place. As a result, the worker took an extended time to complete one cycle of process one.

Figure 4.6: Cycle 5 of Process 1with 80 cm Circular Knitting Needle

Cycle 7 in process 2 has the highest time taken, which is 15.6 s, and the time taken for cycle 8 is 10.9 s. The difference is significant. Cycle 7 has the highest duration due to the difficulty encountered by the working while rolling the circular knitting needle, as shown in Figure 4.7. The circular knitting needle does not roll smoothly.



Figure 4.7: Cycle 7 of Process 2 with 80 cm Circular Knitting Needle

The duration of cycle 1 until cycle 7 of process 2 take a longer time than cycle 8 until cycle 10. This is because the circular knitting needle frequently stuck together at cycle 1 until cycle 7. The problem is illustrated in the Figure 4.8. The worker has to exert extra force to pull out one circular knitting needle. During cycle 8 to cycle 10, the worker can easily pull out the circular knitting needle.

Figure 4.8: Cycle 1 to Cycle 7 of Process 2 with 80 cm Circular Knitting Needle



Cycle 1 of process 3 takes 20.6 s, and cycle 2 takes 16.5 s. The difference in the time taken between the two cycles is 4.1 s. This is because the worker put the outer boxes back to its original place before starting to insert five circular knitting needles, as presented in the Figure 4.9.

Figure 4.9: Cycle 1 of Process 3 with 80 cm Circular Knitting Needle

Cycle 4 takes 13.6 s, cycle 5 takes 16.4 s, cycle 6 takes 17 s, and cycle 7 takes 13.5 s in process 3. The time taken for these cycles is inconsistent, and the differences are significant due to the method that is used by the worker to fold the outer boxes. The worker uses a needle to lift the bottom part of the outer box in order to fold it properly. The duration can be extended because the worker encountered difficulties using the needle to push the bottom part of the outer box upward, as shown in the Figure 4.10.



Figure 4.10: Cycle 4 to Cycle 7 of Process 3 with 80 cm Circular Knitting Needle

Table 4.2: Time Study of 80 cm Circular Knitting Needle

| TIME STUDY SHEET | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Size: 80 cm<br>No. of Cycles: 10 | | | | | | | | | | | | |
| Process | Description of Steps | Observed Time Process | | | | | | | | | | Average Observed Time (sec) |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| 1 | i. Fold card and insert into polybag. | 8.4 | 8.2 | 6.8 | 8.1 | 9.5 | 6.5 | 6.7 | 6.4 | 9.1 | 7.8 | 7.8 |
| 2 | i. Roll the circular knitting needle two rounds and insert into polybag.<br>ii. Seal the polybag. | 12.2 | 11.3 | 13.5 | 13.3 | 14.3 | 12.3 | 15.6 | `10.9 | 11.8 | 10.9 | 12.6 |
| 3 | i. Fold outer box.<br>ii. Insert five circular knitting needles in outer box and close the lid.<br>iii. Stick a outer sticker to the outer box and arrange inside carton. | 20.6 | 16.5 | 14.4 | 13.6 | 16.4 | 17.0 | 13.5 | 14.4 | 14.9 | 15.7 | 15.7 |

Table 4.3 is showed the result of the time study for size the 100 cm. Cycle 4 takes 9 s, cycle 5 takes 11.3 s, and cycle 6 takes 8.1 s in process 1. Cycle 5 took longer to complete because the worker encountered difficulty opening the polybag and inserting the card into the polybag, as shown in Figure 4.11.

Figure 4.11: Cycle 5 of Process 1 with 100 cm Circular Knitting Needle

The time taken for cycle 7 is 8.4 s, and cycle 8 is 14.9 s. The duration for cycle 8 is longer than cycle 7 because the polybag is accidentally falling from the worker's hand. Therefore, the worker must replace the polybag with a new polybag and restart the process. The problem is shown in the Figure 4.12.

Figure 4.12: Cycle 8 of Process 1 with 100 cm Circular Knitting Needle

Cycle 9 takes 14.2 s, which is considered to be a longer duration. The polybag accidentally separates from the worker's hand when the worker takes the polybag from the container, as shown in Figure 4.13. The worker is also having difficulty inserting the card into the polybag due to the difficulty to open it.



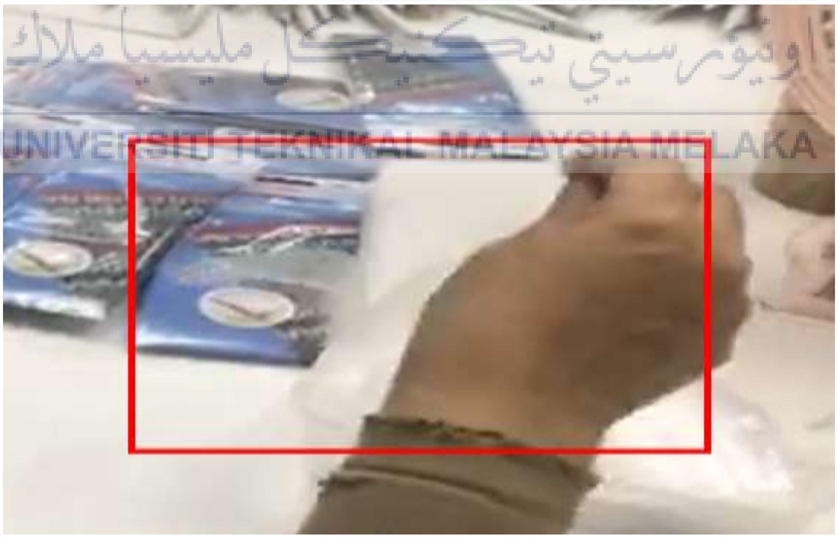


Figure 4.13: Cycle 9 of Process 1 with 100 cm Circular Knitting Needle

In process 2, the time taken for cycle 2 is 16.8 s, and cycle 3 is 12.1 s. The duration for cycle 2 is longer than cycle 3 because the worker struggles to seal the polybag properly after inserting the circular knitting needle, as shown in Figure 4.14. The working takes time to seal the polybag.

Figure 4.14: Cycle 2 of Process 2 with 100 cm Circular Knitting Needle



The time taken for cycle 4 is 16 s, and cycle 5 is 13.5 s. Cycle 4 takes a longer time than cycle 5 because the circular knitting needle stuck together when the worker pulls it out. The worker is required to use both hands to pull out the circular knitting needle, as shown in Figure 4.15.

Figure 4.15: Cycle 4 of Process 2 with 100 cm Circular Knitting Needle

Cycle 7 takes 16.7 s, and cycle 8 takes 13.8 s in process 2. The duration for cycle 7 is longer than cycle 8 due to the worker shakes the polybag twice, which is after inserting the circular knitting needle and after sealing the polybag. The worker usually shakes the polybag once after inserting the needle, but during this cycle, the circular knitting needle appears to be misaligned at the bottom of the polybag. Therefore, the worker is required to shake the polybag twice, as illustrated in Figure 4.16.



Figure 4.16: Cycle 7 of Process 2 with 100 cm Circular Knitting Needle

At cycle 9, the time taken increases to 16.8 s from 13.8 s. This is because the worker's hand accidentally dropped the polybag with a circular knitting needle, as shown in Figure 4.17. The worker has to pick up the polybag. The worker also encountered the same issue during this cycle, which is difficult to seal the polybag.

Figure 4.17: Cycle 9 of Process 2 with 100 cm Circular Knitting Needle

In process 3, the highest time taken is during cycle 10 which is 93.4 s. This is due to the worker is unable to reach the circular knitting needles. Therefore, the worker needs to bend the body in order to reach the needles, as shown in Figure 4.18.



Figure 4.18: Cycle 10 of Process 3 with 100 cm Circular Knitting Needle

The second highest time taken in process 3 is 79 s during cycle 3. The duration is long because the worker taps the outer box on the table in order to properly folds it, as shown in Figure 4.19.

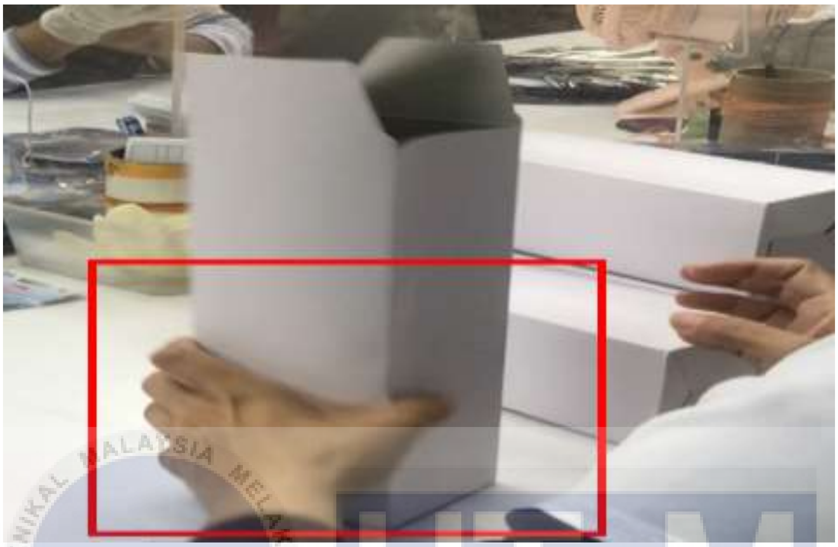


Figure 4.19: Cycle 3 of Process 3 with 100 cm Circular Knitting Needle

Table 4.3: Time Study of 100 cm Circular Knitting Needle

| TIME STUDY SHEET | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Size: 100 cm<br>No. of Cycles: 10 | | | | | | | | | | | | | |
| Process | Description of Steps | | Observed Time Process | | | | | | | | | | Average Observed Time (sec) |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| 1 | i. | Fold card and insert into polybag. | 7.8 | 7.7 | 9.8 | 9.0 | 11.3 | 8.1 | 8.4 | 14.9 | 14.2 | 8.9 | 10.0 |
| 2 | i.<br>ii. | Roll the circular knitting needle two rounds and insert into polybag.<br>Seal the polybag. | 14.0 | 16.8 | 12.1 | 16.0 | 13.5 | 14.5 | 16.7 | 13.8 | 16.8 | 14.8 | 14.9 |
| 3 | i.<br>ii.<br>iii. | Fold outer box.<br>Insert five circular knitting needle in outer box and close the lid.<br>Stick a outer sticker to the outer box and arrange inside carton. | 18.2 | 23.5 | 79.0 | 18.7 | 18.1 | 14.1 | 21.6 | 25.0 | 19.6 | 93.4 | 33.1 |

## 4.3 Production Line Improvement

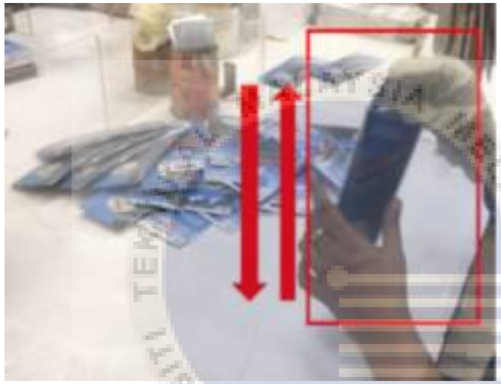
A well-designed production line achieves the optimal balance of raw materials, manufacturing process, available space, and output. It ensures the efficient use of all available space and flexibility in arrangement and manufacturing operations, inventory movement throughout the production line, unnecessary delays, and reduced lead time (Okpala et al., 2016).

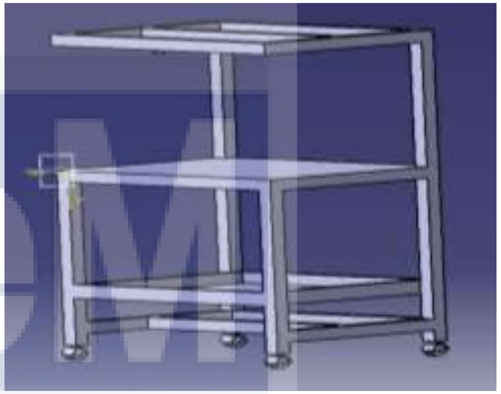
In order to plan a proper layout, the production line of circular knitting needle packaging process has been improved in terms of method. The waste and issues encountered at the production line are analyzed. This is because a good production line layout facilitates the production process, reduces material handling, time, and cost, and enables operational flexibility and easy production flow. Furthermore, it also ensures worker safety, convenience, and comfort (Guoliang Fan et al., 2017).

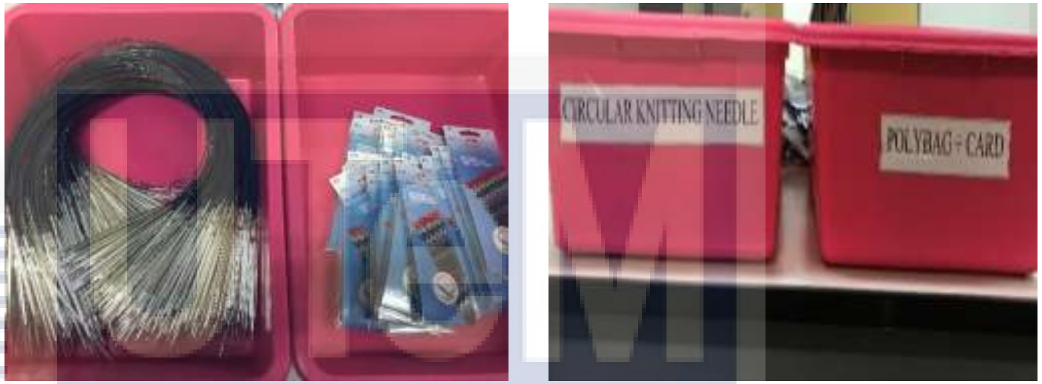
Table 4.4 shows a detailed explanation of the problem that occurred at the production line of circular knitting needle packaging process and the improvements that were implemented to resolve the issue. Several technical enhancements were implemented to improve the production line.

Table 4.4: Before and After Implementing Improvements

| Before | After |
|---|---|
| <br>Figure 4.20: Incorrect Hand Position<br><br>The awkward motion has occurred while the worker is performing the task. The hand position is incorrect, as the worker folds the card while holding the polybag. | <br>Figure 4.21: Correct Hand Position<br><br>The correct position is for the card to be on the right hand and the polybag on the left hand. This is because the worker will find it easier to fold the bottom part of the card and insert it into the polybag. Additionally, the time taken to complete one cycle of the process is quicker. The time taken has been reduced from **10.9 s** to **5.5 s**. |

| Before | After |
|---|---|
| <br>Figure 4.22: Over-processing<br><br>Over-processing is occurred because the worker shakes the polybag in order to ensure the circular knitting needle is positioned correctly at the bottom of the polybag. | <br>Figure 4.23: Arrow Needle<br><br>The arrow needle is used to insert the circular knitting needle into the polybag properly. As a result, the worker is no longer required to shake the polybag. The time taken to complete one cycle of the process is quicker. The time taken has been reduced from **14.9 s** to **11.6 s**. |

| Before | After |
| --- | --- |
| <br>Figure 4.24: Awkward Motion<br><br>i. The worker performs the task in an awkward motion due to her inability to reach the circular knitting needles.<br>ii. The worker is required to stand up to get the circular knitting needles because the workstation is spacious. Therefore, the worker is unable to reach the products easily. | <br>Figure 4.25: Ergonomics Standard Workstation<br><br>The workstation is designed according to ergonomics standards. This is because ergonomics standards have standardized the dimension of the workstation, which is 700mm x 900mm. Therefore, it will be easier for the worker to reach the circular knitting needle (Company, 2012). |

| Before | After |
|---|---|
|  Figure 4.26: Unorganized Materials |   Figure 4.27: Organized Materials |
| The position of the polybags in the container and the cards are not arranged systematically because of the distance. | The containers are used to organize the circular knitting needles and the polybags. The containers are labelled to assist workers in identifying the materials. |

## 4.4 Layout Configuration

Cellular manufacturing is sequenced in such a way that material and components flow smoothly through the process with minimal transport or delay. Furthermore, it enables a single cell to fulfill the entire production requirement. The layout for the production line in the company is a cellular layout. This study focused on the cellular layout as it has been shown to minimize work in process, maximize space utilization, reduce lead time, maximize productivity and quality, and increase flexibility (Sakran et al., 2017). The arrangement of workstations and workers' placement are altered to accommodate the planned layout. Four different layouts have been proposed for comparison in order to determine the optimal layout.

The layouts are created and simulated using product lifecycle management. Various software applications fall under product lifecycle management. Tecnomatix Plant Simulation. Simulation is a process of testing the layout used utilizing a prototype. In this case, the cost can be reduced. A simulation is an analysis tool that helps to decide on which layout is optimal. Furthermore, the real-life system of the production line of the circular knitting needles packaging process can be built using the software (Kadane & Bhatwadekar, 2011).



### 4.4.1 Initial Layout

The initial layout contained four workstations which are workstation 1, workstation 2, workstation 3, and w orkstation 4. Three workers are assigned to the production line, as the packaging process for the circular knitting needles consists of three processes. The placement of the worker is not systematic. Balancing the production line is difficult because workers cannot easily move from one workstation to another.  The initial layout is depicted in Figure 4.28.

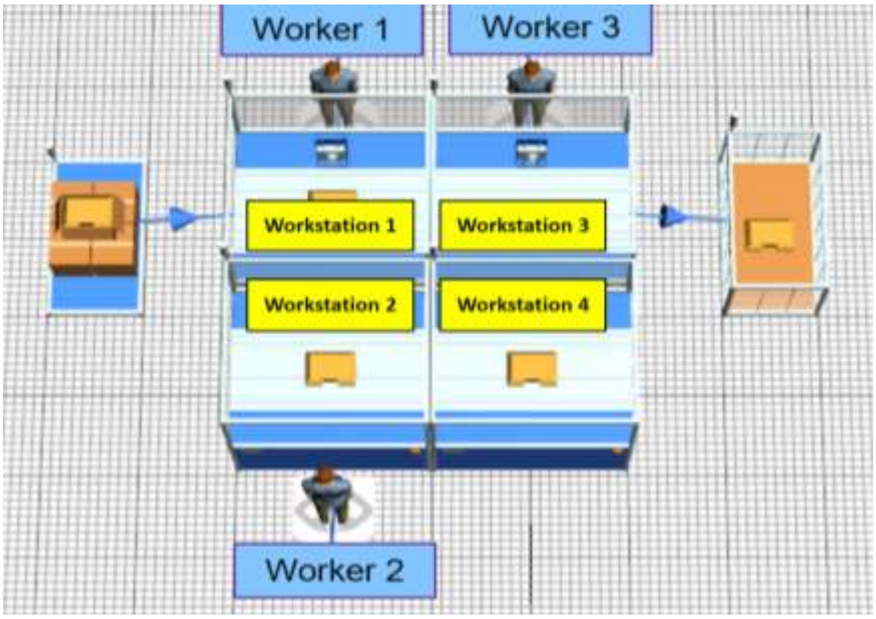



Figure 4.28: Initial Layout

Based on the result shown in Figure 4.29, the total throughput per minute is 0.37, the total throughput per hour is 22.36, and the total throughput per day is 536.75. The indicated result is considered to be insufficient. The total working percentage is 59.17%. The total percentage overall failure rate of the initial layout is 7.76%, which is considered high.



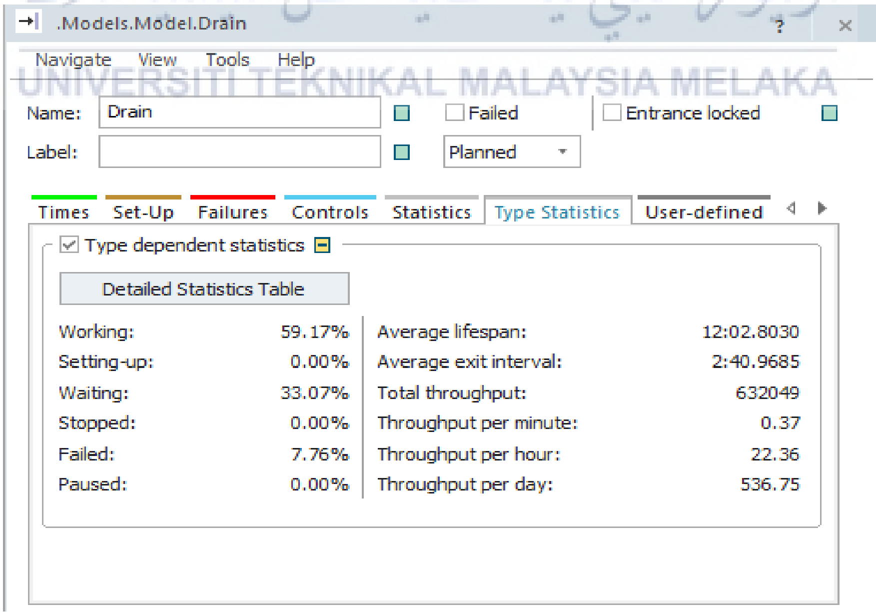



Figure 4.29: Simulation Result Initial Layout

### 4.4.2 Proposed Layout 1

The first proposed layout is maintained with four workstations, designated as workstation 1, workstation 2, workstation 3, and workstation 4. The placement of the worker is altered. workstation 1 is adjacent to workstation 4, workstation 2 is opposite workstation 1, and workstation 2 is adjacent to workstation 3. Workers are unable to move easily between workstations. As a result, balancing the line is difficult. The first proposed layout is shown in Figure 4.30.

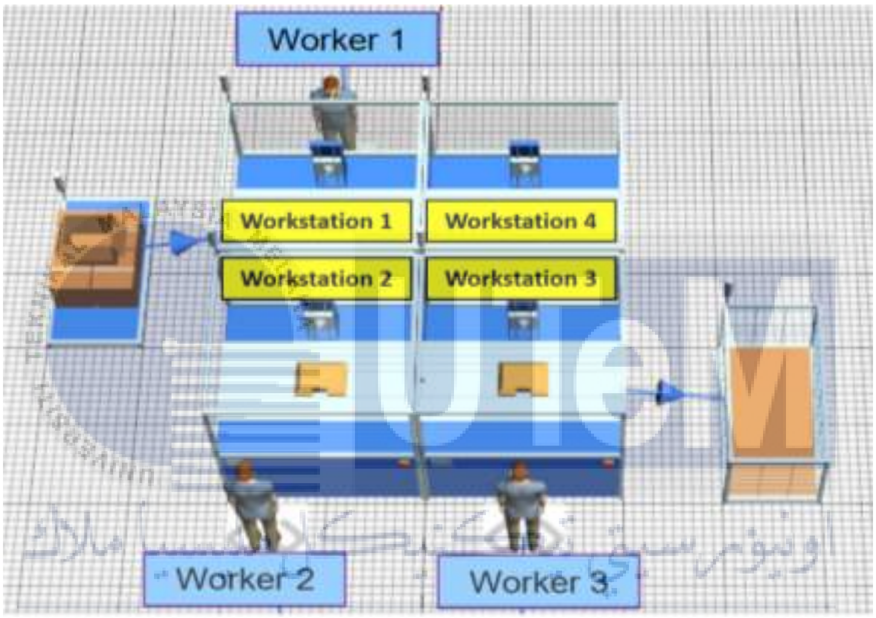





Figure 4.30: Proposed Layout 1

Figure 4.31 is presented the simulation result of proposed layout 1. The proposed layout 1 has a total throughput per minute of 0.35, a total throughout per hour of 20.81, and daily throughput of 499.41. Therefore, the result is shown that the total throughput of proposed layout 1 is lower than the initial layout. The total working percentage is 57.24%. The total failure percentage of proposed layout 1 is 7.20%. The overall failure rate is low, and it is lower than the initial layout.

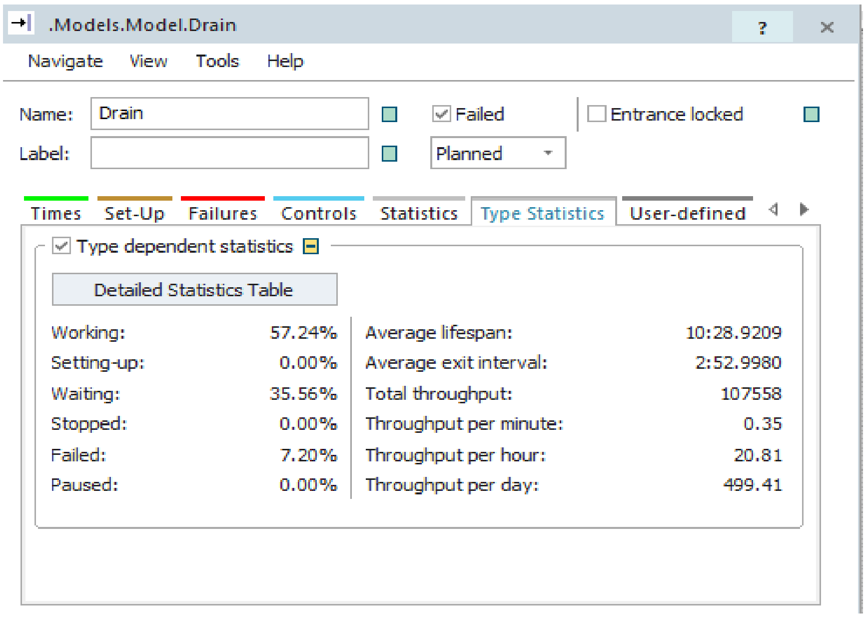



Figure 4.31: Simulation Result Proposed Layout 1

### 4.4.3 Proposed Layout 2

The second proposed layout includes workstation 1, workstation 2, workstation 3 and a conveyor. Workstation 4 is eliminated and replaced with a conveyor. This is because once worker 2 has completed process 2, the circular knitting needle will be directed to workstation 4. Worker 3 is required to stand if unable to reach products. Therefore, the conveyor will bring the circular knitting needle direct to worker 3. As a result, worker 3 will receive the products without having to stand. Proposed layout 2 is presented in Figure 4.32.

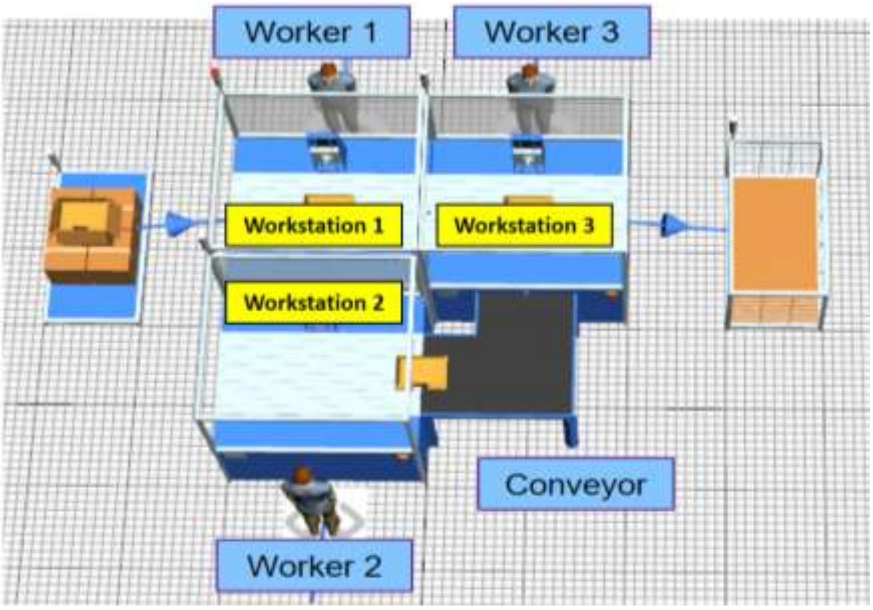



Figure 4.32: Proposed Layout 2

The simulation result of proposed layout 2 is shown in Figure 4.33. According to the result, the total throughput per minute is 0.42, the total throughput per hour is 25.42, and the total throughput per day is 610.18. The result obtained is higher than the initial layout. The total working percentage is 56.98%. The total overall failure percentage is 6.48% which is lower than the initial layout.



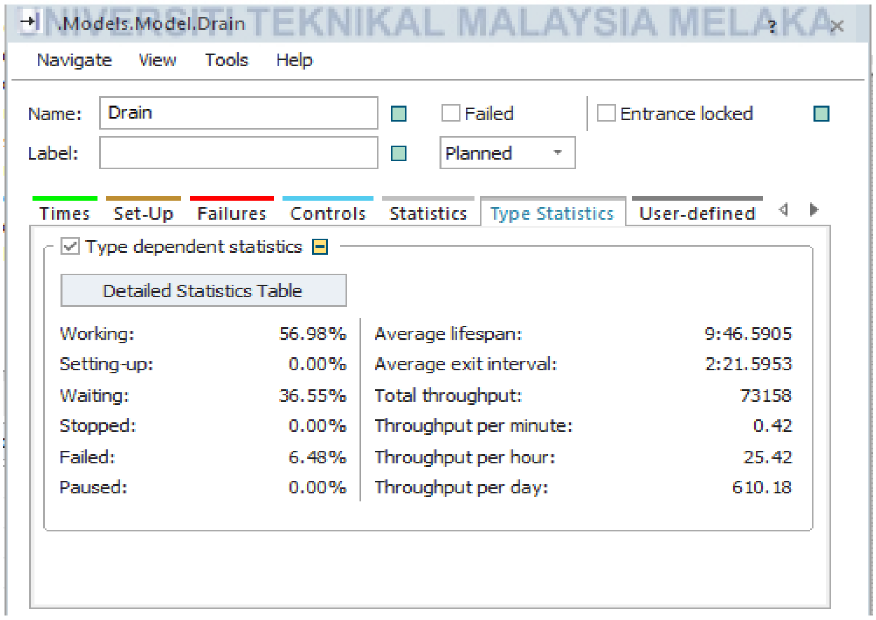



Figure 4.33: Simulation Result Proposed Layout 2

### 4.4.4 Proposed Layout 3

The proposed layout 3 consists of three workstations which are workstation 1, workstation 2, and workstation 3. The production line only has three workstations due to saving space. Moreover, the packaging process of the circular knitting needles consists of three processes. Easy to balance the production line as the workstations are arranged to each other. Additionally, the arrangement of the workstations in the layout is designed to minimize material handling waste. Proposed layout 3 is illustrated in Figure 4.34.

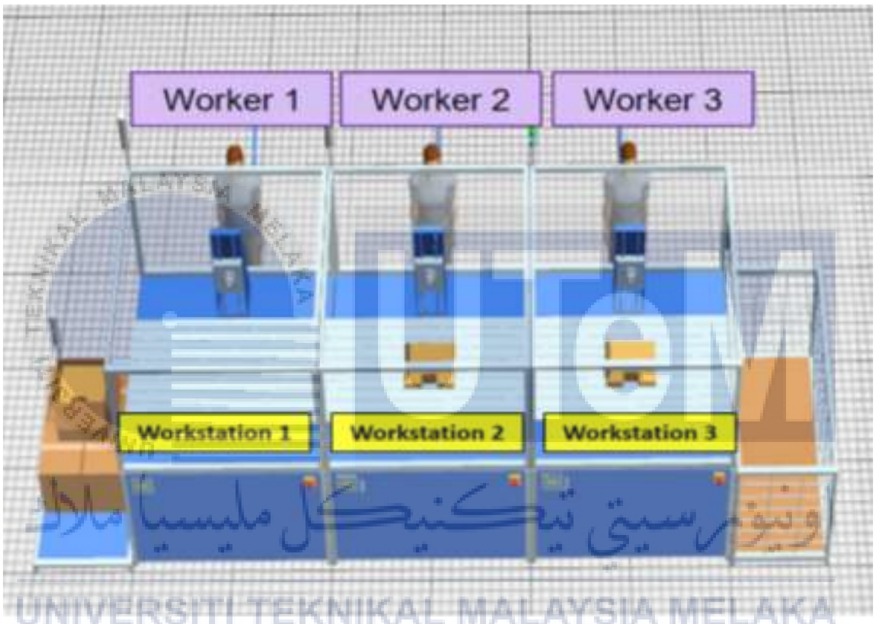



Figure 4.34: Proposed Layout 3

Based on the result presented in the Figure 4.35, the total throughput per minute is 1.81, the total throughput per hour is 108.42, and the total throughput per day is 2602.01. The indicated result is considered to be high, and it is also higher than the initial layout. The total working percentage is 31.20%. The total percentage overall failure rate of the initial layout is 7.76%, which is considered high, and it is higher than the initial layout.

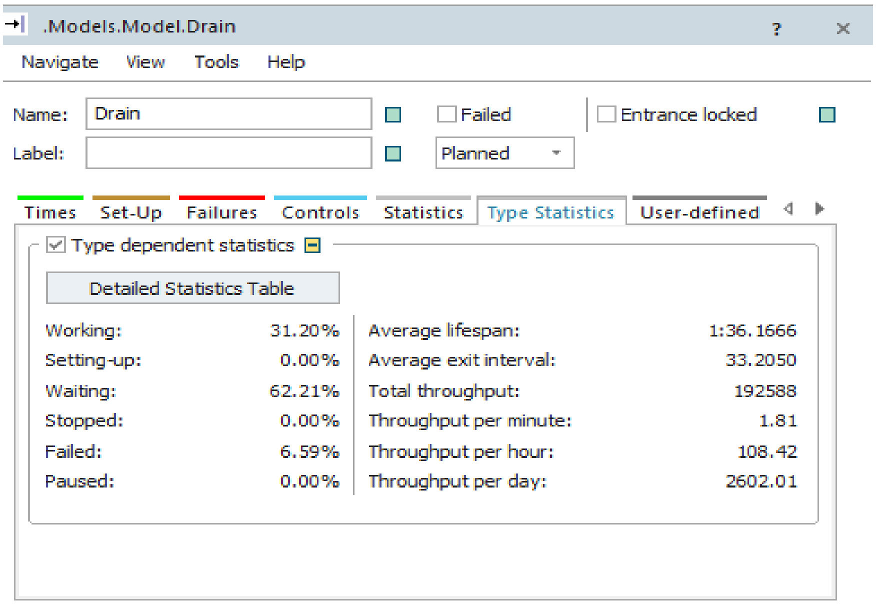



Figure 4.35: Simulation Result Proposed Layout 3

### 4.4.5 Proposed Layout 4

Proposed layout 4 consists of three workstations. The workstations are workstation 1, workstation 2, and workstation 3. The arrangement of the workstations is followed the U-shaped layout. A U-shaped layout allows for greater flexibility in balancing the production line (Sakran et al., 2017). The workers can easily move from one workstation to another, as indicated by the red arrows. The placement of the workers is systematic as they can cover each other work when necessary. Figure 4.36 is showed the proposed layout 4.

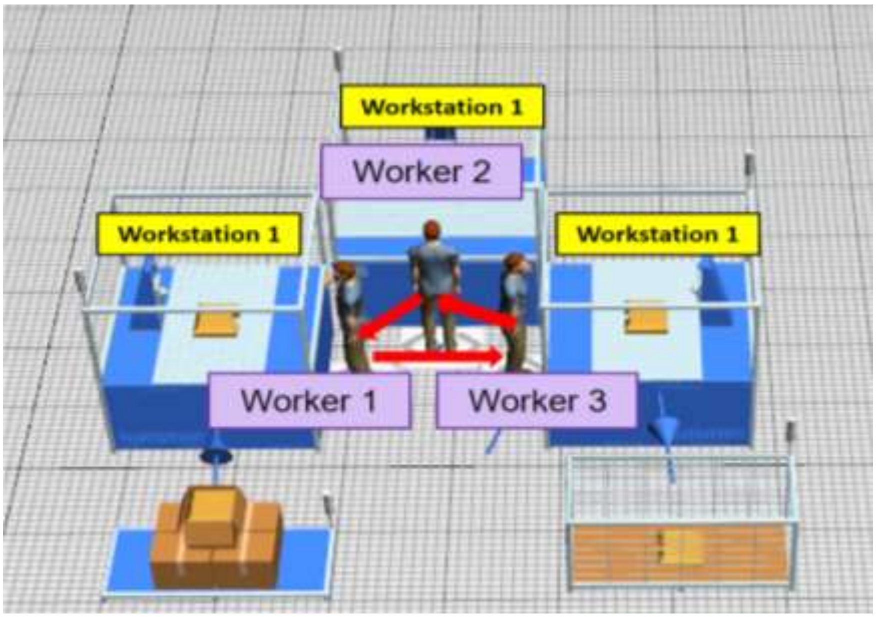



Figure 4.36: Proposed Layout 4

Figure 4.37 is shown the simulation result of the proposed layout 4. Proposed layout 4 has total throughput per minute of 4.38, an hourly throughput of 262.86, and a daily throughput of 6308.62. The total throughput for proposed layout 4 is the highest among all layouts. The working percentage is 58.88%. The overall failure percentage is 7.40% that is considered low.



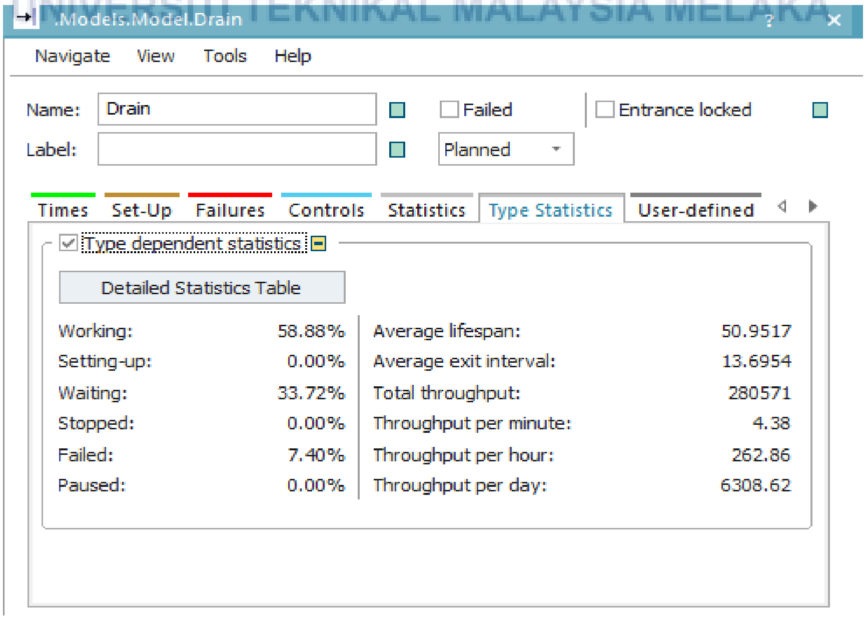



Figure 4.37: Simulation Result Proposed Layout 4

### 4.4.6 Layout Comparison

Table 4.5 is presented the comparison between the initial layout and all the proposed layouts. The initial layout, proposed layout 1, and proposed layout 2 are inflexible due to the difficulty of balancing the line. If the workers are required to cover other processes, they cannot easily move from one workstation to another. The movement of the good from one workstation to another will affect the performance of the production. Although proposed layout 2 has a conveyor but the conveyor contains waste such as waiting. The proposed layouts 3 and 4 are flexible due to the ability of the workers to move within workstations easily. Therefore, it is easy for the workers to cover other processes when necessary. In addition, these are also the reasons that the initial layout, proposed layout 1, and proposed layout 2 are difficult to be balanced.

According to the configuration of the initial layout and proposed layout 1, the structure of the layouts is not systematic because of the empty workstations. The empty workstations are wasting space. The structure of proposed layout 2 is systematic due to the conveyor. The conveyor system enables the empty workstation to be utilized. The structural for proposed layouts 3 and 4 are systematic because the layouts only have three workstations in order to save space. Additionally, the arrangement of the proposed layout 4 is followed the U-shaped layout. This layout enables workstations to be balanced by balancing operations to the right and left of the workstation. A U-shaped layout enables balancing with the workstations on the right and left. Furthermore, the product is moved counter-clockwise one piece at a time, and this technique can significantly reduce cycle time (Sakran et al., 2017).

The total throughput per day for the initial layout is 536.75, proposed layout 1 is 499.41, proposed layout 2 is 610.68, proposed layout 3 is 2602.01, and proposed layout 4 is 6308.61. Based on the result, proposed layouts 3 and 4 have a high total throughput per day. Based on table 4.5, it is reasonable to conclude that the proposed layouts 3 and 4 are the most optimal by comparing all the layouts.

Table 4.5: Comparison Between Layouts

| Attribute | Initial Layout | Proposed Layout 1 | Proposed Layout 2 | Proposed Layout 3 | Proposed Layout 4 |
|---|---|---|---|---|---|
| Flexibility | Inflexible | Inflexible | Inflexible | Flexible | Flexible |
| Structural | Not systematic | Not systematic | Systematic | Systematic | Systematic |
| Balanceable | Difficult | Difficult | Moderate | Easy | Easy |
| Total throughput per day | 536.75 | 499.41 | 610.68 | 2602.01 | 6308.61 |

## 4.5 Summary

This chapter highlights the simulation results obtained from Tecnomatix Plant Simulation and the improvement that implemented in the production line. According to the simulation results, the most optimal layouts that have been proposed are proposed layouts 3 and 4. This is because both of the layouts are flexible and easy to balance the line. The structure of the two layouts is systematic. Furthermore, these two layouts have the highest daily throughput.

# CHAPTER 5

## CONCLUSION AND RECOMMENDATION

This chapter summarized the overview of this study and the relation to the objectives. Additionally, this chapter includes a conclusion and suggestions for further study.



### 5.1 Conclusion

This study set out to determine the optimum layout for the production line by utilizing product lifecycle management. The first objective of the study is to investigate the problem due to the production line layout of the circular knitting needles packaging problem. By analyzing the packaging process of circular knitting needles, the problem is investigated in the Teaching Factory of Universiti Teknikal Malaysia Melaka and Prym Consumer Malaysia Sdn Bhd. After analyzing the packaging process, a time study is conducted for three different sizes of circular knitting needles, which are 60 cm, 80 cm, and 100 cm, in order to compare the cycle time result. Waste generated on the production line of the packaging process is analyzed and identified. For instance, over-processing and unnecessary motion. Several technical improvements have been made in order to improve the production line, including correcting the method to execute the process and the implementating lean tools.

The second objective is to identify the most optimum layout of the packaging process. The main problem of the study was that the output of the circular knitting needles did not achieve the target. In order to overcome the problem, the layout of the circular knitting needles production line is needed to be improved. Therefore, to determine the optimal layout, the initial layout is analyzed in terms of layout structure and worker placement. Additionally, the dimension of the workstation is also considered. The workstation is improved by implementing the ergonomics standards of workstation dimension, which is 700 mm x 900 mm. Four alternative layouts are proposed in order to determine the most optimal layout.

The third objective of the study is to simulate the proposed layout using product lifecycle management. Various software applications fall under product lifecycle management. For this study, Tecnomatix Plant Simulation is used to create and simulate the proposed layouts. This software is indicated which layout is optimal based on the generated results without requiring to be implemented in reality. Therefore, the cost can be reduced. The initial layout has daily throughput of 536.75, proposed layout 1 has daily throughput of 499.41, proposed layout 2 has daily throughput of 610.18, proposed layout 3 has daily throughput of 2602.01, and proposed layout 4 has daily throughput of 6308.62. According to the results, proposed layouts 3 and 4 have a high daily throughput. Therefore, proposed layouts three and four are the most optimal.

## 5.2 Recommendation

For further study, there are a few recommendations that might be made. The most optimal layouts that have been proposed could be implemented in the production line in the future. The production line of the circular knitting needle packaging process might be improved using the proposed layout. Next, a more complex production line layout such as a line that includes machines could be studied using the Tecnomatix Product Lifecycle Management.

## 5.3 Sustainable Design and Development

Having a sustainable layout design can eliminate waste in the production line and increase the productivity of the company. The company will be more sustained, and job security will be assured. The most optimum production line layout can reduce waste, time as well as manufacturing costs. Additionally, an optimal layout can enhance the production rate. Furthermore, the ergonomics workstation can make the workers more comfortable and focused. Therefore, it can increase the productivity and the quality of the product.

## 5.4 Complexity

The complexity of this study is when conducting the time study of the circular knitting needle packaging processes. The processes must be thoroughly analyzed one by one. The waste that may be generated at the production line of the packaging process of circular knitting needles must also be thoroughly analyzed in order to improve the production line. Next, the complexity of this study is when using the Tecnomatix Product Lifecycle Management to do simulation. Sometimes the simulation cannot be run because of the error when creating the layout. The error must be corrected in order to successfully simulating the layout.

Besides, conducting this study during a pandemic is difficult. This study is required to visit Prym Consumer Malaysia Sdn Bhd and Teaching Factory UTeM but sometimes is unable to visit due to movement control orders.



## 5.5 Life Long Learning

The life long learning of this study is self-learning enhances the knowledge of Tecnomatix Plant Simulation. The knowledge of steps involved in creating the layout by inserting the workstations, worker, and source is gained. Additionally, the steps to run the simulation is studied. Besides, the optimal layout for the production line can be used in any industry as it has the potential to reduce costs and increase productivity. Moreover, this study can help to deal with industries in the future when resolving issues.

# REFERENCES

(Okpala et al., 2016). (2016). Plant Layouts' Analysis and Design. International Journal of Advanced Engineering Technology E- Int J Adv Engg Tech, July 2016, 201–206.

Adeppa, A. (2015). A Study on Basics of Assembly Line Balancing. International Journal on Emerging Technologies (Special Issue on NCRIET, 6(2), 294–297.

Adnan, A. N., Arbaai, N. A., & Ismail, A. (2016). Improvement of overall efficiency of production line by using line balancing. ARPN Journal of Engineering and Applied Sciences, 11(12), 7752–7758.

Agrahari, R. S., Dangle, P. A., & Chandratre, K. V. (2015). Implementation of 5S Methodology in the Small Scale Industry : a Case Study. 3(1), 130–137.

Ahuja, J. S. R. I. S. (2017). 5S - A QUALITY IMPROVEMENT TOOL FOR SUSTAINABLE PERFORMANCE: LITERATURE REVIEW AND DIRECTIONS. International Journal of Quality & Reliability Management, 34(3).

Al-Baik, O., & Miller, J. (2015). The kanban approach, between agility and leanness: a systematic review. Empirical Software Engineering, 20(6), 1861–1897. https://doi.org/10.1007/s10664-014-9340-x

Ali Naqvi, S. A., Fahad, M., Atir, M., Zubair, M., & Shehzad, M. M. (2016). Productivity improvement of a manufacturing facility using systematic layout planning. Cogent Engineering, 3(1). https://doi.org/10.1080/23311916.2016.1207296

Antonelli, D., & Stadnicka, D. (2018). Combining factory simulation with value stream mapping: A critical discussion. Procedia CIRP, 67, 30–35. https://doi.org/10.1016/j.procir.2017.12.171

Anurag, P. (2016). Optimization of Plant Layout Using Simulation Software. 6th International & 27th All India Manufacturing Technology, 1–6.

Ariyanti, S., Rifa'i Azhar, M., & Sobron Yamin Lubis, M. (2020). Assembly line balancing with the yamazumi method. IOP Conference Series: Materials Science and Engineering, 1007(1). https://doi.org/10.1088/1757-899X/1007/1/012078

Arya, A. K., & Choudhary, S. (2015). Assessing the application of Kaizen principles in Indian small-scale industry. International Journal of Lean Six Sigma, 6(4), 369–396. https://doi.org/10.1108/IJLSS-11-2014-0033

Azevedo, M. M., Crispim, J. A., & Pinho de Sousa, J. (2017). A dynamic multi-objective approach for the reconfigurable multi-facility layout problem. Journal of Manufacturing Systems, 42, 140–152. https://doi.org/10.1016/j.jmsy.2016.12.008

Barnwal, S., & Dharmadhikari, P. (2016). Optimization of Plant Layout Using SLP Method. International Journal of Innovative Research in Science, Engineering and Technology, 5(3), 3008–3015. https://doi.org/10.15680/IJIRSET.2016.0503046

Bennett, D. (2015a). Cell Layout. Wiley Encyclopedia of Management, January 2015, 1–2. https://doi.org/10.1002/9781118785317.weom100050

Bennett, D. (2015b). Process Layout. Wiley Encyclopedia of Management, January 2015, 1–2. https://doi.org/10.1002/9781118785317.weom100059

Bennett, D. (2015c). Product Layout. Wiley Encyclopedia of Management, January 2015, 1–2. https://doi.org/10.1002/9781118785317.weom100061

Chahal, V., & Narwal, M. (2017). Impact of lean strategies on different industrial lean wastes. International Journal of Theoretical and Applied Mechanics, 12(2), 275–286. http://www.ripublication.com

Company, T. D. & control. (2012). Ergonomics Guidebook for Manual Production Systems The eight rules of ergonomics for work systems. Rexroth Bosch Group, 3, 1–16. www.boschrexroth.com/addresses%0A3

Cury, P. H. A., & Saraiva, J. (2018). Time and motion study applied to a production line of organic lenses in manaus industrial hub. Gestao e Producao, 25(4), 901–915. https://doi.org/10.1590/0104-530X2881-18

Deshpande, V., D.Patil, N., Baviskar, V., & Gandhi, J. (2016). Productivity Journal by National Productivity Council , ISSN : 0032-9924. Productivity Journal by National Productivity Council, 57(1), 32–42.

Dixit, A. (2015). Lean Manufacturing: An Approach for Waste Elimination. International Journal of Engineering Research & Technology (IJERT), 4(04), 532–536.

Duran, C., Cetindere, A., & Aksu, Y. E. (2015). Productivity Improvement by Work and Time Study Technique for Earth Energy-glass Manufacturing Company. Procedia Economics and Finance, 26(December), 109–113. https://doi.org/10.1016/s2212-5671(15)00887-4

Gao, X., Yang, H., Lin, L., & Koo, P. (2015). Wind turbine layout optimization using multi-population genetic algorithm and a case study in Hong Kong offshore. Journal of Wind Engineering and Industrial Aerodynamics, 139, 89–99. https://doi.org/10.1016/j.jweia.2015.01.018

García-Alcaraz, J. L., & Maldonado-Macías, A. A. (2016). Just-in-Time Elements and Benefits. https://doi.org/10.1007/978-3-319-25919-2

García-Alcaraz, J. L., Oropesa-Vento, M., & Maldonado-Macías, A. A. (2017). Kaizen Planning, Implementing and Controlling (Management and Industrial Engineering). https://0-link-springer-com.pugwash.lib.warwick.ac.uk/book/10.1007/978-3-319-47747-3

Goyal, G., & Verma, D. S. (2019). Optimization of plant layout in manufacturing industry. International Journal of Recent Technology and Engineering, 8(2), 3115–3118. https://doi.org/10.35940/ijrte.B2679.078219

Guoliang Fan, Aiping Li, Nan Xie, Liyun Xu, & Xuemei Liu. (2017). Production Line Layout Planning Based On Complexity Measurement. World Academy of Science, Engineering and Technology International Journal of Industrial and Manufacturing Engineering, 11(10), 1614–1617. https://commons.datacite.org/doi.org/10.5281/zenodo.1132229

Helmold, M. (2020). Lean Management and Kaizen. In Management for Professionals. https://link.springer.com/content/pdf/10.1007/978-3-030-46981-8.pdf

Jain, S. G. S. K. (2015). An application of 5S concept to organize the workplace at a scientific instruments manufacturing company. International Journal of Lean Six Sigma, 6(1), 73–88.

John, S. (2016). Product Lifecycle Management (Volume 2).

Jung, S. (2016). Facility siting and plant layout optimization for chemical process safety. Korean Journal of Chemical Engineering, 33(1), 1–7. https://doi.org/10.1007/s11814-015-0242-4

Kadane, S. M., & Bhatwadekar, S. G. (2011). Manufacturing Facility Layout Design and Optimization Using Simulation. International Journal of Advanced Manufacturing Systems, 2(1), 59–65.

Kovács, G., & Kot, S. (2017). Facility layout redesign for efficiency improvement and cost reduction. Journal of Applied Mathematics and Computational Mechanics, 16(1), 63–74. https://doi.org/10.17512/jamcm.2017.1.06

Lacerda, A. P., Xambre, A. R., & Alvelos, H. M. (2016). Applying Value Stream Mapping to eliminate waste: A case study of an original equipment manufacturer for the automotive industry. International Journal of Production Research, 54(6), 1708–1720. https://doi.org/10.1080/00207543.2015.1055349

Lam, N. T., Toi, L. M., Tuyen, V. T. T., & Hien, D. N. (2016). Lean Line Balancing for an Electronics Assembly Line. Procedia CIRP, 40(1), 437–442. https://doi.org/10.1016/j.procir.2016.01.089

Lutz, L. (2015). Product Lifecycle Management.

Lyu, Z., Lin, P., Guo, D., & Huang, G. Q. (2020). Towards Zero-Warehousing Smart Manufacturing from Zero-Inventory Just-In-Time production. Robotics and Computer-Integrated Manufacturing, 64(January), 101932.

https://doi.org/10.1016/j.rcim.2020.101932

Madhusudan Singh, M. (2019). What are the SOPs (Standard Operating Procedures) and its benefits ? November, 1–4. https://www.researchgate.net/publication/337074540

Maina, E., C, M. E., N, M. P., N, K. J., & Author, C. (2018). Improvement of Facility Layout Using Systematic Layout Planning. International Organization of Scientific Research, 08(5), 33–43. www.iosrjen.org

Marin-Garcia, J. A., Juarez-Tarraga, A., & Santandreu-Mascarell, C. (2018). Kaizen philosophy: The keys of the permanent suggestion systems analyzed from the workers' perspective. TQM Journal, 30(4), 296–320. https://doi.org/10.1108/TQM-12-2017-0176

Masuti, P. M., & Dabade, U. A. (2019). Lean manufacturing implementation using value stream mapping at excavator manufacturing company. Materials Today: Proceedings, 19, 606–610. https://doi.org/10.1016/j.matpr.2019.07.740



Mojib, S. (2016). "A survey on lean manufacturing implementation in a selected manufacturing industry in Iran." International Journal of Lean Six Sigma, 7(2), 136–148.

Mostafa, S., & Dumrak, J. (2015). Waste Elimination for Manufacturing Sustainability. Procedia Manufacturing, 2(February), 11–16. https://doi.org/10.1016/j.promfg.2015.07.003

Naik, S. B., & Kallurkar, S. (2016). a Literature Review on Efficient Plant Layout Design. International Journal of Industrial Engineering Research and Development, 7(2), 43–

51. https://doi.org/10.34218/ijierd.7.2.2016.005

Nallusamy, S., & Muthamizhmaran, S. (2015). Enhancement of Productivity and Overall Equipment Efficiency Using Time and Motion Study Technique - A Review. Advanced Engineering Forum, 14, 59–66. https://doi.org/10.4028/www.scientific.net/aef.14.59

Osada, T. (1991). The 5S's: Five Keys to a Total Quality Environment. Asian Productivity Organisation.

Papalexi, M., Bamford, D., & Dehe, B. (2016). A case study of kanban implementation within the pharmaceutical supply chain. International Journal of Logistics Research and Applications, 19(4), 239–255. https://doi.org/10.1080/13675567.2015.1075478

Patel, J., Savsani, V., Patel, V., & Patel, R. (2017). Layout optimization of a wind farm to maximize the power output using enhanced teaching learning based optimization technique. Journal of Cleaner Production, 158, 81–94. https://doi.org/10.1016/j.jclepro.2017.04.132



Prym, C. (2018). Prym Consumer Malaysia.

Radhwan, H., Shayfull, Z., Farizuan, M. R., Effendi, M. S. M., & Irfan, A. R. (2019). Redesign of bahulu production layout to improve the efficiency of process flow. AIP Conference Proceedings, 2019(July). https://doi.org/10.1063/1.5118161

Rewers, P., Trojanowska, J., & Chabowski, P. (2016). Tools and methods of Lean Manufacturing - a literature review. 7th International Technical Conference TECHNOLOGICAL FORUM 2016, 135–139. https://www.researchgate.net/publication/308171328

Rohani, J. M., & Zahraee, S. M. (2015). Production Line Analysis via Value Stream Mapping: A Lean Manufacturing Process of Color Industry. Procedia Manufacturing, 2(February), 6–10. https://doi.org/10.1016/j.promfg.2015.07.002

Sakran, H. K., Mahbuba, H. M., & Jafer, A. S. (2017). a Review of a Basic Concept of Cellular Manufacturing. International Journal of Design and Manufacturing Technology, 8(1). https://doi.org/10.34218/ijdmt.8.1.2017.004

Shaker Abualsaud, A., Ahmed Alhosani, A., Youssef Mohamad, A., Nasser Al Eid, F., & Alsyouf, I. (2019). Using six sigma DMAIC methodology to develop a facility layout for a new production line. 2019 8th International Conference on Modeling Simulation and Applied Optimization, ICMSAO 2019, 1–5. https://doi.org/10.1109/ICMSAO.2019.8880335

Sharma, P., & Singhal, S. (2017). Implementation of fuzzy TOPSIS methodology in selection of procedural approach for facility layout planning. International Journal of Advanced Manufacturing Technology, 88(5–8), 1485–1493. https://doi.org/10.1007/s00170-016-8878-8



Siregar, I., Saedon, J. B., Adenan, M. S., Shawal, S., & Othman, M. F. (2019). Modelling and Analysis of Manufacturing Process Layout. IOP Conference Series: Materials Science and Engineering, 598(1). https://doi.org/10.1088/1757-899X/598/1/012051

Sutrisno, A., Vanany, I., Gunawan, I., & Asjad, M. (2018). Lean waste classification model to support the sustainable operational practice. IOP Conference Series: Materials Science and Engineering, 337(1). https://doi.org/10.1088/1757-899X/337/1/012067

Tanutomo, N. M., & Octavia, T. (2016). Desigining an Integrated Product and Process Layout Using a Simulation: The Case of Plastic Bag Company. International Journal of

Industrial Research and Applied Engineering, 1(1), 15–24. https://doi.org/10.9744/jirae.1.1.15-24

Tarigan, U., Ishak, A., Tarigan, U. P. P., Rizkya, I., Mangoloi, B., & William. (2021). Redesigning production floor layout with process layout and product layout approach in an electronic appliance manufacturing company. IOP Conference Series: Materials Science and Engineering, 1122(1), 012058. https://doi.org/10.1088/1757-899x/1122/1/012058

Varinder Khurana, R. M. (2015). Facility Layout Planning: A Review. International Journal of Innovative Research in Science, Engineering and Technology, 04(03), 976–980. https://doi.org/10.15680/ijirset.2015.0403027

Veres, C., Marian, L., Moica, S., & Al-Akel, K. (2018). Case study concerning 5S method impact in an automotive company. Procedia Manufacturing, 22, 900–905. https://doi.org/10.1016/j.promfg.2018.03.127

Vieira, K. B., Silva, C. A. de S., & Quaresma, J. N. N. (2019). Layout Optimization using Computer Simulation Tool for Decision Making. International Journal of Advanced Engineering Research and Science, 6(3), 296–305. https://doi.org/10.22161/ijaers.6.3.39

Wakode, R. B., Raut, L. P., & Talmale, P. (2015). IJSRD - International Journal for Scientific Research & Development| Vol. 3, Issue 02, 2015 | ISSN (online): 2321-0613. IJSRD - International Journal for Scientific Research & Development|, 3(02online), 2321–2613. www.ijsrd.com

William, S. J. (2020). Operations Management. Mc Graw Hill.

Woo, E. H. C., White, P., & Lai, C. W. K. (2016). Ergonomics standards and guidelines for computer workstation design and the impact on users' health – a review. Ergonomics, 59(3), 464–475. https://doi.org/10.1080/00140139.2015.1076528

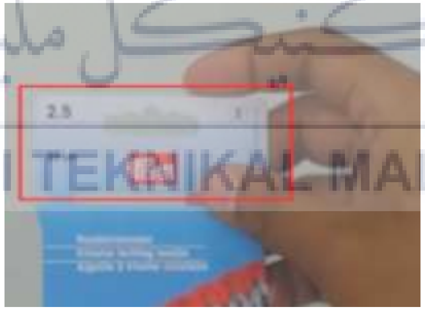
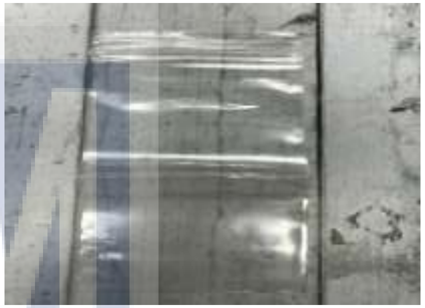
Xu, Y., & Chen, M. (2016). Improving Just-in-Time Manufacturing Operations by Using Internet of Things Based Solutions. Procedia CIRP, 56, 326–331. https://doi.org/10.1016/j.procir.2016.10.030

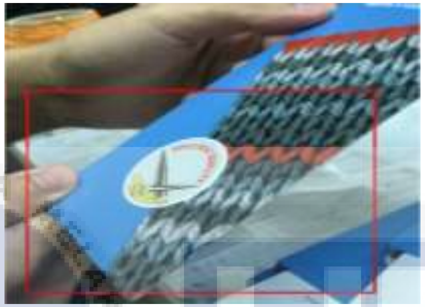
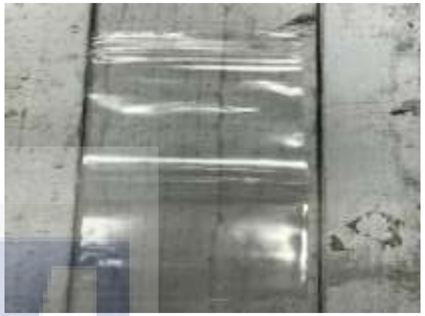
Yeen Gavin Lai, N., Hoong Wong, K., Halim, D., Lu, J., & Siang Kang, H. (2019). Industry 4.0 Enhanced Lean Manufacturing. Proceedings of 2019 8th International Conference on Industrial Technology and Management, ICITM 2019, 206–211. https://doi.org/10.1109/ICITM.2019.8710669

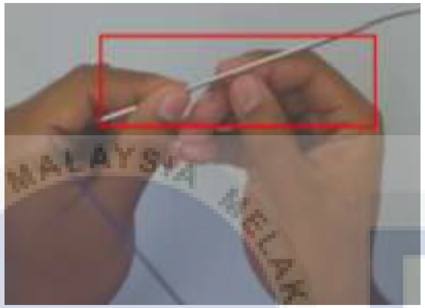
Zúñiga, E. R., Moris, M. U., Syberfeldt, A., Fathi, M., & Rubio-Romero, J. C. (2020). A simulation-based optimization methodology for facility layout design in manufacturing. IEEE Access, 8, 163818–163828. https://doi.org/10.1109/ACCESS.2020.3021753

# APPENDICES

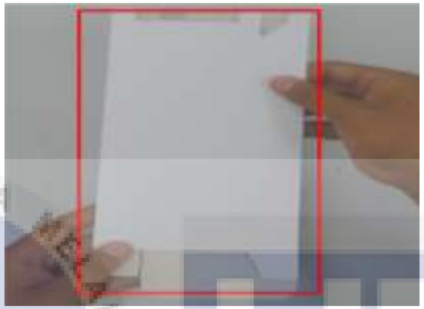
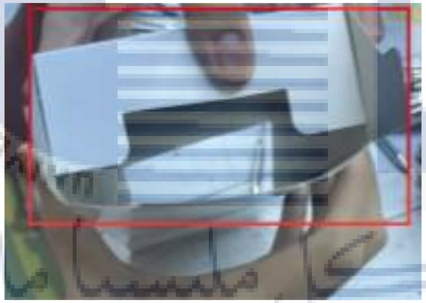
**Appendix A: Standard Operating Procedure of Circular Knitting Needle Packaging Process**

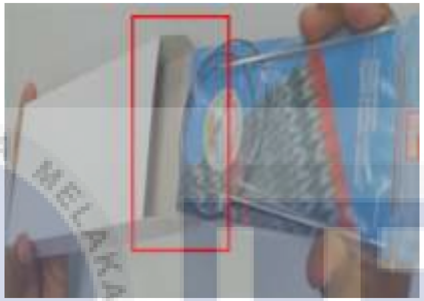
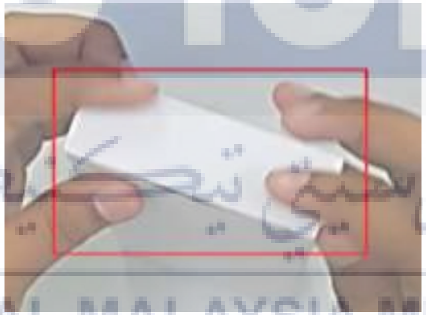
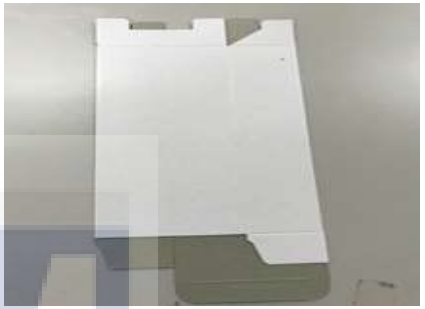
| No. | Name of Process | Description | Required Materials |
|---|---|---|---|
| 1. | Process 1 | i. Ensure there is no scratch on the polybag.<br><br>ii. Check the dimension labelled on the card matches up to the item.<br> | i. Polybag<br><br>ii. Card<br> |

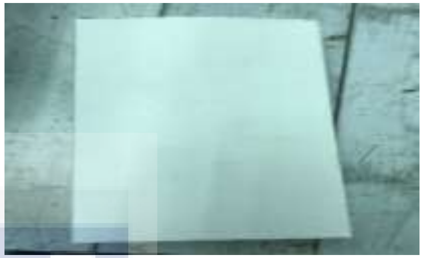
| No. | Name of Process | Description | Required Materials |
|---|---|---|---|
| 1. | Process 1 | iii. Fold the above part of the card.<br><br>iv. Insert the folded card into polybag.<br>  | i. Polybag<br><br>ii. Card<br> |

| No. | Name of Process | Description | Required Materials |
|---|---|---|---|
| 2. | Process 2 | i. Ensure the dimension of the circular knitting needle is correct.<br> <br>ii. Roll the circular knitting needle one round for size 40cm, and 60 cm.<br>iii. Roll the circular knitting needle two rounds for size 80cm, 100cm, and 120cm.<br>  | i. Circular knitting needle<br><br>ii. Polybag and card<br> |

| No. | Name of Process | Description | Required Materials |
|---|---|---|---|
| 2. | Process 2 | iv. Insert the circular knitting needle into polybag. Ensure the needle on top of the wires.<br><br>v. Seal the polybag securely.<br>  | i. Circular knitting needle<br><br>ii. Polybag and card<br> |

| No. | Name of Process | Description | Required Materials |
|---|---|---|---|
| 3. | Process 3 | i. Ensure outer box in clean and good condition.<br><br>ii. Fold the bottom part of the outer box properly.<br>  | i. Outer box<br> |

| No. | Name of Process | Description | Required Materials |
|---|---|---|---|
| 3. | Process 3 | iii. Insert the item into the outer box, with the front surface of the card aligned with the outer box surface.<br><br>iv. An outer box must consist of five circular knitting needles and close the lid of the outer properly.<br>  | i. Outer box<br><br>ii. Polybag with card and circular knitting needle<br> |

| No. | Name of Process | Description | Required Materials |
|---|---|---|---|
| 3. | Process 3 | v. Stick the outer sticker to the top of the outer box. The line of the outer sticker must align with the outer box top side.<br> <br>vi. Arrange complete outer box inside carton.<br> | i. Complete outer box<br><br>ii. Sticker<br><br>iii. Carton<br> |