FINAL PROJECT – TI 184833

IMPROVING WAREHOUSE PERFORMANCE THROUGH LEAN CONCEPT: A DISCRETE EVENT SIMULATION APPROACH

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APPROVAL SHEET

IMPROVING WAREHOUSE PERFORMANCE TRHOUGH LEAN CONCEPT: A DISCRETE EVENT SIMULATION APPROACH

FINAL PROJECT

Submitted as a requisite to achieve a bachelor's degree from
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SURABAYA, AUGUST 2020

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IMPROVING WAREHOUSE PERFORMANCE THROUGH LEAN CONCEPT: A DISCRETE EVENT SIMULATION APPROACH

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ABSTRACT

PT.X has exported various types of X cars from Indonesia to several countries. Consequently, PT X is handling 10500 type of car spare parts for service and repair purpose. To handle this massive scale of operation, 7K warehouse project was born. The idea to store and manage spare part inventories centrally to ensure stock readiness and minimizing backorder. However, the establishment of this project started in the late August 2019 and fully operational just only 6 months after in February 2020 . The short duration of preparation has resulted in pre-mature operations, thus there are many problems which leads to non added value activities (waste) and it is affecting the warehouse performance. Therefore, lean concept is used to reduce and eliminate waste to improve warehouse performance. Wastes that occurs mainly in inventory and waiting wastes. Using root cause analysis to find the source of each waste and using the found source as the basis for formulating improvement. Discrete event simulation is utilized to reduce both time and cost needed to trial the improvement, however, the simulation purpose was not for optimally find the best improvement scenario. The scenarios result shown positive impact in both waste elimination and warehouse performance indicator, proving by applying lean concept in warehousing could increase warehouse performance and reduced or eliminate wastes.

Keywords : Lean Warehousing, Discrete Event Simulation Modelling

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ACKNOWLEDGEMENT

The author apologizes if there are flaws in this project report and expects criticism and constructive suggestions from readers for the improvement of this report in the future. Hopefully, this report provides useful information for the readers and for knowledge development for us all.

Surabaya,   July 2020

Author

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CHAPTER 1
INTRODUCTION

This chapter consists of research background, problem formulation, objectives, benefits, scope, and research systematics of the research.

1.1   Problem Background

Establishing it roots since 1971, PT. Z has been the sole distributer and manufacturer of X cars for Indonesia market. Up until 2003 it was restructured and split into two companies with each specific task but the same goal to still dominate the automotive market in Indonesia. PT. Z focuses solely on marketing and distributing X cars in local Indonesia market and export, and the new PT. X focuses on manufacturing parts and cars. On late 2018 the export operation for X cars from PT. Z is shifted to PT. X. PT. X itself is divided into 5 plants, 2 of them are in Sunter, North Jakarta, which focuses on manufacture parts and component for assembly. The rest of them are in Karawang, West Java, which focuses on assembling finish cars.

The increasing demand and market share impacted on PT. X decision to manufacture and distribute service parts to cover and maintain service level to its customer. To handle this operation, it is given to Sunter 1 Plant specializing in engine and service part production for new and past model, while also as center warehouse for X and Lexus Genuine Parts. Overall distribution for X service part export is shown in the Figure 1.1.
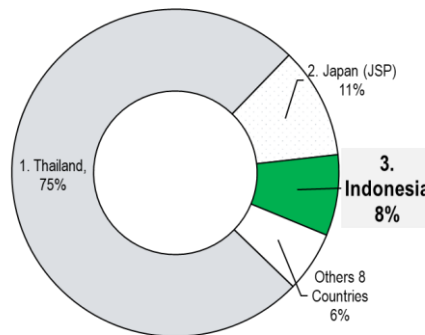
Figure 1.1 X Car Service Part Distribution Volume Worldwide
(source: PT. X)

In the process of order handling of the above customer, it is categorized into three different categorizations, regular, special, and royal order. Regular order comes from dealers on regular basis. Special order comes from events and other spontaneous activities. Royal order comes directly from Saudi Arabia, handling parts for important person or organization
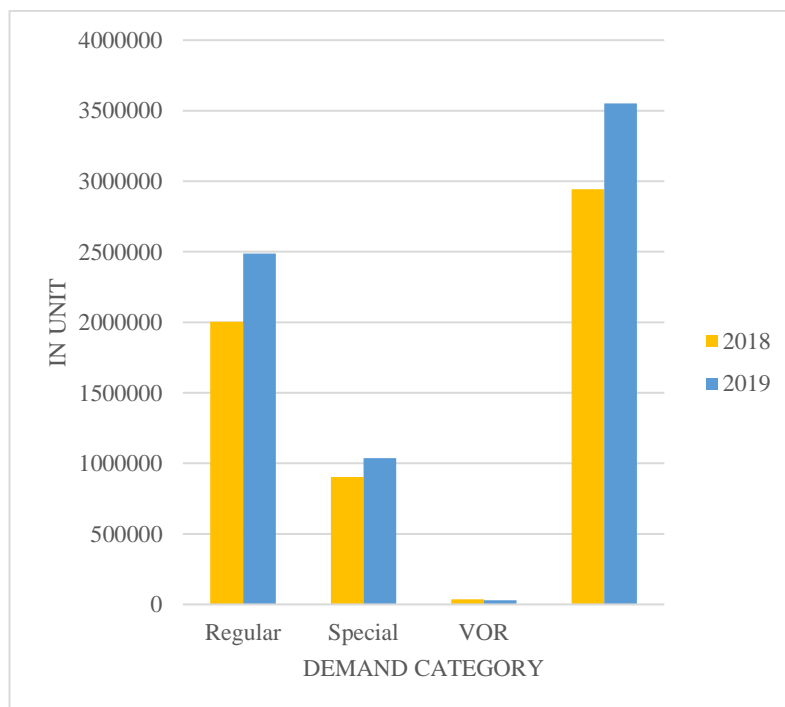
Figure 1.2 Service Part Demand 2018-2019 Categorization

The Figure 1.2 shows the percentage and the overall demand of exported service parts, a significant increase happens between those year. In handling this operation, there are several problems that happened inside the operations. One of the major problems is the demand fulfillment, a lot of backorder happened during the fulfillment process of the orders. To tackle the problem, 7K warehouse project is born.

7K warehouse itself is a former engine production plant discontinued around middle 2011 due to engine plant integration to Sunter 2 Plant, now used as a central warehouse for Sunter 1 Plant. The project aims to solve the backorder problem by increasing the warehouse storing capacity to maximum to accommodate more than 10500 service part and apply new safety stock level and warehouse operation system, centralizing previous 3 under capacity warehouse into 1 central warehouse. The establishment of the new warehouse is relatively new, starting from December 2019 and fully operational on 10th February 2020. The short duration of planning and execution resulted in problems inside the new 7K Warehouse, mainly affecting in the form of inefficiency add by the degree of complexity inside the operations since new regulations, operations, and system are not yet fully operational.

Operations inside 7K Warehouse comes in the flow of several activities starting from unloading, sorting, supply, binning, picking, packing, and vanning. The shipment of incoming parts comes in a daily to monthly basis, while outgoing parts (after vanning) goes out depending on the type of order. 7K was designed to handle 10500 spare parts, each comes with different specifications and handling, these parts demand are also comes in a lot of unpredictability, making it hard to maintain proper inventory level. Thus, creating complexity inside the operations, which highly affect sorting to packing process.

The product sorting and rack zoning inside 7K warehouse are divided into 3 type of product categorization, big, medium, and small parts. Each category is stored in their own specialized zone. The zoning is divided into 7 zone. Zone S is allocated for small part, Zone M and N are allocated for medium parts, and Zone W, X, Y, and Z are allocated for big parts. Also

supported by stagger zone that act as a support for reserving overload racks to store products. Each zone is planned in terms of size bin used for storing products, minimum and maximum parts stored per bin, and the type of product stored. Below is the example of bin mapping for Zone X.

X0236

X0236-2-A 681020K112		X0236-2-B 0		X0236-2-C 82122BZ100		X0236-2-D 681020K114	
3	1	Empty	Empty	3	1	3	1
X0236-1-A 56111BZ390		X0236-1-B 56111BZ311		X0236-1-C 766210K090		X0236-1-D 648010D170	
13	4	4	1	3	1	3	1

Figure 1.3 Bin Mapping for Zone X Rack X0236

Each rack in each zone is mapped accordingly to see the utilization of the racks and see through empty spaces that has not been used. The recap for each zone is shown below.

Table 1.1 Zone Mapping Recapitulation

	Zones							Total	Overall Utilization
	Zone S	Zone M	Zone N	Zone W	Zone X	Zone Y	Zone Z		
Allocated Bin	3325	2715	1155	1179	1126	870	98	10468	**73%**
Empty Address	346	824	442	391	277	526	69	2875	
Average Rack Utilization	80%	78%	74%	73%	81%	45%	30%		

The table above shows the overall mapping of zones inside the warehouse. The result of the mapping can be seen that the each of the zones are not optimally used and maximized, leaving only 73% of overall zone utilization.

Relating to the problem above, some of them is caused by parts mismatching between the database and actual condition, resulting in part readdressing. The readdressing process is recapped in a database, an example is provided in below

Table 1.2 Part Readdressing Database

Update 12 January 2019

Address 7K

	PART_NO	Remark	System	Update 17 Jan 2020	Update 16 Jan 2020
6019	63406BZ010	Step 2 -> already Registered	M0505-6-C	**M0203-7-A**	**M0107-1-B**
8240	68950BZ281	Step 1 -> Not yet register	#N/A		M0202-8-G
2991	85242BZ160	Step 1 -> System OK	M0206-7-C		M0205-5-C
1771	85212BZ290	Step 1 -> System OK	M0204-1-B		M0205-5-D

(source: PT. X)

The Table 1.2 above shows the problem of part readdressing, where parts are moved from racks to racks due to several causes such as mismatching information of part actual size with planned allocated rack size, actual amount of parts incoming with planned amount of parts incoming, and overload and insufficient rack to store parts. This readdressing is done manually and almost in daily basis, highly affecting supply, binning, and picking operations in a way of increased duration of operation which led to longer lead time and bottlenecks for packing operations.

Packing operation is located on near the end of the whole operation, packing requires products prepared by picking operation or directly supplied from sorting operation for special and priority cases. Packing often requires specific parts in size due to maximizing the volume space available inside the container used to pack the products for shipping. To answer that, packing often ask sorting operation directly for parts only to fulfill the remaining

spaces, which affect the flow of supply and picking for the regular process, halting delivery for other regular product flow.

Problems above generates tremendous amount of complexity inside the operations and inefficiency inside its operations. Inefficiency tends to produce wastes, unnecessary and inefficient processes, an activity that does not produce or add any value to the process or products. Waste or "Muda" the Japanese word for waste is a key point in Lean and is critical in understanding lean. Lean is a philosophy that specifically used to handle waste. Lean is a concept that aims to maximize product/processes through minimization of waste (Sundar, et al., 2014). As a concept, it can be versatilely adapted to many types of processes, in this case is warehousing and with familiar name known as lean warehousing.

Lean warehousing itself is an application of lean philosophy in warehousing activities, reducing waste inside the warehouse operation. Those two problems stated earlier cause major problem and inefficient work process which lead into generation of wastes inside those processes. Thus, to try and solve the problem, a lean warehouse approach is needed in improving the warehousing system to create a work process that flows well and provides convenience for those who are directly related to the warehouse. Warehouse performance can be improved using lean concepts by optimizing the flow of material, order picking, replenishment, and other operations in the warehouse. The main key is to reduce non-value-added activities in the process to improve velocity and flow (Garcia, 2004). Table 1.3 shows several studies on lean warehouse and its benefits.

Table 1.3 Lean Warehousing Implementation Result

Authors	Effect
Shah & Ward (2003)	Positive impact on scrap cost, cycle time, lead time, and worker productivity.
Dehdari (2013)	Increase warehouse productivity by 5%.

Authors	Effect
Cook et al. (2005)	71% decrease in cycle time, 76% decrease in inventory level, and 51% decrease in storing platform needed.

Normally after an improvement is proposed, it will take much time and resource to try implementing the proposed improvement to see how much of an impact does the improvement gives. This cause a lot of resources to be expended. Simulation is the solution to efficiently shows what could the improvement do by simulating on a model as close as the real system can be, without the time and resource needed as much.

Simulation itself comes in many disciplines, we can use system dynamics (SD), agent-based system modelling (ABSM), discrete event simulation (DES), etc. Each discipline has its own specific characteristics and best fit condition to use it. SD and ABSM are usually used to model macro environment where a slight change in the system could cause major impact, on the other hand, DES observed and model based on each singular process, fit for micro model and operations.

In the case of this research, using DES approach effectively proof the existing condition due to extreme complexity and variability inside the operations and simulate the proposed improvement without the need to implement it on each of the steps and warehouse operations. DES is useful for gaining an in-depth understanding of a system to improve its performance, as can be seen in Table 1.4. The DES software models distinct sequence of state changes that occur in time (Oleghe Omogbaia, 2016).

Table 1.4 Discrete Event Simulation Implementation Result

Authors	Effect
Salah Uddin (2015)	Determining optimum warehouse lead time, reorder point, and reorder quantity. Maintaining service level at 93.5%.

Authors	Effect
Baril (2015)	Reduced patient waiting time by 74% after improvement observation and 90% in improvement simulation.
Derhami (2019)	Warehouse space optimization and automatic algorithm, dynamically adjust storage utilization with the amount of product stored.

Frazelle (2001) derived warehouse activities into 5 categories each with its own key performance indicator (KPI) to measure its performance. The KPI's of each of the activities consist in an assessment of productivity, financial, utilization, quality, and time. Waste produced from inefficiency of activities could lead to minimum achievement and performance. Thus, this final year project is expected to improve warehouse performance through application of lean concept and DES approach.

1.2   Problem Formulation

Based on the research background above, the problem formulated to be solved in this research is how to improve warehouse performance through lean concept .

1.3   Objectives

The purpose of this research are as follows:
1. Formulate and develop an existing condition simulation model.
2. Identify possible waste occurring inside the warehouse operation and its impact towards warehouse performance.
3. Identify and analyze the root cause of identified wastes.
4. Design and compare improvements to improve warehouse performance by eliminating or reducing wastes.

1.4 Benefits

The expected benefit gained from this research are as follows:

1. By implementing the proposed alternative solution, PT. X could improve their warehouse performance.
2. Through the performance improvement will resulted in reduced operation cost.
3. Decreased cost will opt to increase in company overall profit.

1.5 Research Scope

This section consists of the limitations and assumptions used in this final project.

1.5.1 *Limitations*

Limitations of the problems used in this research are:

1. The data gathered is from 10th February 2020 – 1st March 2020.
2. Direct observation is limited due to inability to visit directly, substituted using historical data for calculation.
3. The observed processes are within the 7K warehouse team responsibility consisting of unloading, sorting, supply, binning, picking, packing, and vanning.
4. The amount of manpower inside the warehouse during this research is in a fixed amount of 30 operators.
5. Products used as entities is only classified by size (small: 300 mm, medium: 900 mm, big: 2000 mm)
6. Dolly used for each product size has specific size of (in L x W x H); small: 700 x 500 x 1000 mm, medium: 900 x 600 x 1000 mm, big: 2000 x 1500 x 1000 mm
7. Module used for packing is limited to type 1 and type 2 module.
8. Warehouse performance to be assessed is limited to three categories: productivity, cycle time, and utilization.

1.5.2 *Assumptions*

The assumptions used in this research are:

1. There is no alteration in the space, layout, and regulation in the warehouse.

2. Historical data used as calculation represent the actual condition of the observed 7K warehouse.

3. Outgoing orders are randomly distributed.

4. Module type selection is on equal proportion.

5. Binning parts are stored within zone by priority rule.

6. Picking parts are picked using priority rule.

7. Manpower cost is based on PERGUB Prov.DKI Jakarta No. 10 Tahun 2020 tentang UPAH MINIMUM SEKTORAL PROVINSI TAHUN 2020.

1.6   Research Systematics

The systematical review of the research which will be divided into several chapters.

CHAPTER 1 INTRODUCTION

In this chapter, it will be given an initial description of the background of the problem, problem formulation, problem limitations and assumptions, research objectives, the benefits and research systematics.

CHAPTER 2 LITERATURE REVIEW

In this chapter, a description of the concepts and theories that support this research will be given. The literature review discussed included lean concepts, waste classification, warehouse management, storage systems, value stream mapping, process activity mapping, root cause analysis, and discrete event simulation modelling.

CHAPTER 3 RESEARCH METHODOLOGY

In this chapter, the description of the steps in resolving the problem and achieving the specified objectives will be given. The research

methodology aims to enable researchers to conduct research systematically to achieve the desired goals.

CHAPTER 4 ACTIVITY MAPPING

In this chapter, the activity inside each operation is mapped and delivered in the form of process activity mapping to classify each activity according to each value given by each activity

CHAPTER 5 MODEL CONSTRUCTION AND INITIAL SIMULATION

In this chapter, the conceptual and simulation model is constructed. The conceptual model is the overall logic that happens inside the real system, the simulation model is the manifestation of those logic in its software form. The model will then be verified and validate and run to see the result of the current system. The model also acts as the media to identify waste occurring inside the system

CHAPTER 6 WASTE IDENTIFICATION & ANALYSIS AND IMPROVEMENT FORMULATION

In this chapter, the result of activity mapping and simulation will then be analyzed to identify each possible occurring waste inside the system. The identified waste will then be analyzed and determine the root cause causing it. Improvement plans will then be formulated to eliminate the root causes.

CHAPTER 7 IMPROVEMENT SIMULATION AND COMPARISON

In this chapter, the proposed improvement plan is applied the simulation model to see how much of impact does the improvement plan gives. The result will then be compared, before and after.

CHAPTER 8 CONCLUSIONS AND RECOMMENDATIONS

In this chapter summarize and conclude the research while giving recommendations for further research in the same topic.

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CHAPTER 2
LITERATURE REVIEW

This chapter consists of several literature that is used as the basis of this research. It concludes what is lean philosophy, root cause analysis, warehouse management, discrete event simulation modelling, lean warehousing, and reviewing previous research on the same research topic.

2.1   Lean Warehousing

Lean concepts originally started in today Japanese biggest automotive industry, Toyota. Founded by Kiichiro Toyoda and Taiichi Ohno, Lean concept firstly known as "Toyota Production System". A concept that aims to maximize the worth of product through minimization of waste (Sundar, et al., 2014). The objectives of lean are to eliminate waste, increase productivity and efficiency, reduce cost, and increase the competitiveness of the corporate.

Lean is not almost waste reduction or prevention; it is about always putting the customer first. And by doing so, waste is automatically removed. (John Bicheno, 2009). It is further stated that "genuine" Lean is behavior-driven, it is what employees do in daily basis without being told. The foremost important behavior in keeping with Bicheno and Holweg (2009) is that the constant reinforcing of the right tools and principles, by level of an organization. Self-demonstration and daily coaching are that the best way for employees to find out these tools and principles.

2.1.1   *5 Lean Principle*

Lean is derived into 5 lean principle (James P. Womack, 2003). The five principles place emphasis on the system, making it relevant to both the manufacturing and service industries. However, several managers believe that Lean is simply applicable within the manufacturing industry, missing the purpose that the most focus is on vision. The five Lean principles as discussed by Womack and Jones (2003) are listed as follows.

1.   Principle 1: Specify value from customer point of view

Identify what is important to the customer and their perspective on value, and not that of the supplier or manufacturer. Value can only be defined by the end customer. Thus, the start line of Lean is to thoroughly understand what the customer perceives as value. this may be accomplished through identifying the value adding activities in an operation. a company has mainly three differing types of value adding activities. They are:

- Value adding activity (VA) – An activity that makes the product or service more valuable to the end customer.

- Non-value adding activity (NVA) – An activity that creates no value to the customer. One of the main focusing points of Lean is to eliminate these nonvalue adding activities.

- Necessary non-value adding activity (NNVA) – An activity that does not create any value to the customer but is seen as necessary or mandatory to achieve the product or service.

The following concept is used to accurately identify what is deemed as unnecessary process or activities known as wastes. Waste or "Muda" the Japanese word for waste is a key point in Lean and is critical in understanding value. One organization has a simple definition of waste, they classify waste as anything other than the minimum activities and materials necessary to get the job done immediately, right the first time and to the satisfaction of the customer.

Taiichi Ohno introduced the seven muda concept, differing and identifying wastes to its specific area. The seven wastes are:

- Overproduction - Waste that happens because of excess production. Overproduction incurs extra costs as converting materials into product that are not required and price of storage and

movement. Overproduction in warehouse may be within the sort of replenishment, packing or picking items before needed.

- Waiting - Waste due to waiting will be because of an unbalanced process therefore the operator or machine must wait to try and do the work. Waiting includes anticipating data, picking, shipping, and inspection.

- Defect - Waste disability and repetition (rework) occur due to damage and poor quality in order that repairs are needed. This waste will cause additional costs such as labor costs, repair components, etc. Defects includes activities such as rework, return for adjustment due to mislabeled product, mistake, warehouse discrepancy.

- Over processing - Waste due to processes that do not seem to be needed because the method does not provide added value to the product and not needed. In warehouse practice, unnecessary processing is often unnecessary packing or picking.

- Transportation - Transportation waste occurs due to inefficient production layout, organizing poor workplaces so that material handling processes are carried out inefficiently. Transportation waste in warehouse is because of unnecessary internal transport of items.

- Inventory - Waste that happens due to inventory is due to errors within the accumulation of finished goods, intermediate goods or work in process, and raw materials at the production stage so it requires a cargo area, inventory supervisor, etc. In warehouse practice, this waste is often within the variety of freezing assets and non-optimal space of warehouse.

- Motion - Waste that happens due to unnecessary activities of workers or machines and does not provide value added products. Unnecessary motion is any movement beyond the minimum

required to finish the process step such as searching, arranging and ergonomic issues.

2.   Principle 2: The value stream

The value stream can be described as a set of processes or activities that a product or service undergoes to meet customers' requirements. It involves the core activities that provide value to the customer.

Mapping out the entire value stream of an organization is an effective way to expose waste. The real purpose of mapping is to design the future state. it is a visualization exercise – showing the vision of the present state, still because the desired future state. Value stream mapping (VSM) is additionally an impressive thanks to get employees involved and to participate. Mapping may be an excellent tool to get new ideas. It provides a more robust understanding of how material and data flow are connected. It builds the idea for a good Lean implementation plan, by optimizing how information and material flow co-operate to minimize waste.

In examining detail of processes, VSM cannot identify and analyze thoroughly through those processes. Process activity mapping (PAM) is one of the detailed mapping tools. The difference between PAM and VSM is that PAM does not describe the overall process flow, but each of the process individually in detail. PAM aims to identify each activity inside a process and categorized it into three type of activities based on whether value adding or not as explained in previous chapter. Those identification and categorization will help determine which activity that has a possibility of generating "waste" inside a process, which will later be confirmed through the matching of PAM and simulation model result. Here are the steps in constructing process activity map based on Hines and Taylor (2000).

1.   Step 1: Fill in the main body of chart

The first step is to record all activities including the location where the activities occur, distances, time to do the activities, number of people or operator and any relevant information. The main body should include the information except the flows. Here is the example of main body chart.

#	Activity	Flow	Area	Distance (metres)	Time (minutes)	People	Comments
Trigger	Arrive at garage		Roadside	0.00	0.00	0	Arrive at 08:30
1	Queue to enter forecourt		Roadside	0.00	0.75	1	Early morning congestion, (usually none)
2	Drive to free pump		Forecourt	25.00	0.20	1	
3	Queue for pump to become free		Forecourt	0.00	5.00	1	Cars parked at pump whilst paying (usually none)
4	Drive to free pump		Forecourt	3.00	0.10	1	
5	Open car door and exit car		Forecourt	0.50	0.10	1	
6	Walk to petrol cap on car		Forecourt	2.00	0.10	1	
7	Unlock petrol cap on car		Forecourt	0.00	1.00	1	Cap is faulty and regularly gives problems
8	Walk to petrol pump nozzle		Forecourt	1.50	0.10	1	
9	Retract nozzle		Forecourt	0.00	0.10	1	
10	Walk to petrol cap on car		Forecourt	1.50	0.10	1	
11	Insert nozzle into petrol tank		Forecourt	0.00	0.10	1	
12	Dispense petrol into tank		Forecourt	0.00	3.00	1	50 litre tank, always fill to top
13	Round up value to nearest £1		Forecourt	0.00	0.50	1	
14	Retract nozzle from petrol tank		Forecourt	0.00	0.10	1	
15	Walk to petrol pump		Forecourt	1.50	0.10	1	
16	Replace nozzle		Forecourt	0.00	0.10	1	
17	Close car door and lock car		Forecourt	0.00	0.10	1	Rule I have set myself
18	Walk to shop		Shop	35.00	0.50	1	
19	Queue for cashier		Shop	0.00	3.00	1	Two people in queue
20	Hand petrol card to cashier		Shop	0.00	0.10	2	Collecting air miles!

Figure 2.1 Example of PAM Main Body Chart

(Source: Hines & Taylor, 2000)

2.   Step 2: Assign flows

After the main body has been built, then the activities need to be classified into four types of flows:

- Operation (●): Value adding activities that is needed to be done.

- Transport (□): The movement in the sites but prefer to be avoided or reduced

- Inspection (■): Checks of the quality or quantity of product or information

- Delay or storage (▼) : product or information waits to be processed or there is no activity.

3. Step 3: Analyze

In this analyze step, then the most frequent activities can be identified. The activities then cab be reduced or improved. Figure 2.2 shows the complete process activity map.

Step		Flow	Machine/ tool	Distance (metres)	Time (minutes)	People	Chart symbol			
							●	→	■	▼
1	Cut and chamfer pins	●	Cutter		60	1				
2	Transportation	→	Crane	20	5	2				
3	Measure length inspect chamfering	■	Calipers		10	2				
4	Set aside	▼	Bag		70	2				
5	Transportation	→	Crane	10	3	2				
6	Polish exterior surface	●	Polisher		15	1				
7	Transportation	→	Crane	20	5	2				
8	Measure outer diameter	■	Calipers		5	2				
9	Transportation	→	Crane	20	5	2				
10	Inspect pin insertion into socket	■			10	2				
11	Transportation	→	Crane	15	4	2				
12	Set aside	▼			10	2				
13	Storage	▼			50					
Total		13 steps		85 metres	252 minutes	22	2 times 75 min	5 times 22 min	3 times 25 min	3 times 130 min

Figure 2.2 Example of Complete PAM

(Source: Hines & Taylor, 2000)

3. Principle 3: Flow

Create processes that make value flow. Minimizing the delays of value adding activities and eliminate non - value adding activities. Womack and Jones (2003) classify flow as the progressive success of activities along the value stream so that products continue from design to launch, order to delivery, and raw materials to delivery and into the hands of the customer without any form of delay or stoppages. Flow is thus the continuous movement of inventory from step to step in an even, steady form and equal amount.

4.   Principle 4: Pull

Pull is the short-terms response to the customer's rate of demand (John Bicheno, 2009). it is important to notice that this is often the end customer's demand, and not distorted by the intermediate bullwhip effect. this is often to cut back and try and eliminate overproduction. Pull needs to happen along the whole demand flow network, and not isolated within one company. this can involve sharing final customer demands along the entire supply chain, which can reduce uncertainty in forecasting numbers.

Pull systems are typically classified as those systems where production relies on consumption of an upstream process. The main benefits of a pull system are reduction in work-in-progress (WIP) and cycle time, because with pull, overproduction is not possible. In addition, higher quality (due to a process with shorter queues) and a smoother flow of production is a further benefit. Ultimately all these lead to a reduction in cost.

5.   Principle 5: Perfection

Perfection is not merely defect free, but rather delivering exactly what the customer requires, when the customer wants it, at a reasonable price and with the least muda. To achieve perfection, kaizen (or continuous improvement) is central to Lean operations. Quality starts at the customer, but the customers' views are ever changing, and standards are increasing, creating the requirement for a continuous improvement environment.

Lean warehousing is a method of applying lean principles inside a warehouse operation. How to maximize the workflow inside a warehouse. The flow of information and material is the streams visualized in the receiving VSM process and then developed into a process mapping activity. In activity mapping, mapping of each activity will be carried out to determine the

operational conditions in the field in the types of activities consisting of operational, transportation, inspection, storage, and delay.

In Nordström (2016). The purpose is to analyze the raw material warehouse in the factory and create improvements. The results show that the problems are because of lack of location labels, material stored between the racks and the placement of the most used materials being stored at random places in the warehouse. Below is the example of lean warehousing usage in a case study on a journal by Anđelković (2016).

Table 2.1 Lean Warehousing Implementation Example

Area	Before Improvement	After Improvement
Reduction of picking error- before and now	0.17%	0.01%
Inventory accuracy- difference in stock take (physical count vs system stock)	9.29%	5.97%
Safety: lost-time accidents reduced (depend on group of material)	15 – 20 days	7 – 10 days
Saved warehouse space	2400 m^2 planned for 2 projects before	2400 m^2 planned for all projects (4 projects)

(Source: Andelkovic, et al., 2016)

2.2   Root Cause Analysis

Root cause analysis (RCA) is defined as a structured investigation that aims to identify the real cause of a problem and the actions necessary to eliminate it (Bjørn Andersen, 2006). RCA incorporates a broad range of approaches, tools, and techniques to uncover causes of problems, starting from standard problem-solving paradigms, business process improvement, benchmarking, and continuous improvement. There are several methods for root cause analysis including 5 whys, fish bone diagram, fault tree analysis,

etc. In this research, the root cause analysis method will be using 5 why's analysis, the example of conducting 5 why's analysis is shown in Figure 2.3.
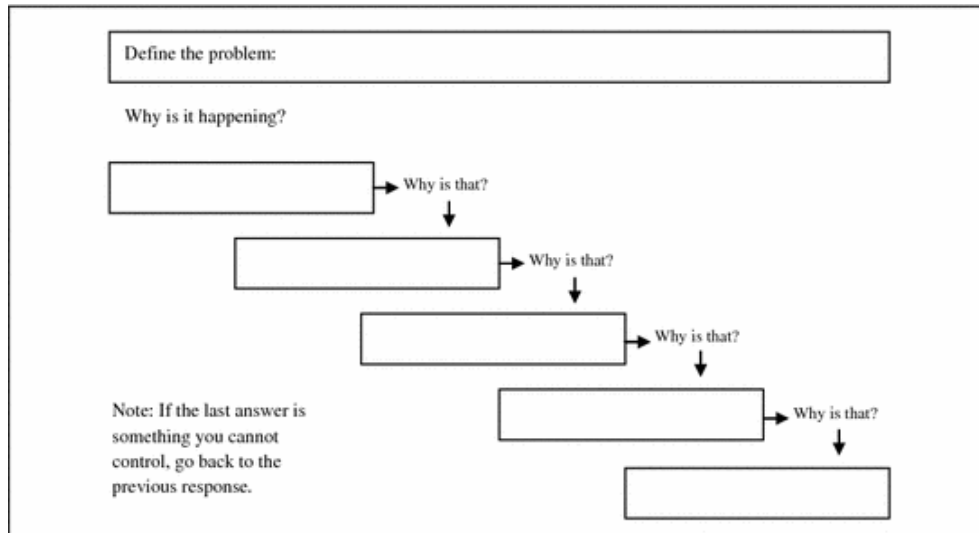
Figure 2.3 5 Why's Analysis Example

(Source: Serrat, 2017)

2.3   Warehouse Management

Warehouse is part of a logistics system in the form of buildings that are used to store goods in the form of raw materials, spare parts, work in process, or finished good (Warman, 2012). According to Lambert (2001) Warehouse is a part of the company's logistics system that stores products at and between the source and consumption points, and provides management with information on the status, condition, and disposition of stored goods.

Inside a warehouse there are several activities or operations, According to Frazelle (2001), warehouse activities are classified into 5 activities including receiving, put away, storage, order picking and delivery.

1.   Receiving, acceptance of all materials used for the production process. The detailed activities carried out are the process of loading and unloading of materials and ensuring the quality and quantity of materials according to the order.

2.   Put Away, the process of placing materials or products in accordance with the location of storage. Activities undertaken

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include material handling, verification of the location of goods, and placement of goods at the location.

3. Storage, temporary storage of materials and products until the material is used for the production process and products are delivered according to customer orders.

4. Order Picking, the process of moving products from the warehouse location to be immediately loaded to meet customer demand. Activities undertaken include verifying the location and type of product, as well as material handling.

5. Delivery, the loading process for the product to be shipped as well as the checking process of the vehicle whether it is proper to use or not.

Warehouse management is the process of organizing all activities carried out in the warehouse with the aim of optimally using the warehouse facilities or equipment / equipment so that the receipt, delivery, and maintenance of goods is easily done by utilizing the available resources. One of warehouse management operation is storing policies, based on Muller (2003) there are several types of storing policies:

1. Memory System

Memory system are solely relying on human recall. There are several conditions for implementing memory system in the warehouse.

- Storage locations are limited in number and size
- The variety of items stored is limited
- The size, shape, and unitization (example: palletization pallet, banding, etc.)
- Only one or limited number of workers within the storage areas
- Workers within storage area do not have duties away from the locations
- The types of items in the inventory do not radically change in short period
- There is not a lot of stock movement

The advantages of using memory system is that it is simple to understand, need little or no ongoing paper-based or computer-based tracking, possible for full space utilization, need no trying particular stocking location, bind, to a specific location. However, the disadvantages are that the company needs to strongly rely on memory, health, availability, and attitude of the individual, high possibility of decreasing accuracy from the changes, once an item is lost to recall, then it is lost to the system.

2. Dedicated Storage

Dedicated storage or fixed location storages is that each stock keeping unit (SKU) has its own storage locations. Fixed location systems need larger amounts of space because of honeycombing and planning around the largest quantity of an item that will be in the facility at one time. Honeycombing is a situation where the is available space but not being fully utilized. This can be caused by:

- Product shape: the physical characteristics prevent the use of cubic space because of inability to stack the stocks.
- Product put away: items are not stacked or placed in a uniform manner so that the vertical or horizontal space is not fully utilized.
- Location system rules: the other item cannot be placed in a place that is not assigned even though the space is empty
- Poor housekeeping: trash, other unnecessary items that force empty space around it.

The implementation of dedicated storage provides immediate knowledge about the item location, so even if there are changes, the performance still high. The other advantages are reducing training for new hires workers, simplifying the receiving, replenishment, order picking, allowing strong control and placement based on SKU's size, weight, or other similar characteristics. The disadvantages of dedicated storage are possibility of honeycombing within the storage, it requires good space planning, and dedicated storage are somewhat inflexible.

3.   Zoning system

Zoning system places the items based on the characteristics such as size, variety, toxicity, weight, lot control, labelling, etc. It also allows for flexibility moving items and addition of storage. In zoning system, the planning is easier since there is no need to plan overall item's requirements because there is no specific position.

4.   Randomized Storage

Randomized storage means that each SKU can be stored in any available location. Pure random storage allows the items to be stored above or in front of one another to occupy a single bin. The difference between random storage and memory system is that the memory system relies on the stock keeper. While the random system has flexibility like memory system if the location is accurately noted in the database. The advantages of random system are space maximization and control of item locations. The disadvantages of random system are that it needs constant update on the information to track the item and it can be unnecessarily complicated if implemented to a company that has small number of SKU.

5.   Class-based Storage

Class-based storage or combination systems is that the SKUs are assigned to classes. For example, is the raw materials are stored in one area that is close to the production line and receiving area while the placement of raw materials in the area is randomized. The classes are dedicated storage while the SKUs in the class follow randomized storage system.

2.3.1   *Type of Warehouse*

Bozer (2012) has identified six different warehouse types. The different types of warehouses are classified according to the customer type.

1.   Raw material and component warehouses

2.   Finished goods warehouses

3.   Distribution warehouses

4.   Retail warehouses

5.   Service/spare parts warehouse

6.   Consolidation warehouse

In the purpose of this research, only one type of warehouse is taken into consideration and as a limitation to the scope of the research. The primary function of a service/spare parts warehouse (after-market warehouse) is that the storing and picking of products for customer orders. This warehouse typically incorporates a big selection of SKUs filling small to large orders. It stores, picks, packs, and ships orders to customers. the shoppers range from individual customers, retail stores, distribution hubs, commercial customers, businesses, and dealers. Although not all inventory kept in these warehouses are service or spare parts, it follows similar processes within the warehouse.

2.3.2   *Warehouse Performance Indicator*

Frazelle (2001) derived warehouse activities into 5 categories each with its own key performance indicator (KPI) to measure its performance. The KPI's of each of the activities consist in an assessment of productivity, financial, utilization, quality, and time. The Table 2.2 Shows the warehouse performance indicator and explanation according to Hector (2018).

Table 2.2 Warehouse Key Performance Indicators

	Financial	**Productivity**	**Utilization**	**Quality**	**Cycle Time**
Receiving	Receiving cost per line	Receipts per man-hour	% Dock door utilization	%Receipts processed accurately	Receipt processing time per receipts

	Financial	**Productivity**	**Utilization**	**Quality**	**Cycle Time**
	The expense incurs on the receiving process of each receiving line including the handling cost.	The volume of goods received per warehouse operator per hour	Percentage of the number of the total dock doors were utilized	Percentage of accurate receipts per purchase orders	The time taken to process each receipt
Put Away	Put away cost per line	Put away per man-hour	% Utilization of put away labor and equipment	% Perfect put away	Put away cycle time (per put away)
	Expenses for putting away stock per line, including labor, handling, and equipment costs	Volume of stock put away per warehouse operator per hour	Percentage of the labor and material handling equipment utilized during the put away process	Percentage of number of items put away accurately at the designed location	Total time taken during the entire process of each put away
Storage	Storage space cost per item	Inventory per square foot	% Locations and cube occupied	% Locations without inventory discrepancies	Inventory days on hand

	Financial	Productivity	Utilization	Quality	Cycle Time
	The cost of storage for storing stocks including handling and equipment costs.	Volume of inventory stored per square foot	Percentage of space occupied by inventory out of the total space available for storage	The accuracy of inventory data in the system	The number of times the entire inventory passes through during a period
Order Picking	Picking cost per order line	Order lines picked per man hour	% Utilization of picking labor and equipment	% Perfect picking lines	Order picking cycle time (per order)
	Cost incurred per order line, including handling, labeling, relabeling, and packing	The number of orders picked per hour	The percentage of labor & picking equipment per total labor and equipment utilized during the process	The percentage of orders picked and packed without error	Time taken to pick each order
Shipping	Shipping cost per customer order	Orders prepared for shipment per man hour	% Utilization of shipping docks	% Perfect shipments	Warehouse order cycle time

	Financial	Productivity	Utilization	Quality	Cycle Time
	Cost incurred during the process of shipping	The number of orders shipped per hour	Percentage of shipping docks per available shipping docks	Number of orders the warehouse delivered without error	The average time taken by an order to reach the customer once the order has been placed.

(Source: Hector, 2018)

2.4 Discrete Event Simulation Modelling

Discrete-event simulation represents modeling, simulating, and analyzing systems utilizing the computational and mathematical techniques, while creating a model construct of a conceptual framework that describes a system. The system is father simulates by performing experiment(s) using computer implementation of the model and analyzed to draw conclusions from output that assist in deciding process. Discrete event simulation technologies are extensively utilized by industry and academia to handle various industrial problems. By late 1990s, the discrete event simulation was in doldrums as global manufacturing industries went through radical changes. The simulation software industry also went through consolidation. The changes have created new problems, challenges and opportunities to the discrete event simulation (Averill M. Law, 2000).

Discrete event simulation quantitatively represents the real world, simulates its dynamics on an event-by-event basis, and generates detailed performance report. it has long become one among the mainstream computer-aided decision-making tools because of availability of powerful computer.
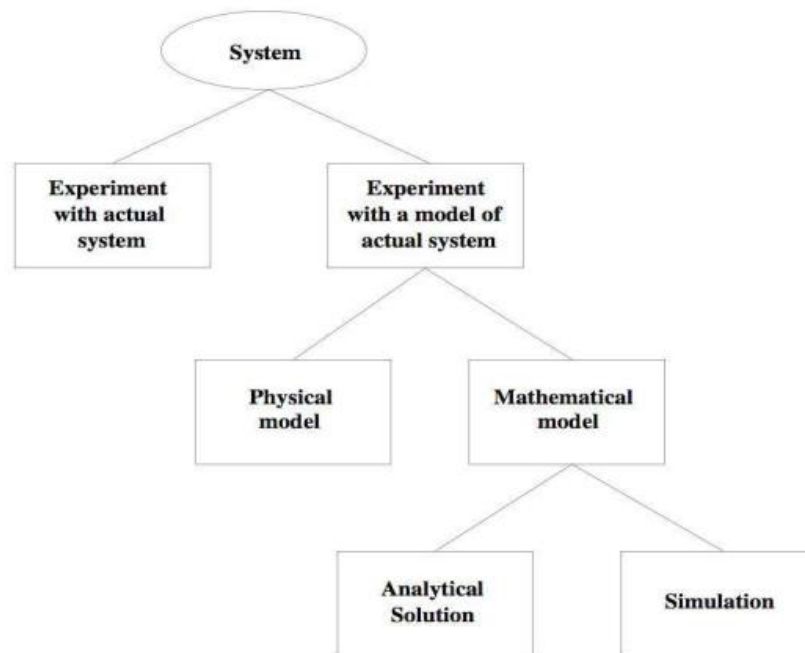
Figure 2.4 How to study a system

(Source: Fishman, 2001)
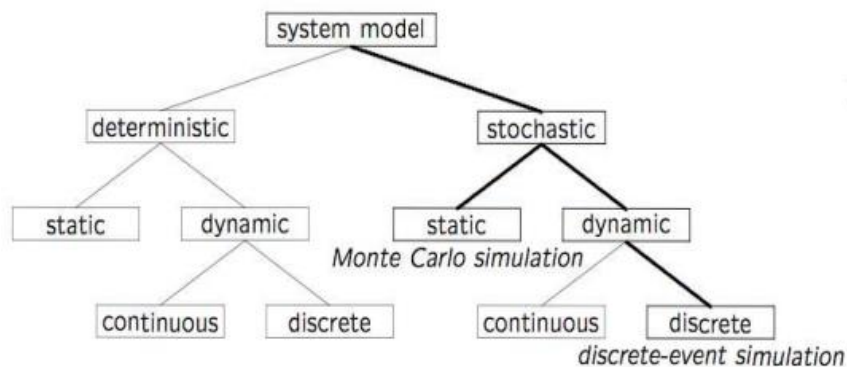
Figure 2.5 Model taxonomy

(Source: Fishman, 2001)

2.4.1   *Complex System*

Complex system are systems whose behavior is intrinsically difficult to model because of the dependencies, competitions, relationships, or other kinds of interactions between their parts or between a given system and its environment. In applying simulation as a tools to analyze given system, the system must have a high degree of complexity or considered as a complex

system that if it is analyzed manually the process will take too long and the result will not delivered maximally. Systems that are "complex" have distinct properties that arise from these relationships (Bar-Yam, 2015) :

- Nonlinearity: Complex systems will respond in several ways to the identical input looking on their state or context.
- Emergence: These are traits of a system that are not apparent from its components in isolation, but which result from the interactions, dependencies, or relationships they form when placed together in an exceedingly system. Emergence broadly describes the looks of such behaviors and properties.
- Spontaneous Order: Activities performed by the system without any specific input or planning.
- Adaptation: Rare traits of a system that can adapt to changes in their capacity from the result of experience, proclaiming the terms of self-adaptation

Complex system always generate complexity inside, the degree of complexity can be measured from the level of the four traits above or to put it simply is the amount variability lies inside the system. When a system contains variability, added by the interaction between entities inside, it will generate complexity.

2.4.2 *Conceptual Model*

A conceptual model is the model of an application that the designers want users to understand. Prototype of pre-simulation to match with the system that would be modelled. A conceptual model explains, abstractly, the function of the software and what concepts people need to be aware of to use it. Conceptual model usually comes in the form of flow diagram where it shows all the process involved in the overall flow. There are typical symbols that commonly used in creation, here are the symbols.

- Start and end symbols, represented as lozenges, ovals or rounded rectangles, usually containing the word "Start" or "End", or another phrase

signaling the start or end of a process, such as "submit enquiry" or "receive product".

- Arrows, showing what is called "flow of control" in computer science. An arrow coming from one symbol and ending at another symbol signifies flow passes to the symbol the arrow points to.

- Processing steps represented as rectangles. Examples: "Add 1 to X"; "replace identified part" or similar.

- Input / Output represented as a parallelogram. Examples: Get A from the user.

- Conditional (or decision), represented as a diamond (rhombus). These typically contain a Yes/No question or True/False test. This symbol is unique in that it has two arrows coming out of it, usually from the bottom point and right point, one corresponding to Yes or True, and one corresponding to No or False.

Process: A defined operation, or set of operations, causing a change in value, form, or location of information.

Descriptive clarification or comment. Dashed line extends to symbols as appropriate.

Input/output: A general I/O function.

Connector: Exit to or entry from another part of the chart.

Arrowheads and Flowlines: Flowlines link symbols and illustrate data flow. Add arrowheads to paths when linkage is not left-to-right or top-to-bottom.

Decision: Allows for program flow control. When a path enters the decision symbol, a question is asked about the state of a variable, and program flow proceeds on the basis of the response.

Predefined Process: Used for subroutine or function call. Process is defined on another flowchart.

Document: Output data to printer.

Off-Line Storage: Results of I/O are stored to disk, tape, etc.

Display: Output data to monitor.

Keyboard: Input data from keyboard.

Figure 2.6 Symbols used in Flowcharts

(source: Myler, 1998)

Steps in conceptual model construction is as follows (Johnson, 2008):

1. Observed the system that would be modelled

2. Trace and recreate the flow process of the system in the form of flow diagram.

3. Validate the model through comparing between the finished conceptual model with the real system whether there is no difference between the flow.

4.   If there is no difference between the conceptual model with the observed real system, then the model is valid and proceed to create simulation model. If there is a difference between the conceptual model with the observed real system, then the model is not valid and need to be reevaluated.

To better understand the interaction and responsibility between processes, the conceptual model framework will be delivered using a swim lane diagram approach. An example of a swim lane diagram is shown in the Figure 2.7.
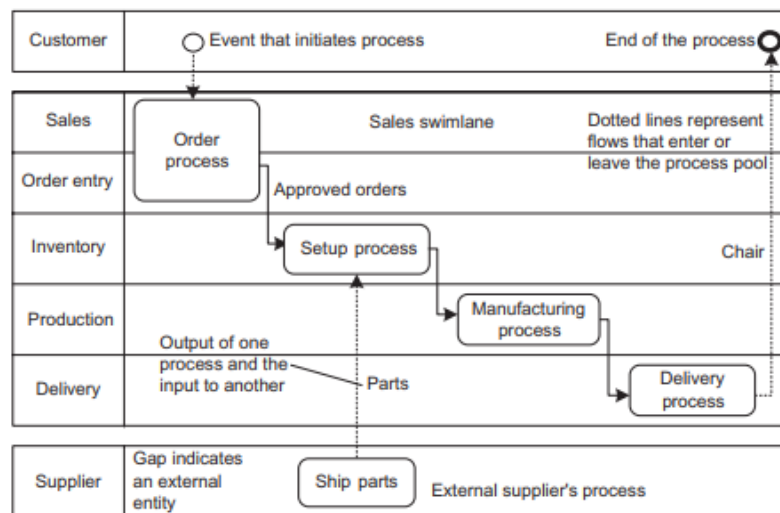
Figure 2.7 Example of Swimlane Diagram

(Source: Harmon, 2019)

2.4.3 *Simulation Model – Arena*

Simulation is the imitation of the operation of a real-world process or system over time. Simulation involves the generation of an artificial history of the system and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system that is represented. it is an important problem-solving methodology for the answer of many real-world problems. it is used to describe and analyze the behavior of a system, ask what-if questions about the real system, and aid within the design of real system (Tesfaye Gashaw, 2015)

Arena uses an entity-based, flowcharting methodology for modeling dynamic processes. Most other commercial simulation products are code-based and require programming in proprietary scripting languages, and many simulation products force you to concentrate primarily on animating a process rather than documenting it. Arena is a Visio-compatible, flowcharting tool. Entities in an Arena model proceed through a flow chart of the process and seize control of resource capacity as they are processed. The flowchart approach to model building makes the most sense to engineers and to process designers who must be able to carefully document a process to accurately model it and analyze it. This results in models that become highly detailed documents of the processes being studied.

In modelling a system, the modeler should identify the system elements of the observed system. These elements define who, what, where, when, and how of entity processing which will later observed on the simulation model (Law, 2015). The system elements consist of:

- Entities: Items/objects/document that travel through some/all part of the simulated system, and then is usually destroyed. Entities are distinguished by their attributes, pieces of information stored with the entity.

- Activities: The required task to performed by the system. It consumes time and often involve the use of resource.

- Resources: The means or requirements by which activities are performed. It can be in the form of equipment, raw material, or anything that is required to run an activity. It can constrain and limit the processing power by limiting its capacity.

- Controls: It dictates how, when, and where activities are performed. It imposes order on the system.

The modeler also needs to define the parameters to observe the performance of the simulation model. It is called system performance metric. The metric can be anything that is related to the performance indicator of the real system, such example is time, quality, efficiency, and utilization.

Designing a new system or improving an existing system requires more than simply identifying the elements and performance goals of the system. It requires an understanding of how system elements affect each other and overall performance objectives. To understand it, modeler need to determine the system variables (Law, 2015). System variables are divided into three types of system variables:

- Decision variables: Input factors or can also be called as independent variables. It acts as the input of the system that can change the system behavior every time the value of a system independent variable changes. Decision variable can be change accordingly to match or see what kind of difference the changes make.

- Response variables: It is defined as the performance or output variables. It measures the performance of the system in response to decision variable settings. Response variable is also known as dependent variable. The goal in system planning is to find the right values or settings of decision variables that give the desired response value.

- State variables: Shows the status of the system at any specific point of time.

2.5   Previous Research

Lean concept has been around for more than two decades but remains as one of the used concepts worldwide. During its usage, the concept began to expand to affect various sector not just manufacturing. The research of implementing lean in warehouse activity are common trend in the past decade. As the lean name suggest, most of the research are aiming to reduce waste happening inside a warehouse.

Dehdari (2014) measures the significance difference of impact on logistic performance indicator through the application of lean techniques. It measures the maturity level of lean assessment used in warehousing and how much of an impact it made. The research used 16 warehouses located across Europe as a sample, grouped and named Warehouse Excellence group. The

WE are the group that implement lean on their operation. Later compared to regular warehouse that does not implement lean shows that there is significant difference in operational excellence from those two comparisons with WE scored higher.

Demeter (2011) in her research titled "The impact of lean practices on inventory turnover" combined lean principle based on four practices of lean by Shah and Ward (2003) which list four different practices; Just In Time (JIT), Total Quality Management (TQM), Total Productive Maintenance (TPM), and Human Resource Management (HRM). Finding optimum result by reducing raw material, work in progress, and finished goods inventory days.

Jaca et al. (2012) shows that employee involvement and organization structural change significantly increase warehouse productivity by 9.34%. Combining lean principle with TQM practices into office and warehousing activities.

M. Dotoli et al. (2015) in her research titled "An integrated approach for warehouse analysis and optimization: A Case Study" integrates Unified Modelling Language (UML) with VSM and Genba-Shikumi philosophy as waste priority ranking tools. Genba-Shikumi prioritize waste elimination through the correlation between each waste identified by classifying waste identified in a waste vector. There is significant increase in total free shelves volume and handling area.

From the previous research above, the author aims to combine lean warehousing practice with discrete event simulation (DES) approach. The aim of DES is to complete and simulate the flow of VSM and as a media to simulate the formulated improvement later.

Table 2.3 Previous Research Comparison with Current Research

Researcher	Research Title	Method	Object	Output
Previous Research				
(Dehdari, 2013)	Measuring the Impact of Lean Techniques on Performance Indicators in Logistics Operations	Lean Maturity Assessment, Dehdari method	16 Warehouse Excellence group from different companies	Increase warehouse productivity by at least 5%.
(Krisztina Demeter, 2011)	The impact of lean practices on inventory turnover	JIT, TQM, TPM, HRM	Survey Data from International Manufacturing Strategy Survey (IMSS)	35,8% reduction of inventory days of raw materials, 33,8% reduction of inventory days of WIP, 46,9% reduction of inventory days of finished goods
(Carmen Jaca, 2012)	Lean thinking with improvement teams in retail distribution: a case study	Employee involvement and organization structural change	A Distribution Company in Spain	9,34% improvement in overall warehouse productivity

Researcher	Research Title	Method	Object	Output
(Mariagrazia Dotoli, 2015)	An integrated approach for warehouse analysis and optimization: A Case Study	Integrating Unified Modelling Language (UML) with VSM and Genba-Shikumi	An Italian producer of interior design object	18.42% increase in free shelves space and 29.63% increase in handling area.
Current Research				
(Raihan Bagus Sakti Aji, 2020)	Improving warehouse performance through lean concept: A discrete event simulation approach	Lean warehousing through discrete event simulation approach	7K Warehouse PT. X	Simulation model construction and improvement formulation for improving warehouse performance

CHAPTER 3
RESEARCH METHODLOGY

This chapter explains the steps needed to perform the research, from processing observed data into activity mapping and initial model construction and simulation, to waste identification and analysis, proposing improvement and simulating to gain result, and to provide the best selection of alternative.
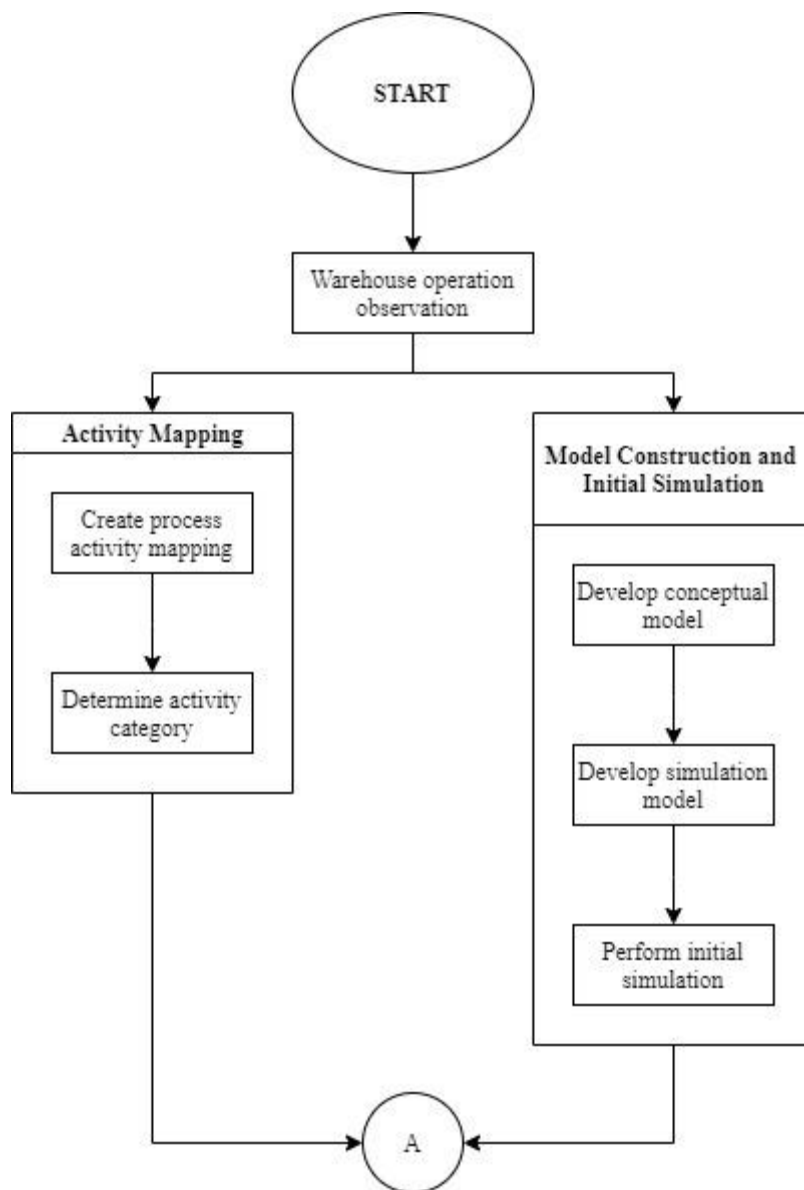
Figure 3.1 Research Methodology Flowchart
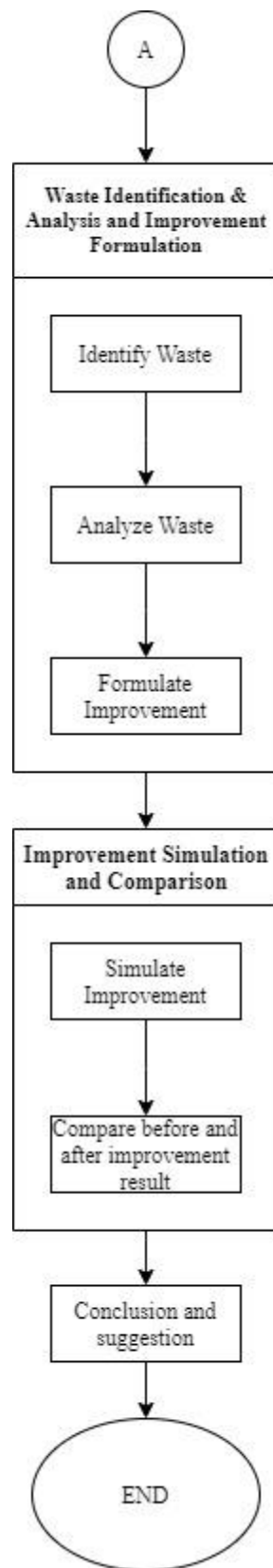
Figure 3.2 Research Methodology Flowchart (cont.)

3.1 Activity Mapping

Normally in common lean implementation, the early identification starts by using value stream mapping (VSM) to identify the overall flow of a process starting from receiving customer order, order processing, supplier order, product processes, and until the product reaches the customer again. VSM also describe the time needed in the form of manufacturing lead time (MLT) and value adding time as explained in literature review previously. The measurement of those parameters requires constant and minimum variability inside so the result will be delivered in a standard time which little to no variability. In the case of this research, the usage of value stream mapping is deemed impossible to use to describe the flow of process since the process itself contain numerous amounts of complexity and variability inside that generate uncertainty and variability in its operations time, thus unable to model using VSM. The proposed substitution is by using simulation modelling to cover the complexity and variability. The model will help identify the flow components and wastes. To verify the result of the model, another tool to use is process activity mapping (PAM) as it has previously explained in the previous chapter.

The PAM will classify each activity inside each specific process starting from, unloading, sorting, supply, binning, picking, packing, and vanning. It will be based on the standard operating procedure of each of the process, Table 1.3 below is an example of the PAM table

Table 3.1 PAM Observation Table

Process: (Observed process)				
No.	Activity	Standard Time after n observation	Activity Category	Description
1	(Activity inside the process)		VA/NVA/NNVA	(Activity description)
2				
3				
4				

Process: (Observed process)				
No.	Activity	Standard Time after n observation	Activity Category	Description
5				
6				

3.2 Model Construction and Initial Simulation

Simulation model is constructed to substitute VSM in identifying and observing the overall flow of the operations considering all complexity and variability, whereas it can run scenarios fitting and relatively identical to the real system. In model constructing, the stages are divided into two stages that is conceptual model construction and simulation model construction.

3.2.1 *Conceptual Model Construction*

The conceptual model will be delivered in the form of swim lane diagram to better understand the overall flow and job division inside the operations. The purpose of the conceptual model is to verify the operations that would be modelled represent the observed system. Table 3.2 shows the proposed conceptual model flowchart delivered in a swim lane diagram.

Conceptual model that has been built will then be validate through an expert judgement, in this case is the 7K Warehouse supervisor Mr. Misbahul Muzakki. The purpose of validating the conceptual model is to check whether the system that will be modelled is thoroughly described in the conceptual model. If, after the validation process the conceptual model is deemed not valid, the modeler should re-evaluate the model to identify possible error in describing the flow of the observed system.

Table 3.2 Swimlane Diagram for Conceptual Model Construction

7K Warehouse Operation						
Unloading	Sorting	Supply	Binning	Picking	Packing	Vanning

3.2.2 *Simulation Model Construction and Initial Simulation*

In constructing the simulation model on Arena software, the author needs to identify all the system elements, performance metric, and the variables explained in the previous chapter as a measure to control and analyze the simulation model. Also, the requirements of crucial observation data to be inputted inside the software. The high degree of complexity inside the system resulted in high variability inside the operation. The previously gathered observation data will then be inputted to generate a formula to represent how the simulation process will perform as closely as the observed system performed. Table 3.3 shows the identification of 7K Warehouse system elements and variables.

The decision variables are the one able to be controlled during the process, while the response is the result of the change of the spoken decision variables. The amount of parts arrived is a limitation set by the company since the warehouse were not fully operational and is one of a short term solution

to reduce the amount of overflowing parts, the limit can be changed, and the changes on the limit affect the performance of the warehouse due to the amount of parts coming inside will determine how well the process handle those parts. For example, handling 100 parts is different when handling 150 parts, the difference in amount of parts resulted in changes of both cycle time and productivity, depends on the capability of the system to handle certain amount of parts. Therefore, the flow of both incoming, during, and outcoming of parts inside the activity truly affect the performance of the warehouse itself in the form of productivity and cycle time. The activity cycle time is set as decision variable since the value of each activity cycle time can be changed accordingly to the company accords. For example, changing the required activity cycle time of sorting activity from 10 minutes to 3 minutes only. In response, the change of activity cycle time would affect the overall cycle time of each process, and the overall lead time of the warehouse operations.

The decision variables mentioned above is still within a short-term solution for the problem since the cause of the problem is not sourced from the warehouse itself but is outside the boundaries of both of this research and the warehouse team responsibility.

Before performing the simulation, the completed model needs to be verified and validate through the verification and validation process. Figure 3.3 and Figure 3.4 shows the flow in undergoing both processes. Verification process is needed to indicate that the model built is correct, building the right model. Validation checks whether the model can be run accordingly with how the observed system run, building the model right.

Table 3.3 Simulation Model System Elements & Variables

System Elements	
Entities	Service Parts
Attributes	Service Parts variety, amount, and demand
Resource	Logistics and Warehouse man power (2 MP unloading, 3 MP sorting, 1 MP supply zone M N S Cross dock, 3 MP Binning Picking zone MN, 2 MP Internal reserve, 1 MP supply zone WXYZ, 1 MP picking zone WXYZ, 1 MP reserve big parts, 3 MP binning picking zone Z, 3 MP packing, 2 MP pre packing, 1 MP yellow line, 1 MP vanning, 3 MP leader)
Activities	(In general) parts unloading, sorting, binning, picking, packing, yellow line, vanning
Controls	Order Priority, Safety Stock
System Variables	
Decision Variables	Amount of parts arrived, activity cycle time, MP availability, racks availability
Response Variables	Process cycle time, racks utilization
State Variables	MP idle/busy, Product idle/on process.
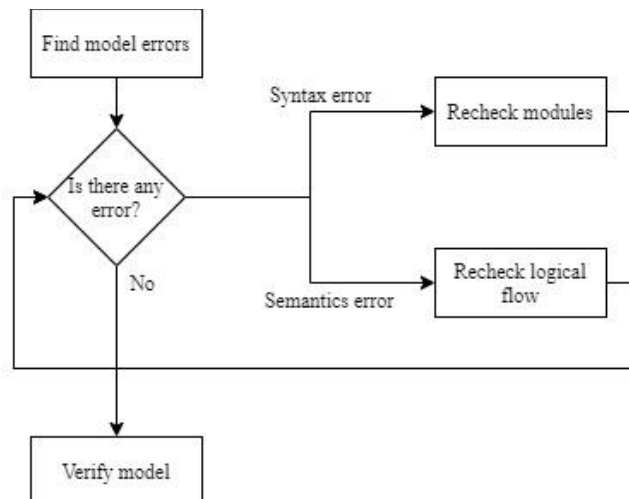
Figure 3.3 Simulation Model Verification Process
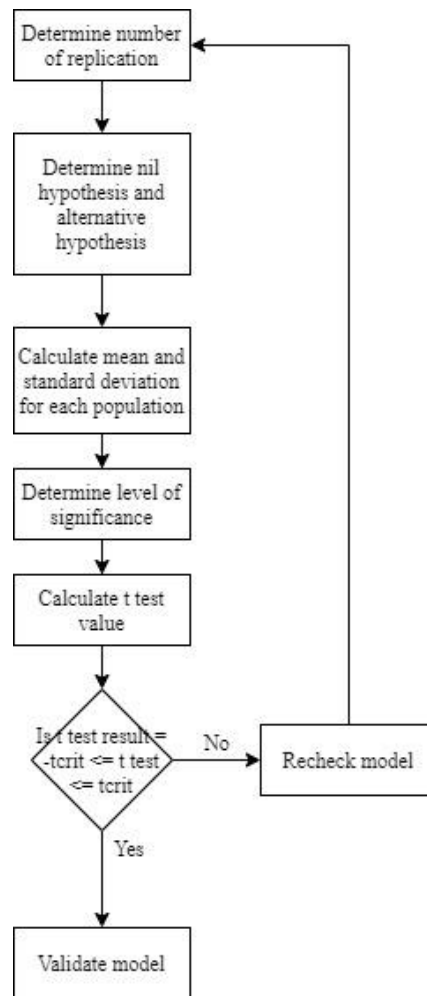
Figure 3.4 Simulation Model Validation Process

3.3   Waste Identification & Analysis and Improvement Formulation

After finishing model construction and initial simulation while also finishing activity mapping through process activity mapping, both of the result is matched to use as a basis for waste identification. As stated in the previous chapter, nonvalue added (waste) is an unnecessary process or activities. Thoroughly inspect every detail and activity mapped and matched between simulation and PAM to get defined every waste possible. After identifying each waste happening inside the warehouse, as a form of validation, the result is crosschecked by the warehouse experts.

Wastes that has been validated will then be called as critical waste and analyzed using root cause analysis (RCA) method. The critical wastes that are

identified will be analyzed by using 5 whys framework so that the causes can be improved by formulating the improvement plans.

3.4   Improvement Simulation and Comparison

Improvement plans is formulated after identifying and analyzing each of the waste occurred and the root cause behind it. Each of the improvement formulated will be based on the impact of waste occurred with warehouse performance indicator achievement as a standardized comparison base.

After thoroughly generate improvement plans, the improvement plans are applied into the simulation model to get and simulate if the improvements are implemented and what are the impact of it. The result from the simulation is then compared with the simulation result before the improvement to see the compare the difference between the before and after improvement result.

3.5   Conclusions and Recommendations

In this phase, the author will draw conclusions based on the results obtained from the research objectives to be achieved. Recommendations are given to improve company performance and further research.

CHAPTER 4
ACTIVITY MAPPING

In this chapter, the activity mapping process is conducted to classify each activity performed in each process, helping to identify possible waste occurring from those activities.

4.1 Process Activity Mapping

As previously explained in chapter 3, flow identification will be substituted using simulation modelling. The model will help identify the flow components and wastes. To identify in more detailed perspective, another tool to use is process activity mapping (PAM). The PAM will classify each activity inside each specific process starting from, unloading, sorting, supply, binning, picking, packing, and vanning. Observing in detail on how each activity inside the processes handle the operations. Since the warehouse handle not only one type of product but three type of product categorized by size into small, medium, and big, therefore the PAM will consider the difference in activities performing inside each processes in a specific way of handling those different parts, due to each type of parts requires different kind of treatment of activity. The activities will be categorized as value-added, necessary but non-value-added, and non-value-added activities. The categorization will be validated through communicating with experts from PT. X. The PAM will be constructed for each specified size operation.

Activity categorization will be divided into three type of activity, value adding (VA), non-value adding but necessary (NNVA), and non-value adding (NVA). The description of the classification is as explained in chapter 2. Table 4.1, Table 4.2, and Table 4.3 shows the process activity mapping for each of the part categorization and also the activity category for each activity occurring on each process.

Table 4.1 Small Part Category Process Activity Mapping

No.	Process	Activity	Type of Activities				Duration (second)	Tools/Medium	Number of Worker(s)	Activity Category
			Operation	Transport	Inspection	Delay				
1	Unloading	Wait incoming truck				▼	3726		2	NVA
2	Unloading	Update board control	●				47		1	VA
3	Unloading	Confirm supplier manifest			■		24		1	NNVA
4	Unloading	Take forklift key	●				37		2	NNVA
5	Unloading	Open wing truck	●				177		2	NNVA
6	Unloading	Take forklift	●				43		2	NNVA
7	Unloading	Drive to truck		→			17	Forklift	2	NNVA
8	Unloading	Take pallet from truck	●				149	Forklift	2	VA
9	Unloading	Drive to staging area		→			96	Forklift	2	NNVA
10	Unloading	Put pallet according to layout	●				232	Forklift	2	NNVA
11	Unloading	Drive to store		→			78	Forklift	2	NNVA
12	Unloading	Pickup empty pallet	●				57	Forklift	2	NNVA
13	Unloading	Drive to truck		→			43	Forklift	2	NNVA
14	Unloading	Load empty pallet to truck	●				59	Forklift	2	VA
15	Unloading	Park forklift back		→			135	Forklift	2	NNVA
16	Unloading	Scan manifest	●				13		2	NNVA

No.	Process	Activity	Operation	Transport	Inspection	Delay	Duration (second)	Tools/Medium	Number of Worker(s)	Activity Category
			Type of Activities							
17	Unloading	Put sub manifest in supplier rack	●				17		2	NNVA
18	Unloading	Take Kanban receiving	●				13		2	NNVA
19	Unloading	Walk to staging area		→			29		2	NNVA
20	Unloading	Write information on Kanban	●				35		2	VA
21	Unloading	Put Kanban receive on the pallet	●				9		2	VA
22	Unloading	Deliver pallet to sorting area		→			78	Forklift	2	NNVA
23	Sorting	Scan user and pass	●				5	Scanner	3	NNVA
24	Sorting	Take the part form mesh pallet	●				8		3	VA
25	Sorting	Scan label and Kanban id	●				13	Scanner	3	NNVA
26	Sorting	Scan BT. No	●				3	Scanner	3	NNVA
27	Sorting	Put the part into BT (Pallet)	●				1783		3	VA
28	Supply	Pick loaded BT	●				10		1	NNVA
29	Supply	Scan BT. No	●				3		1	NNVA
30	Supply	Deliver to zone S		→			173	BT	1	VA
31	Supply	Return empty BT to sorting area	●				147	BT	1	NNVA
32	Binning	Scan BT. No	●				2	Scanner	3	NNVA
33	Binning	Scan primary address and part no	●				11	Scanner	3	NNVA

No.	Process	Activity	Type of Activities				Duration (second)	Tools/Medium	Number of Worker(s)	Activity Category
			Operation	Transport	Inspection	Delay				
34	Binning	Check address and part master data			■		13	Scanner	3	NNVA
35	Binning	Check max stock on master data			■		11	Scanner	3	NNVA
36	Binning	Pick up parts	●				132		3	VA
37	Binning	Walk to respective address		→			27		3	NNVA
38	Binning	Fill into primary address	●				110		3	VA
39	Picking	Take Kanban from rack label picking	●				22		3	NNVA
40	Picking	Scan user and id	●				4	Scanner	3	NNVA
41	Picking	Scan picking header	●				3	Scanner	3	NNVA
42	Picking	Scan picking label	●				3	Scanner	3	NNVA
43	Picking	Walk to respective address		→			39		3	NNVA
44	Picking	Scan part and address no.	●				12	Scanner	3	NNVA
45	Picking	Take part from address	●				19		3	VA
46	Picking	Walk to picking BT area		→			10		3	NNVA
47	Picking	Put the part into BT	●				7		3	VA
48	Supply	Deliver to packing		→			302	BT	1	NNVA
49	Packing	Scan user and id	●				4	Scanner	3	NNVA
50	Packing	Prepare empty module	●				138	Module	3	VA

No.	Process	Activity	Operation	Transport	Inspection	Delay	Duration (second)	Tools/Medium	Number of Worker(s)	Activity Category
			Type of Activities							
51	Packing	Scan BT no. and input module code	●				27	Module	3	VA
52	Packing	Print case label	●				12	Printer	3	VA
53	Packing	Stick label to module	●				25	Module	3	VA
54	Packing	Waiting for parts				▼	1903		3	NVA
55	Packing	Scan case no (open)	●				8	Scanner	3	VA
56	Packing	Take the part in BT	●				39		3	VA
57	Packing	Scan BT label	●				10	Scanner	3	NNVA
58	Packing	Put the parts into module	●				2873	Module	3	VA
59	Packing	Scan module (close) if full	●				7	Scanner	3	VA
60	Packing	Supply to yellow line	●				47	Forklift	3	VA
61	Packing	Pick module from yellow line staging	●				56	Forklift	1	VA
62	Packing	Deliver module to yellow line		→			43	Forklift	1	NNVA
63	Packing	Check if yellow line is full			■		29		1	NNVA
64	Packing	Deliver the modules to vanning		→			192	Forklift	1	NNVA
65	Vanning	Put and arrange modules to the truck	●				78	Forklift	1	VA
66	Vanning	Close the truck	●				65	Forklift	1	NNVA

Table 4.2 Medium Part Category Process Activity Mapping

No.	Process	Activity	Operation	Transport	Inspection	Delay	Duration	Tools/Medium	Number of Worker(s)	Activity Category
			Type of Activities							
1	Unloading	Wait incoming truck				▼	3418		2	NVA
2	Unloading	Update board control	●				45		1	VA
3	Unloading	Confirm supplier manifest			■		22		1	NNVA
4	Unloading	Take forklift key	●				38		2	NNVA
5	Unloading	Open wing truck	●				187		2	NNVA
6	Unloading	Take forklift	●				41		2	NNVA
7	Unloading	Drive to truck		→			17	Forklift	2	NNVA
8	Unloading	Take pallet from truck	●				176	Forklift	2	VA
9	Unloading	Drive to staging area		→			83	Forklift	2	NNVA
10	Unloading	Put pallet according to layout	●				213	Forklift	2	NNVA
11	Unloading	Drive to store		→			72	Forklift	2	NNVA
12	Unloading	Pickup empty pallet	●				57	Forklift	2	NNVA
13	Unloading	Drive to truck		→			42	Forklift	2	NNVA
14	Unloading	Load empty pallet to truck	●				59	Forklift	2	VA
15	Unloading	Park forklift back		→			135	Forklift	2	NNVA

No.	Process	Activity	Operation	Transport	Inspection	Delay	Duration	Tools/Medium	Number of Worker(s)	Activity Category
			Type of Activities							
16	Unloading	Scan manifest	●				13		2	NNVA
17	Unloading	Put sub manifest in supplier rack	●				17		2	NNVA
18	Unloading	Take Kanban receiving	●				13		2	NNVA
19	Unloading	Walk to staging area		→			29		2	NNVA
20	Unloading	Write information on Kanban	●				35		2	VA
21	Unloading	Put Kanban receive on the pallet	●				9		2	VA
22	Unloading	Deliver pallet to sorting area		→			78	Forklift	2	NNVA
23	Sorting	Scan user and pass	●				5	Scanner	3	NNVA
24	Sorting	Take the part form mesh pallet	●				8		3	VA
25	Sorting	Scan label and Kanban id	●				13	Scanner	3	NNVA
26	Sorting	Scan BT. No	●				3	Scanner	3	NNVA
27	Sorting	Put the part into BT (Pallet)	●				548		3	VA
28	Supply	Wait for loaded BT				▼	952		1	NVA
29	Supply	Pick loaded BT	●				9		1	NNVA
30	Supply	Scan BT. No	●				6		1	NNVA
31	Supply	Deliver to zone M/N		→			134	BT	1	VA
32	Supply	Drive to packing		→			165		1	NNVA

No.	Process	Activity	Type of Activities				Duration	Tools/Medium	Number of Worker(s)	Activity Category
			Operation	Transport	Inspection	Delay				
33	Supply	Pick empty BT	●				125		1	NNVA
34	Supply	Return empty BT to sorting area	●				329	BT	1	NNVA
35	Binning	Scan BT. No	●				2	Scanner	3	NNVA
36	Binning	Scan primary address and part no	●				8	Scanner	3	NNVA
37	Binning	Check address and part master data			■		12	Scanner	3	NNVA
38	Binning	Check max stock on master data			■		12	Scanner	3	NNVA
39	Binning	Pick up parts	●				274		3	VA
40	Binning	Walk to respective address		→			27		3	NNVA
41	Binning	Fill into primary address	●				110		3	VA
42	Picking	Take Kanban from rack label picking	●				22		3	NNVA
43	Picking	Scan user and id	●				4	Scanner	3	NNVA
44	Picking	Scan picking header	●				3	Scanner	3	NNVA
45	Picking	Scan picking label	●				3	Scanner	3	NNVA
46	Picking	Walk to respective address		→			39		3	NNVA
47	Picking	Scan part and address no.	●				12	Scanner	3	NNVA
48	Picking	Take part from address	●				19		3	VA
49	Picking	Walk to picking BT area		→			10		3	NNVA

No.	Process	Activity	Operation	Transport	Inspection	Delay	Duration	Tools/Medium	Number of Worker(s)	Activity Category
			Type of Activities							
50	Picking	Put the part into BT	●				7		3	VA
51	Supply	Deliver to packing		→			302	BT	1	NNVA
52	Packing	Scan user and id	●				4	Scanner	3	NNVA
53	Packing	Prepare empty module	●				138	Module	3	VA
54	Packing	Scan BT no. and input module code	●				27	Module	3	VA
55	Packing	Print case label	●				12	Printer	3	VA
56	Packing	Stick label to module	●				25	Module	3	VA
57	Packing	Scan case no (open)	●				1903	Scanner	3	VA
58	Packing	Wait for parts				▼	2239		3	NVA
59	Packing	Take the part in BT	●				39		3	VA
60	Packing	Scan BT label	●				10	Scanner	3	NNVA
61	Packing	Put the part into module	●				2873	Module	3	VA
62	Packing	Scan module (close) if full	●				7	Scanner	3	VA
63	Packing	Supply to yellow line	●				47	Forklift	3	VA
64	Packing	Pick module from yellow line staging	●				56	Forklift	1	VA
65	Packing	Deliver module to yellow line		→			43	Forklift	1	NNVA
66	Packing	Check if yellow line is full			■		29		1	NNVA

No.	Process	Activity	Operation	Transport	Inspection	Delay	Duration	Tools/Medium	Number of Worker(s)	Activity Category
			Type of Activities							
67	Packing	Deliver the modules to vanning		→			197	Forklift	1	NNVA
68	Vanning	Put and arrange modules to the truck	●				68	Forklift	1	VA
69	Vanning	Close the truck	●				54	Forklift	1	NNVA

Table 4.3 Big Part Category Process Activity Mapping

No.	Process	Activity	Operation	Transport	Inspection	Delay	Duration	Tools/Medium	Number of Worker(s)	Activity Category
			Type of Activities							
1	Unloading	Wait incoming truck				▼	4104		2	NVA
2	Unloading	Update board control	●				47		1	VA
3	Unloading	Confirm supplier manifest			■		22		1	NNVA
4	Unloading	Take forklift key	●				37		2	NNVA
5	Unloading	Open wing truck	●				181		2	NNVA

No.	Process	Activity	Type of Activities				Duration	Tools/Medium	Number of Worker(s)	Activity Category
			Operation	Transport	Inspection	Delay				
6	Unloading	Take forklift	●				43		2	NNVA
7	Unloading	Drive to truck		→			17	Forklift	2	NNVA
8	Unloading	Take pallet from truck	●				149	Forklift	2	VA
9	Unloading	Drive to staging area		→			96	Forklift	2	NNVA
10	Unloading	Put pallet according to layout	●				232	Forklift	2	NNVA
11	Unloading	Drive to store		→			78	Forklift	2	NNVA
12	Unloading	Pickup empty pallet	●				57	Forklift	2	NNVA
13	Unloading	Drive to truck		→			43	Forklift	2	NNVA
14	Unloading	Load empty pallet to truck	●				59	Forklift	2	VA
15	Unloading	Park forklift back		→			135	Forklift	2	NNVA
16	Unloading	Scan manifest	●				13		2	NNVA
17	Unloading	Put sub manifest in supplier rack	●				17		2	NNVA
18	Unloading	Take Kanban receiving	●				13		2	NNVA
19	Unloading	Walk to staging area		→			29		2	NNVA
20	Unloading	Write information on Kanban	●				35		2	VA
21	Unloading	Put Kanban receive on the pallet	●				9		2	VA
22	Unloading	Deliver pallet to sorting area		→			78	Forklift	2	NNVA

No.	Process	Activity	Operation	Transport	Inspection	Delay	Duration	Tools/Medium	Number of Worker(s)	Activity Category
			Type of Activities							
23	Sorting	Scan user and pass	●				5	Scanner	3	NNVA
24	Sorting	Take the part form mesh pallet	●				8		3	VA
25	Sorting	Scan label and Kanban id	●				13	Scanner	3	NNVA
26	Sorting	Scan BT. No	●				3	Scanner	3	NNVA
27	Sorting	Put the part into BT (Pallet)	●				1683		3	VA
28	Supply	Wait for loaded BT				▼	76		1	NVA
29	Supply	Pick loaded BT	●				3		1	NNVA
30	Supply	Scan BT. No	●				173		1	NNVA
31	Supply	Deliver to zone W/X/Y/Z		→			231	BT + Towing	1	VA
32	Binning	Arrive at primary address		→			2	BT + Towing	1	NNVA
33	Binning	Scan BT. No	●				11	Scanner	1	NNVA
34	Binning	Scan primary address and part no	●				13	Scanner	1	NNVA
35	Binning	Check address and part master data			■		11	Scanner	1	NNVA
36	Binning	Check max stock on master data			■		132	Scanner	1	NNVA
37	Binning	Pick up parts	●				27		1	VA
38	Binning	Fill into primary address	●				42		1	VA
39	Supply	Drive to sorting area		→			164			NNVA

No.	Process	Activity	Type of Activities				Duration	Tools/Medium	Number of Worker(s)	Activity Category
			Operation	Transport	Inspection	Delay				
40	Supply	Return empty BT	●				27	BT + Towing	1	NNVA
41	Picking	Take Kanban from rack label picking	●				4		1	NNVA
42	Picking	Scan user and id	●				3	Scanner	1	NNVA
43	Picking	Scan picking header	●				3	Scanner	1	NNVA
44	Picking	Scan picking label	●				39	Scanner	1	NNVA
45	Picking	Drive to respective address		→			142	BT + Towing	1	NNVA
46	Picking	Scan part and address no.	●				17	Scanner	1	NNVA
47	Picking	Take part from address	●				23		1	VA
48	Picking	Put the part into BT	●				47		1	VA
49	Supply	Deliver to packing		→			124	BT + Towing	1	NNVA
50	Packing	Scan user and id	●				138	Scanner	1	NNVA
51	Packing	Prepare empty module	●				92	Module	3	VA
52	Packing	Scan BT no. and input module code	●				12	Module	3	VA
53	Packing	Print case label	●				4	Printer	3	VA
54	Packing	Stick label to module	●				12	Module	3	VA
55	Packing	Scan case no (open)	●				8	Scanner	3	VA
56	Packing	Wait for part				▼	823			NVA

No.	Process	Activity	Operation	Transport	Inspection	Delay	Duration	Tools/Medium	Number of Worker(s)	Activity Category
			Type of Activities							
57	Packing	Take the part in BT	●				107		3	VA
58	Packing	Scan BT label	●				10	Scanner	3	NNVA
59	Packing	Put the part into module	●				1273	Module	3	VA
60	Packing	Scan module (close) if full	●				5	Scanner	3	VA
61	Packing	Supply to yellow line	●				51	Forklift	3	VA
62	Packing	Pick module from yellow line staging	●				59	Forklift	1	VA
63	Packing	Deliver module to yellow line		→			43	Forklift	1	NNVA
64	Packing	Check if yellow line is full			■		29		1	NNVA
65	Packing	Deliver the modules to vanning		→			187	Forklift	1	NNVA
66	Vanning	Put and arrange modules to the truck	●				79	Forklift	1	VA
67	Vanning	Close the truck	●				52	Forklift	1	NNVA

Table 4.4 Small Parts Activity Classification Recapitulation (Duration)

Process	Total Duration	VA	NNVA	NVA	%NNVA	%NVA
Unloading	5114	299	1089	3726	21%	73%
Sorting	1812	1783	29	0	2%	0%
Supply	635	173	462	0	73%	0%
Binning	306	242	64	0	21%	0%
Picking	119	26	93	0	78%	0%
Packing	5413	3232	278	1903	5%	35%
Vanning	143	78	65	0	45%	0%
SUM	13542	5833	2080	5629		
%	100%	43%	15%	42%		

Table 4.5 Small Parts Activity Classification Recapitulation

Process	Number of Activities	VA	NNVA	NVA	%NNVA	%NVA
Unloading	23	5	16	1	70%	4%
Sorting	5	2	3	0	60%	0%
Supply	5	1	4	0	80%	0%
Binning	7	2	5	0	71%	0%
Picking	9	2	7	0	78%	0%
Packing	14	9	5	1	36%	7%
Vanning	2	1	1	0	50%	0%
SUM	65	22	41	2		
%	100%	34%	63%	3%		

Table 4.4 and Table 4.5 shows the recapitulation of activities in duration and activity recap. From duration recapitulation, 73% of total duration on unloading is NVA category, specifically waiting for incoming trucks and another NVA of 35% of total duration on packing , waiting for incoming parts. The duration recap completes the activity recapitulation to minimize biased judgement on categorizing activities

Table 4.6 Medium Parts Activity Classification Recapitulation (Duration)

Process	Total Duration	VA	NNVA	NVA	%NNVA	%NVA
Unloading	4799	324	1057	3418	22%	71%
Sorting	577	556	21	0	4%	0%

Process	Total Duration	VA	NNVA	NVA	%NNVA	%NVA
Supply	2022	134	936	952	46%	47%
Binning	445	384	61	0	14%	0%
Picking	119	26	93	0	78%	0%
Packing	7649	5127	283	2239	4%	29%
Vanning	122	68	54	0	44%	0%
SUM	15733	6619	2505	6609		
%	100%	42%	16%	42%		

Table 4.7 Medium Parts Activity Classification Recapitulation

Process	Number of Activities	VA	NNVA	NVA	%NNVA	%NVA
Unloading	22	5	16	1	73%	5%
Sorting	5	2	3	0	60%	0%
Supply	8	1	6	1	75%	13%
Binning	7	2	5	0	71%	0%
Picking	9	2	7	0	78%	0%
Packing	15	10	4	1	27%	7%
Vanning	2	1	1	0	50%	0%
SUM	68	23	42	3		
%	100%	34%	62%	4%		

Table 4.6 and Table 4.7 shows the activity classification recap for medium parts. There is a significant difference in duration due to the process of returning BT after being delivered from sorting to zone M/N requires the process of picking empty BT from packing, forming a milk run pattern for medium parts handling. The problem rises not only from waiting in unloading and packing process but also from supply process returning the empty BT.

Table 4.8 Big Parts Activity Classification Recapitulation (Duration)

Process	Total Duration	VA	NNVA	NVA	%NNVA	%NVA
Unloading	5494	299	1091	4104	20%	75%
Sorting	1712	1691	21	0	1%	0%
Supply	798	231	491	76	62%	10%
Binning	238	69	169	0	71%	0%
Picking	278	70	208	0	75%	0%

Process	Total Duration	VA	NNVA	NVA	%NNVA	%NVA
Packing	2853	1623	407	823	14%	29%
Vanning	131	79	52	0	40%	0%
SUM	11504	4062	2439	5003		
%	100%	35%	21%	43%		

Table 4.9 Big Parts Activity Classification Recapitulation

Process	Number of Activities	VA	NNVA	NVA	%NNVA	%NVA
Unloading	22	5	16	1	73%	5%
Sorting	5	2	3	0	60%	0%
Supply	7	1	5	1	71%	14%
Binning	7	2	5	0	71%	0%
Picking	8	2	6	0	75%	0%
Packing	16	10	5	1	31%	6%
Vanning	2	1	1	0	50%	0%
SUM	67	23	41	3		
%	100%	34%	61%	4%		

Table 4.8 and Table 4.9 shows the activity classification recapitulation for big parts. The shorter duration on big parts is caused due to supply, binning, and picking handled by 1 operator with towing for faster travel between areas. The usage of towing as a mean of transportation greatly reduce the time needed, this is only applicable for big parts handling only.

Overall, the main source of NVA category lies within waiting processes in unloading, supply, and packing. Further analysis on the impact of NVA's and relation to 7 waste categories will be explained in further chapters.

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CHAPTER 5
MODEL CONSTRUCTION AND INITIAL SIMULATION

In this chapter, the process in constructing and developing simulation model starting from conceptual model construction, simulation model construction, verification, and validation.

The observed system itself is a warehouse consisting of several processes. Figure 5.1 shows the general flow of the observed system. The warehouse processes.

First, trucks will dock on inside the warehouse, delivering parts in the form of pallets which will be unloaded and reloaded during the unloading process. Second, unloaded pallets will then be moved to sorting area for the sorting process to be sorted to parts according to its order type, which later affect whether they will be stored inside the warehouse or directly packed and delivered. Third, parts that has been sorted is delivered to the respective designation on supply process. Fourth, parts that are required to be stored inside the warehouse are put into racks on the binning process. If the racks are full and no available space to store, the parts are then put into reserve zone on reserve process that acts as secondary storage for overflowing parts. Refill process is refilling understocked racks on main zone from parts located on reserve zone. Fifth, parts that are listed on receiving order will be picked and delivered to packing. Sixth, orders that suffice the required parts will then be packed into modules. The accumulated modules will then be moved to yellow line for cargo simulation which will later be packed into container on vanning process.
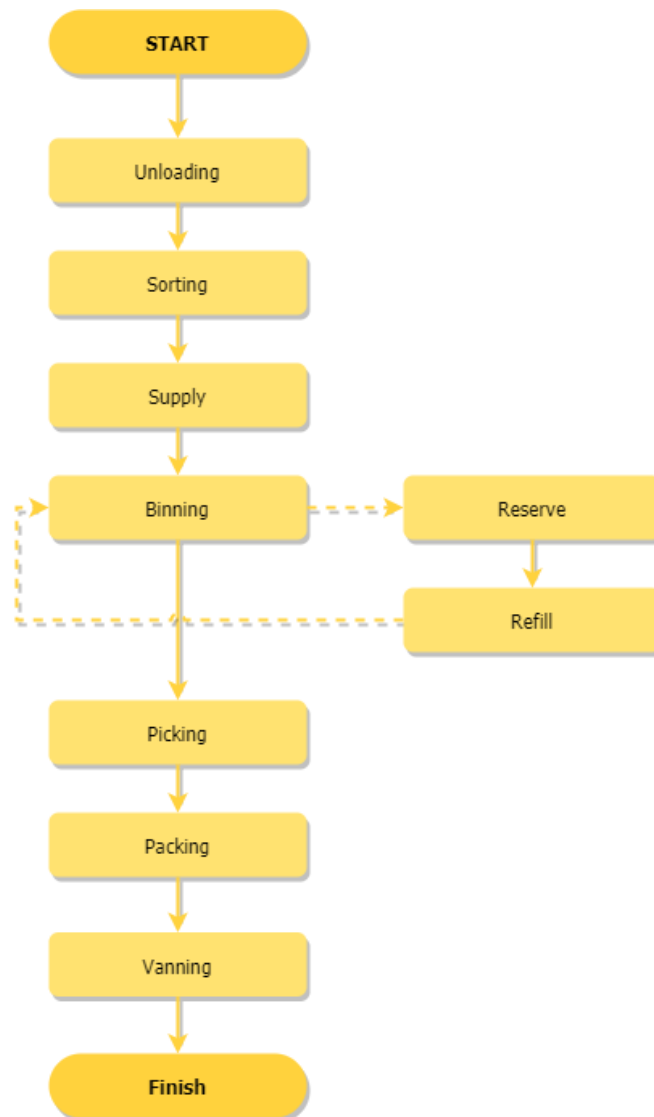
Figure 5.1 Observed System General Flow

5.1   Conceptual Model Construction

In this sub-chapter, the conceptual model for each given process will be delivered. It will be broken down into sections for each occurring process inside 7K warehouse operation. The complete overall conceptual model will be delivered in the form of swimlane diagram in Appendix 1.

5.1.1   *Unloading Process*

Figure 5.2 and Figure 5.3 shows the conceptual model of unloading process. Unloading process is where 7K warehouse accept incoming

shipment of parts from supplier, as stocks or as a crossdocking facility for direct shipment. The amount of incoming shipment is pre-determined by forecasting team, forecasting the demand of spare parts in the market. Due to the nature of the demand, over and under-estimation has a high occurrence, which affect the rest of the process since a warehouse operation is highly affected by the amount of inventory it has.
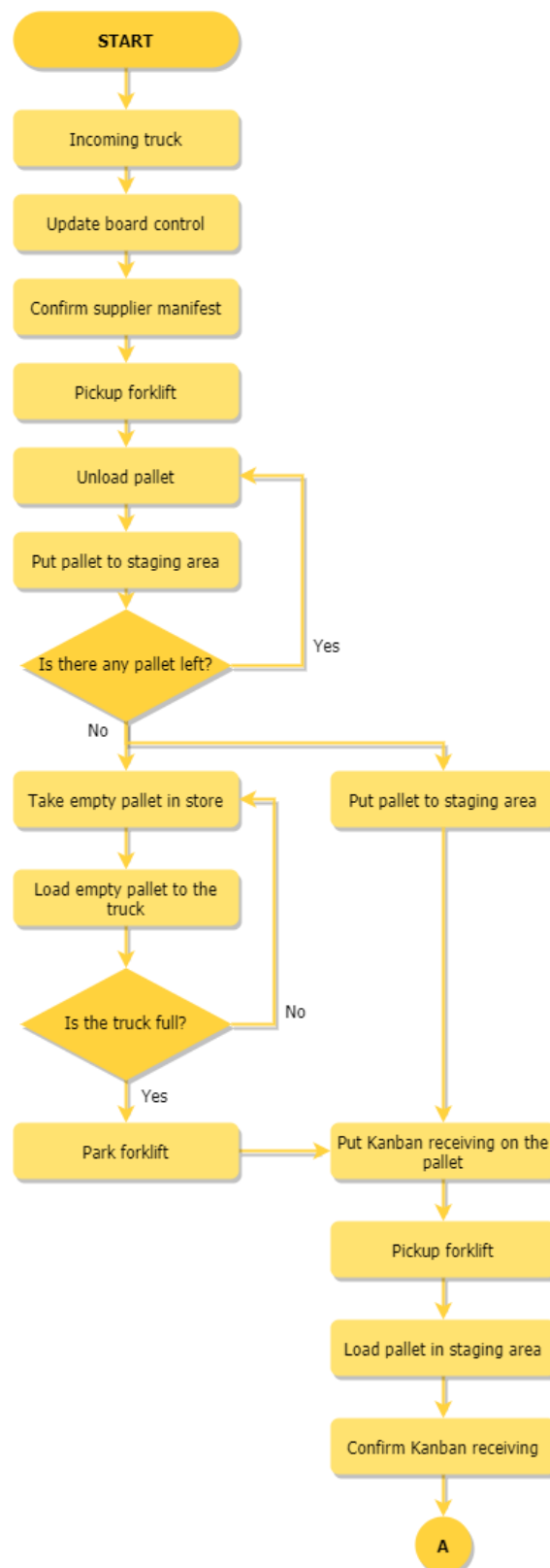
Figure 5.2 Unloading Process Conceptual Model

69
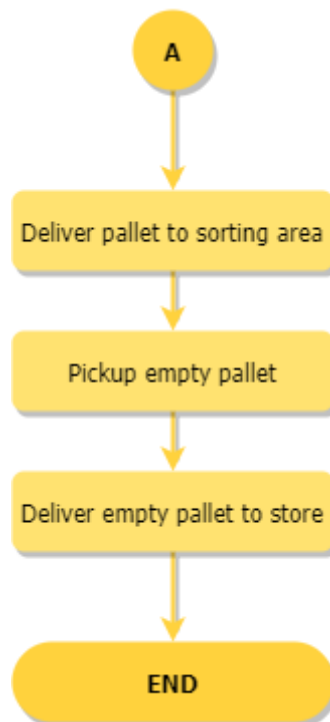
Figure 5.3 Unloading Process Conceptual Model (Continue)

5.1.2 *Sorting Process*

Figure 5.4 shows the conceptual model of sorting process. During sorting process, incoming parts are sort by their Kanban receiving into which type of order they are and where to store it. It differentiates through the order type. Type 1 is classified as regular stock replenishment which will be sorted by size and zone. On the other hand, type 2 indicates that the parts inside the BT are not for stocking purposes, but as a direct shipment or it is called as crossdocking order.
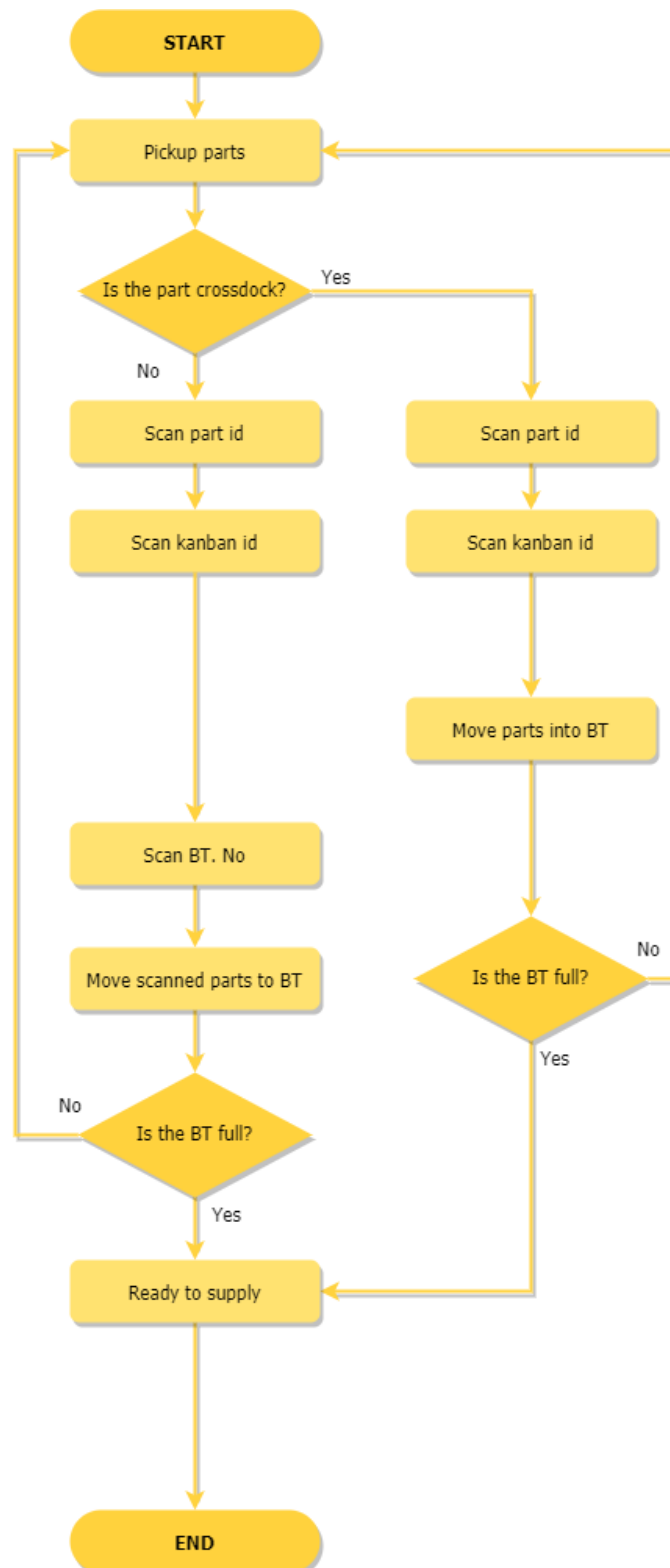
Figure 5.4 Sorting Process Conceptual Model

5.1.3 *Supply Process*

Figure 5.5 shows the conceptual model of supply process. Supply process act as a bridge between sorting and binning process. It delivers already sorted parts to each respective zone and order. If the order is crossdock, it will deliver to packing immediately.
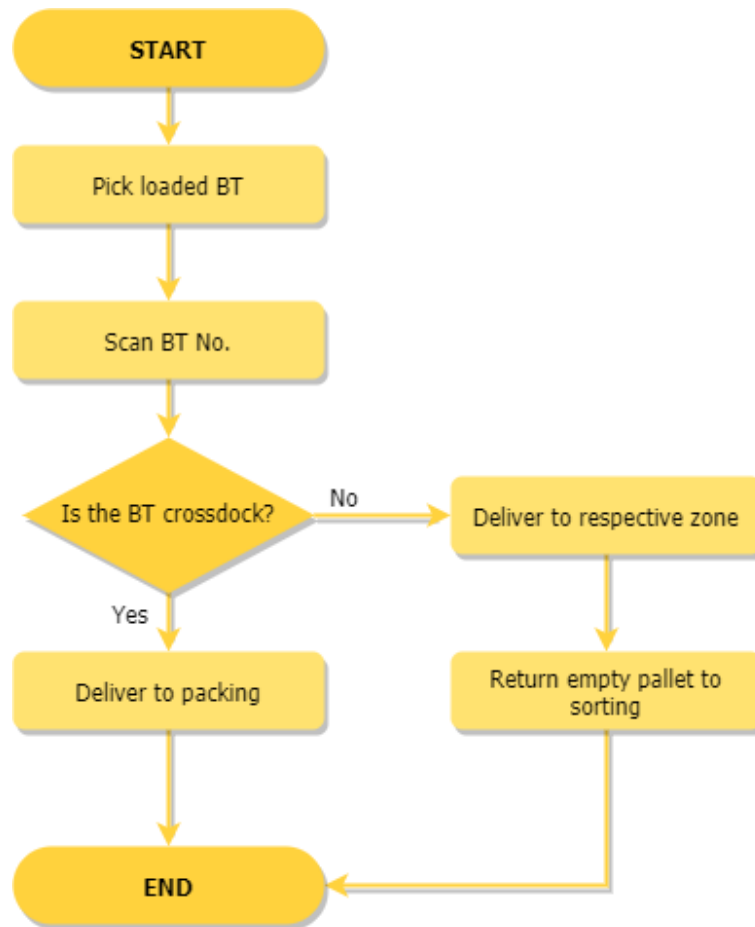
Figure 5.5 Supply Process Conceptual Model

5.1.4 *Binning Process*

Figure 5.6 shows the conceptual model of the binning process. The binning process is the process to store sorted parts according to its zone. The process is done in priority for which each zone is filled based on list. For example, zone W will be filled first until it reaches maximum capacity, then it will move to the next zone.

Figure 5.6 Binning Process Conceptual Model

5.1.5 *Reserve Process*

Reserve act as a backup for refilling understocked zone and as an extension for stocking overflowed zones. If there are space available for reserve, the overflowed parts will be stored. If not, it will be returned to staging and reported as overflow problem. Figure 5.7 shows the flow of the process.
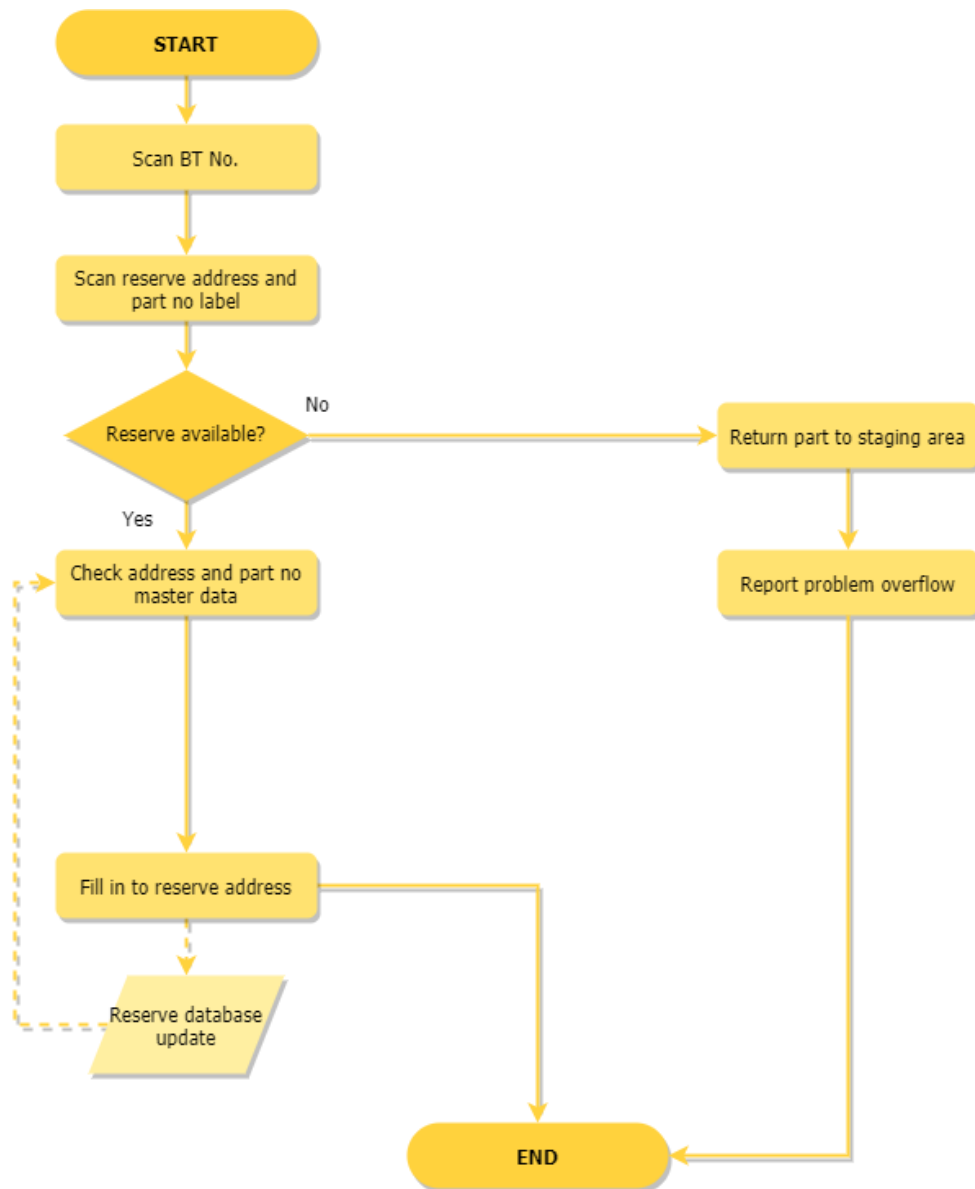
Figure 5.7 Reserve Process Conceptual Model

5.1.6 *Refill Process*

Refilling can be done if there is stock available on reserve zone, if there are no stock available, it will report as an understock problem to be handled by purchasing department. Figure 5.8 shows the flow of refill process.

Figure 5.8 Refill Process Conceptual Model

5.1.7   *Picking Process*

Picking is the order fulfillment operation, where order is processed, and parts are picked accordingly. The picking is done correspondingly between zone starting from zone W for big parts, M for medium parts, and S for small parts. If there is no stock available, it will be recorded as shortage problem and will be handled by other department. Figure 5.19 shows the flow of picking process.
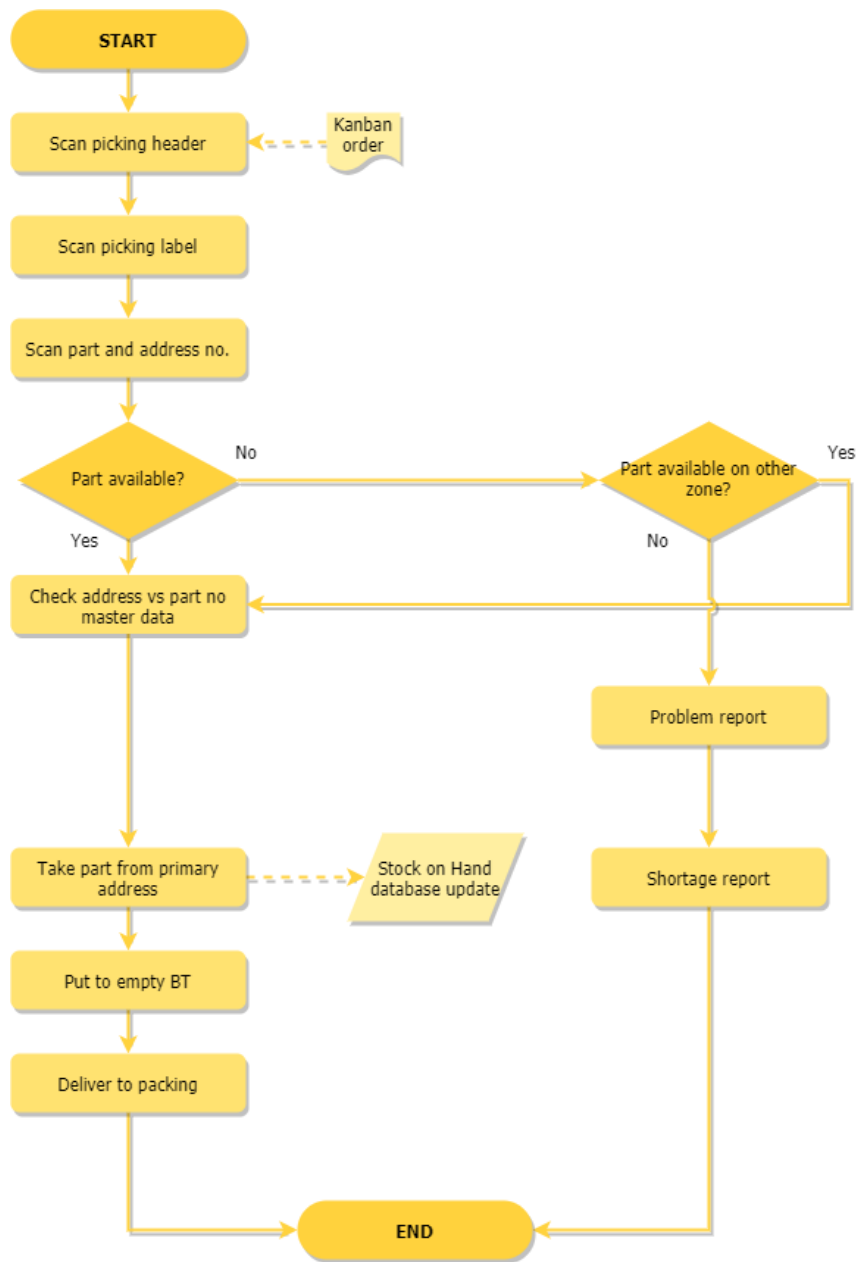
Figure 5.9 Picking Process Conceptual Model

5.1.8 *Packing Process*

Packing is the last 2 steps before finishing the operation. It packs parts into modules. The packing here follows certain combination due to each module can fit with different combination of amount of part. After the parts are carefully packed into modules, the modules will then be delivered to yellow line for fitting before putting it on real container. The purpose of

yellow line is to simulate how many modules needed for one container on one shipment. Figure 5.10 shows the flow of packing process.
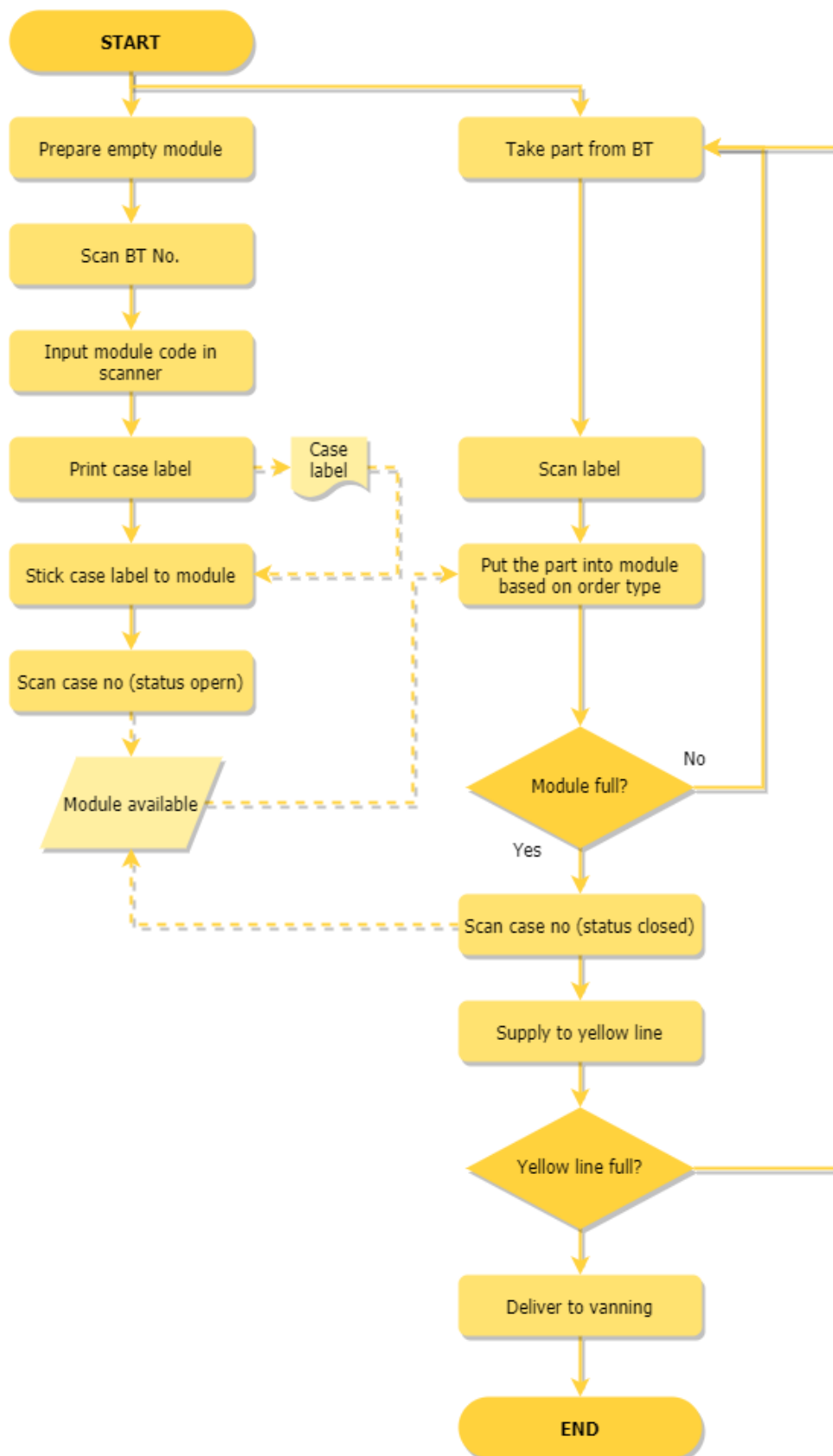
Figure 5.10 Packing Process Conceptual Model

5.1.9 *Vanning Process*

The last step is vanning process, the process of filling modules into containers after the yellow line process. Figure 5.10 shows the flow of vanning process.
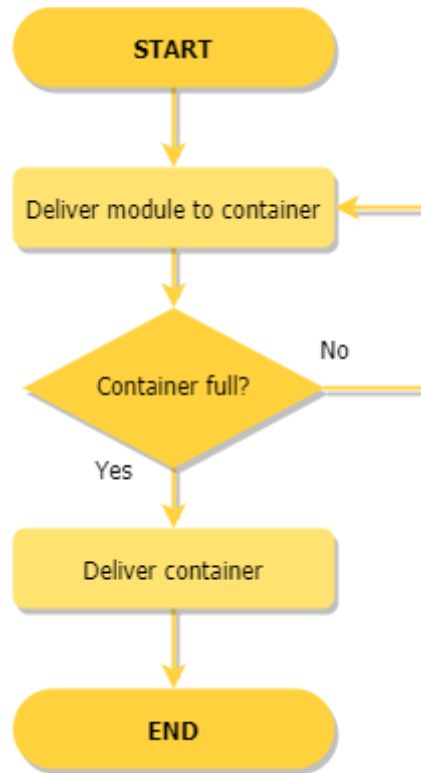
Figure 5.11 Vanning Process Conceptual Model

5.2 Simulation Model

The simulation model is based on the conceptual model constructed previously. The simulation approach is based on discrete event simulation, supported using Arena software that will be used to construct and simulate the model. Simulation period is 30 day, same as the observed period for the existing system.

5.2.1 *Model Overview*

All process will be delivered in the form of sub model to first understand the overview of the process better as shown in Figure 5.12.

Figure 5.12 Simulation Model Process Overview

5.2.1.1 Unloading Sub-Model

     The unloading sub-model consist of processes for unloading and staging process. Figure 5.13 shows the processes inside of the sub model.
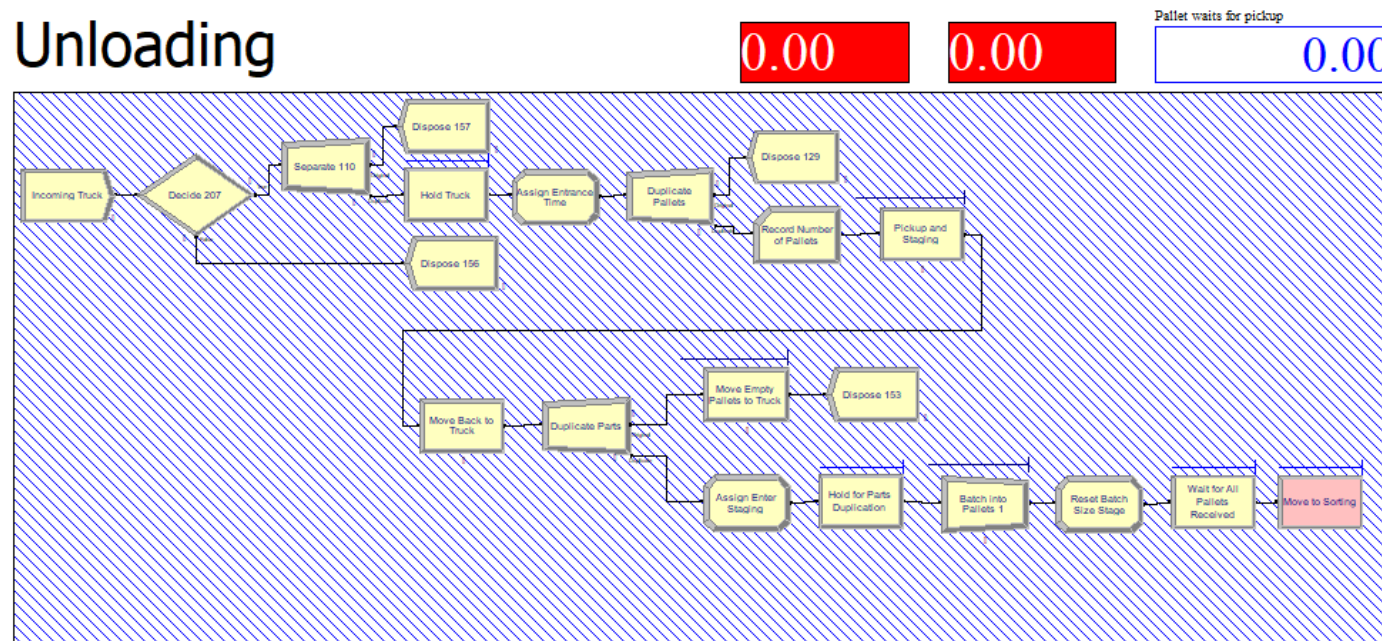
Figure 5.13 Unloading Sub-Model

Unloading process highly affect the course of the overall flow, the amount of incoming trucks is determined using historical data of incoming truck delivery using input analyzer feature to generate shipments. The later shipments then change to pallets. The determining process of how many pallets incoming also uses historical data on how many pallets on each shipment, processed through input analyzer to generate pallets. After the set number of pallets enter, the pallets then changed to parts using the same method to generate shipment and pallets. The parts then batched into 1 pallet for each of the parts generated. The pallet will be loaded on dollies, which will be later delivered to sorting process while the empty one will be loaded back into the truck.

5.2.1.2 Sorting Sub-Model

The next process after unloading is sorting, sorting the parts coming according to its order type and size which later will be delivered and put on each size corresponding zone. Figure 5.14 shows the process inside the sorting sub-model.
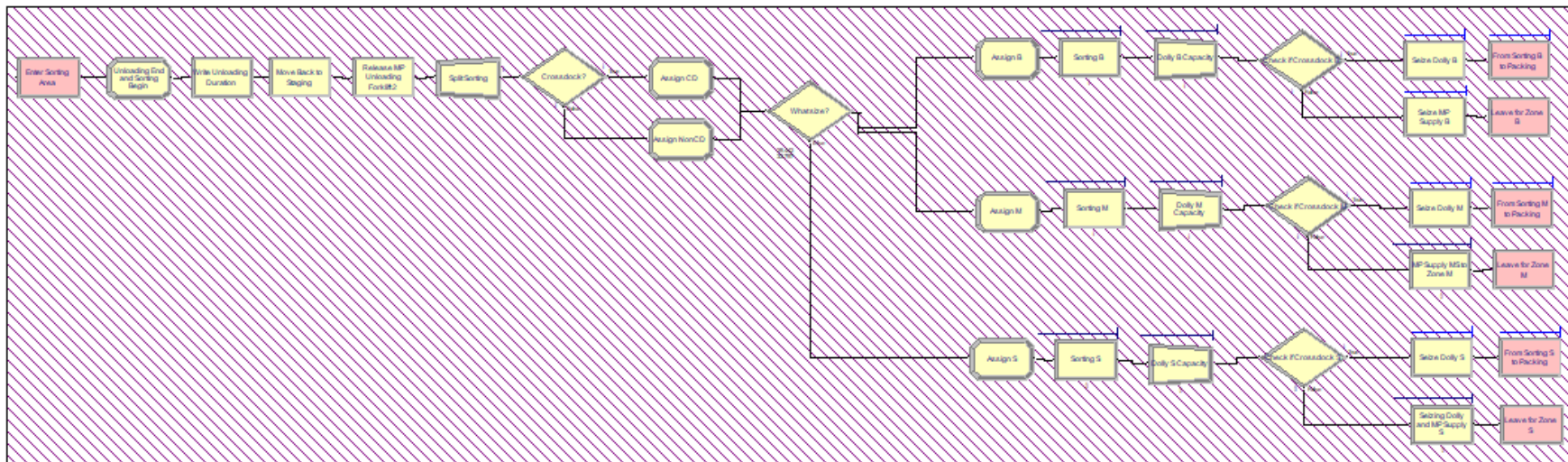
Figure 5.14 Sorting Sub-Model

Incoming parts from staging will be sorted from the order type, size, and zone. Through the decide module, the parts will be assigned attributes whether they are crossdock parts or regular order one. The difference from these two types of order is that crossdock parts will not be put through storing in zone first but directly to packing for shipment. Both will still be sorted through size, and for regular one will be sorted again for corresponding zone according to its size.

5.2.1.3 Binning Sub-Model

After thoroughly sorted, the parts are supplied to each zones available, 4 zones for big parts (W,X,Y,Z), 2 zones for medium parts (M,N), and 1 zone for small parts (S). Figure 5.15 and Figure 5.16 shows the overall process inside the sub-model.
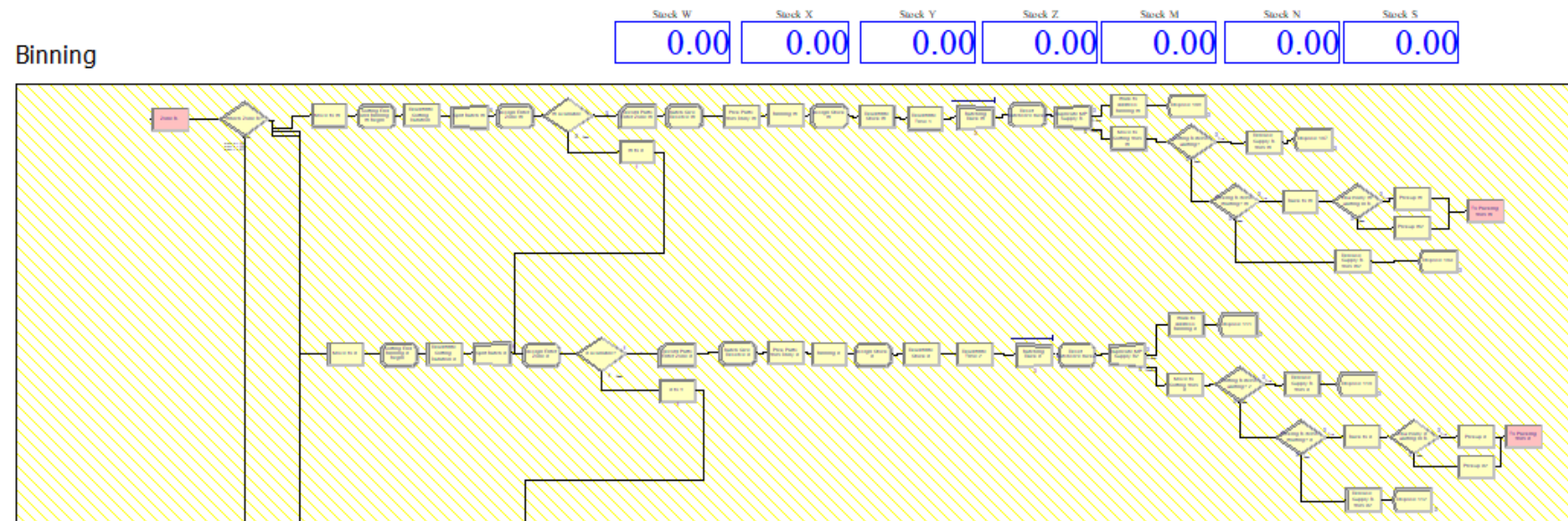
Figure 5.15 Binning Sub-Model
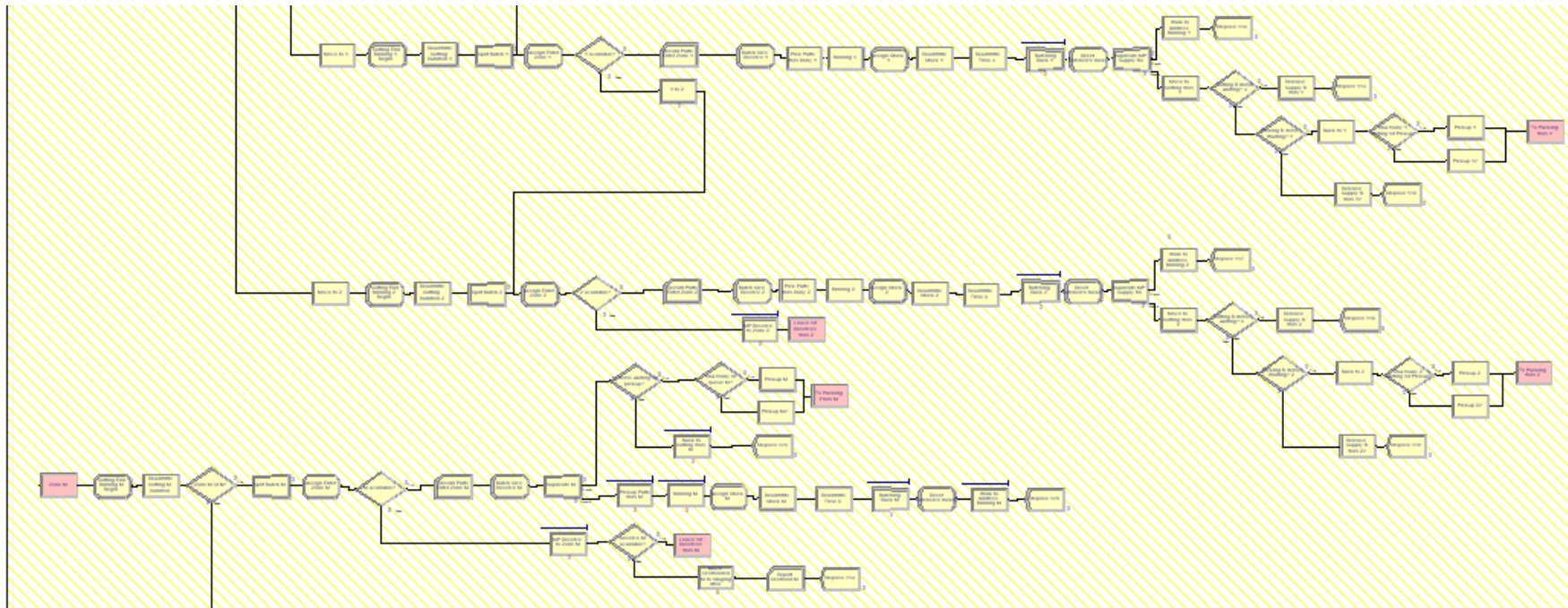
Figure 5.16 Binning Sub-Model (continue)
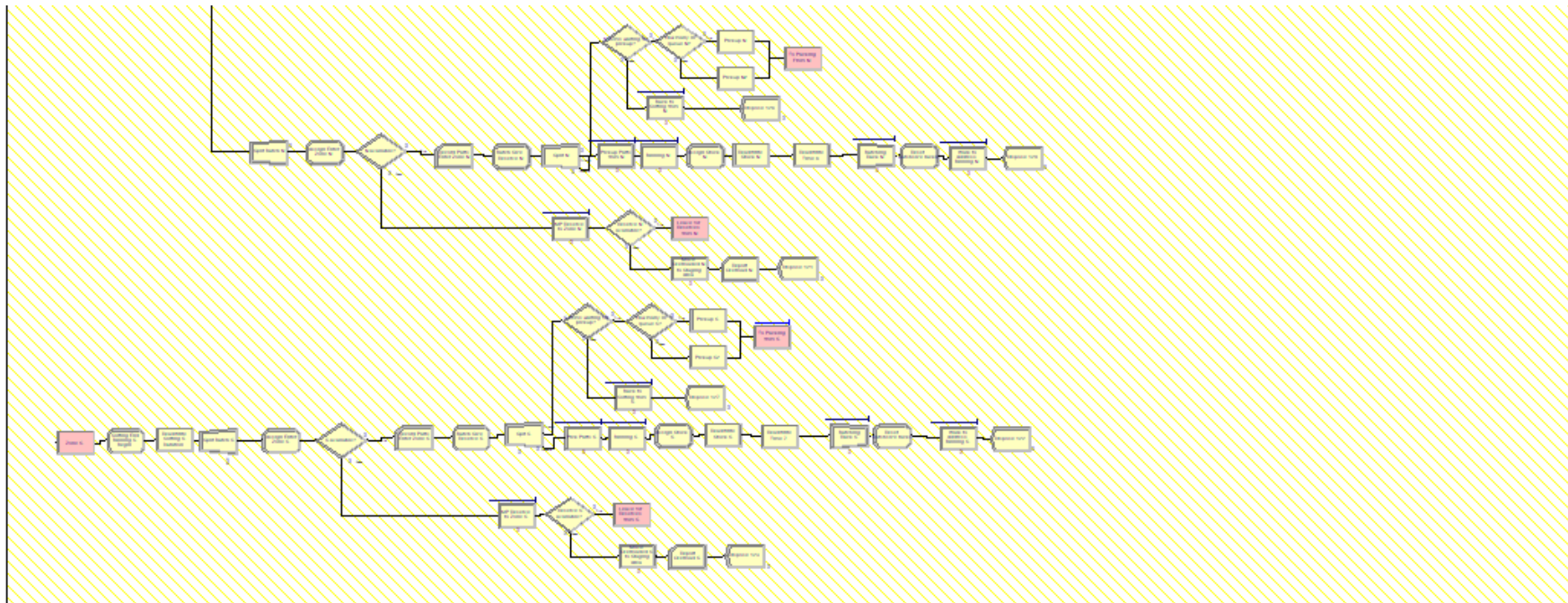
Figure 5.17 Binning Sub-Model (continue 2)

For big and medium parts, binning is done in a priority order, meaning that zone W and zone M will be filled first until they reach maximum capacity, then the parts will move on to the next zone which is X and M. If all the zones are not available, the parts will then be moved to reserve zone specifically design to hold overflowing racks.

5.2.1.4 Reserve Sub-Model

As stated previously, each rack has a maximum capacity. When a rack reaches it maximum capacity while there are still parts needed to be put, the parts will then be moved and stored to reserve zones. Each type of parts has its own reserve zone, except for medium and small parts are merge into one reserve zone. The sub-model consists of reserve and refill process, Figure 5.18 shows the overall process of the reserve sub-model.

Figure 5.18 Reserve Sub-Model

The mechanism does not differ too much from the normal binning operation, except it is done in reserve zones. Each zone has its own capacity, and the model will check whether there are available spaces to fill in, if there are no more spot to fill in the parts will then

be moved back to staging area for problem report on overflowing products. The reserve sub model also covers the refill process of the overall operation where basically refilling up empty racks on binning process by picking overflowing parts from reserve zones rather than ordering new parts from suppliers. The model checks what zone is under the minimum threshold and will the deliver the exact amount needed to refill. If there are no stock left on reserve zones, it will be reported as understock problem to be handled by other department.

5.2.1.5 Picking Sub-Model

Order fulfillment is done in the picking process, operator will receive order on what part to pick and deliver to packing. Figure 5.19 shows the overall process inside picking sub-model.
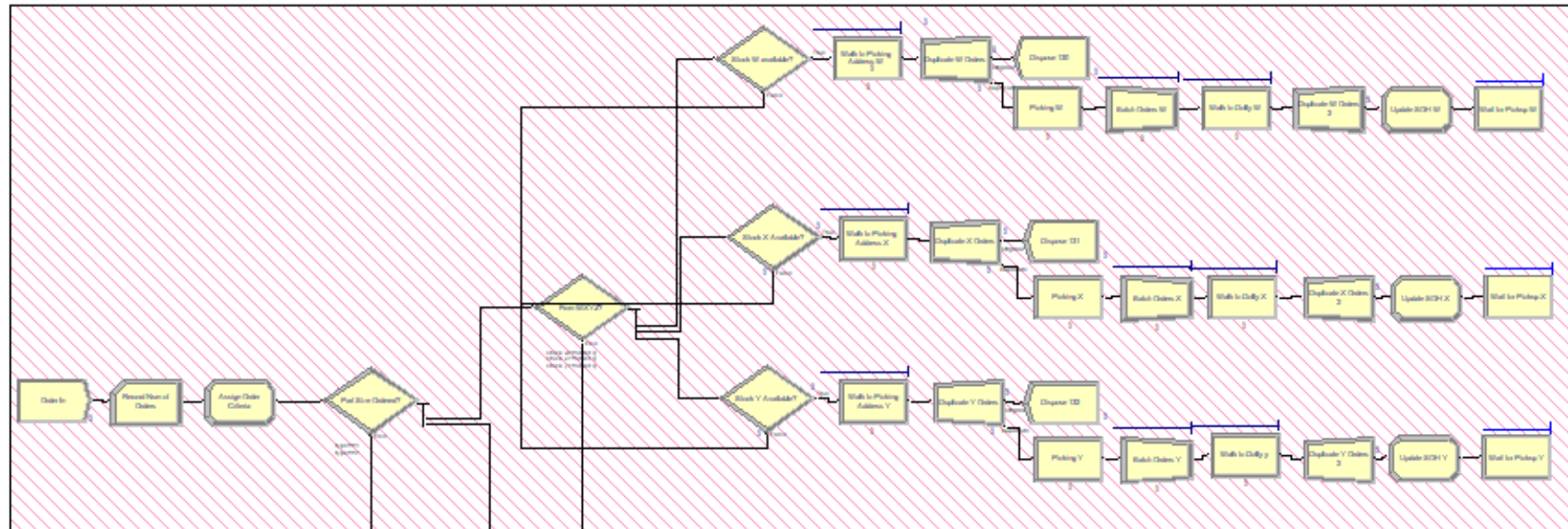
Figure 5.19 Picking Sub-Model
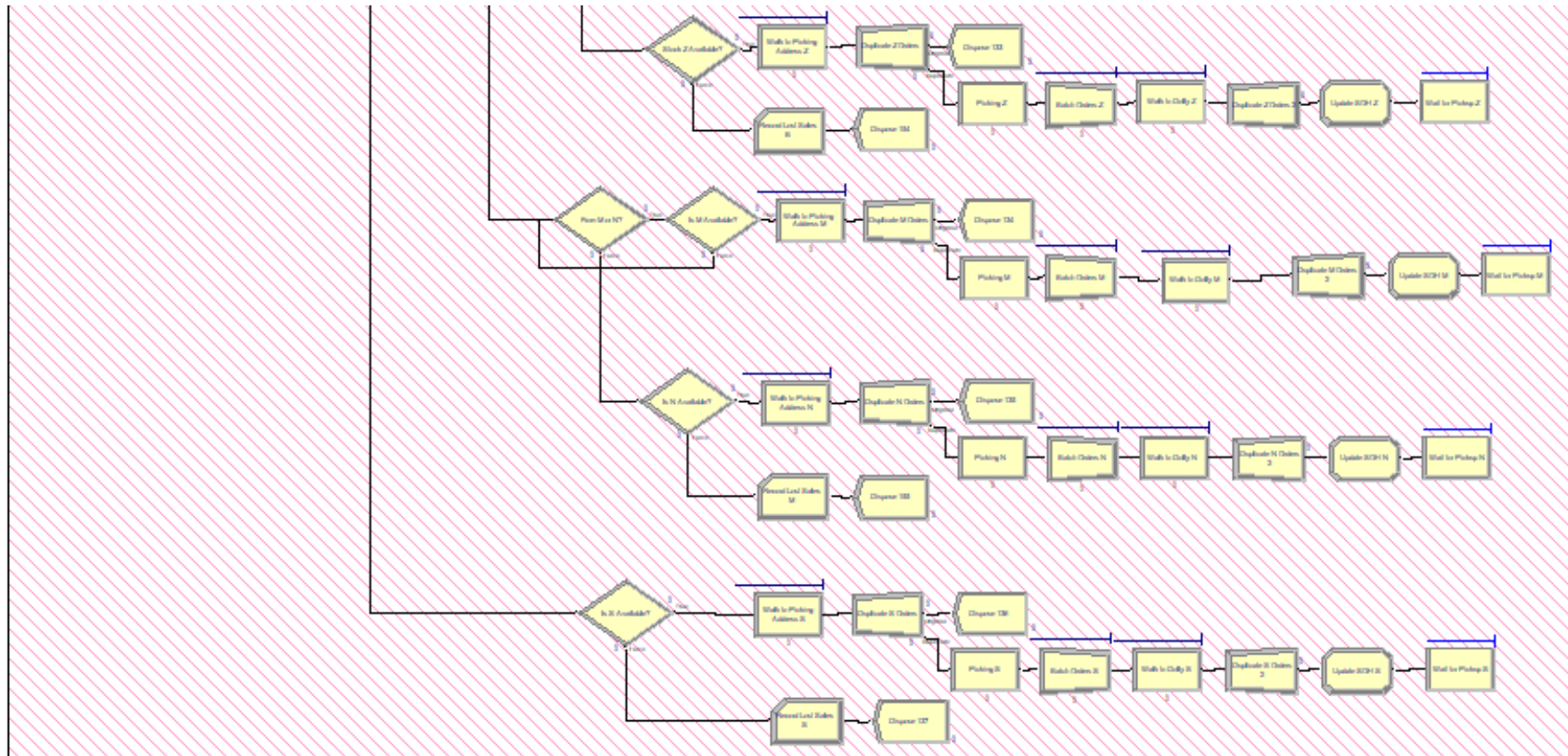
Figure 5.20 Picking Sub-Model (continue)

Order are generated randomly to mimic the unpredictability nature of spare part demand pattern. The incoming order will then be defined to what size and amount the order need. The picking process will then pick starting from the first zone for each part size, if it cannot find on the first zone, it will move to the next one, roughly the same process on binning process except in pick parts out from the racks. If there are no parts available to pick, it will be reported as lost sales.

5.2.1.6 Packing Sub-Model

The last step in fulfilling the order is packing, the sub-model consist the packing and vanning process. Figure 5.21 shows the overall process inside packing sub-model.
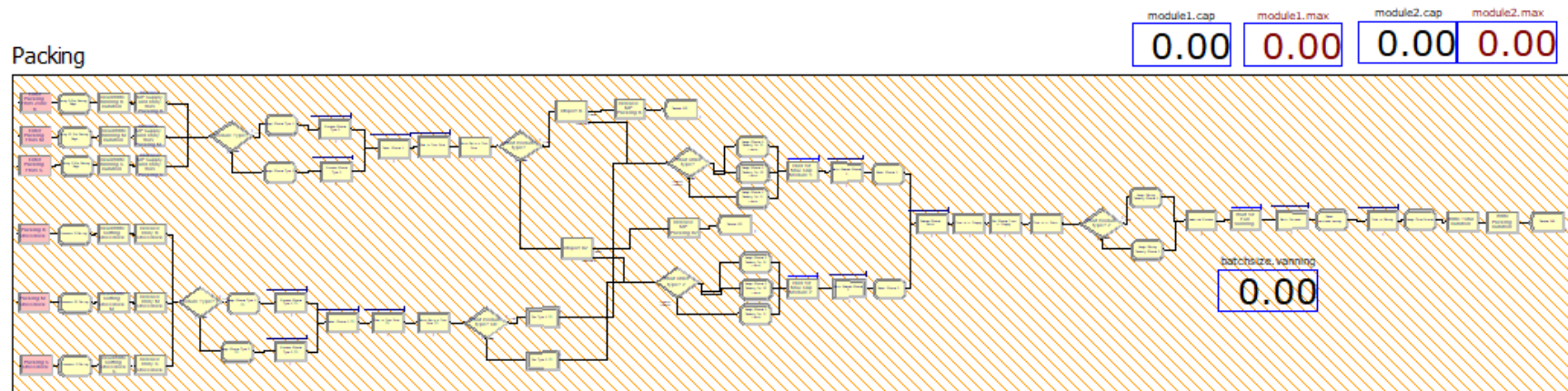
Figure 5.21 Packing Sub-Model

The parts arrived from both sorting and picking process will be processed for delivery in packing. The parts will then be assigned on which case will be used for packing; the decision is still based on proportion since arena is incapable of modelling the logic from too many combinations to fill the module. The parts will then be batched to one case and will then be delivered to yellow line for fitting before

stored in container for delivery. The logic follows the same as the case logic in for the yellow line fitting. After completing one yellow line, it will then the cases will be delivered to container for delivery.

5.2.2   *Model Verification*

Verification is the process to determine whether the model operates as intended (Harrel, 2011). In other words, building the model right. In this step, two types of verification will be performed which are syntax error verification and semantic error verification.

5.2.2.1 Syntax Error Verification

Verifying syntax error is intended to check whether there is an error in coding or building the input of modules in ARENA by using the debug feature available on ARENA. Figure 5.22 shows the result of the error checking.
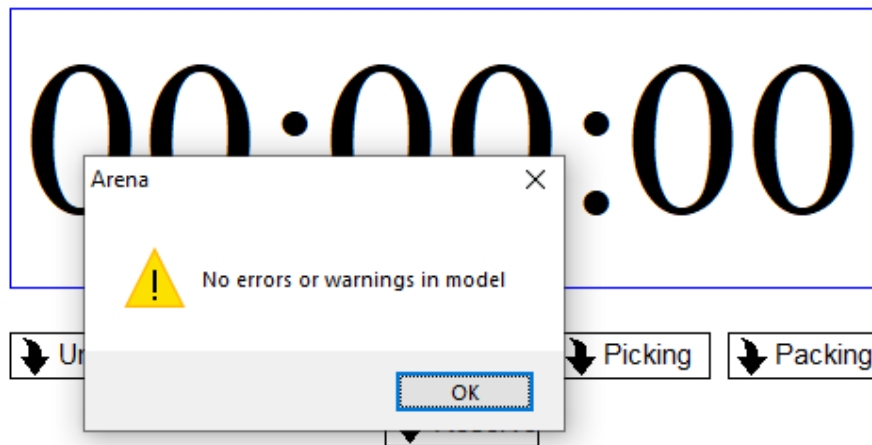
Figure 5.22 Syntax Error Verification

The model already pass verification for syntax error. Therefore, the model has no error in term of coding or building the module or blocks on ARENA.

5.2.2.2 Semantic Error Verification

Semantic error verification is intended to trace the error in term of logic to follow based on conceptual model. The animation feature provided by ARENA will be used to conduct verification of semantic error.

A.   Unloading Sub-Model

First to verify is the unloading sub-model. Following the conceptual model, the logic that should be checked is the manpower (MP) status for picking pallets. Figure 5.23 shows the check for unloading sub-model.
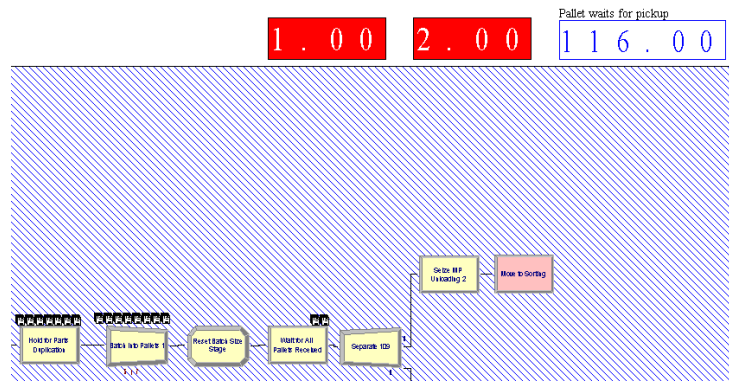
Figure 5.23 Semantic Error Check Unloading Sub-Model

Pallets will be moved from unloading or staging to sorting if the MP is available. The idling is shown by the red box showing number 1. 2 indicates that the MP is being used to transfer. Another thing to check is the batching of parts into one pallet. Every incoming part will be batch into one pallet for delivery.

B. Sorting Sub-Model

Sorting logic itself is not too different from unloading process. The process would carry on if the resources used are available, from MP to dollies. Figure 5.24 shows the check for sorting sub-model.
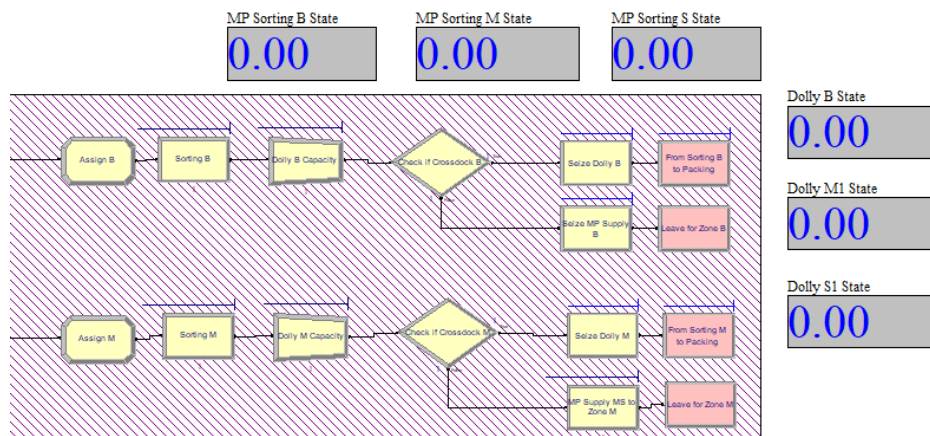
Figure 5.24 Semantic Error Check Sorting Sub-Model

C. Binning Sub-Model

Using plot graph and variable animation to measure the level of space available to stock parts. Figure 5.25 shows the check for binning sub-model.
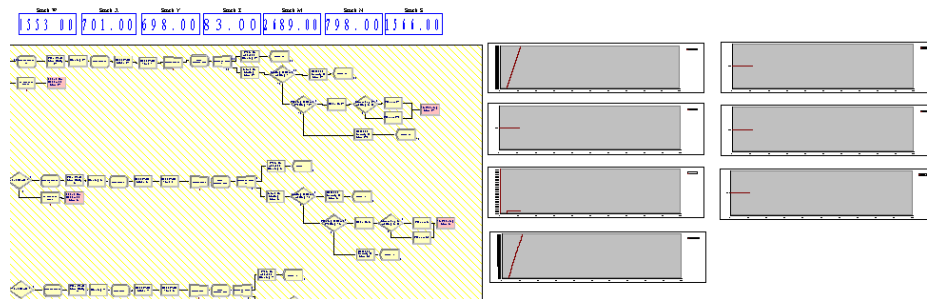
Figure 5.25 Semantic Error Check Binning Sub-Model

The variable animation shows the current available space on racks to store parts. The plot graph shows the increase of space used relative to time.

D. Reserve Sub-Model

Reserve also uses variable animation to show the level of spaces used on reserve zones. Figure 5.26 shows the check for reserve sub-model

100
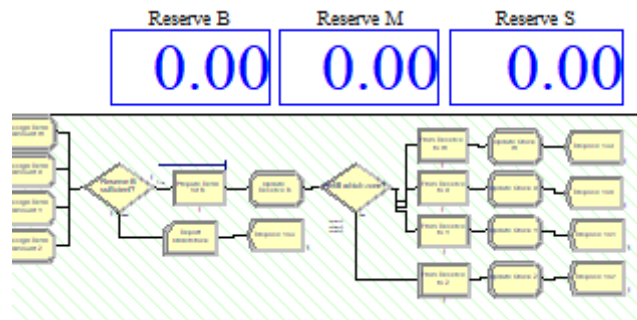
Figure 5.26 Semantic Error Check Reserve Sub-Model

The refill process will run if the conditions are met, if the stock stored inside the zones dropped to certain level while there is still reserves available, the refill process can be executed.

E. Picking Sub-Model

Using variable animation to show the level of available stock ready to be picked. If there is no stock available the process will record as lost sales. Figure 5.27 shows the check for picking sub-model.
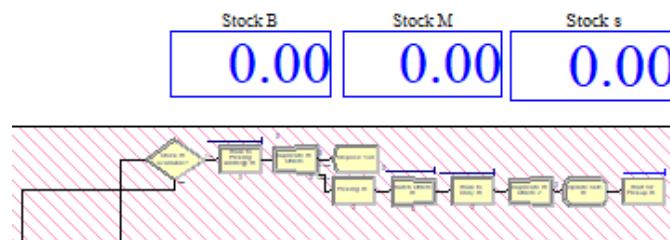
Figure 5.27 Semantic Error Check Picking Sub-Model

F. Packing Sub-Model

The last one to verify is the packing sub-model. Using variable animation to check the capacity for each case used for packing. If the case has reach maximum capacity, it will move forward to yellow line process for fitting before storing to container. Figure 5.28 shows the check for packing sub-model.
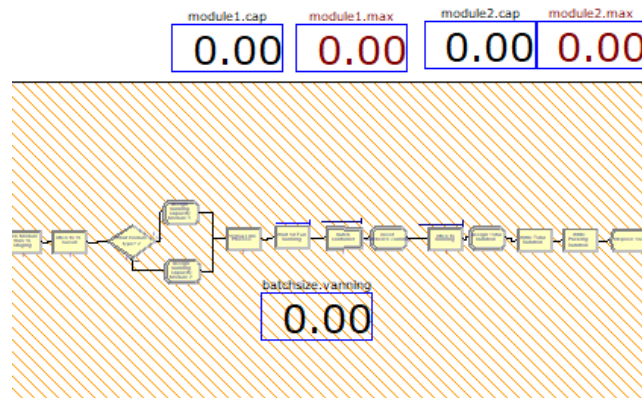
Figure 5.28 Semantic Error Check Packing Sub-Model

5.2.3 *Number of Replication*

The nature of simulation is what to be called random input random output (RIRO). Running the simulation model once may not give enough sample to represent the real system being observed. Thus, it is necessary to run the simulation several times. The amount of this repetitive process is what is called replication. Without replication, simulation output will be unable to form an estimation interval (Nurhadi Siswanto, 2017).

In determining the number of replications needed, the performance parameter is the racks utilized for stock keeping. The rack utilization will be based on the period of 1 month, on the February 2020. The initial number of replications is 8, with each replication consist of 30 days simulation time. The result of the simulation over the course of 8 replication is shown in the table below.

Table 5.1 Simulation and Existing Result Comparison

Replication number	Rack Utilization	
	Simulation	Existing
1	68%	73%
2	72%	73%
3	74%	73%

Replication number	Rack Utilization	
	Simulation	Existing
4	69%	73%
5	72%	73%
6	78%	73%
7	73%	73%
8	70%	73%
Average	72%	73%
St. Deviation	3%	0%

Racks utilization is calculated on the data generated from the read write module that capture the racks condition during the simulation period. After obtaining result shown on table above, the next step is determining the desired half width (hw). From the simulation report, the obtained hw value is 2%. The author wishes the hw would not exceed the maximum value the author set on 4%. The calculation is shown below.

$$hw = 2\%$$
$$hw' = 4\% \times 73\% = 2.92\%$$
$$hw < hw' (replication\ is\ sufficient)$$

Previous calculation showed that the 8 replication is enough since the hw is less than hw'. However, the author is interested in finding how many replications exactly needed to run. The calculation is shown below.

$$n' = \left[\frac{Z_{\alpha/2} \times s}{hw'}\right] = \left[\frac{1.96 \times 3\%}{2.92}\right] = 3.94 \approx 4\ replications$$

From the calculation above, it only needs 4 replications to reach the desired half width. However, 8 replications are taken anyway to run the simulation to get better and more representative result.

5.2.4 *Model Validation*

Validation is the last step in constructing simulation model. The process to determine whether the model is meaningful and accurate representation of the real system. In other words, checking whether we built the right model or not. In validating, comparing the output of simulation and real system is necessary. Since the samples are independent, Student's t hypothesis test is used to compare the average from the simulation output to the real system. The parameter used remain the same with the one during determining the number of replications which is rack utilization. The hypothesis for validation is formulated below.

$$H_0 : \mu_1 = \mu_2 \ (no \ difference \ between \ simulation \ and \ real \ system)$$
$$H_A : \mu_1 \neq \mu_2 \ (difference \ between \ simulation \ and \ real \ system)$$

Using the Data Analysis feature on Microsoft excel, the parameters used for Student T test are:

- Hypothesized mean difference is 0
- Significance level (α) is 5%
- Degree of freedom (df) is 14

Table 5.2 *Student's t* Hypothesis Test Result

Parameters	Simulation	Existing
Mean	0.72	0.73
Variance	0.001	0
Observations	8	8
Pooled Variance	0.0005	
Hypothesized Mean Difference	0	
df	14	
t Stat	-0.894427191	
P(T<=t) one-tail	0.19310611	
t Critical one-tail	1.761310136	
P(T<=t) two-tail	0.38621222	
t Critical two-tail	2.144786688	

From the table above, the t Stat value is -0.89. This value will be compared to t Critical two tail value as follow.

$$-t\ critical < t\ stat < t\ critical$$
$$-2.144 < -0.89 < 2.144$$
$$Do\ not\ reject\ H_0$$

The comparison above shows that the t Stat is still within the range bounded by t Critical. Moreover, the p value of 0.08 is greater than 0.05 as error level. By this result, it can be concluded that the author should not reject the null hypothesis. Thus, the simulation model is valid and can represent the real system.

5.3   Initial Warehouse Performance

The warehouse performance will be based on 25 indicators by Frazelle (2002) as explained in sub-sub chapter 2.3.2, although the measured category is only three category of productivity, cycle time, and utilization. The performance result is shown in the Table 5.3

Table 5.3 Initial Warehouse Performance Indicator

Process	Warehouse Performance Indicator		
	Productivity	Cycle Time	Utilization
Unloading	10.68 pallets/manhour	1.24 hours/unloading	100% MP and Area
Sorting	296.48 parts/manhour	1.28 hours/sorting	100% MP and Area
Supply	14.8 part/manhour	8.40 hours/sorting	100% MP
Binning	7.23 parts/manhour (zone S) 6.32 parts/manhour (zone MN) 16.73 parts/manhour (zone WXYZ)	0.21 hours/binning S 1.93 hours/binning MN 16.07 hours/binning WXYZ	100% MP 73% Storage area
Reserve	1 part per manhour	3.56 minutes/reserve	100% MP and area

Process	Warehouse Performance Indicator		
	Productivity	Cycle Time	Utilization
Picking	3.59 orders/manhour	5.42 hours/sorting	100% MP and Area
Packing	2.89 modules/manhour	15.02 hours/packing	100% MP and Area

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CHAPTER 6

WASTE IDENTIFICATION & ANALYSIS AND IMPROVEMENT FORMULATION

In this chapter, both result from process activity mapping and simulation model will be analyzed to identify each waste occurs inside the operation. After identifying the occurring waste, the next step is to analyze and find the root cause of the waste, while formulating improvement plans to eliminate those waste.

6.1 Waste Identification

The identification process is through observing the result from simulation to see how the process work, and from the direct observation from the making of process activity mapping (PAM). As it has previously explained in chapter 2, wastes are identified to 7 waste that is over production, over processing, inventory, defect, waiting, motion, and transportation.

From the model simulation and report after simulation, it indicates that there are few problems in waiting time throughout the processes. It is shown in the simulation that the waiting occurs when there is no resource to handle the operation, resulting in stacks of queue. Other waste to see is the inventory, lots of parts coming and the warehouse just does not have enough space available to accommodate it.. Transportation, the complexity of routing for supply manpower. However, there are no findings for other waste occurring inside the warehouse. Table 6.1 shows the waste identification recapitulation for the whole warehouse operation.

Table 6.1 Waste Identification Recapitulation

Waste	Found in process	Sub-Waste	Sub-Waste ID	Simulation result
Inventory	Binning – Medium Part	Part overload	W01	394 overloaded parts

Waste	Found in process	Sub-Waste	Sub-Waste ID	Simulation result
Waiting	Unloading	Wait incoming trucks	W02	311.47 minutes average waiting time
		Loading empty pallets	W03	16.84 minutes average waiting time
		Pallets waiting for pickup	W04	28.56 pallets waiting in average
	Sorting	Parts about to be sorted	W05	5.9 parts waiting in average
	Picking	Wait for pickup Small	W06	0.3 hours average waiting time per order
		Wait for pickup Medium	W07	3.8 hours average waiting time per order
		Wait for pickup Big	W08	50.7 hours average waiting time per order
	Packing	Finished module pickup	W09	3.87 modules waiting for picking
		Deliver module to yellow line	W10	0.01 minutes waiting time for regular
		Process module	W11	0.05 minutes waiting time for fill in module

These identified wastes will then be analyzed on what is the root cause of these waste, using 5 why's analysis.

6.2 Root Cause Analysis of Waste Identified

To better eliminate waste, all the identified waste need more thorough analysis on how those waste occur and what is the root cause of it. Finding the root cause will create better improvement ideas that will effectively eliminate occurring wastes. The process of finding the root cause of each occurring waste using the 5 why's method is shown in the Table 6.2.

Table 6.2 Identified Waste 5 Why's Analysis

Waste	Process	Sub-Waste	1st Why	2nd Why	3rd Why	4th Why	5th Why
Inventory	Binning	Part overload	No more available space to store	Unused available racks to store			
			Too much part ordered	Error in part forecasting			
	Unloading	Wait incoming truck	No dock bay available				
		Loading empty pallets	No manpower available	Not enough manpower			
		Pallets waiting for pickup	Parts overflowing	No manpower available	Not enough manpower		
	Sorting	Parts about to be sorted and supplied	Parts overflowing	Slow operation	Unskilled / Unlevelled manpower skill		
					No manpower available	Not enough manpower	

Waste	Process	Sub-Waste	1st Why	2nd Why	3rd Why	4th Why	5th Why
	Picking	Wait for pickup small parts	No dollies and manpower available	Supply cycle takes too long	Not enough manpower	Route too complex	Too many variabilities in one cycle
		Wait for pickup medium parts					
		Wait for pickup big parts	Big parts binning not finished yet	Not enough manpower			
	Packing	Finished module pickup	No manpower available	Yellow line slow operation	Not enough manpower		
		Deliver module to yellow line					
		Process module type 1	Module preparation takes too long	Parts needed to complete module not available			

Table 6.3 Waste Root Cause Recapitulation

Waste	Sub-Waste	Root Cause	Root Cause ID
Inventory	Part overload	Unused available racks to store	RC01
		Error in part forecasting	RC02

Waste	Sub-Waste	Root Cause	Root Cause ID
Waiting	Wait incoming truck	No dock bay available	RC03
	Loading empty pallets	Not enough manpower	RC04
	Pallets waiting for pickup		
	Parts about to be sorted and supplied	Unskilled / Unlevelled manpower skill	RC05
		Not enough manpower	RC06
	Wait for pickup small parts	Too many variabilities in one cycle	RC07
	Wait for pickup medium parts		
	Wait for pickup big parts	Not enough manpower	RC08
	Finished module pickup	Not enough manpower	RC09
	Deliver module to yellow line		
	Process module type 1	Parts needed to complete module not available	RC10

Table 6.3 shows the recapitulation of the root cause of each waste occurring except for RC02 will not be analyzed for improvement since it is out of this research limitation. The root cause itself is the major cause to the waste and by eliminating it, the waste will not occur anymore.

6.3   Improvement Formulation

There will be improvement plans to eliminate the warehouse waste, improvement plans will be formulated based on the data collection and processing and the analysis conducted before. Since there are several improvement plans that are related between root causes, then the description will be done based on the improvement plans. Each improvement plans will explain what wastes that are going to be addressed along with the detail of each plan implementation. The improvement will later then be simulated to see the significant change and expected improve condition of the system on the next chapter.

6.3.1   *Maximizing Available Racks*

The system uses bins to store parts, the current system design that each bin is allocated for one specific part. However, in this research since the parts are categorized into size, it deletes the rule of one specific bin for one specific part and replace it with only zone limitation. The basic still apply, not all available spaces are used. By using the rest of available space, it will help and eliminate this waste.

- RC01 (Inventory) – Unused available racks to store

Currently the system utilizes 10648 bins from the total of 13342 bins, meaning there are 2875 unused and empty bins. From the simulation result, using the capacity of 10648 total, generates problem of overloading parts and to make it worse it is found in all the zones, meaning that with the current capacity it impossible to manage handling all incoming parts even though it is assisted through the reserve zones. By allocating the remaining bins to handle the incoming parts, it will achieve maximum utilization and hopefully

able to solve the waste. The detail of the improvement is shown in the Table 6.4.

Table 6.4 Details on Maximizing Available Racks

5W + 1H	Description
What	Maximizing available racks to store parts.
Who	• Warehouse team → allocates remaining racks for usage • Supply MP (Big) and Binning MP (Med and Small) → begin storing parts at the prepared area
Where	Remaining empty bins on each zone.
Why	Unused bins are the root cause of minimum racks utilization and incapability of storing parts.
When	Every day during work hours.
How	Binning process as usual with addition of new bins to fill.

Another alternative to support if the problem does persist is increasing the storing capacity of each bins to fully accommodate all incoming parts.

6.3.2 *Manpower Addition*

Each operation on each zone has a specific amount of manpower. The current amount of manpower resulted in quite lot of problem in the form of waiting in several activities inside some operations. Adding additional manpower, it will help eliminating these wastes.

- RC04, RC06, RC08, RC09 (Waiting) – Not enough manpower (Unloading, sorting, picking, and packing process)
- RC05 (Waiting) – Unskilled / Unlevelled manpower skill (Sorting)

Waiting in unloading could prolong the duration of truck idle time and the overall warehouse processing. Loading of empty pallets into trucks and pallets pickup to be delivered to sorting are limited into only two manpower.

If there is a certain amount of variation on the amount of incoming parts, the result is the waiting waste above.

In sorting process, there are parts that left ready to be sorted and parts ready to be supplied. Incoming parts for sorting are stuck in bottlenecks due to varying processing time from the operators doing the activity, this is confirmed not only from simulation model but also from direct observation and interview with the line leader for sorting process. Parts ready to be supplied is held back by the unavailability of dollies since it is still in usage of previous cycle.

On the other hand, waiting in yellow line activity on packing process is due to slow operation for yellow line processing. Generating a significant waiting time for module for pickup to yellow line and delivering it into yellow line itself.

By the addition of manpower, either in the form of outsourcing or contracting full time operators, hopefully will be able to fill in the gap of manpower need. The detail of the improvement is shown in the Table 6.5.

Table 6.5 Details on Manpower Addition

5W + 1H	Description
What	Manpower addition
Who	• Warehouse team → allocates more manpower for warehouse
Where	• Unloading • Sorting • Picking zone M and S • Packing
Why	Lots of the waiting problem is sourced from the lack of manpower availability.
When	Every day during work hours.
How	Manpower addition either from outsourcing or contract workers.

6.3.3 *Fix Milk-run Routing Duration*

Specifically, for medium and small parts, the process of supply is done in the form of a route, starting from sorting → corresponding zone → packing → back to sorting. The route contains variables that affect the duration to complete the route. For example, when the manpower arrived in zone M, it will drop off the dolly containing parts for binning, and to check whether there is dolly containing part for packing. If there is a dolly, it will be delivered to packing, if there is not the manpower will directly go to packing. The same pattern applied to packing also, check whether there is empty dolly to take to sorting or not. And finally, in sorting, whether there is dolly needed to be supplied or not. Fix milk-run routing will hopefully help eliminating these wastes.

- RC07 (Waiting) – Too many variabilities in one cycle
- RC10 (Waiting) – Parts needed to complete module not available

Through those examples, the application of fix milk-run should be able to solve most of the variability inside by applying fix duration on the route even with or without the variables affecting it. Meaning that the manpower can simply perform continuous loop in a constant linear duration. The detail of the improvement is shown in the

Table 6.6 Details on Fix Milk-run Routing Duration

5W + 1H	Description
What	Fix milk-run routing duration
Who	- Warehouse team → regulates fix duration on the route - Supply MP → perform the routing process on the set amount of duration
Where	- Sorting - Zone M and S - Packing

5W + 1H	Description
Why	Variability in the duration to complete the route which affect certain activities on some processes.
When	Every day during work hours.
How	Manpower complete the route in the given set time.

6.3.4 *Docking bay addition*

Current system utilizes one docking bay for trucks unloading process. It only has the capacity of one truck, so the process needed to be done in sequence to process each incoming truck. Through bay addition, hopefully it will eliminate this waste.

- RC03 (Waiting) – Wait incoming truck

Although the addition is constrained by the docking area size, hence the maximum addition is limited to one docking bay. The addition of docking bay will help streamline the flow of incoming trucks, allowing to process not only one truck at a time but two. The detail of the improvement is shown in the Table 6.7.

Table 6.7 Details on Docking Bay Addition

5W + 1H	Description
What	Docking bay addition
Who	• Warehouse team → prepare and allocate one additional docking bay for incoming trucks with consideration of unloading area and staging area.
Where	• Unloading area
Why	Significantly high waiting duration for truck to enter the warehouse and unused additional space for truck docking.
When	Every day during work hours.

5W + 1H	Description
How	Add one additional bay for incoming truck to enter the warehouse and unload. Also adjusting the previous layout for staging area to fit with the additional docking bay.

CHAPTER 7

IMPROVEMENT SIMULATION AND COMPARISON

In this chapter, the improvement plans that has been formulated is inputted to the simulation model to see and compare the result of before and after improvement plans has been implemented. The result to be expected is the formulated improvement plans will be able to reduce and eliminate wastes identified.

7.1   Improvement Simulation Result and Analysis

The formulated improvement will be trialed on the model in the form of scenarios. The model will then run each scenario which will be later compared before and after improvement applied. Variable factors that change within the scenario is the manpower addition and milk run routing duration improvement, due to racks and bay addition is set as a standard for each improvement scenario. The scenarios will then be compared in terms of how much of an impact given by the scenario in reducing or eliminating waste, the impact on warehouse performance indicator, and the expected investment cost needed to implement the result with the expected benefit given from the simulation result.

Performance Indicator Additional Information:

- P= Productivity

  Unloading (pallets/manhour)

  Sorting, supply, binning, reserve (parts/manhour)

  Picking (orders/manhour)

  Packing (module/manhour)

- CT = Cycle Time

  Unloading, sorting, supply, binning, picking, packing (hours)

  Reserve (minutes)

- U = Utilization (%)

The given scenario detail is as shown in the Table 7.1.

Table 7.1 Listed Improvement Scenarios

Scenario	Docking bay	Racks Cap	MP addition	Fix routing
1	1	Max	1 MP Yellow line (packing) 1 MP Unloading 1 MP Packing	Yes 2 minutes
2	1	Max	1 MP Yellow line (packing) 1 MP Unloading 1 MP Packing 3 MP Sorting 1 MP Supply 1 MP Picking B	Yes 2 minutes
3	2	Max	None	Yes 2 minutes
4	2	Max	1 MP Yellow line (packing) 1 MP Unloading 1 MP Packing	Yes 2 minutes
5	2	Max	1 MP Yellow line (packing 1 MP Unloading 1 MP Packing 3 MP Sorting 1 MP Supply 1 MP Picking B	Yes 2 minutes

Notes: MP = Manpower

The listed scenarios are based on the previously formulated improvement. Each scenario is designed to see and trial which of specific changes in variables on the improvement could affect the result. The company regulation is used in determining the change of variables that is the bay and manpower addition, limiting and constraining the addition of docking bay into 2 spaces maximum due to the limited space available inside the warehouse, while the addition of manpower is also limited by the maximum amount of manpower to be added according to the regulation with the maximum is 8 manpower.

7.1.1   *Scenario 1*

On this scenario, the modifier is only manpower addition for packing (yellow line), unloading, and packing (module). The result of the scenario on waste parameter performance is shown in Table 7.2 and Figure 7.1.

Table 7.2 Waste Parameters Result Scenario 1

Waste Parameters	Result		Percentage Increase/Decrease
	Initial	Scenario 1	
Part Overload (parts)	394	0	-100%
Wait incoming truck (minutes)	311.47	273.24	-12%
Loading empty pallets (minutes)	16.83	10.37	-38%
Pallets waiting for pickup (parts)	28.56	13.65	-52%
Parts about to be sorted (parts)	5.9	7.2	22%
Wait for pickup small (hours)	0.3	0	-100%
Wait for pickup med (hours)	3.8	3.8	0%
Wait for pickup big (hours)	50.7	20.7	-59%
Finished module pickup queue (modules)	3.87	0	-100%
Deliver module to YL (minutes)	0.01	0	-100%
Process module (minutes)	0.05	0	-100%
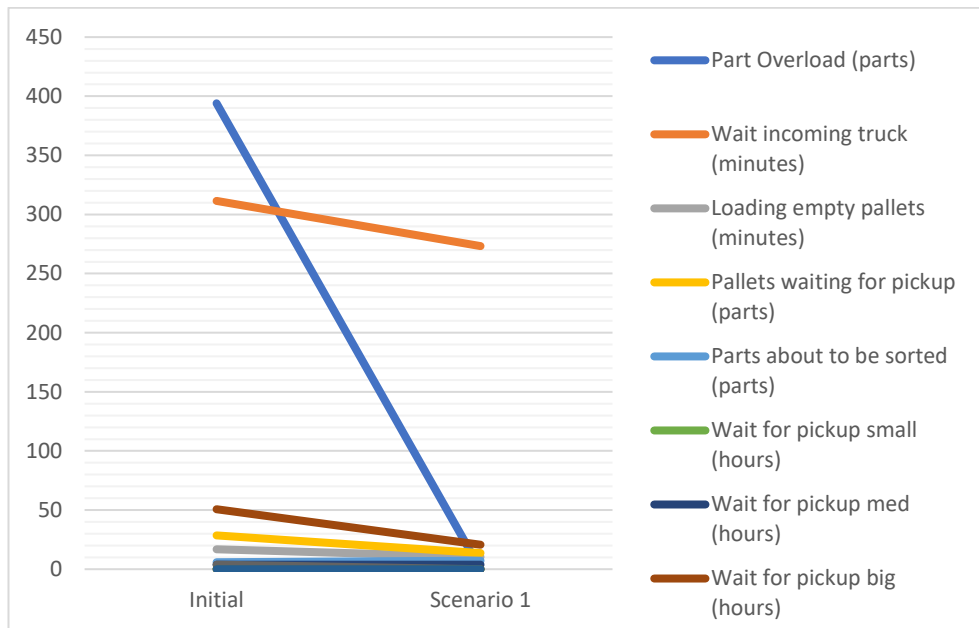
Figure 7.1 Waste Parameters Result Graph Scenario 1

The addition proves some significant decrease in several parameters apart from sorted parts increase to 22%. It is due to increase in flow of pallets incoming from trucks, resulting in increased parts coming to sorting which overwhelm the current manpower handling the sorting process. The rest of the parameter proves positive result in the effect of the scenario, -52% on pallets waiting for pickups from 28.56 parts to 13.65 parts. Also fully reduced on module queue on packing process.

Table 7.3 Warehouse Performance Result Scenario 2

Scenario	Warehouse Performance Indicator											
	Unloading			Sorting			Supply			Binning		
	P	CT	U	P	CT	U	P	CT	U	P	CT	U
Initial	10.68	1.24	100	296.48	1.28	100	14.80	8.40	100	16.73 / 6.32 / 7.23	16.07 / 1.93 / 0.21	73
SC1	15.35	1.35	100	425.34	1.87	100	12.69	2.00	100	14.01 / 6.16 / 7.65	4.53 / 1.91 / 0.20	100
Percentage Increase/Decrease	43.73%	8.87%	0.00%	43.46%	46.09%	0.00%	-14.26%	-76.19%	0.00%	-16.26% / -2.53% / 5.81%	-71.82% / -1.25% / -6.66%	36.99%

Scenario	Reserve			Picking			Packing		
	P	CT	U	P	CT	U	P	CT	U
Initial	4.25	3.56	100	3.59	5.42	100	2.89	15.02	100
SC1	2.48	3.20	100	3.73	5.03	100	2.32	10.03	100
Percentage Increase/Decrease	-41.65%	-10.11%	0.00%	3.90%	-7.20%	0.00%	-19.78%	-33.23%	0.00%

P = Productivity, CT = Cycle Time, U = Utilization

Table 7.3 shows the implementation of scenario 1 on the warehouse performance indicator. There is no change in utilization since all the resource available is used accordingly. Although there is an increase in unloading productivity up to 43.73% and 8.87% decrease in unloading cycle time from initial condition due to addition in unloading manpower. The increase in pallet coming into the warehouse affect the amount of parts coming too, which led to increase in parts process per manhour up to 425.34 parts/manhour although with increase in sorting cycle time due to more incoming parts into sorting. The increase in parts from unloading and sorting lead to overflowed supply process, inability to deliver parts which led to lower binning performance.

The performance also shows problem in order picking on picking process, decrease in 3.9% productivity on order picked/manhours. This problem will be tried to solve in the next several scenarios.

7.1.2 *Scenario 2*

On this scenario, the modifier is only manpower addition for unloading, sorting, supply, picking, and packing. The result of the scenario on waste parameter performance is shown in Table 7.4 and Figure 7.2.

Table 7.4 Waste Parameters Result Scenario 2

Waste Parameters	Result		Percentage Increase/Decrease
	Initial	Scenario 2	
Part Overload (parts)	394	0	-100%
Wait incoming truck (minutes)	311.47	295.89	-5%
Loading empty pallets (minutes)	16.83	10.36	-38%
Pallets waiting for pickup (parts)	28.56	12.63	-56%
Parts about to be sorted (parts)	5.9	2.56	-57%
Wait for pickup small (hours)	0.3	0.14	-53%
Wait for pickup med (hours)	3.8	0.14	-96%

Waste Parameters	Result		Percentage Increase/Decrease
	Initial	Scenario 2	
Wait for pickup big (hours)	50.7	27.7	-45%
Finished module pickup queue (modules)	3.87	0	-100%
Deliver module to YL (minutes)	0.01	0.01	0%
Process module (minutes)	0.05	0	-100%
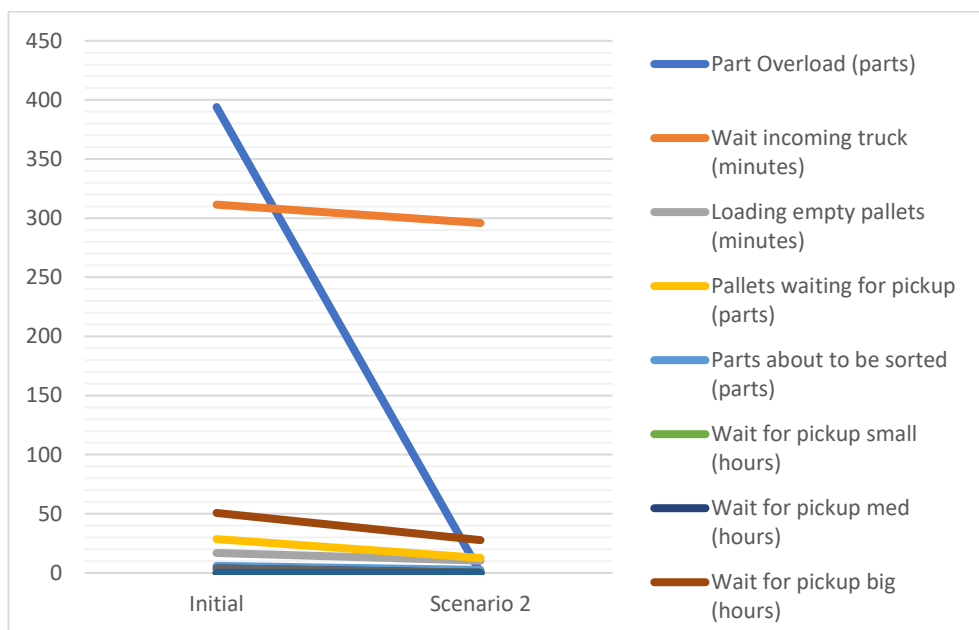
Figure 7.2 Waste Parameters Result Graph Scenario 2

With the addition of sorting manpower, reduce the amount of parts waiting to be sorted by 56%, creating more streamline flow inside the sorting process. Although there is slight gap in pickup queue from the previous scenario, it may be caused due to randomly generated order that might maxed out during this scenario. The rest of the parameters are proven positively affected by the scenario.

Table 7.5 Warehouse Performance Result Scenario 2

Scenario	Warehouse Performance Indicator											
	Unloading			Sorting			Supply			Binning		
	P	CT	U	P	CT	U	P	CT	U	P	CT	U
Initial	10.68	1.24	100	296.48	1.28	100	14.80	8.40	100	16.73 6.32 7.23	16.07 1.93 0.21	73
SC2	15.73	0.96	100	435.00	1.18	100	13.49	2.00	100	13.56 7.07 7.09	3.98 0.15 0.13	100
Percentage Increase/Decrease	47.28%	-22.58%	0.00%	46.72%	-7.81%	0.00%	-8.85%	-76.19%	0.00%	-18.95% 11.87% -1.94%	-75.24% -92.24% -39.33%	36.99%

Scenario	Reserve			Picking			Packing		
	P	CT	U	P	CT	U	P	CT	U
Initial	4.25	3.56	100	3.59	5.42	100	2.89	15.02	100
SC2	2.69	2.12	100	3.64	4.34	100	2.54	11.31	100
Percentage Increase/Decrease	-36.71%	-40.45%	0.00%	1.29%	-19.93%	0.00%	-12.15%	-24.71%	0.00%

P = Productivity, CT = Cycle Time, U = Utilization

Table 7.5 shows the impact of scenario 2 on the warehouse performance. With the addition of sorting manpower, affects the productivity increase to 46.72% and 7.81% decrease of cycle time for the operation. 1.29% increase in picking productivity with 19.93% decrease in its cycle time. Although there is some reduction in productivity for binning operation, this could be from the amount of parts coming from supply shown in decrease of productivity in supply operation.

7.1.3 *Scenario 3*

On this scenario, the modifier is only docking bay addition. The result of the scenario on waste parameter performance is shown in Table 7.6 and Figure 7.3.

Table 7.6 Waste Parameters Result Scenario 3

Waste Parameters	Result		Percentage Increase/Decrease
	Initial	Scenario 3	
Part Overload (parts)	394	0	-100%
Wait incoming truck (minutes)	311.47	145.12	-53%
Loading empty pallets (minutes)	16.83	36.33	116%
Pallets waiting for pickup (parts)	28.56	42.34	48%
Parts about to be sorted (parts)	5.9	8.92	51%
Wait for pickup small (hours)	0.3	2.68	793%
Wait for pickup med (hours)	3.8	0	-100%
Wait for pickup big (hours)	50.7	69.46	37%
Finished module pickup queue (modules)	3.87	0	-100%
Deliver module to YL (minutes)	0.01	0.01	0%
Process module (minutes)	0.05	0.04	-20%
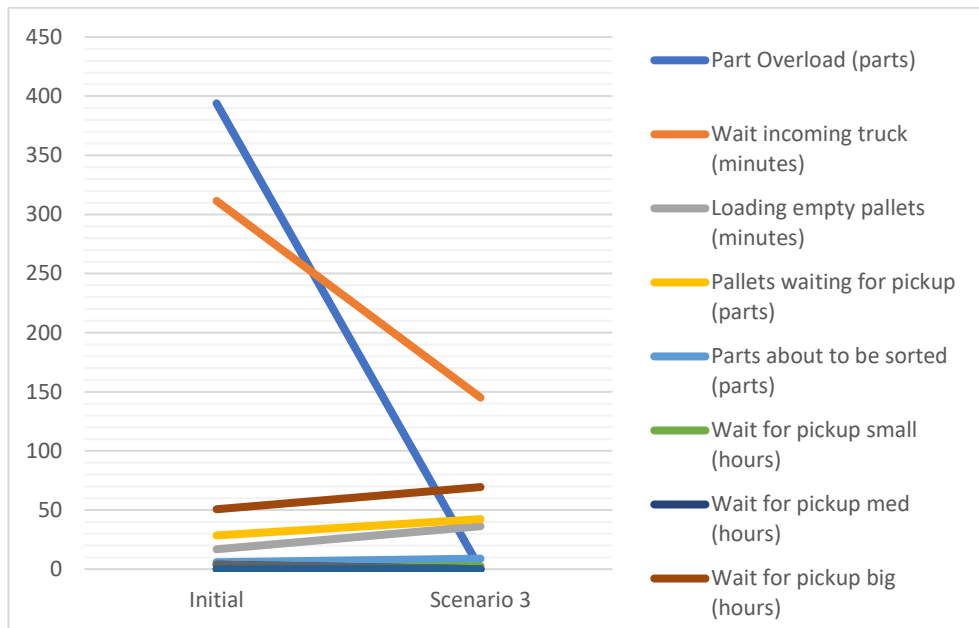
Figure 7.3 Waste Parameters Result Graph Scenario 3

On this scenario, with the addition of docking bay affect the unloading on drastic amount. Reducing 53% of initial waiting time from 311.47 minutes to 145.12 minutes, capable of handling 2 trucks at once, doubling the capacity. However, this create another problem. With the addition of more trucks but with the same amount of manpower resulted in stacking of pallets and empty pallets waiting to be loaded, an increase of whopping 116% of empty pallets queuing for loading and 48% pallets waiting to be picked up. The amount of parts coming also affect sorting process capability to sort parts, a sudden increase of 51% parts waiting for sorting. While picking also has a significant increase in waiting time due to supply manpower who supposed to pick the orders are not available for pickup.

Table 7.7 Warehouse Performance Result Scenario 3

Scenario	Warehouse Performance Indicator											
	Unloading			Sorting			Supply			Binning		
	P	CT	U	P	CT	U	P	CT	U	P	CT	U
Initial	10.68	1.24	100	296.48	1.28	100	14.80	8.40	100	16.73 6.32 7.23	16.07 1.93 0.21	73
SC3	20.88	1.45	100	271.30	3.04	100	18.09	2.00	100	18.23 9.42 10.1	16.95 2.23 0.56	100
Percentage Increase/Decrease	95.51%	16.94%	0.00%	-8.49%	137.50%	0.00%	22.23%	-76.19%	0.00%	8.97% 49.05% 39.70%	5.45% 15.29% 161.34%	36.99%

Scenario	Reserve			Picking			Packing		
	P	CT	U	P	CT	U	P	CT	U
Initial	4.25	3.56	100	3.59	5.42	100	2.89	15.02	100
SC3	6.6	2.33	100	3.83	4.73	100	3.69	26.85	100
Percentage Increase/Decrease	55.29%	-34.55%	0.00%	6.50%	-12.73%	0.00%	27.40%	78.73%	0.00%

P = Productivity, CT = Cycle Time, U = Utilization

Table 7.7 shows the impact of implementing scenario 3 on the warehouse performance. 95.51% increase in productivity for unloading process, although with increase in its cycle time due to possibly manpower incapable of handling the increased amount of trucks and pallets entering the warehouse. This affect the sorting process which with increased amount of parts coming from those pallets, and with the current manpower it is simply not enough to sort the amount, resulting in decrease productivity while the cycle time of the operation increases. On the other hand, since the operation on sorting has slowed down, it affects the interval on which dolly is ready to be supplied shown an increase of 22.23% on supply productivity, which affect parts that comes into zones and eventually be putted in racks during binning.

7.1.4 *Scenario 4*

On this scenario, the modifier is the addition of docking bay and manpower the same as scenario 1. The result of the scenario on waste parameter performance is shown in **Error! Reference source not found.** and Figure 7.4

Table 7.8 Waste Parameters Result Scenario 4

Waste Parameters	Result		Percentage Increase/Decrease
	Initial	Scenario 4	
Part Overload (parts)	394	0	-100%
Wait incoming truck (minutes)	311.47	123.88	-60%
Loading empty pallets (minutes)	16.83	27.33	62%
Pallets waiting for pickup (parts)	28.56	31.09	9%
Parts about to be sorted (parts)	5.9	7.59	29%
Wait for pickup small (hours)	0.3	0.84	180%
Wait for pickup med (hours)	3.8	5.15	36%
Wait for pickup big (hours)	50.7	26.9629	-47%

Waste Parameters	Result		Percentage Increase/Decrease
	Initial	Scenario 4	
Finished module pickup queue (modules)	3.87	0	-100%
Deliver module to YL (minutes)	0.01	0	-100%
Process module (minutes)	0.05	0.01	-80%
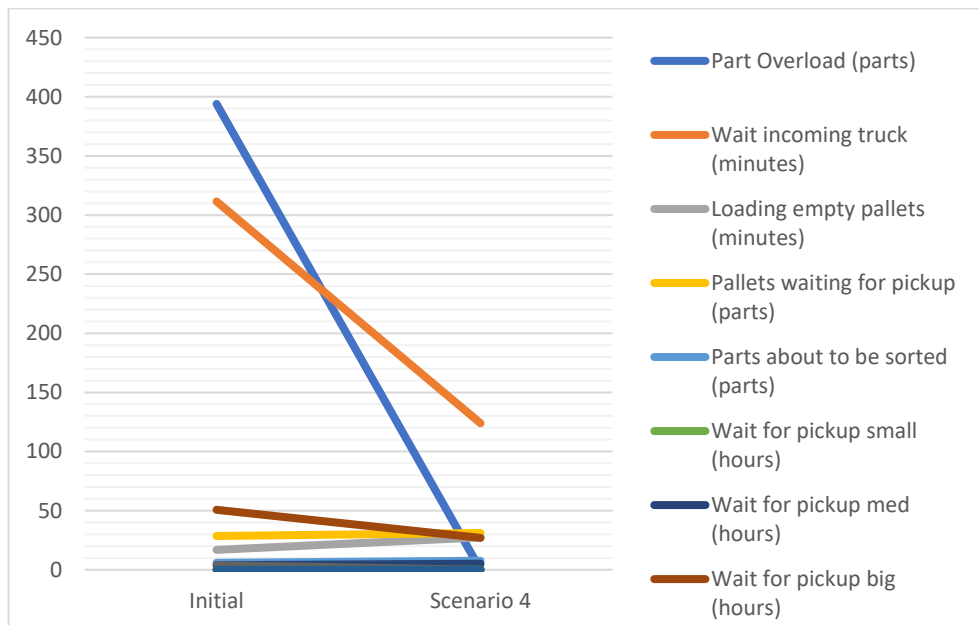
Figure 7.4 Waste Parameters Result Graph Scenario 4

From the previous scenario 3 of adding docking bay to the operation resulted in more parts flowing into the warehouse, which create problems on sorting, supply, and binning. On this scenario, to balance out the incoming parts, the manpower addition option is used. From the **Error! Reference source not found.**, it is shown that a slight decrease from previous scenario 3 on truck waiting time, empty pallets queue, pallets to be picked up queue. This indicates that the addition of manpower on unloading gives positive result on the operation. Although, the same problem persists on picking, like other scenarios, it depends on the randomly generated amount of order coming into the warehouse, so there is a high chance of fluctuating.

Table 7.9 Warehouse Performance Result Scenario 4

Scenario	Warehouse Performance Indicator											
	Unloading			Sorting			Supply			Binning		
	P	CT	U	P	CT	U	P	CT	U	P	CT	U
Initial	10.68	1.24	100	296.48	1.28	100	14.80	8.40	100	16.73 6.32 7.23	16.07 1.93 0.21	73
SC4	33.72	0.93	100	410.47	1.34	100	12.12	2.00	100	13.92 6.44 7.34	13.95 2.58 0.85	100
Percentage Increase/Decrease	215.73%	-25.00%	0.00%	38.45%	4.69%	0.00%	-18.11%	-76.19%	0.00%	-16.80% 1.90% 1.52%	-13.22% 33.39% 296.68%	36.99%

Scenario	Reserve			Picking			Packing		
	P	CT	U	P	CT	U	P	CT	U
Initial	4.25	3.56	100	3.59	5.42	100	2.89	15.02	100
SC4	2.48	2.03	100	3.55	5.87	100	2.22	13.11	100
Percentage Increase/Decrease	-41.65%	-42.98%	0.00%	-1.32%	8.30%	0.00%	-23.13%	-12.73%	0.00%

P = Productivity, CT = Cycle Time, U = Utilization

On the warehouse performance side, unloading performance increase drastically, with more productivity and less time to perform. Sorting has a slight increase in cycle time due to the amount of parts coming to be sorted although not as much as the increase from the previous scenario. With increasing volume of part sorted and with current number of manpower in supply even with the set time of 2 minutes still cannot suffice the amount part to be supplied. Though it does not affect too much on binning process, the decrease in productivity could means that the simulation for scenario 4 produces less big parts then the previous scenario or the initial one.

7.1.5 *Scenario 5*

On this scenario, the modifier is the addition of docking bay and manpower the same as scenario 2. The result of the scenario on waste parameter performance is shown in

Table 7.10 Waste Parameters Result Scenario 5

Waste Parameters	Result		Percentage Increase/Decrease
	Initial	Scenario 5	
Part Overload (parts)	394	0	-100%
Wait incoming truck (minutes)	311.47	75.86	-76%
Loading empty pallets (minutes)	16.83	23.57	40%
Pallets waiting for pickup (parts)	28.56	29.84	4%
Parts about to be sorted (parts)	5.9	2	-66%
Wait for pickup small (hours)	0.3	0.84	180%
Wait for pickup med (hours)	3.8	5.15	36%
Wait for pickup big (hours)	50.7	34.34	-32%
Finished module pickup queue (modules)	3.87	0	-100%
Deliver module to YL (minutes)	0.01	0	-100%
Process module (minutes)	0.05	0	-100%
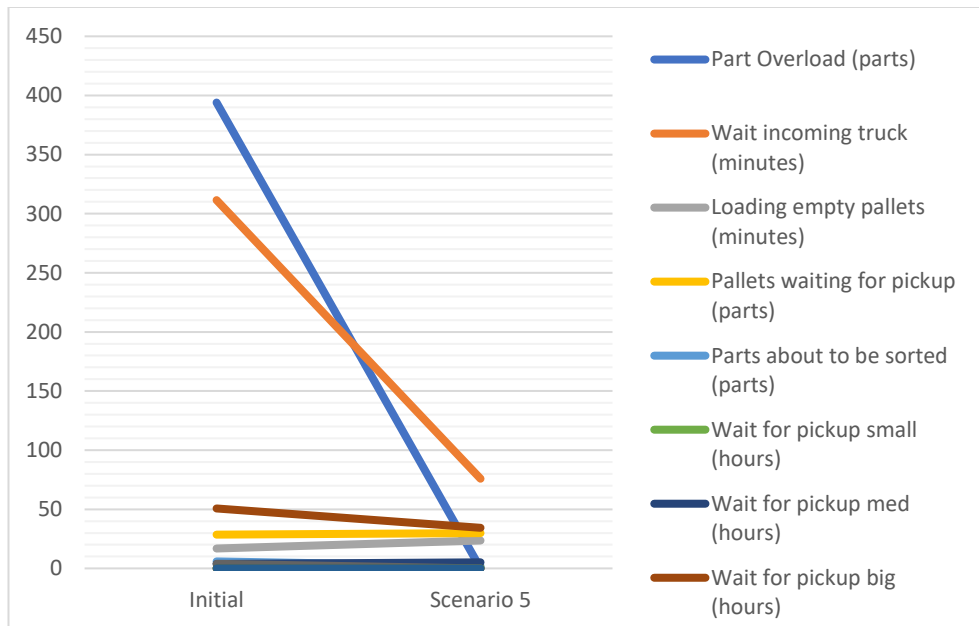
Figure 7.5 Waste Parameters Result Graph Scenario 5

The final scenario is by adding docking bay with manpower addition from scenario 2. A significant decrease in truck waiting time, drops 76% from the initial condition and roughly 60% from scenario 4 which means more trucks coming to the warehouse, although the unloading and staging process not differ too much from other scenario indicates that the addition needed adjustment. On sorting process, by adding manpower resulted a quite significant decrease of 66% on sorting queue even with the number of parts needed to be sorted doubled due to more trucks mean more parts. Picking process, however, still indicates the same problem with most of the scenario. The rest of the parameters remain on positive result.

Table 7.11 Warehouse Performance Result Scenario 5

Scenario	Warehouse Performance Indicator											
	Unloading			Sorting			Supply			Binning		
	P	CT	U	P	CT	U	P	CT	U	P	CT	U
Initial	10.68	1.24	100	296.48	1.28	100	14.80	8.40	100	16.73 6.32 7.23	16.07 1.93 0.21	73
SC5	37.42	0.93	100	450.67	1.43	100	14.82	2.00	100	13.87 6.68 6.98	13.11 2.55 0.43	100
Percentage Increase/Decrease	250.37%	-25.00%	0.00%	52.01%	11.72%	0.00%	0.14%	-76.19%	0.00%	-17.10% 5.70% -3.46%	-18.44% 31.84% 100.67%	36.99%

Scenario	Reserve			Picking			Packing		
	P	CT	U	P	CT	U	P	CT	U
Initial	4.25	3.56	100	3.59	5.42	100	2.89	15.02	100
SC5	3.29	1.89	100	4.13	4.87	100	2.88	13.00	100
Percentage Increase/Decrease	-22.59%	-46.91%	0.00%	14.78%	-10.15%	0.00%	-0.63%	-13.46%	0.00%

P = Productivity, CT = Cycle Time, U = Utilization

The performance indicator results for scenario 5 as shown in the Table 7.11 shows significant increase in productivity for unloading, sorting, and supply. This is due to the increased amount of trucks coming into the warehouse and handled accordingly, generating increased productivity on unloading process which later be sorted through with the additional manpower on sorting to sort more parts, and a well-timed supply cycle. Although, on binning process there is a slight decrease in productivity for big and small parts, this may be due to the parts coming and sorted did not contain that much of parts on small and big size.

7.1.6   *Overall Comparison*

After thorough analysis on each of the performed scenario, the final step is to see and compare overall scenario.

7.1.6.1 Waste Parameters

The detailed comparison table on waste parameters are presented on the Figure 7.6 shows the overall comparison for the given scenarios on waste parameters.

Table 7.12 Waste Parameters Overall Comparison

Scenario	Waste Parameters										
	Part Overload (parts)	Wait incoming truck (minutes)	Loading empty pallets (minutes)	Pallets waiting for pickup (parts)	Parts about to be sorted (parts)	Wait for pickup small (hours)	Wait for pickup med (hours)	Wait for pickup big (hours)	Finished module pickup queue (modules)	Deliver module to YL (minutes)	Process module (minutes)
Initial	394	311.47	16.83	28.56	5.9	0.3	3.8	50.7	3.87	0.01	0.05
SC1	0	273.24	10.37	13.65	7.2	0	3.8	20.7	0	0	0
SC2	0	295.89	10.36	12.63	2.56	0.14	0.14	27.7	0	0.01	0
SC3	0	145.12	36.33	42.34	8.92	2.68	0	69.46	0	0.01	0.04
SC4	0	123.88	27.33	31.09	7.59	0.84	5.15	26.9629	0	0	0.01
SC5	0	75.86	23.57	29.84	2	0.84	5.15	34.34	0	0	0
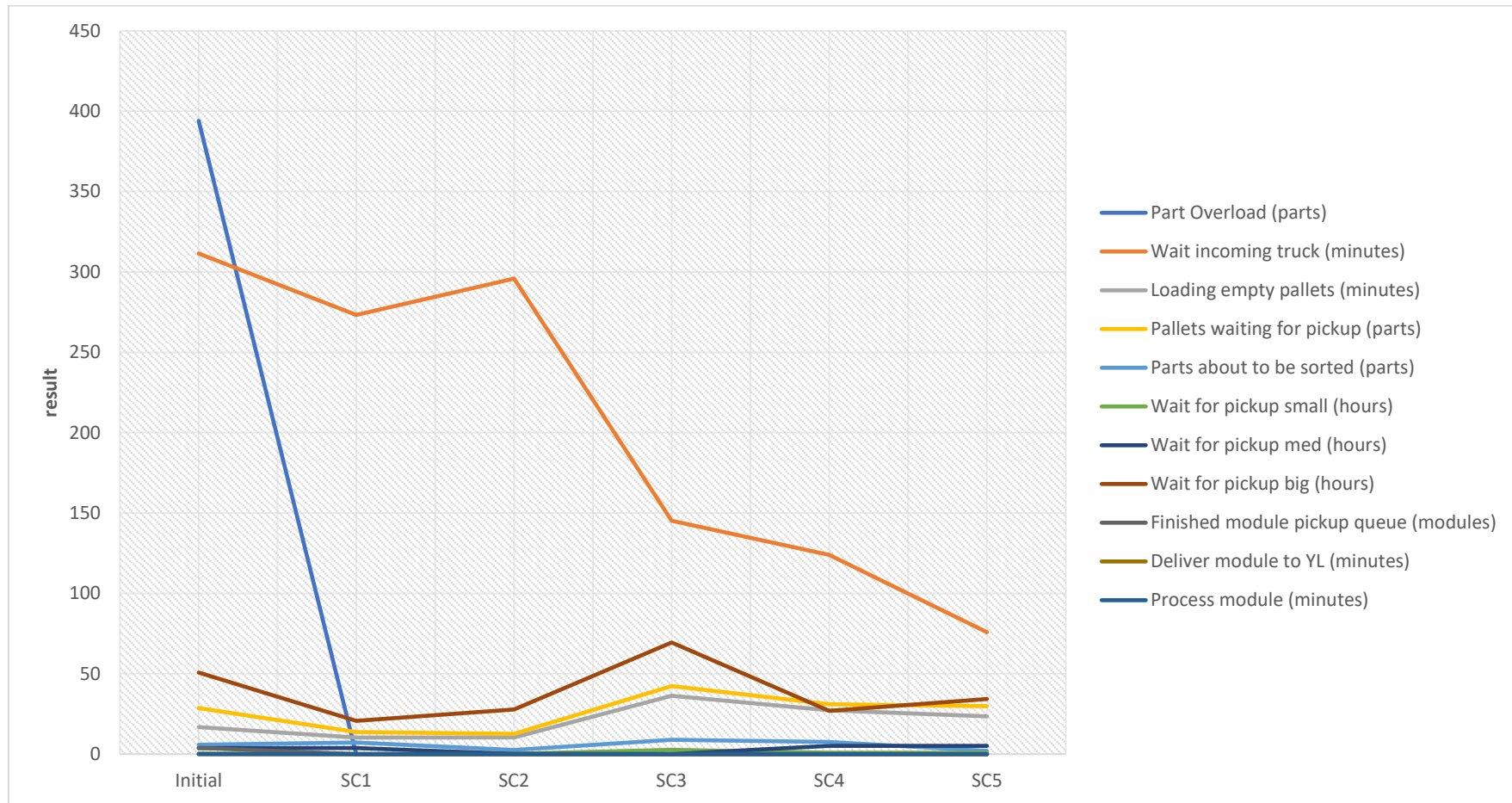
Figure 7.6 Overall Waste Parameter Result After Improvement Graph

The graph indicates that the scenarios given and simulated provide positive result on the initial waste parameters. From the 5 scenarios, all of them are capable of fully eliminated the overloading parts waste. On scenario 1 and 2, proves that single docking bay cannot give maximum result on the rest of the operation performance, indicated by the waiting time of 273.24 minutes and 295.89 minutes for scenario 1 and 2 respectively even with the addition of manpower. The rest of the scenario, however, proves that although the bay addition may create another waiting and bottleneck problem, but with the addition of manpower to handle the operation resulted in significant decrease in waiting time.

With the addition of docking bay means more trucks can unload with the maximum of 2 trucks at a time. Even with the addition of manpower on unloading, the graph shown that the waiting time for empty pallets loading and pallets pickup increases although the increase is not too significant. This indicates that even with the addition of 2 manpower, the amount of manpower required is more than that.

On sorting process waste of parts waiting to be sorted queue, problem arises on scenarios that does not add manpower on sorting process. Scenarios that has additional manpower on sorting process proves significantly capable of handling with or without the docking bay addition.

The problem that persist on every scenario is the order pickup waiting queue. This problem is due to the randomly generated order amount since the demand pattern for spare parts shown no trends or tendency towards specific pattern. That is why on this research, the order is randomly generated and are not tried to be solved, since the problem is sourced from the forecasting division.

7.1.6.2 Warehouse Performance Indicator

On the warehouse performance side, the Table 7.13 shows the overall comparison for all scenarios and its impact on the warehouse performance. The performance shows close connection with the waste parameters, as the decrease of waiting time for trucks incoming and additional manpower on

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unloading, generates increased productivity and decreased cycle time.as shown in the Figure 7.7.

Table 7.13 Warehouse Performance Indicator Result After Improvement Recapitulation

Scenario	Warehouse Performance Indicator																				
	Unloading			Sorting			Supply			Binning			Reserve			Picking			Packing		
	P	CT	U	P	CT	U	P	CT	U	P	CT	U	P	CT	U	P	CT	U	P	CT	U
Initial	10.68	1.24	100	296.48	1.28	100	14.80	8.40	100	16.73 6.32 7.23	16.07 1.93 0.21	73	4.25	3.56	100	3.59	5.42	100	2.89	15.02	100
SC1	15.35	1.13	100	425.34	1.87	100	12.69	2.00	100	14.01 6.16 7.65	4.53 1.91 0.20	100	2.48	3.20	100	3.73	5.03	100	2.32	10.03	100
SC2	15.73	0.96	100	435.00	1.18	100	13.49	2.00	100	13.56 7.07 7.09	3.98 0.15 0.13	100	2.69	2.12	100	3.64	4.34	100	2.54	11.31	100
SC3	20.88	0.98	100	271.30	3.04	100	18.09	2.00	100	13.64 4.37 5.23	9.93 0.41 0.25	100	6.6	2.33	100	3.83	4.73	100	3.69	26.85	100
SC4	33.72	0.93	100	410.47	1.34	100	12.12	2.00	100	13.92 6.44 7.34	13.95 2.58 0.85	100	2.48	2.03	100	3.55	4.87	100	2.22	13.11	100
SC5	35.93	0.93	100	450.67	1.43	100	14.82	2.00	100	13.87 6.68 6.98	13.11 2.55 0.83	100	3.29	1.89	100	4.13	4.31	100	2.88	13.00	100

Notes: P = Productivity, CT = Cycle Time, U = Utilization
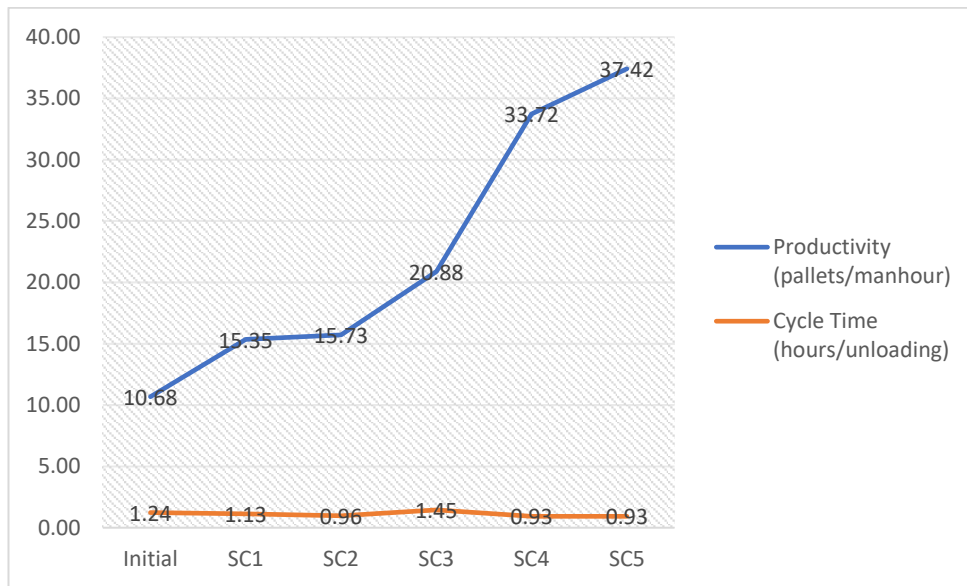
Figure 7.7 Unloading Performance Graph

Sorting also indicates that the increase amount of parts coming inside the warehouse, with or without the addition of sorting manpower proves an increase of productivity, although the cycle time increases for all scenarios, but the increase is more significant on scenarios that does not add sorting manpower. As it shown in the Figure 7.8.
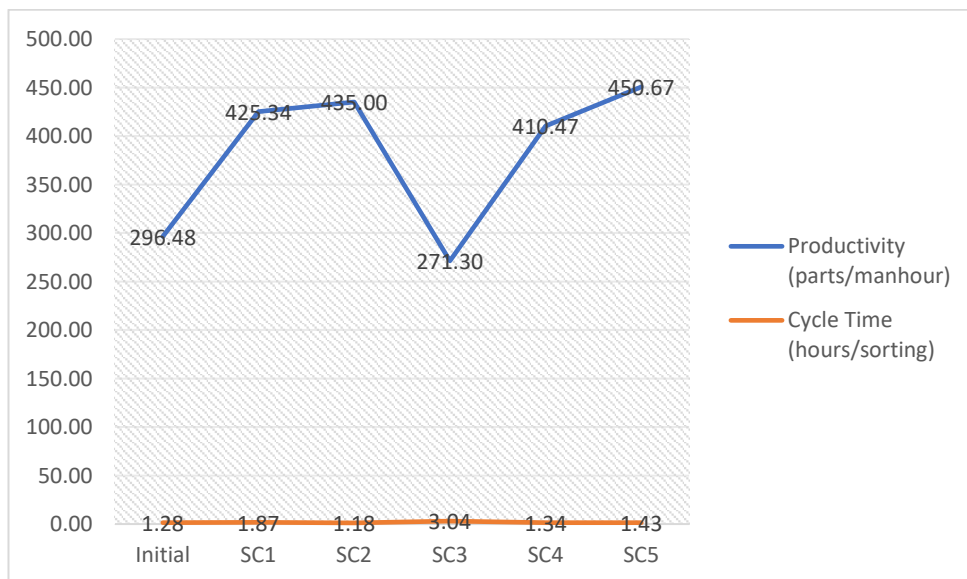
Figure 7.8 Sorting Performance Graph

Supply process varies on its productivity result. On scenario 1, 3, and 4 shows that the productivity varies and is correlated with the sorting cycle time, the increase of sorting cycle time provide less dollies available to be supplied. However, on scenarios that add supply manpower provide better productivity even with or without the addition of docking bay and both of productivity and cycle time of the sorting process. The Figure 7.9 shows the performance graph of supply process.
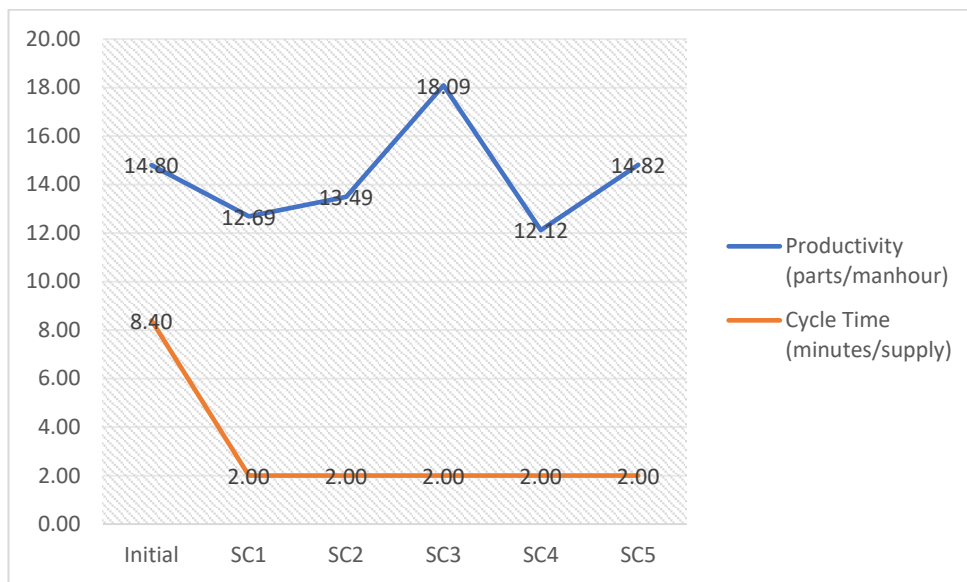
Figure 7.9 Supply Performance Graph

Binning process performance is divided into three for big, medium, and small parts. The Figure 7.10, Figure 7.11, Figure 7.12 shows the performance graph for big, medium, and small parts binning respectively.
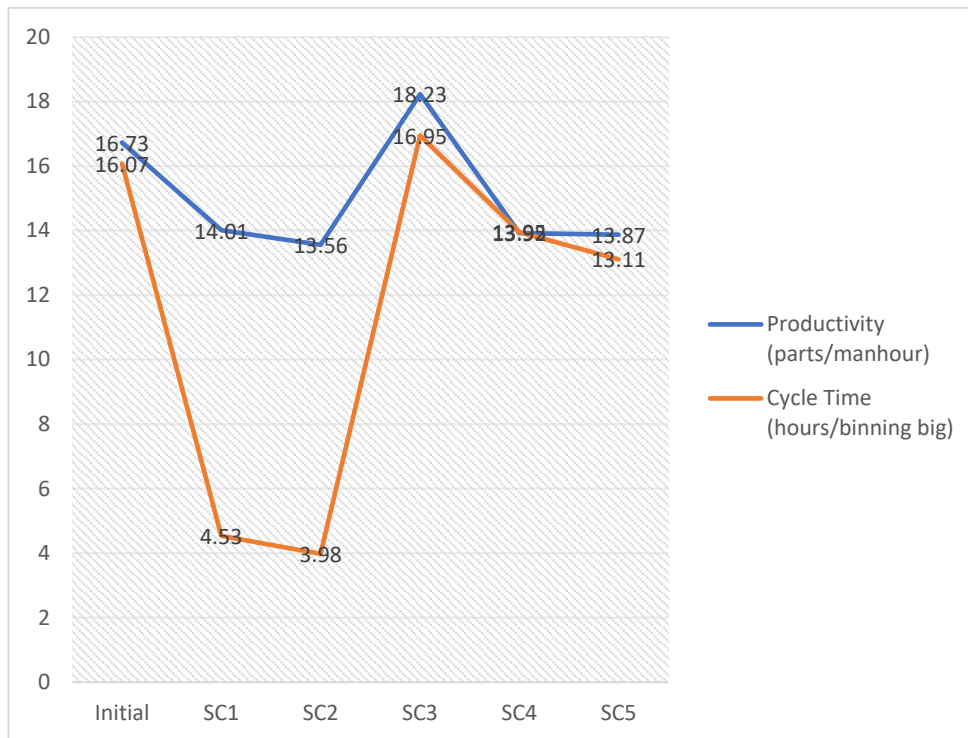
Figure 7.10 Binning (big) Performance Graph
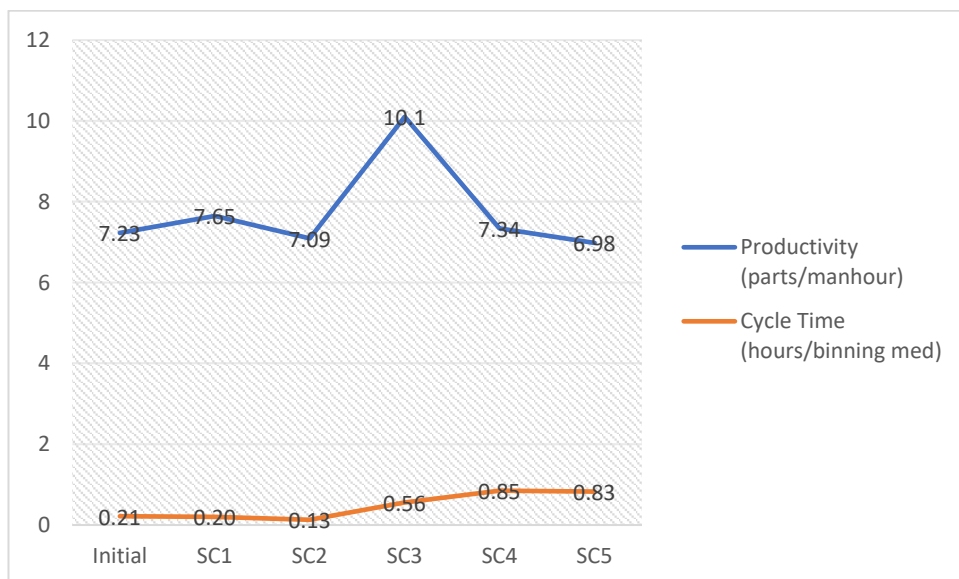
Figure 7.11 Binning (medium) Performance Graph
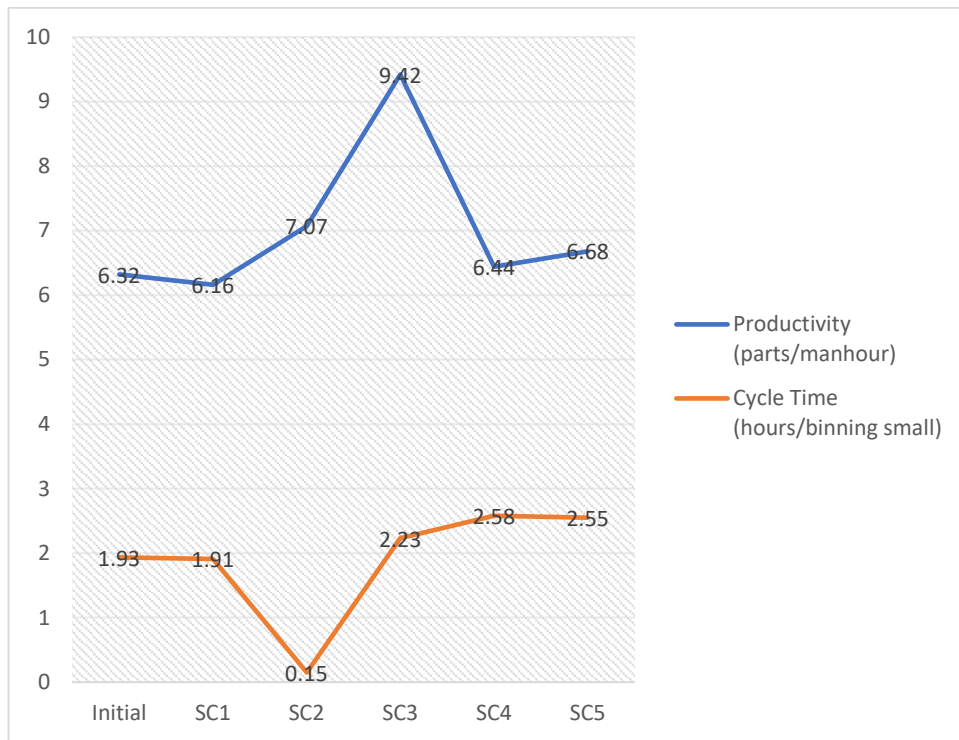
Figure 7.12 Binning (small) Performance Graph

Binning productivity for all the part category varies on all scenarios, aside from it is impacted from the sorting and supply process, it also affect the probability of incoming trucks containing how much of the specific part sizes since the trucks are generated using distribution for historical data and the basic characteristic of simulation that is random input and random output (RIRO). This characteristic also affects picking process, which the orders are randomly generated causing fluctuations on the process productivity as shown in the Figure 7.13.
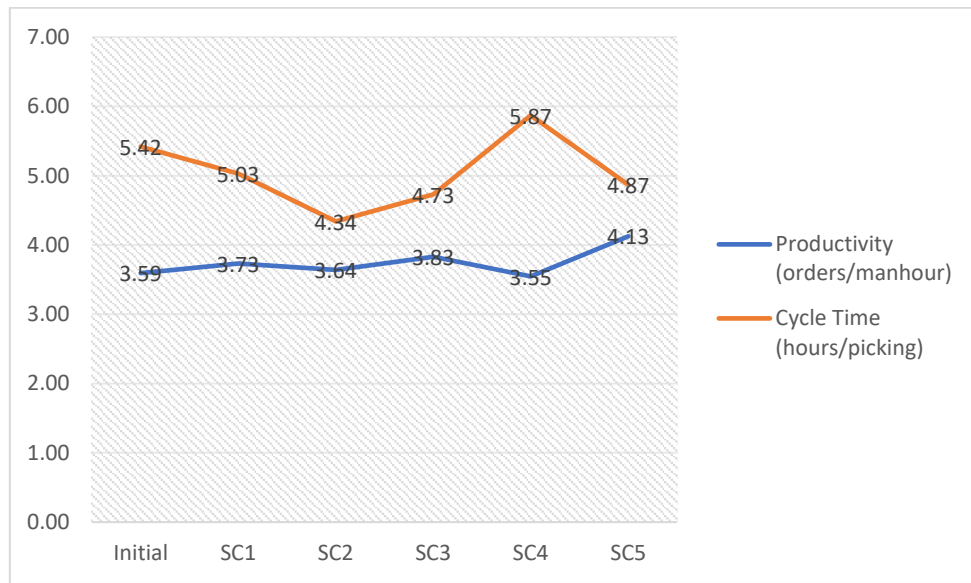
Figure 7.13 Picking Performance Graph
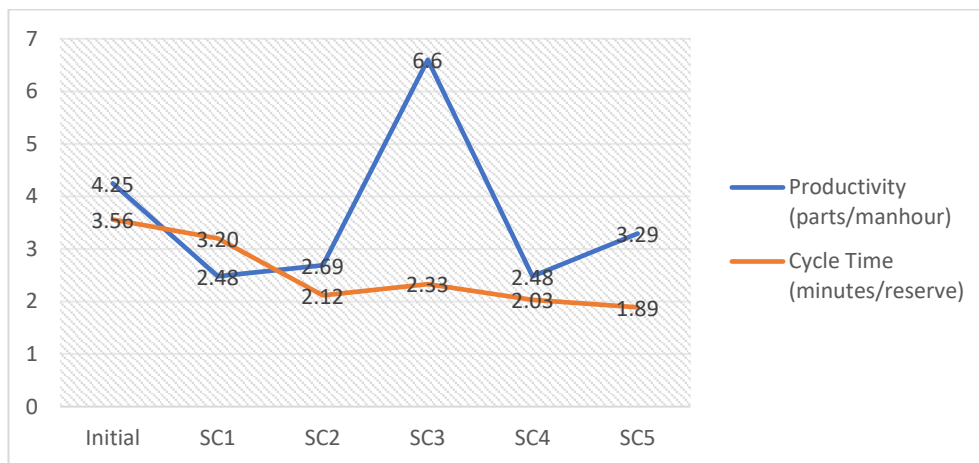
Figure 7.14 Reserve Performance Graph

On reserve performance, productivity varies on all replications, even when the condition of the storage is overflowing up to part overload on the initial condition. It depends on the amount of parts coming inside the warehouse. The cycle time varies and tends to decline is also affected by the amount of parts needed to be reserved.
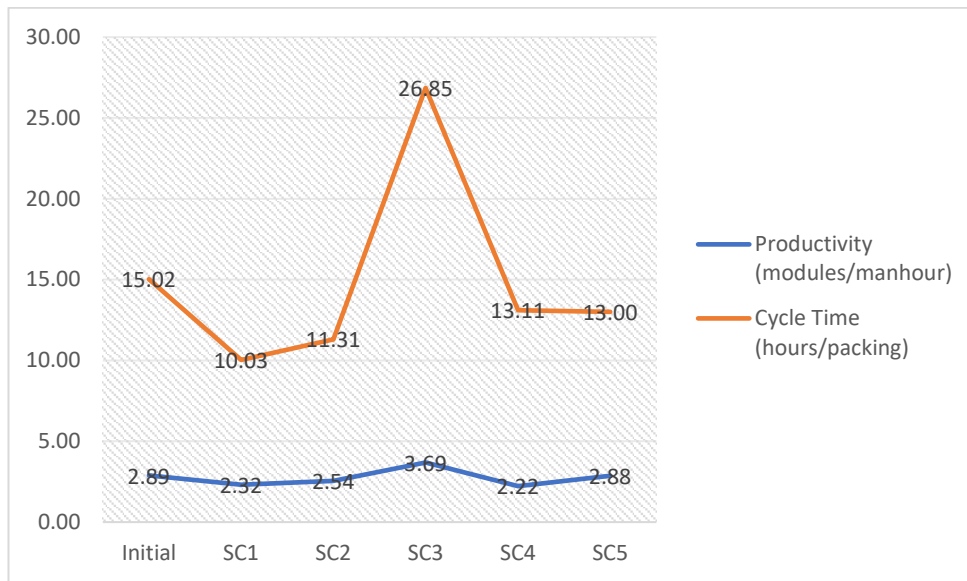
Figure 7.15 Packing Performance Graph

The last one is the packing process, productivity varies because of how much orders are picked and since it is on random distribution, the probability of order coming is also random. On the other hand, cycle time varies on the effect of the manpower handling it. On scenarios without manpower tends to produce longer cycle time compared to the scenarios with the addition of manpower. But this is also affected by the number of modules needed to complete.

7.1.6.3 Estimated Cost to Benefits

After analyzing both waste parameters and warehouse performance, on this section the result is then ranked accordingly with the addition of estimated cost needed to perform each proposed scenario. The cost incurred here is only the cost of manpower addition. The cost itself is as stated on 1.5.2. The docking bay addition requires no additional cost since the space is already available, just not yet utilized.

Table 7.14 Estimated Cost Needed per Scenario

Scenario	Labor addition	Wages per labor	Incurred wages per month	Docking bay addition	Docking bay addition cost	Total investment cost
SC1	3		Rp12,802,317	0		Rp12,802,317
SC2	8		Rp34,139,512	0		Rp34,139,512
SC3	0	Rp4,267,439	Rp0	1	Rp0	Rp0
SC4	3		Rp12,802,317	1		Rp12,802,317
SC5	8		Rp34,139,512	1		Rp34,139,512

Table 7.14 shows the required investment cost needed to perform each scenario. Docking bay provided no additional cost since the space for adding the additional docking bay is available and ready to use without any modification or addition towards the working area.

Table 7.15 Estimated Cost to Waste Parameter

Scenario	Investment Cost	W01	W02	W03	W04	W05	W06	W07	W08	W09	W10	W11
SC1	Rp12,802,317	1	4	2	2	3	1	3	1	1	1	1
SC2	Rp34,139,512	1	5	1	1	2	2	2	3	1	4	1
SC3	Rp0	1	3	5	5	5	5	1	5	1	4	5
SC4	Rp12,802,317	1	2	4	4	4	3	4	2	1	1	4
SC5	Rp34,139,512	1	1	3	3	1	3	4	4	1	1	1

Table 7.16 Estimated Cost to Warehouse Performance

Scenario	Investment Cost	Unloading P	Unloading CT	Sorting P	Sorting CT	Supply P	Supply CT	Binning P	Binning CT	Reserve P	Reserve CT	Picking P	Picking CT	Packing P	Packing CT
SC1	Rp12,802,317	5	4	3	4	4	1	2	2	4	5	3	4	4	1
								2	2						
								5	2						
SC2	Rp34,139,512	4	3	2	1	3	1	5	1	3	3	4	1	3	2
								4	1						
								2	1						
SC3	Rp0	3	5	5	5	1	1	1	5	1	4	2	2	1	5
								1	3						

Scenario	Investment Cost	Warehouse Performance Rank												
		Unloading		Sorting		Supply		Binning		Reserve		Picking		Packing
		P	CT	P	CT	P	CT	P	CT	P	CT	P	CT	P	CT
								1	3						
SC4	Rp12,802,317	2	1	4	2	5	1	3	4	4	2	5	5	5	4
								3	5						
								4	5						
SC5	Rp34,139,512	1	1	1	3	2	1	4	3	2	1	1	3	2	3
								5	4						
								3	4						

Notes: P = Productivity, CT = Cycle Time

Table 7.15 and Table 7.16 shows the ranking on each scenario on waste parameters and warehouse performance result, respectively. The decision to pick and choose what scenario to be implemented is solely based on the company preference, the comparison tables only provided a glimpse and recapitulation of the result of each scenario on both waste parameters and warehouse performance.

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CHAPTER 8
CONCLUSIONS AND RECOMMENDATIONS

This chapter consists of the conclusions and recommendations. The conclusions will answer the objectives stated during this research, and the recommendations given for future research on the same topic.

8.1 Conclusions

The conclusions of this research are as follows:

1. The simulation model is created using the basis of the conceptual model gathered from direct observation and standard operating procedures. The input for each of the process inside the simulation model are using historical data during the range of this research is conducted, processed through data analyzer to generate patterns and distribution, similar to the real system. The model itself is valid, through the comparison and validation of performance indicator of racks utilization which the simulation model result proves no to less deviation from the real system. The use of the model is not time restricted. Meaning that the model is valid to use no matter when the input data is used. The 30 day simulation period is used to mimic the observed system during the observation period of 30 days starting from February to March 2020, and the short duration of operation also provided less data required to run the simulation model for more than 30 days. If the company choose to run the model for a year time, then the company should change the data input to a year worth of data.

2. Using simulation model, the process of identifying waste throughout the system is done in much faster time. The waste identified is only inventory and waiting wastes. Inventory waste is found in unloading process of wait for incoming trucks. Waiting waste spread out towards the process, happening on

unloading process in waiting for incoming trucks, empty pallet loading queue time, and pallets waiting for pickup to sorting queue time. On sorting process for parts waiting to be sorted, on picking process in picking queue time for all order type, and in packing process for module queue time, module delivery queue time, and module pickup queue time.

3. The identified wastes are analyzed to find the root cause. Inventory waste is caused by the unused yet available racks to used, only 10648 bins from the total of 13342 bins, meaning there are 2875 unused and empty bins. The empty bins remain unused and thus not enabling to fully utilize all the racks. Waiting waste for unloading process on truck waiting time is caused by limited number of docking bay, even though there is available docking bay to use. The rest of the waiting waste is mainly due to lack of manpower on the process, creating bottlenecks on the activities inside. Few exceptions on picking waiting waste for medium and small pickup wait is caused by the variability on the supply cycle which affect the order pickup activity and affecting packing process. On sorting process, besides from the lack of manpower, the skills on the current manpower has a high deviation creating an unbalanced skill worker on the process.

4. Through simulation, improvement can be trialed with much shorter time and less cost needed to perform and trial the improvement manually on the system. By implementing the proposed improvement on the simulation model, all the scenarios of the proposed improvement gave exceptional result on both waste parameters and warehouse performance, with almost all of the waste are reduced significantly. Shown in the fully eliminated inventory waste, waiting on packing process, up to 76% reduction in truck waiting time, 38% reduction empty pallets loading time, 56% reduction in pallet picking waiting queue time, and 66% reduction in parts to be sorted queue time. Warehouse

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performance also shows positive result with exceptionally high increase in unloading productivity of 250.37% increase on scenario 5 with its cycle time reduced by 25%, also an increase over 50% on sorting and reserve productivity. Each scenario differs not too roughly on the investment cost incurred to perform and implement the scenario on the real system. Although, the selection of scenarios is the authority of the company to choose what scenario is within and meet their expected outcomes.

8.2 Recommendations

Some recommendations for future research are as follows:

1. The fluctuations of demand generate randomly generated orders on the model. This problem is an exception for this research since it is the responsibility of forecasting team, however, with better forecasting patterns, the model will then be more perfect in simulating the order picking process.

2. Each software has a limitation. It is better to study and compare and probably get the best software for the research available on the market to better create and simulate the system more complete.

3. In this scale of a simulation, it is better to thoroughly calculate the maximum capability of a software to carefully determine the span of data that will be used as an input for the simulation model.

4. It is best to used real observation data compared to historical data to fully understand and represent the real system to be simulated.

5. Larger amount of data is required to run the simulation model for more than 30 days. If the company chooses to run for 1 year, then the required data for input so that the model becomes valid is a 1 year data also.

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APPENDIX

Appendix 1 7 K Warehouse Flow Conceptual Model

Refill

Undertocked zone

Stock on Hand database update

Identify zone

Identify part no

Scan reserve number and BT number

Scan part no label & input Qty

Reserve available? — No → Problem report → Report understock

Yes

Deliver for binning

Reserve database update

PIcking

Kanban order

Scan picking header

Scan picking label

Scan part and address no.

Part available? — No → Part available on other zone? — Yes → Check address vs part no master data

Yes

No → Problem report → Shortage report

Take part from primary address → Stock on Hand database update

Put to empty BT

Deliver to packing

Packing

Prepare empty module

Scan BT No.

Input module code in scanner

Print case label → Case label

Stick case label to module

Scan case no (status opern)

Module available

Take part from BT

Scan label

Put the part into module based on order type

Module full? — No

Yes

Scan case no (status closed)

Supply to yellow line

Yellow line full?

Deliver to vanning

Vanning

Deliver module to container

Container full? — No

Yes

Deliver container

END

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Appendix 2 Simulation Model

Packing

| 0.00 | 0.00 | 0.00 | 0.00 |

0.00

Appendix 3 Waste Performance Result After Improvement

Scenario	Docking bay	Racks Cap	MP addition	Fix routing	Result										
					W01	W02	W03	W04	W05	W06	W07	W08	W09	W10	W11
Initial					394	311.47	16.83	6.89	5.9	0.3	3.8	50.7	3.87	0.01	0.05
1	1	Max	1 MP YL 2 MP Unloading 1 MP Packing	Yes, 2 minutes	None	273.24	10.37	1.98	7.2	0	3.8	20.7	0	0	0
2	1	Max	1 MP YL 2 MP Unloading 1 MP Packing 6 MP Sorting 1 MP Supply 1 MP Picking B	Yes, 2 minutes	None	295.89	10.36	1.44	2.56	0.14	0.14	27.7	0	0.01	0
3	2	Max	None	Yes, 2 minutes	None	145.12	36.33	178.09	2.8	2.68	0	69.46	0	0.01	0.04
4	2	Max	1 MP YL 2 MP Unloading 1 MP Packing	Yes, 2 minutes	None	75.86	27.33	264.73	6	0.84	5.15	26.96	0	0.03	0.01
5	2	Max	1 MP YL 2 MP Unloading 1 MP Packing 6 MP Sorting 1 MP Supply 1 MP Picking B	Yes, 2 minutes	None	123.88	32.51	321.04	2	0.84	5.15	34.34	0	0	0

Notes: Waste ID is identified on Table 6.1 Waste Identification Recapitulation

Appendix 4 Warehouse Performance After Improvement

Scenario	Docking bay	Racks Cap	MP addition	Fix routing	Unloading			Sorting			Supply			Binning			Reserve			Picking			Packing		
					p	CT	U	P	CT	U	P	CT	U	P	CT	U	P	CT	U	P	CT	U	P	CT	U
Initial					10.68	1.24	100	296.48	1.28	100	14.80	8.40	100	16.73 6.32 7.23	16.07 1.93 0.21	73%	1	3.56	100	3.59	5.42	100	2.89	15.02	100
1	1	Max	1 MP YL 2 MP Unloading 1 MP Packing	Yes 2 minutes	15.35	1.13	100	425.34	1.06	100	12.69	2.00	100	14.01 6.16 7.65	4.53 1.91 0.20	100	1	3.20	100	3.73	5.03	100	2.32	10.03	100
2	1	Max	1 MP YL 2 MP Unloading 1 MP Packing 6 MP Sorting 1 MP Supply 1 MP Picking B	Yes 2 minutes	15.73	0.96	100	435.00	1.18	100	13.49	2.00	100	13.56 7.07 7.09	3.98 0.15 0.13	100	1	2.12	100	3.64	4.34	100	2.54	11.31	100
3	2	Max	None	Yes 2 minutes	20.88	0.98	100	271.30	3.04	100	18.09	2.00	100	13.64 4.37 5.23	9.93 0.41 0.25	100	1	2.33	100	3.83	4.73	100	3.69	26.85	100
4	2	Max	1 MP YL 2 MP Unloading 1 MP Packing	Yes 2 minutes	33.72	0.93	100	410.47	1.34	100	12.12	2.00	100	13.92 6.44 7.34	13.95 2.58 0.85	100	1	2.03	100	3.55	4.87	100	2.22	13.11	100
5	2	Max	1 MP YL 2 MP Unloading 1 MP Packing 6 MP Sorting 1 MP Supply 1 MP Picking B	Yes 2 minutes	35.93	0.93	100	450.67	1.43	100	14.82	2.00	100	13.87 6.68	13.11 2.55	100	1	1.89	100	4.13	4.31	100	2.88	13.00	100

Scenario	Docking bay	Racks Cap	MP addition	Fix routing	Warehouse Performance Indicator																					
					Unloading			Sorting			Supply			Binning			Reserve			Picking			Packing		
					p	CT	U	P	CT	U	P	CT	U	P	CT	U	P	CT	U	P	CT	U	P	CT	U
														6.98	0.83										

P = Productivity, CT = Cycle Time, U = Utilization

BIOGRAPHY

Born in Bogor, on 21st November 1998, Raihan Bagus Sakti Aji was born as the eldest son of three siblings. The author started his formal emelentary education at SDIT Al-Azhar 27 Cibinong (2004-2010) Then, continued to middle school at SMPN 2 Dumai only in the course of 2 years through acceleration program (2011-2013) Continuing to high school at SMAN 5 Mataram for a year which later moved to SMAN 3 Bogor (2013-2016). In 2016, the author continued his study to university, majoring in Industrial Engineering on Industrial Engineering Department, Institut Teknologi Sepuluh Nopember, Surabaya. During his college years, the author is actively joining several campus organizations. Starting in the second year, the author joined Himpunan Mahasiswa Teknik Industri (HMTI ITS) as member of IE Fair Staff (2017 – 2018). In the third year, the author joined as an assistant of Manufacturing System Laboratory (2018-2020) and also the ITS Website Development Team (2018-2019). The author also actively involved in business development, along with his college collageu, creating and running a scientific research startup named Science Hunter, working as the creative manager for the company (2018-2020). The author also worked as an intern on PT. Mercedes Benz Indonesia in Quality Assurance Department (2019) and on PT. Toyota Motor Manufacturing Indonesia Sunter Plant I on After Sales and Service Parts Division. For further communication, the author can be reached through email: raihanbagus.work@gmail.com or through linkedin: linkedin.com/raihanbagussa.