FINAL PROJECT – TI 184833

A DEVELOPMENT OF INVENTORY POLICY AND MATERIAL REQUIREMENT PLANNING SYSTEM: CASE STUDY ON BOTTLED WATER COMPANY

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APPROVAL SHEET

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FINAL PROJECT

Submitted to Qualify the Requirement of Bachelor Degree
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SURABAYA, JULY 2020

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ABSTRACT

PT. XYZ is one of the largest bottled water companies in Indonesia with 800 billion IDR annual revenue and has been continuously expanding its business. Under its operation, the company has been facing numerous challenges in inventory control issues, particularly on inventory policy and material requirement planning (MRP) system. On inventory policy, the company implements generalized inventory policy across all products, indicating that the policy does not yet consider a unique behavior between each product. On the MRP system, the company has a difficulty to accurately measure how many goods to be purchased and its scheduling system. This issue has been happening due to the insufficiency of the existing system to perform the procurement system effectively and efficiently. This research aims to develop a better MRP system and strategic inventory policy that will be examined by Monte Carlo Simulation. The suggested MRP system comprises of the development and integration of four main parts, namely the master data, bill of material, demand management, and planning & monitoring. Two MRP models are developed, namely the improved MRP Excel model and software requirement specification for digitalization purposes. To ensure that the system produces more robust and efficient inventory control, usability testing must be carried out consisting of both system usability scale assessment and feedback form. In the inventory policy, three methodologies are assessed including the existing system, continuous review (s, S), and Fixed-Order-Interval (FOI). The simulations results suggest the company to implement 21 continuous review (s, S), 4 FOI, and maintaining two existing inventory policy across 27 observed finished goods. By implementing those suggested policies, the company can reduce the total cost up to around 40 billion IDR while still maintaining the service level above the target of 99.5%.

Keywords: Continuous Review (s, S), Fixed-Order-Interval (FOI), Material Requirement Planning System, Monte Carlo simulation.

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The author realizes that there are still many drawbacks in this research. Therefore, the author is open to any critics and suggestions for this research. Finally, the author hopes that this research can give insights for any interested parties.

Surabaya, July 2019

Author

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CHAPTER 1
INTRODUCTION

This chapter consists of the background, problem formulation, objectives, benefits, research scope, and report outline of this research.

1.1 Background

The consumption of bottled water (AMDK) in Indonesia has been rising over the past few years. It is commonly derived from population growth, especially in the middle-income market, and the popular healthy lifestyles that promote large quantities of water consumption. These major reasons drove up the consumption of bottled water with an average of 12.5 percent every year from 2009 to 2014, making Indonesia as the fifth largest country on total bottled water consumption in the world (Jakarta Post, 2015). In 2020, the projected consumption of water bottled segment in Indonesia reaches 26,565 million liters with projected revenue of US$12,386 million and 5.5% annual market growth. Figure 1.1 shows the growth of bottled water consumption volume in Indonesia.

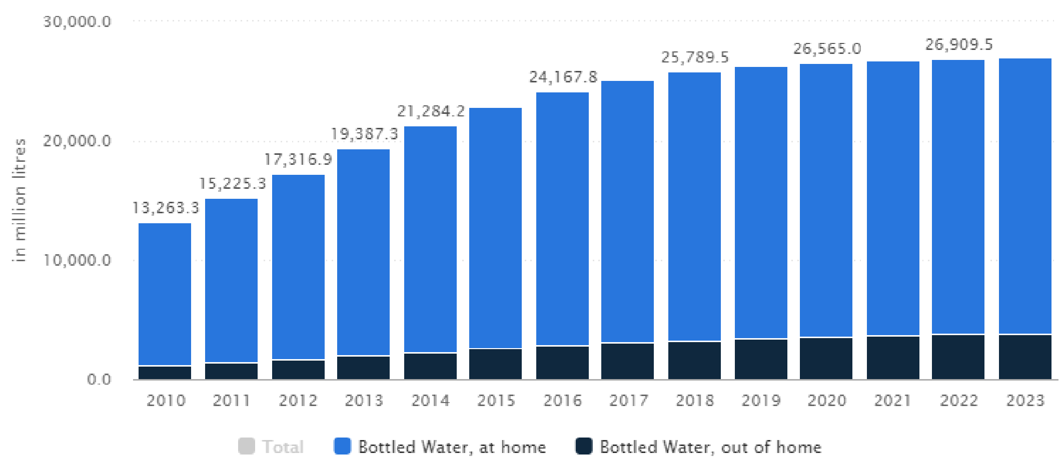

Figure 1.1 Indonesia's Bottled Water Consumption Volume 2010-2023

(Source: Statista, 2019)

Generally, the bottled water industry has three product varieties which are cup, gallon, and bottle. In the cup segment, the trend of consumption continues to increase with IDR 500 players as the driver. In the bottle segment, the main players are mostly placing the medium bottle in minimarkets and general trades. General trade accounts 71% of channel contribution followed with minimarkets and supermarkets with 24.5% and 4.5% channel contribution, respectively. The companies with a strong bottle market leverage brand image heavily in marketing strategy as the cheaper price is not the main factor to drive the sales performance. In the gallon segment, 69% of branded gallon buyers are dominated by upper socioeconomic society, indicating that branding is not the only strategy to drive sales. Each of the product varieties has different behavior in pricing policies and marketing strategies but has the same uniqueness in sales growth as all off products tend to have a growing number of consumptions (Nielsen, 2017).

Despite the continuous growth of the market, the bottled water industry has been facing challenges over the years, ranging from the regulatory based to the internal cost structure constraints. In a regulatory-based challenge, the import duty of plastic pellets and the regulation on the management of water resources affects the expense that companies need to deal with. Besides that, the cost structure which is dominated by the cost of plastic packaging, distribution cost, and inventory cost has made this industry quite sensitive. Due to the reliance on imported plastic and raw material, this industry is sensitive to fluctuations in the exchange rate. The distribution cost also plays an important cost structure constraint due to the sensitivity of rising fuel and labor costs. Furthermore, the rise of inventory cost due to a continuous growing demand is also a challenge of this industry due to the high number of capital and operational expenditures that are necessary to maintain the inventory at a proper level. Therefore, a management of several important cost structures is necessary to be conducted to maintain the competitive advantage of the company while operating at the lowest possible cost.

PT. XYZ is one of the largest bottled water companies in Indonesia with more than 800 million IDR annual revenue and has been continuously expanding its market. PT. XYZ has various competitive advantages such as, but not limited to, quality water and product innovation. The water quality of this company has been exceptional due to high technology utilization such as hyper membrane filter. Besides that, the company has also been striving for product innovation by developing safe products, unique product design, wide product varieties, and others.

Currently, PT. XYZ faces challenges in inventory policy due to numerous practical reasons. Firstly, the company has a problem in determining the inventory policy. The company still uses the subjective judgment of experienced employees to determine the parameters. Figure 1.2 represents the inventory policy of end products from different plants. Apparently, the company implements a generalized inventory policy according to the location of the plant. In this case, for plants located in Java, the buffer Days of Inventory (DOI) is 15 days and it should be added with the lead time around 30 days. Hence, the current minimum DOI is around 45 DOI while the ordering quantity is around 90 DOI. Theoretically, this should be a problem as different products might have different behavior on demand and lead time which underlines the importance of unique DOI across the products. Therefore, a study to analyze the unique characteristics across items are needed as a plant based minimum DOI policy could not cover the unique products' behavior according to its demand and lead time.

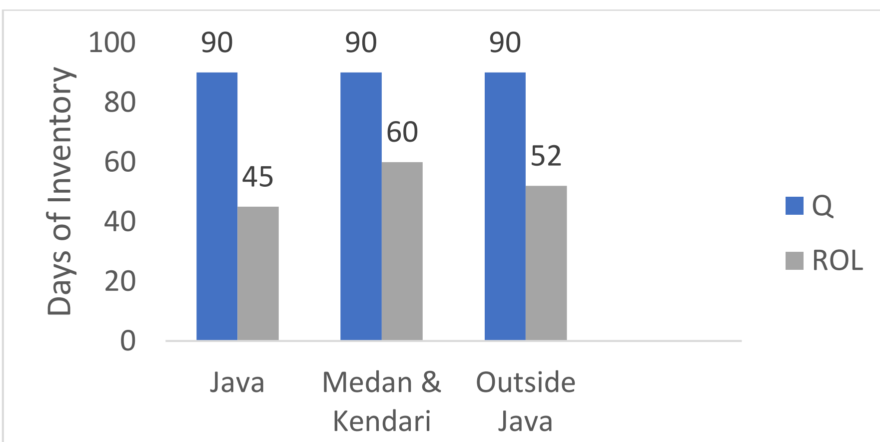

Figure 1.2 Existing Plant-Based Inventory Policy

Besides the minimum stock issue, the company also has a problem with the maximum stock. This has happened due to the absence of maximum stock Key Performance Indicators (KPI) of Production Planning and Inventory Control (PPIC) division which results in uncontrolled maximum inventory. This is, indeed, burdening the company in the scope of inventory cost as there are a lot of assets, handling, and treatments that are necessary to maintain the product continuously depreciated.

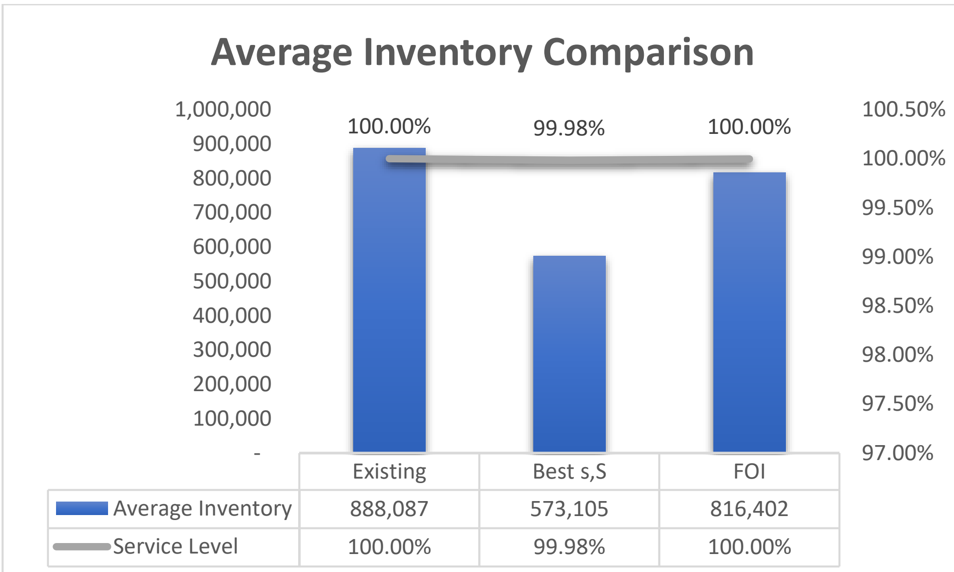

Figure 1.3 Average Inventory and Service Level of Product 1A

Figure 1.3 signifies overstock condition of product 1A. After conducting a simulation, the existing inventory policy seems to have excessive inventory. By comparing the existing condition with the best (s, S) scenario, there is a reduction for about 311,611 functional units of average inventory while still maintaining the service level target – above 99.5%. It indicates that having that much average inventory in the existing inventory policy is completely unnecessary since the reduction with that amount can still maintain the service level close to 100%. The condition of overstock was also subjectively validated by directly observing into the company's largest warehouse. The plant manager confirmed that excessive stock is a problem and it was visually confirmed by the existence of huge stocks placed in the warehouse's aisle.

Asides from the inventory policy, the company has been facing challenges during the calculation of MRP. Firstly, the company has difficulty to determine the number of goods to be purchased. This has happened due to the condition of extensive manual calculation which is subject to mistakes and the absence of material arrival schedule in their system. The MRP employees are having difficulty during the calculation of MRP due to various reasons including, but not limited to, extensive manual copy-paste, not updated reference data, and logic consistency. Secondly, the company also has difficulty to determine when the goods should be received. This is due to the absence of a time horizon in the system thus creating a problem in the scheduling system. Besides that, the existing system has less integration between the company’s information system such as the inconsistency of data format, bad user experience, and others. Hence, besides having a long time doing the calculation, the computed calculations are also prone to mistakes which are producing inaccurate goods to be purchased and the inability to accurately schedule the material.

According to the aforementioned problems, this research aims to improve the inventory policy of PT. XYZ along with the development of a material requirement planning system to create more effective and efficient inventory control – effectiveness is represented by accuracy while efficiency is represented by processing time. A Monte Carlo simulation will be conducted to review both existing and proposed inventory strategies, namely continuous review (s, S) and Fixed-Order-Interval (FOI). The Monte Carlo simulation is conducted to simulate the behavior of probabilistic parameters, which in this case are demand and lead time, and its effect on the inventory policy. The inventory parameters are calculated using various parameters including, but not limited to, Economic Order Quantity (EOQ), reorder level (s), maximum inventory (S), review period (R), and safety stock (SS). The material planning system will be developed in the form of both Excel modeling as a prototype and software requirement documents that will be given to the Information Technology (IT) department. A recommendation of an inventory strategy will be given to improve the existing strategy thus capable to achieve targeted service level with the lowest possible cost.

1.2 Problem Formulation

According to the aforementioned background, the problem formulation of this research is to develop an inventory policy and material requirement planning system thus achieving the most strategic inventory policy and sophisticated inventory control system. The decision of which inventory policy to be used will be compared by using rigorous assessment on calculating various observed impact parameters including, but not limited to, total cost and service level.

1.3 Objectives

The objectives of this research are listed as follows.

1. Develop a material requirement planning system to create a more effective and efficient inventory control.
2. Develop a strategic inventory policy for finished products according to each unique product’s behavior.
3. Examine the inventory policy and material requirement planning system between the improved and existing condition.

1.4 Benefits

The benefits of this research are listed as follows.

1. The recommendation of inventory policy can improve inventory performance in reducing its cost while still maintaining the targeted service level.
2. The recommendation of a material requirement planning system will act as a tool to improve the end-to-end business process of inventory control thus capable to execute the proposed inventory policy.
3. For the author, this research contributes to the learning process on the development of strategic inventory policy and its technical material requirement planning system.

1.5 Research Scope

1.5.1 Limitation

The limitations of this research are defined as follows:

1. In MRP system, the template is developed to monitor nation-wide products which consist of 27 plants.
2. Inventory policy assessment is for finished products in Pandaan plant.
3. The demand and lead time to be observed is the last one-year data (2019).
4. Inventory policy is developed only for finished products.

1.5.2 Assumption

The assumptions of this research are defined as follows:

1. All products are received in good condition.
2. No machine breakdown and availability issue.

1.6 Report Outline

The report outlines and its brief explanation for each chapter are described as follows.

CHAPTER 1: INTRODUCTION

The initial chapter of this research consists of a background of the problem, problem formulation, objectives, benefits, research scope, and report outline of this research.

CHAPTER 2: LITERATURE REVIEW

This chapter discusses several references used as the foundation of this research. The references are gathered from a literature review including, but not limited to, scientific journals, books, articles, and credible news.

CHAPTER 3: METHODOLOGY

This chapter discusses the systematic methodologies of this research. It consists of processes and flows, starting from problem identification from system study that includes business process understanding, until the conclusion and suggestion of this research.

CHAPTER 4: DATA COLLECTION AND PROCESSING

This chapter discusses the data collection given by the company. The data that are collected are some critical data used for inventory policy analysis and the development of material requirement planning system such as, but not limited to, the existing MRP template, a list of products, demand, lead time, and cost components. The collected data will be used for simulation and analysis to find a better inventory policy.

CHAPTER 5: ANALYSIS AND INTERPRETATION

This chapter consists of data interpretation and analysis derived from the previous data processing. A comparison analysis will also be conducted in this chapter to compare the performance of the proposed policy to the existing policy. Hence, a better inventory policy and material requirement planning system can be derived in this chapter.

CHAPTER 6: CONCLUSION AND SUGGESTION

This chapter concludes the overall research by answering the predetermined objectives. Several suggestions will also be conducted both for research development and notes for the company.

CHAPTER 2
LITERATURE REVIEW

This chapter consists of several references and related information used as the foundations of this research.

2.1 Inventory

2.1.1 Inventory Definition and Functions

According to Waters (2003), inventory is a list of items, both finished goods and raw materials, that are stored by an organization. There are various reasons that a company holds inventories. The main reasons for a company hold inventories are due to giving a buffer, given that demand usually fluctuates, and the company needs to prepare a demand that is larger than expected. Besides, according to Tersine (1994), inventory has several functions including, but not limited to:

a) Time Factor

   As the demand for an item cannot be fulfilled immediately, inventory plays a role to compensate the time needed to produce a material or usually called lead time.

b) Uncertainty factor

   Inventory can accommodate various uncertainties such as demand forecasting errors, delivery delays, machine breakdown, and others.

c) Economic factor

   Factors such as rising materials prices and different policies will highly affect the cost structure of the company thus inventory plays an economic factor in this matter.

d) Discontinuity factors

   Inventory allows the treatment of operations in an independent and economical manner. The discontinuity factor permits the firm to schedule many operations at a more desirable performance level than if they were integrated dependently.

2.1.2 Inventory Classification

To achieve the purpose of inventory as a buffer, there are several classifications of inventory which include:

a) *Raw materials*, a material that has arrived from suppliers and kept until needed for production.

b) *Work in progress*, a unit that is currently being produced and not yet finished.

c) *Finished goods*, a finished product that is ready to be dispatched.

d) *Spare parts*, a product that is usually used for machinery, equipment, facilities, and others.

e) *Consumables*, a product that will be elapsed when consumed such as oil, paper, cleaners, and others.

2.1.3 Inventory Cost Components

To achieve higher profits, a company must have at least four main objectives which are providing the best customer service, lowest production costs, lowest distribution costs, and lowest inventory investment (Arnold et al., 2008). Therefore, inventory cost plays an important role in the business objective thus should be carefully managed. Generally, inventory cost calculation comprises several important parameters including demand (D), order quantity (Q), and others. Below is the formula to calculate the total cost of inventory (TC) and the explanation of each inventory cost component.

$$TC = (UC \times D) + \left(\frac{RC \times D}{Q}\right) + \left(\frac{HC \times Q}{2}\right) \qquad (2.1)$$

a) Unit Cost (UC)

The cost charged by the suppliers for one unit of an item is called as unit cost. When the company produces one item independently, then the unit cost consists of both variable and fixed cost to produce or acquire it. Sometimes, the unit cost might be difficult when the company has multiple suppliers, which at the same time, having different prices or offering a quantity discount. Thus, at some moments, unit cost calculation is conducted by the best possible approximation.

b) Reorder Cost (RC)

The cost of placing an order for an item is called reorder cost. It includes allowances for drawing-up an order (with checking, getting authorization, clearance, and distribution), correspondence and telephone costs, receiving (with unloading, checking or inspection, and testing), supervision, use of the equipment and follows up. The value of reorder cost is dynamic as it highly depends on how much orders are placed in a year.

c) Holding Cost (HC)

The cost of holding one unit of an item in stock during one period of time is called as holding cost. The unit of holding cost is usually represented in a price per unit per year such as 100/unit/year IDR. Holding cost also has several categories including, but not limited to, storage space (supplying a warehouse, rent, rates, heat, light), loss (due to damage, obsolescence, and pilferage), handling, administration, and insurance. The value of these costs is difficult to be determined as a different type of industry has different uniqueness on its holding cost components, but table 2.1 represents the percentage approximation of holding cost.

Table 2.1 Holding Cost

Type of Cost	**% of unit cost**
Cost of Money	10-15
Storage Space	2-5
Loss	4-6
Handling	1-2
Administration	1-2
Insurance	1-5
Total	19-35

(Source: Waters, 2003)

However, holding cost components might vary according to the condition of the industry. The holding cost components could also be categorized in other ways including, but not limited to, capital cost, storage cost, and risk cost. Capital cost is a cost of investment that have incurred on land, buildings, and equipment used in the production of products for the manufacturing company. Asides from capital cost, another important holding cost component is storage cost which includes worker's cost, assets cost, electricity, and others. Lastly, risk cost is a cost associated with the possibility of loss including, but not limited to, damage, obsolescence, and expired.

2.2 Probabilistic Inventory Control Model

An inventory control which sets parameters are subject to change and contain uncertainties is called probabilistic inventory control. There are two related variable parameters which are demand and lead time, which will also impact the variability of inventory cost value. As the demand and lead time varies, the value of inventory parameters must also accommodate this variability. The parameters, including safety stock and reorder point, would be highly impacted by the variability. To address this, there is a formula developed to calculate safety stock which under lead time and demand variability shown in table 2.2 below. The value of safety stock will impact the reorder level as it is one of the components in reorder level calculation, thus reorder level is also subject to variability.

Table 2.2 Demand and Lead Time Variability on Safety Stock

Demand	Lead Time: Constant	Lead Time: Variable
Variable	$SS = Z \times \sigma_D \times \sqrt{LT}$ Safety stock under demand uncertainty (2.2)	$SS = Z \times \sqrt{(D^2 \times \sigma_{LT}{}^2) + (LT \times \sigma_D{}^2)}$ Safety stock under both uncertainties (2.3)
Constant	$SS = 0$ Unnecessary to create a safety stock (2.4)	$SS = Z \times \sigma_{LT} \times D$ Safety stock under lead time uncertainty (2.5)

Lead Time

(Source: Pujawan, 2017)

Where:

σ_D = Demand standard deviation,

σ_{LT} = Lead time standard deviation,

SS = Safety stock,

D = Demand,

Z = Statistical significance, which lists are shown in table 2.3 below.

Table 2.3 Z Table

Service Level (%)	Z	Shortage Probability
50	0.00	0.500
80	0.84	0.200
84.1	1.00	0.159
85	1.04	0.150
90	1.28	0.100
93	1.48	0.070
95	1.64	0.050
97	1.88	0.030
97.7	2.00	0.023
99	2.33	0.010
99.5	2.58	0.005
99.9	3.00	0.001

(Source: Waters, 2003)

Besides that, as reorder point calculation includes the safety stock parameter, the reorder point is also subject to variability. Below is the formula of reorder level that consists of lead time (LT), demand (D), and safety stock (SS)—which in this case would be affected by the condition of safety stock that is influenced by demand and lead time variability.

$$ROL = (LT \times D) + SS \tag{2.6}$$

Probabilistic inventory control has two kinds of models which are continuous review and periodic review. An explanation below would elaborate on each of the probabilistic inventory control models.

2.2.1 Continuous Review Policy

A policy in which periods of review is continuous are called continuous review policy. However, the policy requires a system that can monitor the inventory in a continuous condition. There are two continuous review methods which are explained below.

a. (s, Q) Method

In this method, an order quantity of Q will be placed whenever the inventory reaches or below the minimum inventory (s). Two main practical calculations have to be considered on this method which are to calculate the minimum inventory and the amount of inventory and goods to be purchased with Economic Order Quantity. Below is the formula for both parameters.

$$Q = \sqrt{\frac{2 \times D \times RC}{HC}} \quad (2.7)$$

Where:

Q = economic order quantity

D = demand

RC = reorder cost

HC = holding cost

In this method, the value of s depends on the condition of parameters' variability. The formula to calculate the minimum inventory (s) can be derived from table 2.2 and the illustration of (s, Q) method is presented in figure 2.1. In this method, an order quantity is fixed in Q quantity. In comparison with (s, S), this method has a relatively lower amount of inventory as the quantity to be ordered is not filling the maximum inventory. This method is also easier to be used by the workers as the orders are fixed thus easier to replenish the order. Besides, this method is also easier for the supplier as the supplier can also perform a fixed delivery quantity.

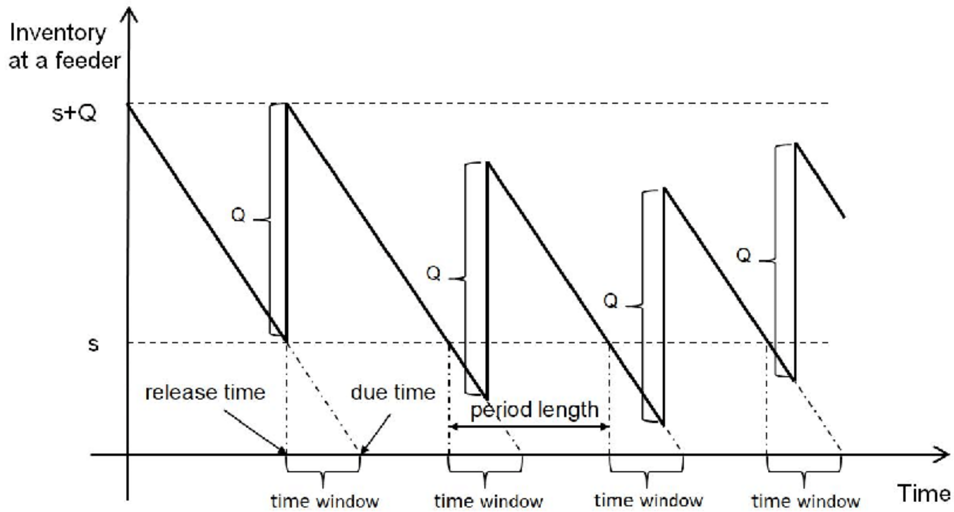

Figure 2.1 (s, Q) Inventory Model

(Source: Liu et al., 2017)

b. (s, S) Method

In this method, an order quantity to maximum inventory (S) will be placed whenever the inventory reaches the minimum inventory (s). Different from (s, Q) method which orders are placed in a fixed quantity, this method has a variety in its ordering quantity as it depends on the value of ending inventory at the moment. This method is usually called as min-max with s as the minimum and S as the maximum inventory value. Figure 2.2 represents the illustration of (s, S) inventory control method.

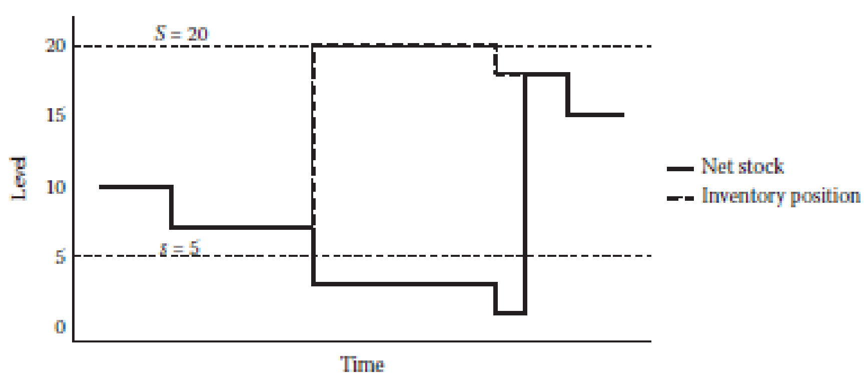

Figure 2.2 (s, S) Inventory Model

(Source: Silver et al., 2017)

2.2.2 Periodic Review Policy

An inventory replenishment policy in which reviews are conducted at regular time intervals is called a periodic review policy. In this case, the decision the order size will vary according to the inventory position of the firm at the end of each period. Therefore, a variety of ordering quantities becomes the main disadvantage of this method as it is harder for both the planner and supplier to fulfill the order. In comparison to continuous review policy, this policy requires a simpler monitoring process as it is not monitored continuously but regularly. Two models of periodic review policy will be explained in this section are Fixed Order Interval (FOI), and (R, s, S).

a. Fixed-Order-Interval (FOI)

The fixed-order-interval model is used when orders must be placed at fixed time intervals (weekly, monthly, etc.) This approach is quite different with EOQ approach in which the order size generally comes fixed between each cycle. The usage of this policy is usually due to the policy coming from the supplier that might encourage to order at a fixed interval. Furthermore, grouping orders for items from the same supplier would also reduce their shipping cost which possibly creates a lower cost for the firm.

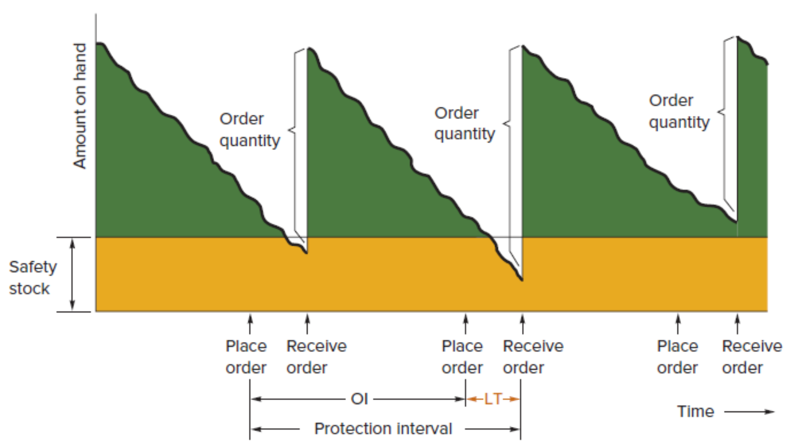

Figure 2.3 FOI Inventory Model

(Source: Stevenson, 2014)

Figure 2.3 represents the scheme of fixed order interval inventory control model. In the fixed quantity arrangement, orders are triggered by reorder point, while in the fixed-interval arrangements orders are arranged by a time. Therefore, the fixed-interval model must have stockout protection for lead time plus the next order cycle, but the fixed-quantity only needs protection during lead time because additional orders can be place at any time and will be received thereafter. Consequently, it is indeed a sign that this model requires greater need for safety stock than the fixed-quantity model. The formula of this model is depicted in the formula below.

$Amount\ to\ Order\ (Q) = Expected\ demand\ during$ protection interval $+ SS - Inventory$

$$Q = D\ (OI + LT) + Z \times \sqrt{(D^2 \times \sigma_{LT}{}^2) + (LT \times \sigma_D{}^2)} - A \quad (2.8)$$

Where:

Q = Ordering quantity,

D = Demand,

OI = Order interval (length between orders),

A = Amount of on-hand or inventory at reorder time,

σ_D = Demand standard deviation,

σ_{LT} = Lead time standard deviation,

Z = Statistical significance,

b. (R, s, S) method

This method is a combination between (R, S) and (s, S) methods. In this method, the inventory is checked at every R unit of time and the order of maximum inventory (S) will be placed whenever the inventory position reaches or below minimum inventory (s) value. If the inventory level is above s, an order would not be placed until the next R period. In another word, (R, s, S) is a periodic version of (s, S) system as it is only monitored every R unit of time. The (R, S) situation can also be viewed as a periodic implementation of (s, S) with s = S-1.

2.3 Monte Carlo Simulation

Monte Carlo simulation is a probabilistic type of simulation that approximates the solution of a problem by sampling from a random process (Tersine, 1994). It is a study by evaluating alternative designs or decision rules to capture some recommended alternative designs that will be taken into consideration. Random numbers are used to describe the movement of each random variable over a period. The simulation helps the decision-makers to take a decision by analyzing the behavior of strategies that will be implemented. There are several stages in conducting a Monte Carlo simulation depicted in figure 2.4 below.

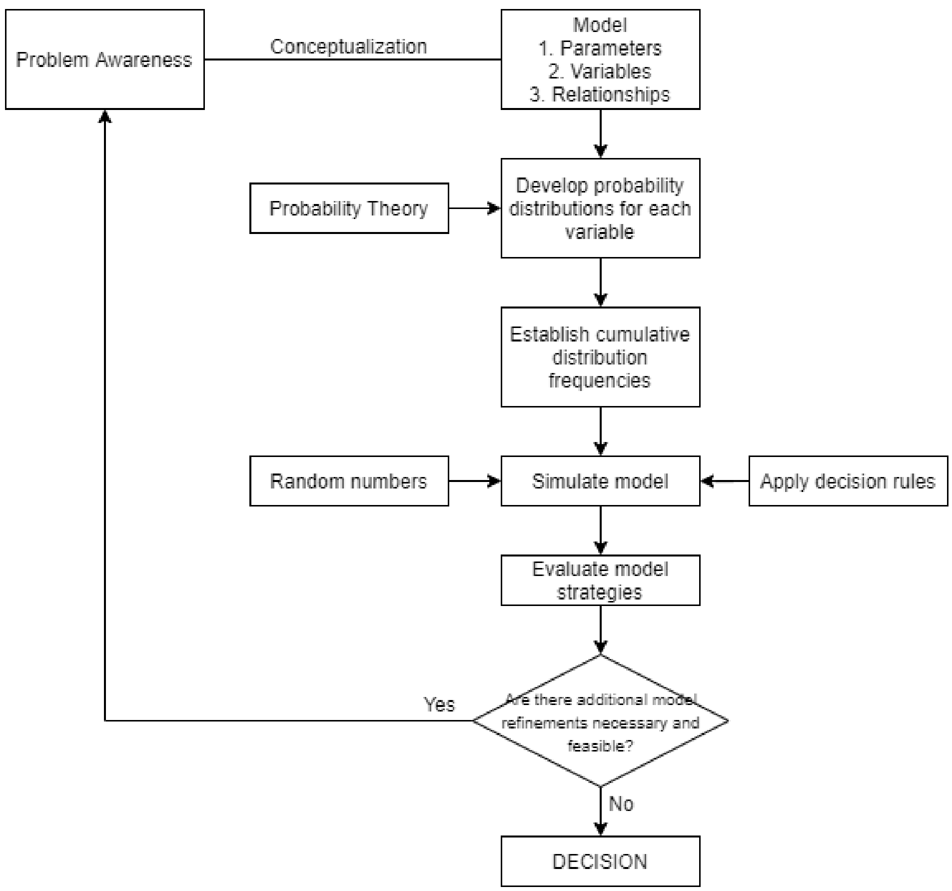

Figure 2.4 Monte Carlo Simulation

(Source: Tersine, 1994)

Figure 2.4 represents the overall stages of conducting Monte Carlo simulation and below is the explanation of the steps.

1. Determine distributions for targeted variables. The distribution might vary such as, but not limited to, Poisson, Normal, and Exponential, according to the historical records.
2. Establish cumulative probability distribution for each variable and determine the random number interval for each variable.
3. Generate random numbers and samples at random from cumulative probability distributions to approximate the value of variables.
4. Conduct the simulation with a certain number of observations according to the necessary number of replications for data sufficiency.

In Monte Carlo simulation, several replications must be rigorously determined to reduce the bias of resulted numbers. This is due to the existence of data adequacy reasons as the number of replications must be enough before moving into the decision. Below are the steps to determine the replication number.

1. Experiment with n number of replications
2. Determine the halfwidth (*hw*) value with the formula below.

$$hw = \frac{(t_{n-1,\frac{\propto}{2}})s}{\sqrt{n}} \tag{2.8}$$

where

$(t_{n-1,\frac{\propto}{2}})$	= value from t distribution table with n-1 degree of freedom
$\propto$	= 5%
s	= standard deviation from simulation sample
n	= number of replications

3. Evaluate the half-width value. If smaller *hw* value is needed, then the number of replications must be added to ensure data adequacy.

$$n' = \left(\frac{(t_{n-1,\frac{\propto}{2}})s}{hw\prime}\right)^2 \tag{2.9}$$

2.4 Material Requirements Planning (MRP)

A priority plan showing the components required at each level of assembly, based on lead times, and calculates the time when these components needed is called material requirement planning (Arnold et al., 2008). There are two main objectives of MRP which are to determine requirements and keep priorities current. In determine requirements objective, MRP allows the company to have the right quantities available at the right quantity to meet the demand. In keep priorities current objective, MRP can delete, expedite, delay, and change orders to keep plans current. There are three main inputs to the material requirement planning system which are master production schedule, inventory records, and bill of material. MRP results in decisions on purchasing and production activity control. Figure 2.5 represents the input and output as well as a holistic visual representation of material requirement planning and its connection to other processes.

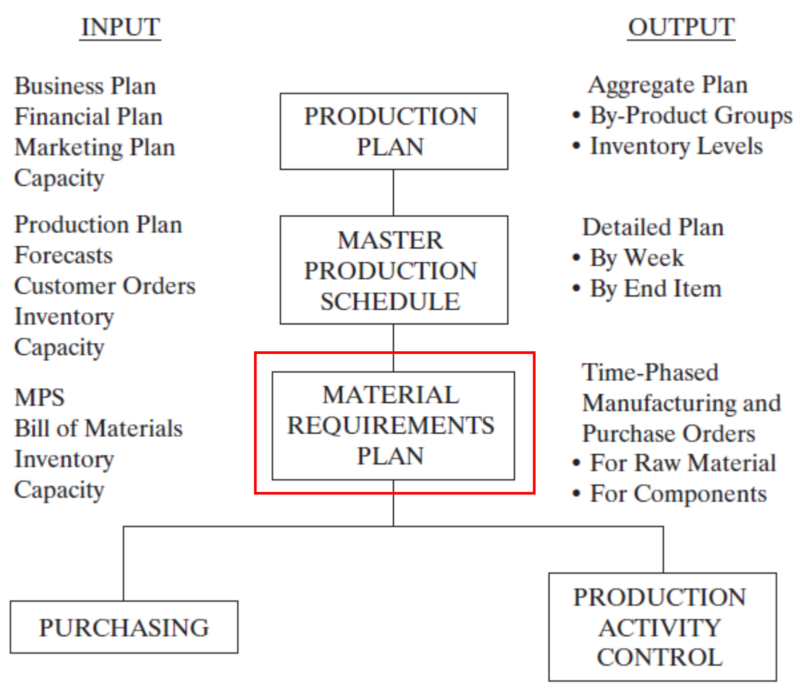

Figure 2.5 Material Planning and Control System

(Source: Arnold et al., 2008)

MRP needs a Master Production Schedule (MPS) to capture which end items to be produced, the quantity of each, and the dates they are to be completed. Besides, inventory record is also a major input to MRP system as the quantity available must be considered to find how many items are needed. Finally, as items consist of independent and dependent demand, the Bill of Materials (BOM) is also needed to show all parts required, along with its quantity, to produce one item. Figure 2.6 illustrates several important parameters and the example of MRP template.

Part Number		Week				
		1	2	3	4	5
A	Gross Requirements					50
	Projected Available 20	20	20	20	20	0
	Net Requirements					30
	Planned Order Receipt					30
	Planned Order Release				30	
B	Gross Requirements				30	
	Projected Available 10	10	10	10	0	
	Net Requirements				20	
	Planned Order Receipt				20	
	Planned Order Release		20			
C	Gross Requirements				30	
	Projected Available		0		0	
	Net Requirements				30	
	Planned Order Receipt				30	
	Planned Order Release			30		
D	Gross Requirements		20			
	Projected Available	0	0			
	Net Requirements		20			
	Planned Order Receipt		20			
	Planned Order Release	20				
E	Gross Requirements		20			
	Projected Available	0	0			
	Net Requirements		20			
	Planned Order Receipt		20			
	Planned Order Release	20				

Figure 2.6 Important Parameters and Example of Simple MRP

(Source: Arnold et al., 2008)

In the implementation, there are several pitfalls in using MRP. Firstly, data management failure could be a big obstacle as the firm generate masses of data where the processing is prone to mistakes, causing inaccurate MRP system. Data integrity is highly required to produce useful and effective MRP results. Secondly, supply chain problems could also be an issue as the firm has to decide when and what quantities to order. Challenges such as supplier's reliability and production problems would highly affect the complexity of managing MRP.

2.5 Software Requirement Specifications

According to ISO-IEEE 830, Software Requirement Specifications (SRS) or usually called as SRS document is a specification for a software product, program, or set of programs that perform certain functions in a specific environment. SRD consists of user stories, use cases, rules, mockups, and models to translate the functional requirements into a software design. SRS document establishes a basis of agreements between users and developers on how the product should function. There are several basic issues that SRS shall address including, but not limited to:

a) *Functionality*, which entails what the software supposed to do.
b) *External interfaces*, which entail the interaction between people and system.
c) *Performance*, which entails the speed, availability, response time, recovery time of various software functions.
d) *Attributes*, which entails portability, correctness, maintainability, and security.
e) *Design constraints imposed on an implementation*, which entails standard in effect, implementation language, policies for database integrity, resource limits, and operating environment.

Therefore, to properly write SRS document, there are eight important characteristics which a good SRS ideally should have.

a) *Correctness*, referring about the requirement fulfillment that the software shall meet.
b) *Unambiguity*, referring about a single interpretation on every requirement.
c) *Completeness*, referring about the fulfillment of all significant requirements (functionality, performance, attribute) and definition of the responses of the software to all realizable classes of input data.
d) *Consistency*, referring about the absence of conflict on individual requirements such as logical or temporal conflict and format characteristic inconsistency.
e) *Verifiability*, referring to the ability of stakeholder to verify every requirement proven by the existence of finite cost-effective process with which a person or machine can check that the software product meets the requirement.

f) *Modifiability*, referring to the easiness and consistency to modify.

Generally, the SRS document has various formats according to the necessity of the existing condition. Some SRS documents could have a full format while the others are not due to the availability of the user to directly transfer the requirement on a person-to-person basis. However, The IEEE Recommended Practice for Software Requirements Specifications (IEEE 830) document proposes a structure for SRS documents described in Table 2.4.

Table 2.4 Software Requirements Specification Recommendation

Table of Content		3.1.2	Hardware interfaces
1.	Introduction	3.1.3	Software interfaces
1.1	Purpose	3.1.4	Communication interfaces
1.2	Scope	3.2	Functional requirements
1.3	Definitions, acronyms, and abbreviations	3.2.1	User class 1
1.4	References	3.2.1.1	Functional requirements
1.5	Overview	3.2.1. n	n functional requirements
2.	Overall description	3.2.m	User class 2
2.1	Product perspective	3.2. m.1	m user class m
2.2	Product functions	3.2.m. n	m.n functional requirement
2.3	User characteristics	3.3	Performance requirement
2.4	Constraints	3.4	Design constraints
2.5	Assumption and dependencies	3.5	Software system attributes
3	Specific requirements	3.6	Other requirements
3.1	User interfaces	Appendix	
3.1.1	Hardware interfaces	Index	

(Source: ISO-IEEE 830, 1998)

2.6 Fourier Transform

Fourier transformation is a transformation which decomposes a function of time into its frequencies. The Fourier transform converts a signal that depends on time into a representation that depends on the frequency. This method has been proven to be a successful method to detect the seasonality of a time series by describing the fluctuation of time series in terms of sinusoidal behavior at various frequencies (Jackson, 2020). Below are the steps in Fourier Transform to detect the seasonality of a time-series.

1. Pick a Frequency

Firstly, the Fourier transform starts with examining the smallest frequency. As an example, for a signal made of 200 points, the smallest frequency possible is 1/200 or equal to 0.005 Hz.

2. Draw the Signal

Drawing the signal means decomposing the entire signal on the circle. In this case, when the signal measurement is high, the clock alarm of the circle is high.

3. Compute the Periodogram

Summing the vectors of the previous circle would result into the power of the frequency. This can happen due to the sum of all the vectors line up and point in the same direction, creating values that represent the frequency.

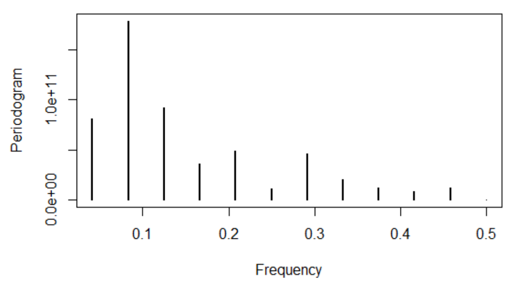

Figure 2.7 Periodogram

4. Repeat with Different Frequencies

Completing the calculation with different frequencies is necessary until all the power of each possible frequency is computed. The frequency with the highest power represents the greatest periodicity.

2.7 Research Position

Prior to this research, there are various research focusing on inventory policy with each of its uniqueness. There are three samples of benchmarking to compare this research position. Firstly, research from Tao et al. (2017) discusses inventory control policy for a periodic review system or usually named on (R, s, S) notation. Tao et al. also focuses on the possibility of having expediting mode, other than a regular mode, which enables the company to order with a shorter lead time at a higher cost when necessary. Secondly, research from Qiu et al. (2017) discusses about the optimization of (s, S) inventory models with demand distribution uncertainty. Thirdly, research from Mousavi et al. (2019) discusses about a combination of continuous review (s, Q) and periodic review inventory policy based on which an order size of Q placed by the firm in a fixed period (R) when the inventory reaches the reorder point (s). Mousavi et al. also emphasizes vendor-buyer supply chain uncertainty in which lead times are constant and the demands of buyers follow a normal distribution. Meanwhile, this research focuses on the assessment of inventory policy (s, S) and FOI by also implementing seasonality analysis using Fourier transformation. Besides that, this research also develops a material requirement planning system both on excel model and software improvement to enhance the implementation of inventory policy. The summary of research position is summarized on table 2.5 below.

Table 2.5 Research Position

Scope of Research	Tao et al. (2017)	Qiu et al. (2017)	Mousavi et al. (2019)	This Research (2020)
Demand	Stochastic	Stochastic	Stochastic	Stochastic
Leadtime	Stochastic	Constant	Constant	Stochastic
Review Method	(R, s, S)	(s, S)	(R, s, Q)	(s, S), FOI
Seasonality Identification				V
MRP Development				V
Software Requirement Documents				V

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CHAPTER 3
METHODOLOGY

This chapter on elaborates the methodology used in this research. Generally, the methodology consists of a study phase to analyze both general business process of the industry and conducting problem identification, data collection, system development, and data processing to obtain the best inventory policy and material requirement planning system. The depiction of the methodology is presented in figure 3.1 below.

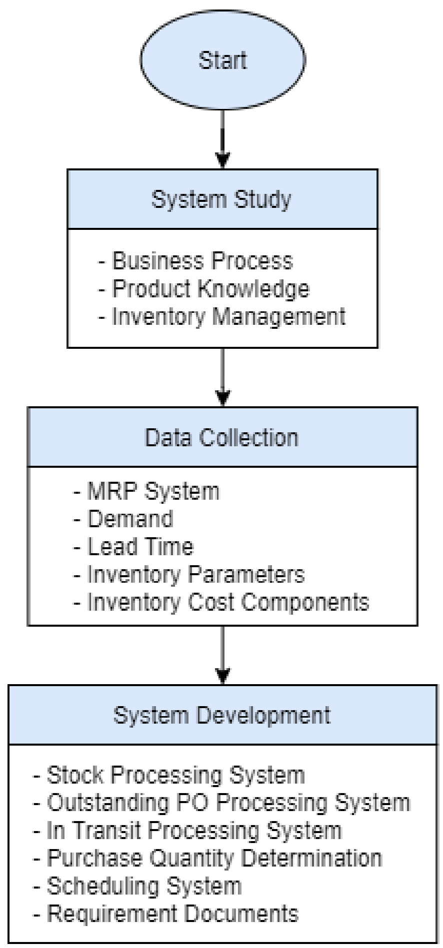

Figure 3.1 Research Methodology

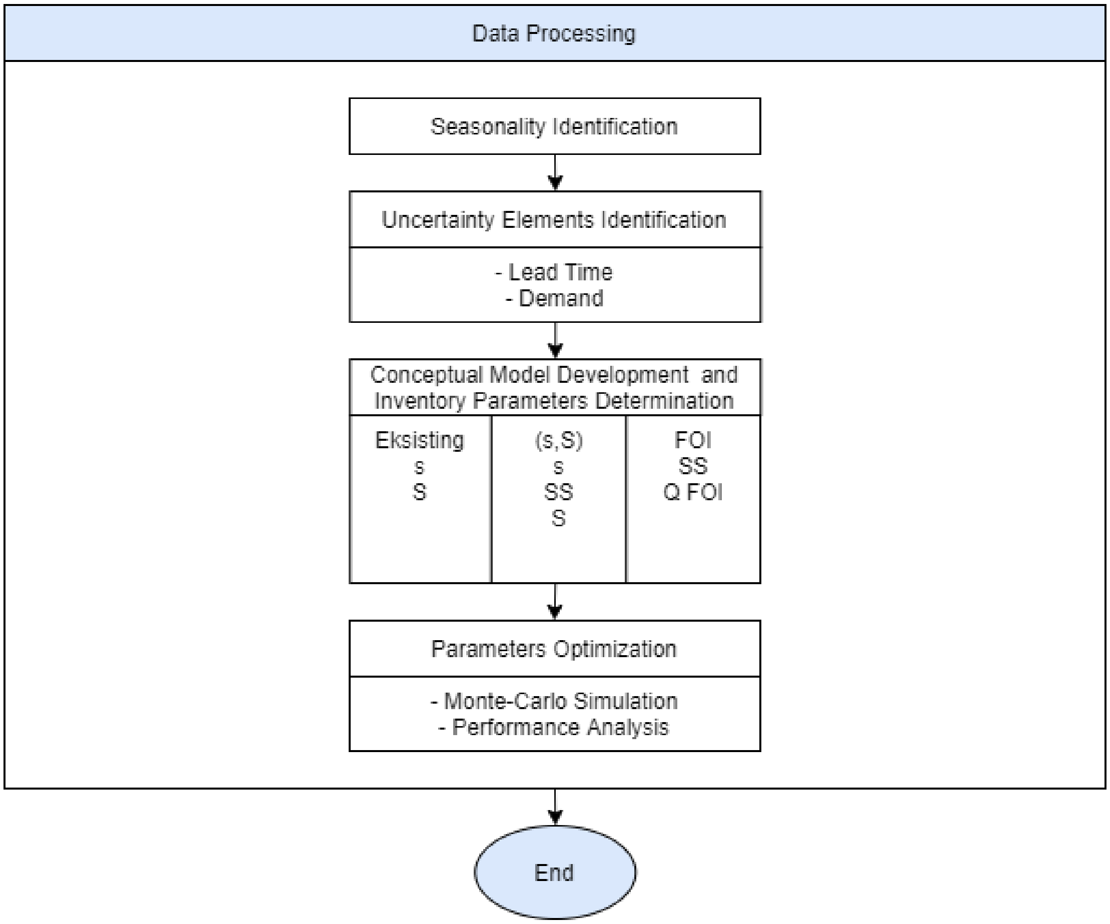

Figure 3.1 Research Methodology

3.1 System Study

In this phase, three activities are conducted to study the existing system which consists of understanding the business process, product knowledge, and inventory management of the observed industry. The system study is conducted by doing direct observations, interviews, and system understanding both from inventory policy documents and material planning system documents. This phase aims to deeply understand the pain points and challenges that the company wants to solve to avoid mismatch solutions that will be suggested to the company. An assessment to prioritize action plans would be also conducted on this study as a means of choosing which problem has to be solved first.

3.2 Data Collection

In this phase, data collection is conducted as the input of data processing. Below is the list of data that are needed in this research.

a. Existing MRP system.
b. List of products and packaging (carton) and its historical demand per month for the last two years (2018-2019).
c. Lead time of products.
d. Existing inventory policy and parameters.
e. Inventory cost components including, but not limited to, unit cost, holding cost, and reorder cost.

3.3 System Development

In this phase, a material requirement planning system is developed. After understanding the business process of the existing material planning system, a list of problems that should be improved is documented. The development comprises both software and its integration to the MRP template that will be documented on software requirement specifications or documents. There are important key parameters that will be improved—in a way how it should be integrated— which are stock, outstanding PO, and in-transit processing system. Besides, a process of how much product should be produced and when should be arrived at the warehouse—or called as scheduling system—will also be assessed and improved.

In system development, two main activities will be conducted. Firstly, an improvement of the existing conventional template which uses Microsoft Excel platform will be conducted. The improvement comprises on development of a new MRP template that includes a time horizon and scheduling system. This is due to the absence of time horizon in the existing system which creates loopholes on the possibility of stock-outs, the difficulty of a monitoring system, and a problematic scheduling system. Therefore, a new model of MRP will be developed that will not consist of only a new template, but also the way how the data should be processed−with the help of Excel's advance function, Macro, and Visual Basic for Application (VBA). Secondly, best practice improvement will also be conducted. In this phase, the improvement will be on digitalizing the existing process that will be integrated into the company's information system. The improvement will be presented in the form of software requirement specifications that will be given to the Information Technology (IT) department.

After development phase, a design of usability testing will also be developed. The development of the test is to ensure that the proposed system will produce more effective and efficient inventory control by examining its performance and gaining feedbacks from the users.

3.4 Data Processing

In this phase, data processing and analysis are conducted. The data processing comprises of both existing and improved inventory model that is depicted in figure 3.1. The steps of data processing and analysis are explained below.

3.4.1 Seasonality Identification

In the initial phase, seasonality identification is conducted using Fourier transformation. The seasonality identification aims to see the condition of seasonality of each product throughout the year and as an input for random number and inventory policy division. In this case, when the product has seasonality, it means that the data randomization and inventory policy should be divided by its seasonality frequency.

3.4.2 Uncertainty Elements Identification

In this case, the uncertainty elements to be considered are demand and lead time. To accommodate the uncertainty, a distribution fitting must be conducted as those parameters will be inputted in the simulation. The distribution fitting uses Microsoft Excel's. The software will give distribution options that can be chosen along with the parameters.

3.4.3 Conceptual Model Development

In this research, three conceptual models will be assessed which are the existing model, (s, S), and FOI. To assess these models, inventory parameters calculations including, but not limited to, safety stock, minimum, maximum, and Q are also conducted by using several formulas explained in chapter two.

3.4.4 Parameters Optimization

To find an optimized aforementioned parameter, Monte Carlo simulation is conducted. A simulation validation must be carried out first to ensure that the simulation model can represent the actual problem. This can be conducted by comparing simulation model output with the real system using t-test. Below are the fundamentals of manual hypothesis testing used in t-test for validation.

1. Determine the sample mean, population mean, sample standard deviation and sample size.
2. Calculate t-score using the t-test formula.
3. Identify the critical t-score on t-score table according to the degree of freedom and alpha value.
4. Compare the calculated t-score to the critical t-score. If the t-score is not under the critical t-score interval, then the sample mean is statistically different than the population mean.

After validation steps, simulation can be conducted to capture the best possible parameters. The inputs of the simulation are both demand and lead time derived from distribution fitting and several key inventory parameters. The outputs of the simulation are total cost, number of stockouts, and service level. To determine the best inventory policy, performance analysis should be conducted. Below are the steps to select the best inventor policy for each product.

1. Conducting a parameters comparison for all products to eliminate inventory policy that is not suitable with the company standard. In this case, the minimum

and maximum service level is 99.5% and 100% for all products, respectively – while there is no maximum and minimum total cost set by the company. This step will erase inventory policy that has lower service level as than the standard of the company.

2. Performing normalization step to find both normalized value (0-1) on service level and total cost which formula is shown below.
3. Performing weighting step to select the best inventory policy according to both service level and total cost factors. The value of weight would be set by the company as it is dependent to its optimization focus. Below is the formula of weighting to select the best inventory policy of each product.

$$Weighting\ Value = (Weight \times Result)_{SL} \times (Weight \times Result)_{TC}$$

4. Performing scenario assessment to capture the behavior of outputs which are service level and total cost when the input parameters are changed – maximum inventory (S) and reorder level (s). This step aims to see its influence on service level and total cost. The expected outcome in this scenario is an optimal value of the parameters that can be driven from the value of service level and total cost of inventory.
5. Performing sensitivity testing to the selected scenario to see the behavior of the uncertain parameters, which in this case are demand and lead time, against the outputs to be observed which are total cost and service level.

CHAPTER 4
DATA COLLECTION AND PROCESSING

In this chapter, the existing system description and data collection will be explained. The MRP system improvement, both on process flow digitalization and algorithm, will also be presented. Besides that, Monte Carlo simulation until its sensitivity testing will also be carried out to determine the best possible inventory policy and parameters.

4.1 Material Requirement Planning System

In this subchapter, a description of both the existing MRP system and the suggested MRP system is presented. The explanation comprises both the process flow improvement and algorithm recommendation.

4.1.1 Existing MRP System

Below is the explanation about the existing material requirement planning system, both on the flow process and data integration.

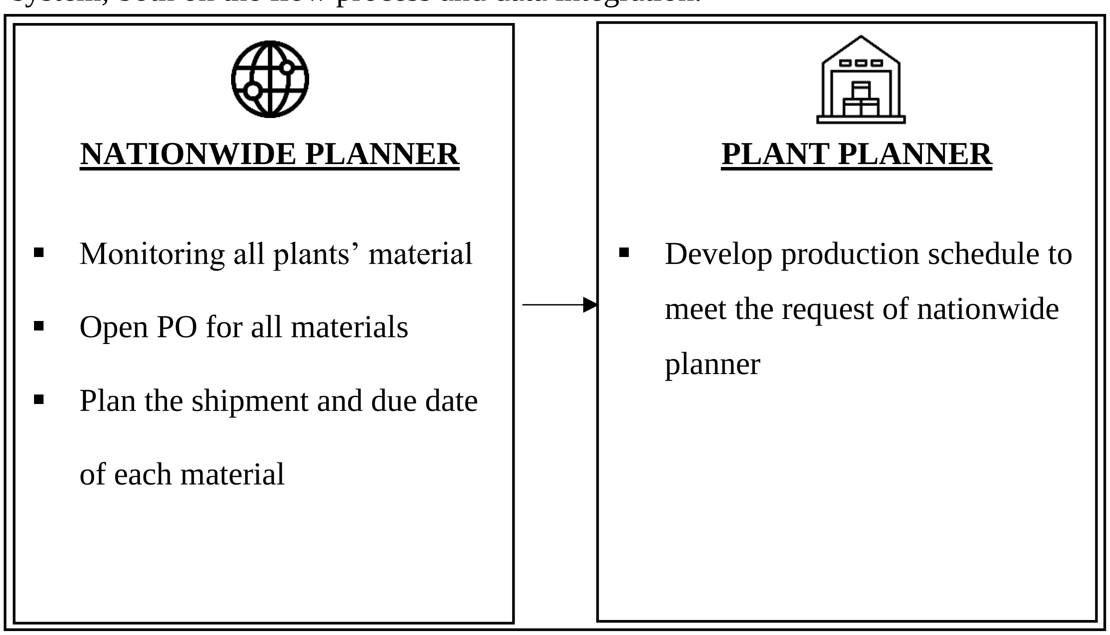

Figure 4.1 Flow Process of Material Planning

Figure 4.1 represents the flow process of material planning in the existing system. The planning process is started aggregately under nationwide planners whose responsibilities are to monitor the inventory of all plants, opening purchase order for all materials necessary, and planning the shipment and due date for each material. After the nationwide planner planning the materials, the ordering quantity list will be given to the plant planner as well as the due date, in days basis, where the materials should be received in each plant. Apparently, the methodology currently being implemented by the company is slightly different from the theory, where the planning process is conducted monthly while it should be on a weekly basis. However, the company implements this policy due to the business complications such as materials aggregation, minimum ordering quantity (MOQ), quantity discount, and other factors where the plant planner has no authority to create a decision on this matter. Therefore, the decision of ordering quantity is on the hand of nationwide planners due to the reason of authority and the plant planner is responsible to execute by creating a production schedule according to the nationwide planner's request.

In this section, a description of the MRP process along with its algorithm is presented. Figure 4.2 represents the platforms used on the existing MRP system, namely the company information system and excel template for calculation.

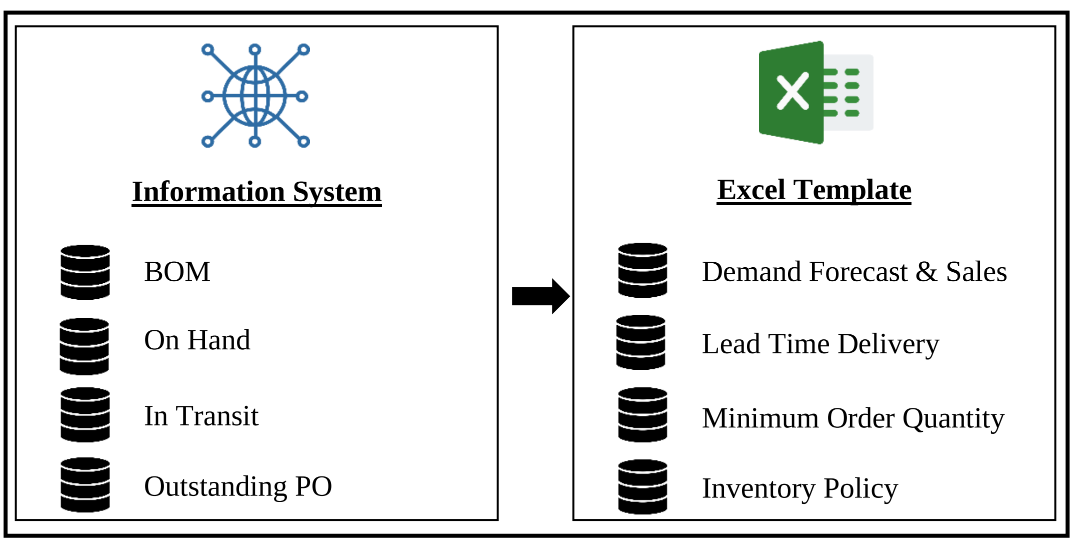

Figure 4.2 Existing MRP Platform

Figure 4.2 depicts the existing MRP process which comprises of two major platforms, namely the information system and database Excel template for a manual calculation. In the information system of the company, several data can be downloaded which are the Bill of Material (BOM), on-hand inventory, in-transit inventory, and outstanding purchase order. These data must undergo the pre-processing part to clean and adjust with the predetermined standard that can be calculated in the Excel template. After the pre-processing part, the next process is to calculate the ordering quantity which is described in the figure below.

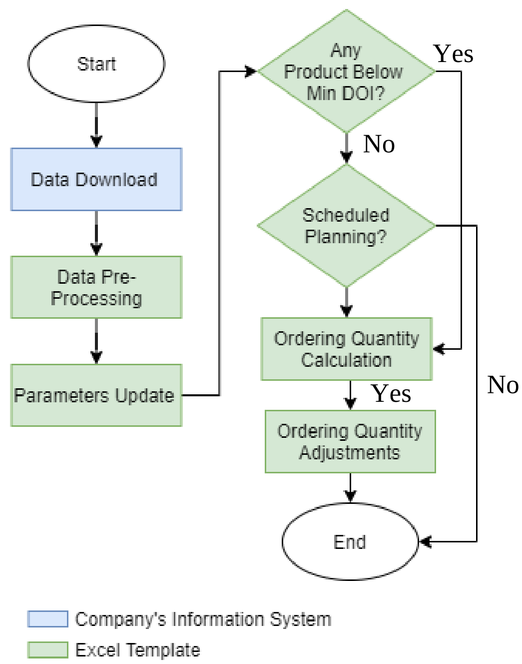

Figure 4.3 Existing MRP Process

Figure 4.3 depicts the existing process of the MRP system with information on the platform used inside each of the processes. After downloading the data necessary as described earlier, data pre-processing should be carried out including the process of matching the index plant, data compiling, and other necessary processes. After that, the data is being placed on the calculation template to update the value into the most recent one. The workers then monitor each of the materials and check the occurrence of critical product – a product that has reached the minimum Days of Inventory (DOI). If there is any, the next process is to calculate the ordering quantity in the Excel template. Otherwise, the workers need to check the scheduled planning date as an ordering decision determination. As an example, material X has not reached the minimum DOI but has reached the date of scheduled planning which means that the workers must calculate the ordering quantity to order the material. This case means that an ordering decision can be based on two reasons which are DOI-based decision and schedule-based decision. After doing the calculation, the workers then validate the sheet into the PPIC Manager and or Supply Chain Director to see the adjustment.

To calculate the order quantity, there are several formulas used by the company to calculate the ordering quantity (Q) which described as follows:

$$Q = Forecast - (Stock + OS\ PO + In\ Transit) \quad (4.1)$$

$$Q = Average\ Sales - (Stock + OS\ PO + In\ Transit) \quad (4.2)$$

Currently, the company uses monthly lot size as the basis to determine the ordering quantity. This means that the company uses either the forecast or the average sales of previous months and combine it to the inventory parameters to calculate the order quantity. Below is the example of calculation.

Table 4.1 Data Sample

	January	February	March	Data	Quantity
Forecast	1,000	1,000	1,000	Stock	200
	October	November	December	OS PO	100
Sales	1,000	1,200	1,000	In Transit	0

a. Forecast-based planning

$$Q = (1{,}000 + 1{,}000 + 1{,}000) - (200 + 100 + 0) = 2{,}700$$

b. Sales-based planning

$$Q = (1{,}500 + 1{,}200 + 1{,}000) - (200 + 100 + 0) = 2{,}900$$

In the above calculation, there are two ways of calculating the ordering quantity on monthly lot size technique. The period of planning indeed depends on the type of materials due to various reasons such as the minimum ordering quantity, material's size, and others. As an example, a big material such as carton as the packaging materials has a monthly lot size of 1.5 months while the small-size material usually has the monthly lot size of three months. These values are subjectively determined by the experienced workers yet must undergo an assessment to assure its quality and sufficiency.

4.1.2 Suggested MRP System

In this part, suggested MRP system will be presented. Initially, figure 4.4 below is the explanation of the suggested overall business process while the explanation for each will be explained afterwards.

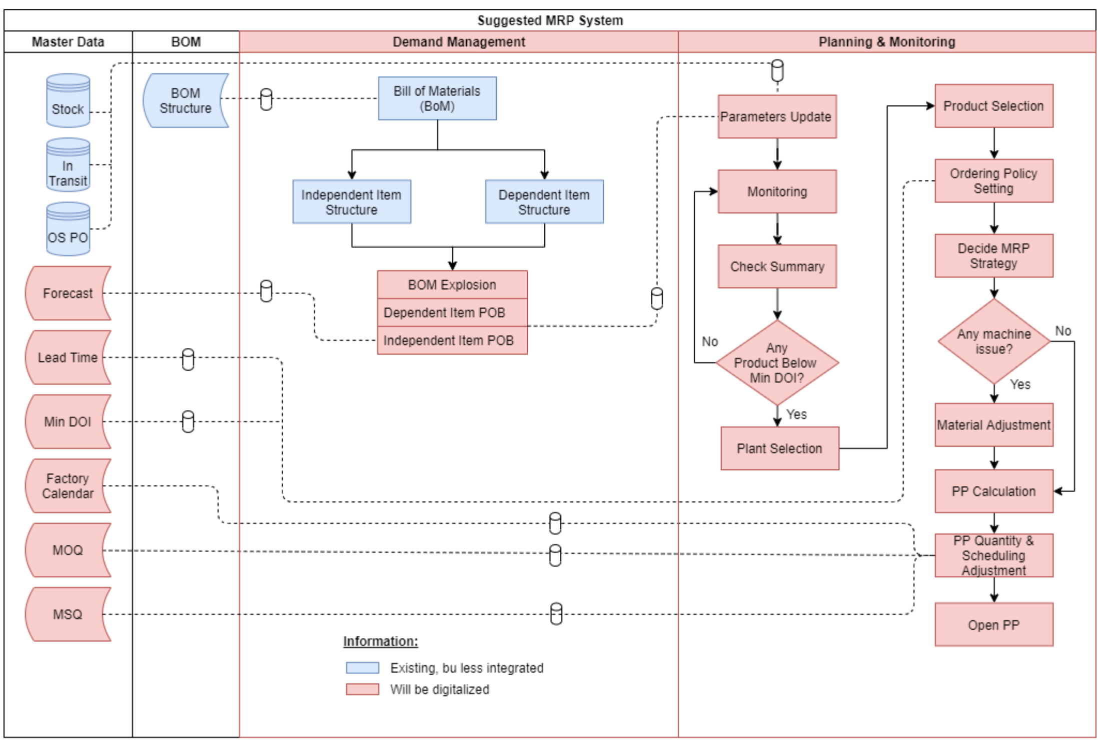

Figure 4.4 Suggested Business Process of MRP System

Figure 4.3 represents the flow of the improved MRP business process. There are four main important components that should be provided, namely master data, BOM, demand management, and planning & monitoring. Below is the explanation of each of them.

4.1.2.1 Master Data

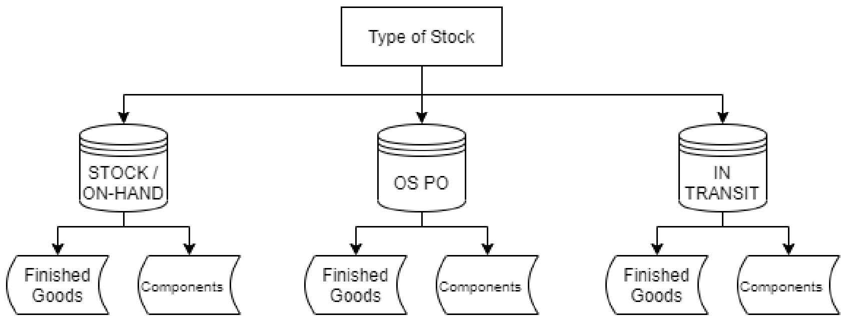

Figure 4.5 Type of Stock

Figure 4.5 represents the type of stock in the company. There are three main stocks which are on-hand inventory, Outstanding Purchase Order (OS PO), and In-Transit Inventory. On-hand inventory is a type of inventory which products have been received by the company while OS PO and In-Transit is a type of inventory which products have not been received – OS PO's inventory is on the supplier while In-Transit is on the way to the plant. These three parameters will be accumulated to find the quantity needed by the company. Currently, these data have been provided in the company's information system but have not yet been integrated with other components. Below is the suggested User Interface (UI) that should be developed on the type of stock information which comprises on-hand, OS PO, and In-Transit UI.

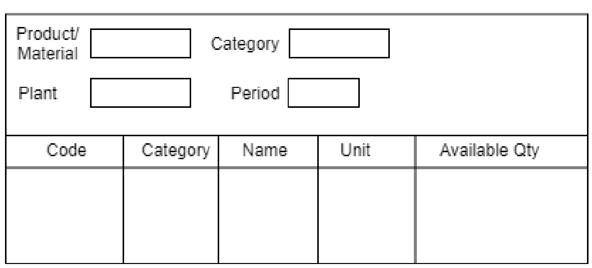

Figure 4.6 User Interface (UI) of On-Hand

In figure 4.6, several filter components in the on-hand UI should be provided. It consists of product/material, plant, category, and period. Product filter is used to select which materials to be monitored, plant filter is used to select which plant to be monitored, category filter is to select the category of product – including cup, bottle, carton, packaging, and others. Lastly, period filter is used to select the period interval of observation. In the data column, several presented data consist of material code, category, material's name, unit of measurement, and the remaining stock.

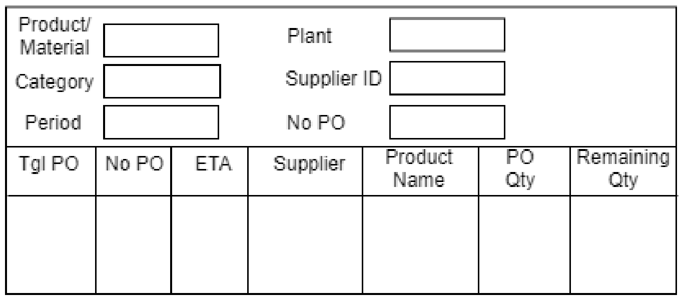

Figure 4.7 User Interface (UI) of OS PO

In figure 4.7, several filter components in the OS PO UI should be provided. Product, category, plant, and period filter has the same function as the previous. In Supplier ID filter, it is used to see the inventory on a supplier and No PO filter used to see the inventory with given PO number. In the data column, several data that will be presented consist of PO date, PO number, ETA, supplier's name, product's name, PO quantity, and remaining quantity. The data that will be inputted in the calculation is not the PO quantity, but the remaining OS PO quantity.

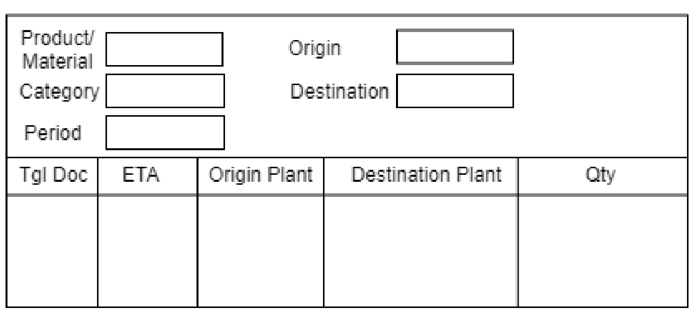

Figure 4.8 User Interface (UI) of In-Transit

In figure 4.8, new filter is located on origin and destination filter, where the origin represents the sender plant of the inventory and the destination represents the plant that receive the inventory. In data column, several important elements including the delivery date, ETA, origin plant, destination plant, and the quantity of delivery.

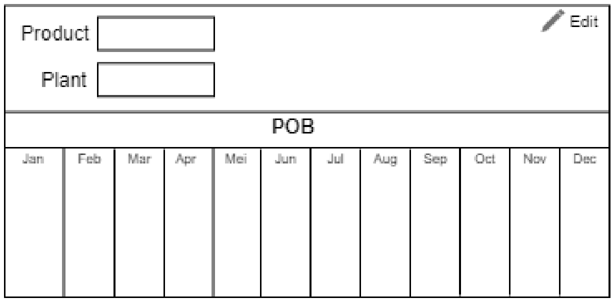

Figure 4.9 Forecast Master

Besides an information on the type of stocks, figure 4.9 represents the UI of forecasted sales or usually named as *Permintaan Order Bulanan* (POB). There are two necessary filters in the forecast master which are product and plant filter. This forecast master will be integrated with other process part which is Bill of Materials (BOM).

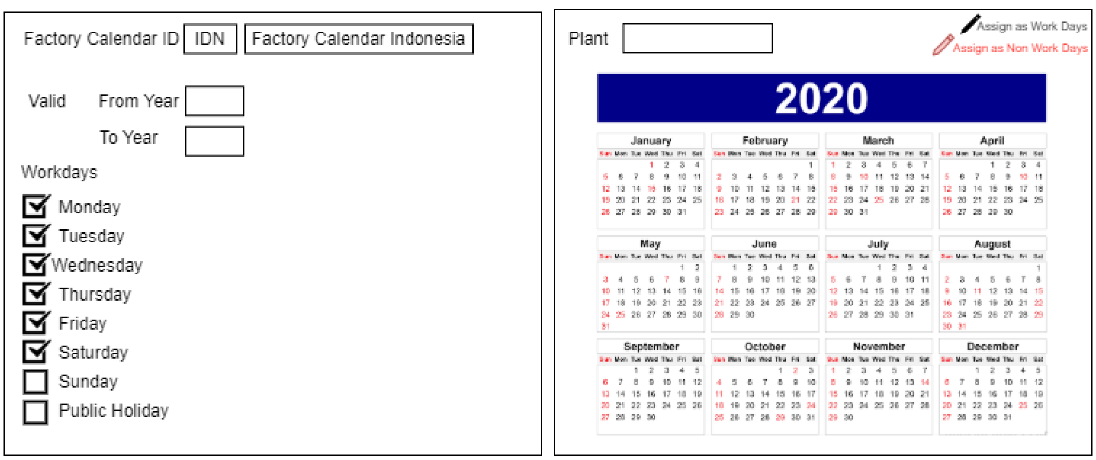

Figure 4.10 Factory Calendar

Factory calendar represented in figure 4.10 has the function to trace the working days of each plant within the company. The planner can select the working days in a week and modify the overall working day in the calendar to count the number of working days in each respective month.

4.1.2.2 Bill of Materials (BOM)

In this section, three components of BOM consist of general item overview, graphical display, and BOM edit will be displayed.

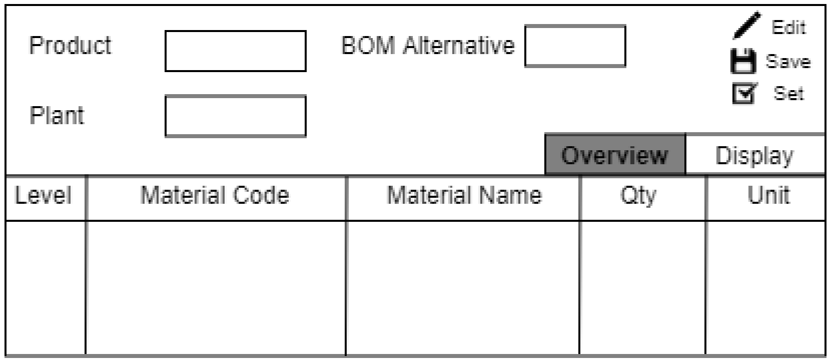

Figure 4.11 General Item Overview

Figure 4.11 represents the UI of General Item Overview at BOM. Three filters are provided which are product, plant, and BOM alternative. In the implementation, one product may have different BOM alternative hence a filter of BOM alternative should be provided to see the present determined BOM. In data column, five information would be provided which consist of material, material code, material name, conversion quantity, and unit of measurement.

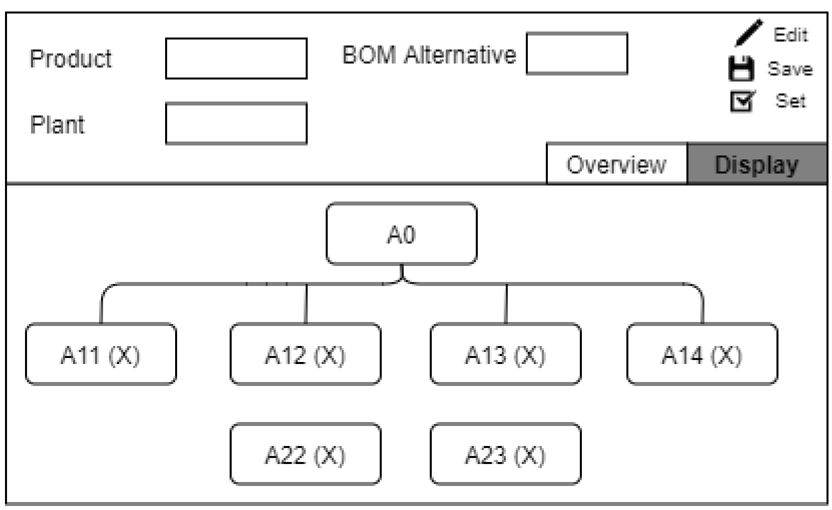

Figure 4.12 BOM Graphical Display

Beside general item overview, graphical BOM interface should also be provided which is depicted in figure 4.12. This aims to give more visual representation and assure the planner to have deeper understanding about the materials and its conversion inside the BOM.

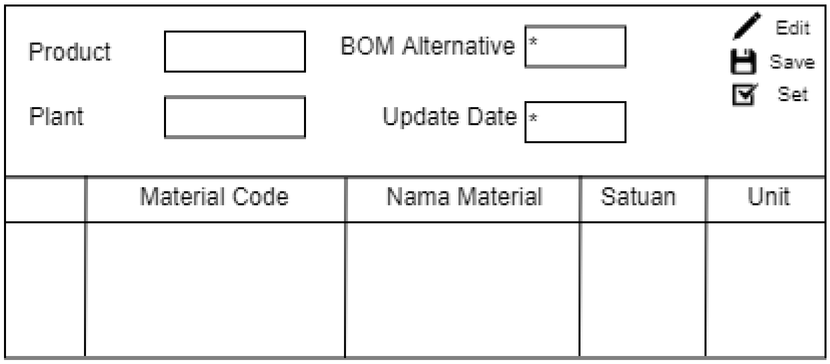

Figure 4.13 Edit BOM Interface

To accommodate different BOM selection, edit feature should be provided presented in figure 4.13. The feature may change the data in each respective existing BOM and create new BOM. Save feature has a function to record changes and set has a function to select which alternative BOM to be used. Besides that, update date has a function to give an information on when the BOM is updated.

4.1.2.3 Demand Management

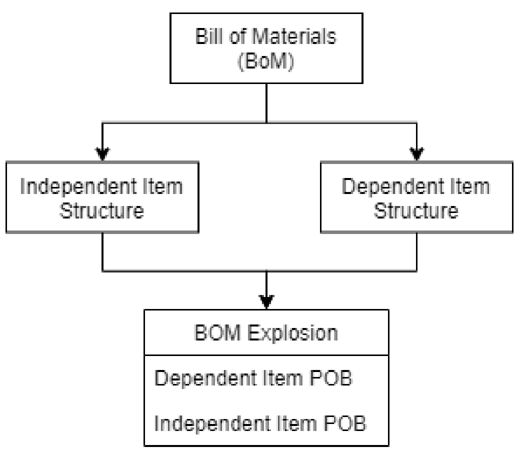

Figure 4.14 BOM Explosion

In this part, the forecasted sales in master data and the material's structure in BOM will be connected. There will be a BOM explosion to convert the materials under the finished goods according to each of the materials' conversion and the projected or historical sales.

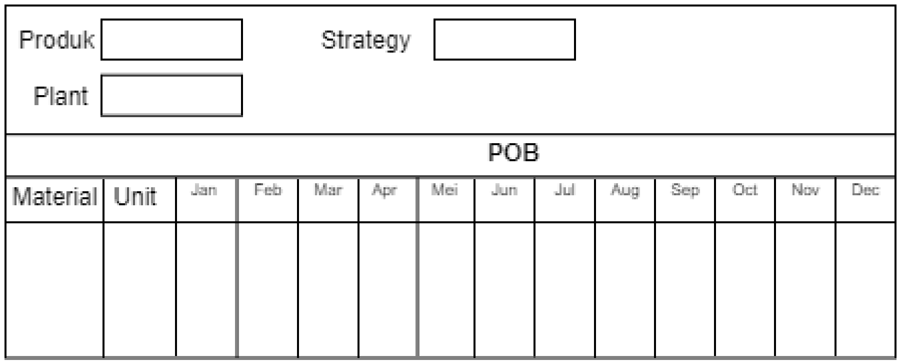

Figure 4.15 Demand Management Interface

Figure 4.15 is the UI of sales conversion inside demand management that connects conversion unit in BOM and the forecasted sales. Below is the example of demand management conversion in one of the products.

Table 4.2 Forecast of Sample Item

PRODUK	POB / Forecast		
	Jan	Feb	Mar
A1	100,000	200,000	300,000

Table 4.3 Conversion Example of Sample Item

Material	Conversion	Unit
A12	0.00096	ROLL
A13	0.00065	ROLL
A14	1.00000	PCS
A15	40.00000	PCS
A16	40.00000	PCS
A17	1.00000	PCS

$$POB\ Material = POB\ Finished\ Goods\ (Month)\ x\ Conversion \tag{4.3}$$

Example:

A12 (January) = 100,000 x 0.00096 = 96 ROLL

Table 4.4 Conversion Table Example

Material	Unit	POB		
		Jan	Feb	Mar
A12	ROLL	96	192	288
A13	ROLL	65	130	195
A14	PCS	100,000	200,000	300,000
A15	PCS	4,000,000	8,000,000	12,000,000
A16	PCS	4,000,000	8,000,000	12,000,000
A17	PCS	100,000	200,000	300,000

Besides the information about materials conversion, demand management also includes the information of ordering policy used in each of the product or materials. It aims to give an information for the planner about what is the current inventory strategy used in a material or product. There are several strategies to be used which are listed below.

Table 4.5 MRP Strategy Explanation

No	Strategy	Explanation
1	Forecast-based	Ordering quantity is based on the forecast from the sales department.
2	Sales-based	Ordering quantity is based on the average actual sales of the previous month.
3	(s, S)	Ordering quantity is based on the maximum value (S) based of each material.
4	FOI	Ordering quantity is the value of Q computed in the algorithm of Fixed-Order-Interval.

4.1.2.4 Planning & Monitoring

In this part, the planning and monitoring of MRP system will be explained. Generally, figure 4.16 represents the flow of proposed planning & monitoring system.

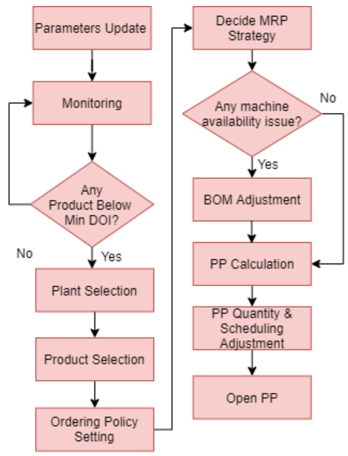

Figure 4.16 Flow of Planning & Monitoring

The planning and monitoring are started with parameters update to see the net requirements of a certain material or usually called as netting. This includes the connection between the forecast which has undergone BOM explosion and its combination with the inventory parameters including on-hand, in-transit, and OS PO. After that, a monitoring is conducted to see whether there is a critical material reaching the minimum DOI. If there is any, the planner then should execute a planning by doing plant and product selection as well as ensuring the ordering policy setting and MRP strategy. If there is any machine issue including the availability, a material adjustment must be conducted. This means that there will be a material mix in one single product according to the available machine. As an example, product A initially has dependent items of B, C, D and when this event occurs, a material B could be divided into B1 and B2 due to machine availability. After that, an ordering quantity calculation is conducted according to the previously mentioned algorithm. If there is an issue regarding the ordering quantity such as capacity-issue and the sufficiency of MOQ and MSQ, adjustments might be conducted by the PPIC Manager and Supply Chain Director.

In planning and monitoring, there are several formulas used to calculate the ordering quantity and its scheduling system which is shown below.

$$Requirements_{Forecast-based} = POB_n + POB_{n+1} + POB_{n+2} \tag{4.4}$$

$$\text{Requirements}_{\text{Sales-based}} = Sales_{n-1} + Sales_{n-2} + Sales_{n-3} \tag{4.5}$$

$$Days\ of\ Inventory\ (DOI) = \frac{\text{Stock + OS PO + In Transit}}{Requirements} \times 30 \tag{4.6}$$

$$PP_{forecast\ or\ sales-based} = Requirements - (Stock + OS\ PO + In\ Transit) \tag{4.7}$$

$$PP_{FOI} = Q \tag{4.8}$$

$$PP_{Max} = s + Q \tag{4.9}$$

$$Quantity/Shipment = \frac{PP}{n_{Shipment\ Strategy}} \tag{4.10}$$

$$Shipment\ Date_{\ n} = \frac{\sum_1^{n-1} Shipment\ Quantity}{POB} \times 30 + DOI - Min\ DOI + PP\ Date + LT \tag{4.11}$$

Table 4.6 Sample Data for Planning & Monitoring

DATA	UNIT	DATA	UNIT
POB APRIL	3,200,000 pcs	STOCK	2,269,258 pcs
POB MAY	3,200,000 pcs	OS PO	0
POB JUNE	3,498,840 pcs	IN TRANSIT	0
LEAD TIME	24	MIN DOI	45 days
Shipment Strategy	2	PP Date	$April\ 22^{nd}$ 2020

$Requirements_{Forecast-based} = 3{,}200{,}000 + 3{,}200{,}000 + 3{,}498{,}840 = 9{,}898{,}840$ pcs

$Days\ of\ Inventory(DOI) = \frac{9{,}898{,}840}{3{,}200{,}000} \times 30 = 21$ days

$PP_{forecast-based} = 9{,}898{,}840 - (2{,}269{,}258 + 0 + 0) = 7{,}629{,}582$ pcs

$Quantity/Shipment = \frac{7{,}629{,}582}{2} = 3{,}814{,}791$ pcs/shipment

$$Shipment\ Date_{\ 1} = \frac{0}{3{,}200{,}000} \times 30 + 21 - 45 + April\ 22^{nd}\ 2020 + 24 = June\ 9^{th}\ 2020$$

$$Shipment\ Date_{\ 2} = \frac{3{,}814{,}791}{3{,}200{,}000} \times 30 + 21 - 45 + April\ 22^{nd}\ 2020 + 24 = July\ 15^{th}\ 2020$$

Therefore, by having the previous sales forecast and stock, the quantity to be ordered is 7,629,582 pcs with two ordering shipment in 3,814,791 for each with the due date of $June\ 9^{th}$ 2020 and $July\ 15^{th}$ 2020 for the first and second shipment. In addition to that, the data presentation will be calculated automatically with the system and below are some interfaces associated to support the abovementioned process.

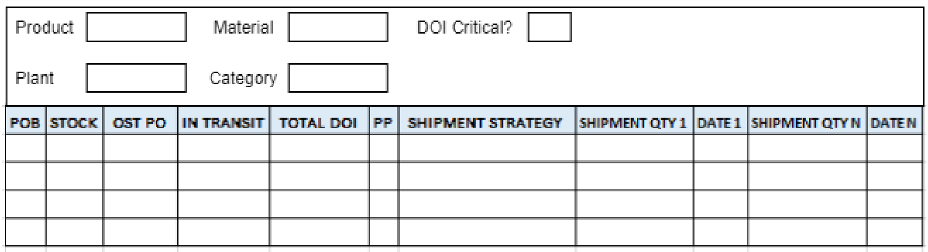

Figure 4.17 Planning & Monitoring Main Interface

Figure 4.17 depicts the main interface with several data filters which are product, plant, material, category, and criticality of DOI. The criticality of DOI is a binary option, yes or no, to monitor a material that is critical or below the minimum DOI. In data column, several information to be presented are the forecasted sales or the previous average sales – according to the strategy, the inventory parameters, total DOI, ordering quantity, and shipment strategy as well as its due date.

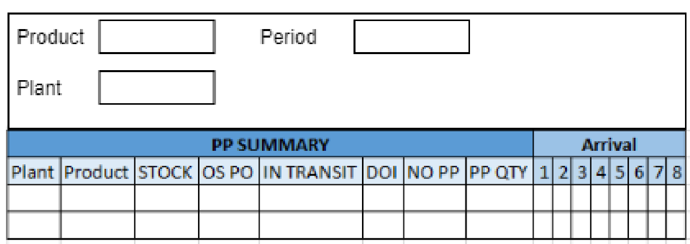

Figure 4.18 Planning & Monitoring Summary

Figure 4.18 depicts the planning & monitoring summary. This interface has a function to check all the ordering quantity that will be sent. Generally, this summary will be checked by the PPIC Manager and Supply Chain Director to undergo, if necessary, an order adjustment according to the existing condition considering numerous externalities happening on the operations such as quantity discount, supplier relationship, and other.

4.1.3 Usability Testing Design

To make sure that the proposed system will produce an intended features and function, a usability testing is needed to be conducted. The usability testing comprises for two main parts, which are an assessment using Standard Usability Scale (SUS) questionnaire and feedbacks form consisting of four main concerned parts – the master data, BOM, demand management, and planning & monitoring.

Table 4.7 System Usability Scale (SUS)

			Strongly Disagree 1	2	3	4	Strongly Agree 5
1	I think that I would like to use this system frequently.						
2	I found the system unnecessarily complex.						
3	I thought the system was easy to use.						
4	I think that I would need the support of a technical person to be able to use this system.						
5	I found the various functions in this system were well integrated.						
6	I thought there was too much inconsistency in this system.						
7	I would imagine that most people would learn to use this system very quickly.						
8	I found the system very cumbersome to use.						
9	I felt very confident using the system.						
10	I needed to learn a lot of things before I could get going with this system.						

To calculate the score of SUS, the odd-numbered items must be subtracted by 1 from the raw score. For the even-numbered items, subtract the raw score the raw score from 5. Compute the sum of adjusted scores, then multiply by 2.5 to get the standard SUS Score. Statistically, the average System Usability Scale score is 68. If the score is under 68, then there are probably serious problems with the proposed system usability which be addressed. Below is the formula to calculate the score.

$$SUS = 2.5(20 + SUM\,(SUS01, SUS03, SUS05, SUS07, SUS09) - SUM\,(SUS02, SUS04, SUS06, SUS08, SUS10)) \quad (4.12)$$

Asides from having the previous threshold of SUS score to measure whether or not the system has been good for the users, as the concern is more on the development phase and how the system satisfies the users, a feedback form is highly necessary. The form acts as a tool to continuously improve the proposed system by directly empathizing with what the users' feel about the proposed system. The form will later be given to nation-wide users consisting of both head office material planner and plant material planner.

There are four sections to be considered which are master data, BOM, demand management, and planning & monitoring – as the section or part developed earlier. The feedback concerns three major things, namely the speed of systems' processing, data accuracy, and UI/UX as the open-ended feedback part if the users feel that there are concerns that they need to address outside of the speed and accuracy. These three parts are fundamental things that must be considered, considering that the purpose of building and developing a new system is to create more robust, effective, and efficient inventory control. The feedback form will later be given to the software developer to improve the performance of the proposed MRP system.

Table 4.8 Feedback Form

Section	**Feedback**		
	Speed	Accuracy	UI/UX
Master Data			
BOM			
Demand Management			
Planning & Monitoring			

4.2 Inventory Parameters Data Collection

In this research, there are 30 observed products where its inventory policy will be assessed. Below is the data and its unique code of each product. In this part, the demand data, functional unit, and unit price of finished goods in 2019 are presented. These data will later be used as the input for inventory parameters as a basis for Monte Carlo simulation.

Table 4.9 Demand Data (2019)

Product	Functional Unit (FU)	Price/FU (Rp)	Days						
			1	2	3	4	5	…	365
1A	Per 48 pcs	15,494.70	1,878	4,294	10,930	11,359	10,280	…	19,123
2B	Per 40 pcs	13,395.92	602	2,258	3,764	2,158	1,699	…	1962
3C	Per 24 pcs	13,930.00	396	271	731	1,956	2,233	…	73
4D	Per 24 pcs	23,284.17	616	2,461	6,197	7,542	8,993	…	5571
5E	Per 24 pcs	25,716.76	9,063	1,651	8,499	16,845	21,997	…	15915
6F	Per 12 pcs	22,794.55	477	629	3,523	7,956	8,457	…	6530
7G	Per 1 pc	26,026.74	6,121	9,543	27,832	42,020	43,428	…	37230
8H	Per 24 pcs	10,929.38	6,925	11,510	19,509	14,407	8,721	…	27907
9I	Per 24 pcs	13,104.87	-	-	-	-	-	…	3539
10J	Per 24 pcs	14,764.35	-	250	1,364	2,003	889	…	206
11K	Per 24 pcs	27,637.32	281	-	-	-	-	…	0
12L	Per 24 pcs	25,811.97	-	-	-	150	450	…	150
13M	Per 24 pcs	33,189.16	-	907	1,056	624	467	…	101
14N	Per 24 pcs	34,094.78	-	-	-	268	300	…	10
15O	Per 4 pcs	34,036.24	20	0	59	60	63	…	225
16P	Per 2 pcs	41,537.84	199	0	632	968	983	…	903
17Q	Per 24 pcs	18,021.56	-	-	-	644	859	…	534
18R	Per 1 pc	37,811.91	570	571	756	715	1,597	…	1248
19S	Per 24 pcs	8,045.38	-	-	1	318	319	…	2
20T	Per 12 pcs	21,917.46	-	-	-	150	150	…	75
21V	Per 12 pcs	22,605.72	-	-	-	500	1,000	…	759
22W	Per 48 pcs	13,762.98	-	-	-	-	-	…	0
23X	Per 48 pcs	12,865.58	-	-	-	-	-	…	0
24Y	Per 24 pcs	22,168.56	-	-	-	-	-	…	1
25Z	Per 24 pcs	21,136.61	-	-	-	-	-	…	0
26A	Per 12 pcs	22,413.64	-	-	-	-	-	…	0
27B	Per 12 pcs	21,136.61	-	-	-	-	-	…	0

4.3 Inventory Cost Components

In this subchapter, a calculation of inventory cost components consisting of ordering cost and holding cost is presented. The inventory cost components are used to weigh the inventory policy to see how each inventory policy affects the total cost. Below is the calculation of both ordering cost and holding cost.

4.3.1 Ordering Cost

The holding cost is a cost incurred whenever the firm purchases an order. In this part, the ordering cost consists of three main components namely cost of assets; cost of salary; and cost of electricity, administration, and telecommunication. Below is the recapitulation of these costs.

Table 4.10 Cost of Electricity, Administration, and Telecommunications

Cost of Electricity, Administration, and Telecommunications			
Item	**Amount/Year**	**Value/Unit (Rp)**	**Total Value (Rp)**
Paper	5 boxes	250,000	1,250,000
Print		50,000	250,000
Electricity	7208 kWh	1,115	8,036,920
Internet	1	780,000	780,000
Telephone	1	120,725	120,725
SAP	1	200,000,000	200,000,000
Total/Year			210,437,645
Number of PO			1572
Total/PO			Rp 133,867

Table 4.10 represents the cost of electricity, administration, and telecommunications. These costs including the cost of paper, print electricity, internet, telephone, and SAP maintenance fee per year. The calculation is conducted by finding the approximate value of all those cost components by conducting interviews with the employee. To get a total cost in a year, the total yearly value is divided by the number of PO that happened in 2019 which was 1572. Therefore, the cost of electricity, administration, and telecommunications in each PO is Rp 133,867.

Table 4.11 Cost of Salary

Cost of Salary			
Item	**Amount**	**Salary/Month (Rp)**	**Value/Year (Rp)**
PPIC Manager	1	17,000,000.00	204,000,000.00
Head of MRP	2	13,000,000.00	156,000,000.00
PPIC Staff	2	6,000,000.00	72,000,000.00
Purchasing Manager	1	15,000,000.00	180,000,000.00
Purchasing Supervisors	1	8,000,000.00	96,000,000.00
Total/Year			336,000,000.00
Number of PO			1572
Total/PO			Rp 229,007.63

Table 4.11 represents the cost of salary for workers contributed to the process of ordering materials. There are five types of workers in charge during this process, namely the PPIC Manager, Head of MRP, PPIC Staff, Purchasing Manager, and Purchasing Supervisors. The salary of them is calculated yearly and divided by the total number of PO to find the cost of salary per order. The total cost of salary is Rp 336,000,000 and the total cost of salary per PO is Rp 229,007.

Table 4.12 Cost of Assets

Cost of Assets					
Item	**Amount**	**Lifetime**	**Price/Unit (Rp)**	**Total Value (Rp)**	**Depreciation (Rp)**
PC	3	5	6,349,000	19,047,000	3,809,400
Note Printer	1	5	795,000	795,000	159,000
Printer	1	5	5,000,000	5,000,000	1,000,000
Telephone	1	10	107,000	107,000	10,700
Chair	3	2	470,000	1,410,000	705,000
Total/Year					5,684,100
Number of PO					1572
Total/PO					Rp 3,616

Table 4.12 represents the cost of assets related to the process of ordering materials where the value of this cost per PO is Rp 3,616. The way to calculate the cost of assets is by finding the depreciation of each material using straight line method with an assumption of zero salvage value and below is the example of the calculation.

$$Depreciation\ per\ Material = \frac{Initial\ Value - Salvage\ Value}{Lifetime\ (years)}$$

$$Depreciation\ of\ PC = \frac{19{,}047{,}000 - 0}{5} = Rp\ 3{,}809{,}400$$

Table 4.13 Ordering Cost Recapitulation

Item	Value/PO (Rp)
Cost of Assets	3,616
Cost of Salary	229,007
Cost of Electricity, Administration, and Telecommunication	133,867
Ordering Cost / PO	Rp 366,490

Table 4.13 represents the ordering cost recapitulation per PO. The ordering cost consists of the cost of assets; cost of salary; and the cost of electricity, administration, and telecommunication. The value of ordering cost is the sum of all those three costs which results in Rp 366,490 per PO. This means that when a PO occurs, the firm is charged in each of respective PO for about Rp 361,490.

4.3.2 Holding Cost

Holding cost is a cost incurred for maintaining the product in the warehouse. In this research, the holding cost comprises of three elements which are cost of salary, cost of assets, and cost of capital. Below is the detailed calculation of each of the cost element.

Table 4.14 Cost of Salary

Cost of Salary			
Item	**Salary/Year**	**Amount**	**Total Salary/Year**
Warehouse Staff Cost	Rp 50,400,000.00	148	Rp 7,459,200,000.00
Total/Year			Rp 7,459,200,000.00
Total/Pallet			Rp 4,347.69

Table 4.14 represents the cost of salary for warehouse workers. There are approximately 148 warehouse workers with a salary of Rp 50,400,000 for each which, in 2019, handled approximately 1,715,669 pallets. Therefore, the cost of salary for each of the pallet is Rp 4,347.69.

Table 4.15 Cost of Assets

Cost of Assets					
Item	**Unit**	**Lifet ime**	**Total Cost / Unit**	**Total Cost**	**Depreciation/Year**
Warehouse	3572 m^2	20	Rp 3,500,000	Rp12,502,000,000	Rp 625,100,000
Forklift	9 pcs	20	Rp 300,000,000	Rp 2,700,000,000	Rp 135,000,000
Hand Lift	4 pcs	20	Rp 320,000,000	Rp 1,280,000,000	Rp 64,000,000
Hand Pallet	4 pcs	7	Rp 5,000,000	Rp 20,000,000	Rp 2,857,143
Nestainer	3014 pcs	5	Rp 2,500,000	Rp 7,535,000,000	Rp 1,507,000,000
Plastic Pallet	5060 pcs	3	Rp 400,000	Rp 2,024,000,000	Rp 674,666,667
Total/Year					Rp 3,008,623,810
Total/Pallet					Rp 1,754

Table 4.15 represents the cost of assets within the warehouse. The cost items include the warehouse cost, forklift, hand lift, hand pallet, nestainer, and plastic pallet. The way to calculate the cost of assets is derived from the total depreciation per year and divided by the total number of boxes handled on that year. Ultimately, the cost of assets per pallet is Rp 1,754.

Besides cost of assets, the cost of capital is also calculated. To calculate the cost of capital, a calculation on Weighted Average Cost of Capital (WACC) is conducted. It is an approximation by how much a company owes for a dollar it finances according to the proportional weight of equity and debt. Below is the formula of WACC.

$$WACC = Cost\ of\ Equity \times \%Equity + Cost\ of\ Debt \times \%\ Debt \tag{4.13}$$

$$Cost\ of\ Equity = Rf + \beta(Rm - Rf) \tag{4.14}$$

$$Cost\ of\ Debt = Interest\ (1 - Tax) \tag{4.15}$$

Where:

Rf = Risk free rate

β = Relative market risk

Rm = Annual market risk

Firstly, β as the relative market risk is obtained through finding the slope with the Adj Close of IHSG as the X and Adj Close of the company as the Y with a data from 2015 to March of 2020. As a result, the value of β is 0.833. After that, the risk free or Rf is obtained through finding the coupon rate of obligation with a due date of 2022. The selected Rf is FR043 with a due date of 15 July 2022 as an approximation of the validity of the inventory policy. Besides that, the value of Rm as the annual market risk is obtained through secondary data which studies the value based on rigorous annual return study for Indonesia's stock that equals to 16.5%. In the value of cost of debt, the interest is obtained by finding the financial statement's note which value is 12% and the tax is 25%. Below is data recapitulation of those components.

Table 4.16 Cost of Equity and Cost of Debt

Item	Value	Item	Value
Rf	10.25%	Interest	12.00%
Beta	0.833263549	Tax	25.00%
Rm	16.50%	Cost of Debt	9.00%
Cost of Equity	15.46%		

Table 4.16 represents the recapitulation of both cost of equity and cost of debt. The cost of equity equals to 15.46% and the cost of debt is 9.00%. After obtaining these values, a calculation of WACC is conducted with using 4.13-4.15 formula.

Table 4.17 WACC

Item	Value
%Debt	23.80%
%Equity	76.20%
WACC	13.92%

Table 4.17 represents the WACC of the observed firm which equals to 10.54%. The percentage of equity and the percentage of debt is obtained by examining the financial statements of the company. The amount of liability within the firm is Rp 198,455,391,702 while the total liability and equity is around Rp 833,933,861,594.

Therefore, the equity represents around 76.2% while the debt represents 23.80%. Ultimately, the value of WACC is 13.92%.

To calculate the holding cost of each material, a combination between cost of assets, cost of capital, and cost of salary are needed. Below is one of the examples of calculation on holding cost using product 1A.

$$Holding\ Cost\ =\frac{(Cost\ of\ Assets+Cost\ of\ Salary)}{Box/Pallet}+Cost\ of\ Capital\ \times Unit\ Cost \qquad (4.16)$$

$$Holding\ Cost\ (1A)\ =\frac{(1{,}754\ +\ 4{,}348)}{75}+13.92\%\times 15{,}495\ =\ Rp\ 2{,}238\ per\ box\ per\ year$$

$$\%HC\ =\frac{Holding\ Cost}{Unit\ Cost}=\frac{2{,}238}{15{,}495}=14\%$$

The recapitulation of holding cost calculation for each material is presented in table 4.9 below.

Table 4.18 Holding Cost Recapitulation

Item	Price/FU	FU/Pallet	Price/FU	Cost of Salary	Cost of Assets	Cost of Capital	Holding Cost/Year	Percentage of Holding Cost
1A	322.8063	75	15,495	58	23.38	2,157	2,238	14%
2B	348.25	70	13,930	62	25.05	1,939	2,026	15%
3C	970.1739	5	23,284	892	359.72	3,241	4,493	19%
4D	1071.531	4	25,717	1,054	425.12	3,580	5,059	20%
5E	949.7731	4	22,795	1,054	425.12	3,173	4,652	20%
6F	2168.895	7	26,027	652	263.04	3,623	4,538	17%
7G	10929.38	180	10,929	24	9.74	1,521	1,555	14%
8H	546.0361	150	13,105	29	11.69	1,824	1,865	14%
9I	615.1811	150	14,764	29	11.69	2,055	2,096	14%
10J	1151.555	5	27,637	892	359.72	3,847	5,099	18%
11K	1075.499	5	25,812	892	359.72	3,593	4,845	19%
12L	1382.882	5	33,189	892	359.72	4,620	5,872	18%
13M	1420.616	4	34,095	1,054	425.12	4,746	6,225	18%
14N	1418.176	4	34,036	1,054	425.12	4,738	6,217	18%
15O	10384.46	4	41,538	1,087	438.40	5,783	7,308	18%
16P	9010.779	8	18,022	543	219.20	2,509	3,271	18%
17Q	1575.496	4	37,812	1,054	425.12	5,264	6,743	18%
18R	8045.38	180	8,045	24	9.74	1,120	1,154	14%
19S	708.9297	4	17,014	1,054	425.12	2,369	3,848	23%
20T	1826.455	8	21,917	527	212.56	3,051	3,791	17%
21U	1883.81	8	22,606	527	212.56	3,147	3,887	17%
22V	286.7288	67	13,763	65	26.30	1,916	2,007	15%
23W	268.0329	67	12,866	65	26.30	1,791	1,883	15%
24X	923.6899	4	22,169	1,054	425.12	3,086	4,565	21%
25Y	880.6921	4	21,137	1,054	425.12	2,942	4,422	21%
26Z	1867.803	7	22,414	652	263.04	3,120	4,035	18%
27A	1761.384	7	21,137	652	263.04	2,942	3,858	18%

4.4 Seasonality Identification

To capture the data pattern more carefully and produce inventory policy more accurately, seasonality identification is conducted. The seasonality identification aims to detect the seasonality within the time-series. This identification will be acting as a basis of period division in inventory policy and a basis to randomize the data in Monte Carlo simulation. As mentioned in chapter two, the seasonality identification uses Fourier transformation which decomposes time series as a composition of sinusoidal functions. The seasonality identification is run in R Studio software and below is the example of data output along with the summary for each of the products.

```
> dataset<-read.csv("CLEO 250.csv",stringsAsFactors = F,header=F)
> dataset<-ts(dataset[,-1],frequency=12,start=c(2018,1))
> dataset
        Jan    Feb    Mar    Apr    May    Jun    Jul    Aug    Sep    Oct
2018 195761 177668 214999 259644 308121 236679 348560 304658 248022 275739
2019 244325 223536 313722 370612 416083 427789 406582 479118 311462 338117
        Nov    Dec
2018 307192 284598
2019 464665 156647
> p<-periodogram(dataset)
> dd <-data.frame(freq=p$freq,spec=p$spec)
> order<-dd[order(-dd$spec),]
> top2<-head(order,2)
> time<-1/top2$freq
> time
[1] 12 24
> |
```

Figure 4.19. Seasonality Output of product 1A

According to figure 4.19, there is no seasonality in product 1A. This is because of the seasonality result is 12 which means that the data pattern repeats after 12 months. This step of seasonality identification is carried out for all products and table 4.19 below is the recapitulation of them with N is the location when seasonality occurs.

Table 4.19 Seasonality Recapitulation

Item	N	Item	N	Item	N	Item	N	Item	N	Item	N
1A	12	6F	12	11K	12	16P	3	21U	6	26Z	12
2B	6	7G	6	12L	12	17Q	6	22V	12	27A	12
3C	12	8H	12	13M	8	18R	12	23W	12		
4D	12	9I	12	14N	12	19S	2.4	24X	12		
5E	6	10J	12	15O	12	20T	2.4	25Y	12		

4.5 Uncertainty Elements Identification

This section aims to identify the uncertainty elements within the model, namely the demand and lead time. The uncertainty identification is conducted by finding the distribution parameters in each of the product by doing distribution fitting. Later, the result of distribution fitting will be used as a basis to generate random numbers. The result of the distribution fitting that will be chosen is a parameter that follows the distribution normal due to the assumption of previous safety stock formula.

As different product has different seasonality, the distribution fitting is conducted according to the uniqueness of the product's seasonality. In this case, when a product does not have seasonality within a year, a distribution fitting of the whole year is conducted. Otherwise, the distribution fitting is conducted in each season such as per 6 months and quarterly. Figure 4.20 below is the example of demand fitting results using Excel @RISK.

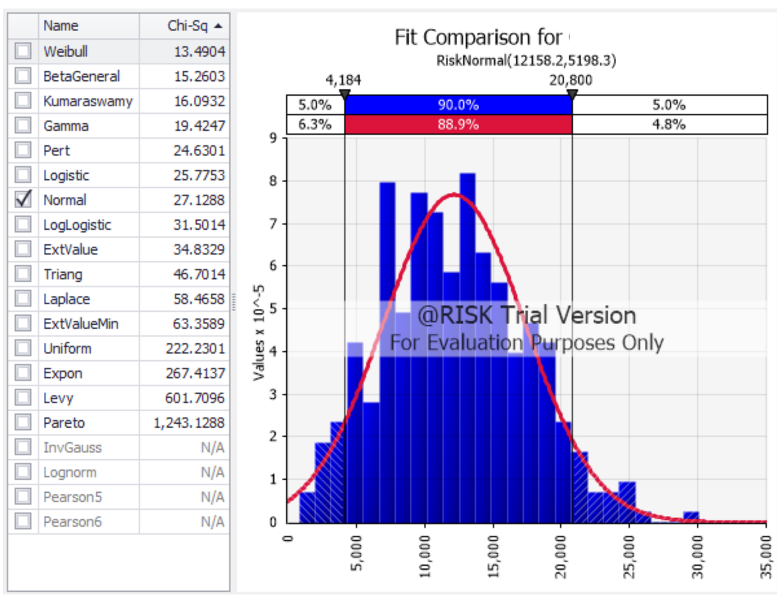

Figure 4.20 Demand Fitting for Product 1A

With 5% error threshold, table 4.20-4.26 is the recapitulation of demand distribution according to the uniqueness of time-series characteristics in each of the product.

Table 4.20 Demand Distribution for Non-Intermittent Demand with No Seasonality

Item	T (Jan-Dec)	Demand Distribution
1A	12	Norm (12158, 5198)
3C	12	Norm (991, 720)
4D	12	Norm (4443, 2475)
6F	12	Norm (3724, 2113)
8H	12	Norm (11989, 6358)
9I	12	Norm (1198, 956)
18R	12	Norm (1427 867)

Table 4.21 Demand Distribution for Non-Intermittent Demand with T=6

Item	T	T1 (Jan-Jun) Distribution	T2 (Jul-Dec) Distribution
2B	6	Norm (5138, 5021)	Norm (3021, 2112)
5E	6	Norm (5689, 3881)	Norm (7949, 4141)
7G	6	Norm (27524, 11388)	Norm (30884, 13799)

Table 4.22 Demand Distribution for Non-Intermittent Demand with T=3

Item	T	T1(Jan-Mar) Distribution	T2(Apr-Jun) Distribution	T3(Jul-Sep) Distribution	T4(Oct-Dec) Distribution
16P	3	Norm (485,300)	Norm (414,275)	Norm (526,357)	Norm (555,368)

Table 4.23 Demand Distribution for Intermittent Demand with No Seasonality

Item	T (Jan-Dec)	Demand Distribution & Cumulative Probability			
		C1	C2	C3	C4
10J	12	0	Norm (76,45)	Norm (21,40)	Norm (587, 233)
		0.285	0.513	0.730	1
11K	12	0	Norm (21,16)	Norm (72,14)	Norm (207,115)
		0.268	0.608	0.797	1
12L	12	0	Norm (109,48)	Norm (269,66)	Norm (724,407)
		0.372	0.627	0.854	1
14N	12	0	Norm (47,19)	Norm (167,83)	-
		0.457	0.750	1	-
15O	12	0	Norm (34,16)	Norm (104,27)	Norm (242,102)
		0.082	0.332	0.682	1.000
22W	12	0	Norm (171,157)	Norm (567,104)	Norm(1211,476)
		0.298	0.570	0.763	1
23X	12	0	Norm (21,19)	Norm (179,75)	Norm(1211,977)
		0.51	0.71	0.85	1
24Y	12	0	Norm (175,120)	Norm (593,131)	Norm(1266,337)
		0.042	0.401	0.689	1
25Z	12	0	Norm (23,19)	Norm (279,118)	Norm (915,426)
		0.519	0.689	0.833	1
26A	12	0	Norm (51,45)	Norm (506,167)	Norm(1642,944)
		0.336	0.558	0.787	1
27B	12	0	Norm (64,61)	Norm (381,76)	Norm(1079,358)
		0.573	0.761	0.898	1

Table 4.24 Demand Distribution for Intermittent Demand with T=6

Item	T (6)	Demand Distribution & Cumulative Probability			
		C1	C2	C3	C4
17Q	Jan-Jun	0	Norm(304,131)	Norm(487,94)	Norm(1236,656)
		0.541	0.685	0.840	1
	Jul-Dec	0	Norm(230,100)	Norm(645,175)	Norm(1498,591)
		0.457	0.652	0.842	1
21V	Jan-Jun	0	Norm(187,68)	Norm(422,90)	Norm(964,305)
		0.165	0.441	0.718	1
	Jul-Dec	0	Norm(212,75)	Norm(453,100)	Norm(1164,450)
		0.081	0.413	0.733	1

Table 4.25 Demand Distribution for Intermittent Demand with T=8

Item	T (8)	Demand Distribution & Cumulative Probability			
		C1	C2	C3	C4
13M	Jan-Aug	0	Norm (67,63)	Norm (524,221)	-
		0.403	0.720	1	-
	Sept-Dec	0	Norm (56,53)	Norm (430,189)	-
		0.344	0.705	1	-

Table 4.26 Demand Distribution for Intermittent Demand with T=2.4

Item	T (2.4)	Demand Distribution & Cumulative Probability			
		C1	C2	C3	C4
19S	Day (1-73)	0	Norm(161,105)	Norm(635,316)	-
		0.397	0.657	1	-
	Day (74-146)	0	Norm(107,75)	Norm(518,283)	-
		0.424	0.698	1	-
	Day (147-219)	0	Norm(125,84)	Norm(724,386)	-
		0.506	0.753	1	-
	Day (220-292)	0	Norm(132,99)	Norm(623,212)	-
		0.424	0.78	1	-
	Day (293-365)	0	Norm(73,43)	Norm(547,502)	-
		0.534	0.767	1	-
20T	Day (1-73)	0	Norm(65,39)	Norm(233,152)	-
		0.383	0.712	1	-
	Day (74-146)	0	Norm(61,28)	Norm(147,35)	-
		0.082	0.534	1	-
	Day (147-219)	0	Norm(38,19)	Norm(123,45)	-
		0.068	0.561	1	-
	Day (220-292)	0	Norm(121,26)	Norm(229,65)	-
		0.342	0.739	1	-
	Day (293-365)	0	Norm(79,40)	Norm(267,79)	-
		0.342	0.739	1	-

Besides demand distribution fitting, the lead time uncertainty identification is also conducted. The lead time presented in the table 4.27 below is not dependent to how many quantities to be produced and how many products to be ordered. This means the lead time to order two or more products is not a function of sum, but a function of max since order combination would not affect the lead time. For example, the lead time of ordering product 1A and 2B is not the sum of lead time for those two products but the maximum value, which in this case is 24 days in average.

Table 4.27 Lead Time Data (2019)

Product	Functional Unit (FU)	Lead Time Distribution (Days)
1A	Per 48 pcs	Norm (24,8)
2B	Per 40 pcs	Norm (21,7)
3C	Per 24 pcs	Norm (25,6)
4D	Per 24 pcs	Norm (27,7)
5E	Per 24 pcs	Norm (27,7)
6F	Per 12 pcs	Norm (25,6)
7G	Per 1 pc	Norm (24,5)
8H	Per 24 pcs	Norm (22,6)
9I	Per 24 pcs	Norm (17,7)
10J	Per 24 pcs	Norm (27,5)
11K	Per 24 pcs	Norm (20,8)
12L	Per 24 pcs	Norm (26,8)
13M	Per 24 pcs	Norm (26,4)
14N	Per 24 pcs	Norm (24,6)
15O	Per 4 pcs	Norm (23,7)
16P	Per 2 pcs	Norm (23,7)
17Q	Per 24 pcs	Norm (26,5)
18R	Per 1 pc	Norm (23,5)
19S	Per 24 pcs	Norm (24,6)
20T	Per 12 pcs	Norm (22,5)
21U	Per 12 pcs	Norm (24, 5)
22V	Per 48 pcs	Norm (26,6)
23W	Per 48 pcs	Norm (25,7)
24X	Per 24 pcs	Norm (25,6)
25Y	Per 24 pcs	Norm (23,8)
26Z	Per 12 pcs	Norm (23,8)
27A	Per 12 pcs	Norm (22,8)
28C	Per 48 pcs	Norm (24,8)

4.6 Existing Inventory Policy Simulation

In this section, the existing inventory policy simulation using (s, Q) method is conducted using Monte Carlo Simulation. Therefore, whenever the inventory reaches the s or minimum inventory, an order of Q must be carried out. However, there is no difference on the inventory policy between one to another product in the observed plant as the workers implement generalized inventory policy. Table 4.28 is the recapitulation of existing inventory policy.

Table 4.28 Some Input Parameters of Existing Inventory Policy

Product	Lead Time Distribution (Days)	s (DOI)	Q (DOI)
1A	Norm (24,8)	52	90
2B	Norm (21,7)	52	90
3C	Norm (25,6)	52	90
4D	Norm (27,7)	52	90
5E	Norm (27,7)	52	90
6F	Norm (25,6)	52	90
7G	Norm (24,5)	52	90
8H	Norm (22,6)	52	90
9I	Norm (17,7)	52	90
10J	Norm (27,5)	52	90
11K	Norm (20,8)	52	90
12L	Norm (26,8)	52	90
13M	Norm (26,4)	52	90
14N	Norm (24,6)	52	90
15O	Norm (23,7)	52	90
16P	Norm (23,7)	52	90
17Q	Norm (26,5)	52	90
18R	Norm (23,5)	52	90
19S	Norm (24,6)	52	90
20T	Norm (22,5)	52	90
21U	Norm (24, 5)	52	90
22V	Norm (26,6)	52	90
23W	Norm (25,7)	52	90
24X	Norm (25,6)	52	90
25Y	Norm (23,8)	52	90
26Z	Norm (23,8)	52	90
27A	Norm (22,8)	52	90
28C	Norm (24,8)	52	90

1. Initial Inventory

The initial inventory is defined as the inventory of the last period. Meanwhile, the initial inventory in the beginning period is assumed as the maximum inventory, given the fact that usually at the end of the period the inventory returns relatively to the maximum period. The formula of 4.17 and 4.18 below is the formula of the initial inventory.

$$Initial\ Inventory_{(t=1)} = \frac{Maximum\ Days\ of\ Inventory}{30} \times Demand \quad (4.17)$$

$$Initial\ Inventory_{(t)} = End\ Inventory_{t-1} \quad (4.18)$$

2. Order Received

The order received is defined as the order that was made in the last period where the end inventory reaches the minimum inventory. The order received would be on 90 days of DOI as it is the ordering quantity that the existing policy has. Practically, SUMIF function in the Excel simulation is used as the way drag the previous order to the future received period.

3. Available Inventory

The available inventory is the result of adding initial inventory and order received. The formula of available inventory is described in the formula 4.19 below.

$$Available\ Inventory_t = Initial\ Inventory_{(t)} + Order\ Received_{(t)} \quad (4.19)$$

4. Demand

The demand is a result of random generation according to each parameter and data distribution. The demand acts as the input of how many quantities each product is demanded daily.

5. Fulfilled Demand

The fulfilled demand is the quantity of demand that can be fulfilled given the existing amount of initial inventory. When the amount of demand is lower than the amount of available inventory, then all demand in that day is fully fulfilled. Otherwise, the amount of fulfilled demand is equal to the number of available inventories.

$$Fulfilled\ Demand_{(t)} = Min(Available\ Inventories_{(t)}, Demand_{(t)}) \quad (4.20)$$

6. End Inventory

The amount of end inventory is the difference between available inventory and fulfilled demand. Besides that, the end inventory in period t will be also acting as the initial inventory in period t+1. The end inventory is the inventory where the holding cost occurs as the space and treatments are needed. Formula 4.21 below is the formula of end inventory.

$$End\ Inventory_{(t)} = Available\ Inventory_{(t)} - Fulfilled\ Demand_{(t)} \quad (4.21)$$

7. Days of Inventory (DOI)

Days of inventory is defined as how many days the inventory is capable to fulfill the demand. The parameter of DOI is used for the inventory policy so when the end inventory's DOI reaches the minimum DOI, an order of Q must be carried out. Formula 4.22 below is the formula of DOI.

$$Days\ of\ Inventory\ (DOI) = \frac{End\ Inventory}{Average\ Demand/Month} \times 30 \quad (4.22)$$

8. Stockout

The stockout happens when the firm cannot fulfill the demand of the day or in another word, when the demand > fulfilled demand. The stockout phenomenon will affect the service level of the company. The formula 4.23 below shows the equation of the stockout in each of the day.

$$Stockout_{(t)} = Demand_{(t)} - Fulfilled\ Demand_{(t)} \quad (4.23)$$

9. Order

The decision of order appears when the end inventory's DOI is lower than the minimum stock (s). The quantity of ordering will be fulfilling around 90 DOI and the quantity might vary between each month due to the different demand as the denominator. The formula 4.24 below shows the equation of ordering quantity.

$$Order = (\frac{\#Days\ Remaining\ in\ Month_t}{\#Days\ in\ Month_t} \times Demand\ Month_t) + Demand\ Month_{t+1} + Demand\ Month_{t+2} \quad (4.24)$$

10. Lead Time

Lead time, which units is day, is the amount of days that the product will be arrived, started when the firm replenish the order. As the lead time is probabilistic, a random number is generated using Excel @Risk.

11. Order Arrival

Product arrival is defined as in what period that specific order will be arrived. Therefore, whenever the order occurs, product arrival will also occur. Formula 4.25 below is the formula to calculate product arrival.

$$Order\ Arrival_{(t)} = Period_{(t)} + Lead\ Time \tag{4.25}$$

12. Purchasing Cost

Purchasing cost is the cost needed to purchase the material per unit. The purchasing cost is indeed a variable cost which depends to the quantity of items bought to the supplier. Formula 4.26 below is the formula of unit cost.

$$Unit\ Cost_{(t)} = Ordering\ Quantity \times Unit\ Cost \tag{4.26}$$

13. Ordering Cost

Ordering cost is the cost needed in each of the ordering decision. It is indeed a fixed cost as whatever the quantity that the firm purchases, the ordering cost would be the same. Formula 4.27 below is the way to calculate ordering cost.

$$Ordering\ \ Cost_{(t)} = Ordering\ Decision_{\ (t)} \times Ordering\ Cost \tag{4.27}$$

14. Holding Cost

Holding cost is the cost needed whenever the ending inventory occurs. The amount of holding cost is variable as it depends on the quantity of end inventory in each of the period. Formula 4.28 below is the way to calculate the holding cost.

$$Holding\ Cost_{(t)} = End\ Inventory_{(t)} \times Holding\ Cost \tag{4.28}$$

15. Total Cost

The total cost in each of the period is the sum of purchasing cost, holding cost, and ordering cost. The accumulation of total cost in all periods will be used as a foundation to determine the inventory policy.

$$Total\ Cost = Purchasing\ Cost + Holding\ Cost + Ordering\ Cost \tag{4.29}$$

16. Service Level

Service Level is defined as the percentage of how much demand can be fulfilled given the amount of inventory that the firm has. The larger the stockout, the lower the service level as it cannot fulfill the demand in several specific periods. The average of service level in a year will be used as the foundation to determine the inventory policy. Formula 4.30 below is the formula of service level.

$$Service\ Level_{(t)} = \frac{Fulfilled\ Demand}{Demand} \times 100\% \tag{4.30}$$

Initially, a Monte Carlo simulation with 1,000 iterations and 5 iterations is conducted using the above model. However, to ensure that the number of replications is sufficient, an error calculation using half-width is conducted with ∝ or the error threshold is 5% which results in the value of t = 1.98. An example of half-width calculation using the total cost of product 1A as the sample is conducted. The total cost of existing policy, without simulation is, Rp 74,925,129,533.

Table 4.29 Simulations Result of Product 1A

Replications	Total Cost of Simulation
1	Rp75,932,930,000.00
2	Rp76,102,010,000.00
3	Rp75,750,470,000.00
4	Rp75,504,760,000.00
5	Rp75,145,440,000.00
s	Rp75,932,930,000.00
$\frac{hw}{\lvert x \rvert}$	0.09%

According to the result in the table 4.29, the number of replications is sufficient as it is below the threshold error of 5%. After ensuring the number of replications is sufficient for all products, the next step is validation. The parameter to be validated is the end inventory and below is the result of the simulation with 1000 replications and 5 iterations shown in table 4.30.

Table 4.30 End Inventory Comparison

Day	Actual	Day	Simulation
1	778,123	1	769,614
2	773,830	2	769,204
3	762,901	3	769,388
4	751,542	4	769,132
5	741,263	5	769,131
6	733,403	6	757,571
7	726,171	7	757,245
8	716,959	8	756,802
9	706,810	9	757,153
10	695,614	10	756,823
11	683,830	11	745,678
12	674,590	12	745,101
13	670,192	13	744,902
14	663,478	14	744,860
15	653,916	15	744,661
…		…	
365	1,047,038	1825	711,474

Table 4.31 is the result of validation using t-test. As the value of t Stat is located inside of the t Critical two-tail's interval, the simulation result is valid. This validation process is conducted for all products to ensure that the simulation model is valid. Table 4.32 is the recapitulation of both data adequacy test and validation test.

Table 4.31 End Inventory Validation Result of 1A

	Variable 1	*Variable 2*
Mean	887641.6	888666.9
Variance	3.64E+10	9.12E+10
Observations	1825	365
Pooled Variance	4.55E+10	
Hypothesized Mean Difference	0	
df	2188	
t Stat	-0.08382	
P(T<=t) one-tail	0.466602	
t Critical one-tail	1.64555	
P(T<=t) two-tail	0.933204	
t Critical two-tail	1.961049	

Table 4.32 Recapitulation of Half-Width and Validation Result

Product	Half Width (*Hw*)	Validation
1A	0.0887%	Valid
2B	0.0381%	Valid
3C	0.0392%	Valid
4D	0.0810%	Valid
5E	0.0404%	Valid
6F	0.0340%	Valid
7G	0.0238%	Valid
8H	0.0549%	Valid
9I	0.0380%	Valid
10J	0.1128%	Valid
11K	0.2790%	Valid
12L	0.1960%	Valid
13M	0.2360%	Valid
14N	0.1163%	Valid
15O	0.0649%	Valid
16P	0.0338%	Valid
17Q	0.3735%	Valid
18R	0.0648%	Valid
19S	0.0581%	Valid
20T	0.1558%	Valid
21U	0.1050%	Valid
22V	0.1893%	Valid
23W	0.5544%	Valid
24X	0.1211%	Valid
25Y	0.0361%	Valid
26Z	0.1547%	Valid
27A	0.1080%	Valid

Table 4.33 Simulation Template 1A

Month	Date (%)	Day	Demand	Initial Inventory	Order Received	Available Inventory	Fulfilled Demand	End Inventory
Jan	**31**	**1**	11,211	781,583		781,583	11,211	770,372
Jan	**30**	**2**	13,667	770,372	-	770,372	13,667	756,705
Jan	**29**	**3**	11,633	756,705	-	756,705	11,633	745,072
Jan	**28**	**4**	3,943	745,072	-	745,072	3,943	741,129
Jan	**27**	**5**	12,923	741,129	-	741,129	12,923	728,206
Jan	**26**	**6**	9,773	728,206	-	728,206	9,773	718,433
Jan	**25**	**7**	15,039	718,433	-	718,433	15,039	703,394
Jan	**24**	**8**	6,171	703,394	-	703,394	6,171	697,223
Jan	**23**	**9**	15,688	697,223	-	697,223	15,688	681,535
Jan	**22**	**10**	15,564	681,535	-	681,535	15,564	665,972
Jan	**21**	**11**	9,770	665,972	-	665,972	9,770	656,201
Jan	**20**	**12**	7,862	656,201	-	656,201	7,862	648,339
Jan	**19**	**13**	17,374	648,339	-	648,339	17,374	630,965
Jan	**18**	**14**	6,874	630,965	-	630,965	6,874	624,091
Jan	**17**	**15**	13,258	624,091	-	624,091	13,258	610,833
Jan	**16**	**16**	56	610,833	-	610,833	56	610,776
Jan	**15**	**17**	8,383	610,776	-	610,776	8,383	602,394
Jan	**14**	**18**	7,419	602,394	-	602,394	7,419	594,975
Jan	**13**	**19**	1,836	594,975	-	594,975	1,836	593,138
Jan	**12**	**20**	6,190	593,138	-	593,138	6,190	586,948
Jan	**11**	**21**	5,836	586,948	-	586,948	5,836	581,113
…	**…**	**…**	12,615	540,729	-	540,729	12,615	528,115
Dec	**…**	**365**	15,518	528,115	-	528,115	15,518	512,597

Table 4.33 Simulation Template 1A (Cont.)

DOI	Stockout	Order	Product Arrival	Lead Time	UC (Rp)	RC (Rp)	HC (Rp)	TC (Rp)	SL
62	-		0	24	-	-	4,724,342	4,724,342	1
61	-	-	0	25	-	-	4,640,531	4,640,531	1
60	-	-	0	25	-	-	4,569,193	4,569,193	1
60	-	-	0	26	-	-	4,545,011	4,545,011	1
59	-	-	0	31	-	-	4,465,759	4,465,759	1
58	-	-	0	32	-	-	4,405,826	4,405,826	1
57	-	-	0	27	-	-	4,313,598	4,313,598	1
57	-	-	0	15	-	-	4,275,754	4,275,754	1
55	-	-	0	26	-	-	4,179,550	4,179,550	1
54	-	-	0	18	-	-	4,084,104	4,084,104	1
53	-	-	0	28	-	-	4,024,186	4,024,186	1
53	-	-	0	12	-	-	3,975,971	3,975,971	1
51	-	821,340	35	22	12,726,416,594	366,490	3,869,425	12,730,652,509	1
51	-	-	35	21	-	-	3,827,271	3,827,271	1
50	-	-	46	31	-	-	3,745,963	3,745,963	1
50	-	-	43	27	-	-	3,745,617	3,745,617	1
49	-	-	58	41	-	-	3,694,210	3,694,210	1
48	-	-	43	25	-	-	3,648,712	3,648,712	1
48	-	-	44	25	-	-	3,637,451	3,637,451	1
48	-	-	38	18	-	-	3,599,489	3,599,489	1
…	…	…	…	…	…	…	…	…	…
90	-	-	0	19	-	-	6,782,599	6,782,599	1

Table 4.34 Simulation Input and Result of 1A

Input Parameters	
Demand	Norm (12158,5198)
Lead Time	Norm (24,6)
Unit Cost	Rp 15,495
Holding Cost	Rp 2,238
Ordering Cost	Rp 366,490
Simulation Results	
Service Level	100%
Total Cost	Rp 75,687,122,000

After conducting simulation which templates is depicted in table 4.33, the recapitulation of simulation input and output is depicted in table 4.34. The service level of product 1A is 99.997% with the total cost of Rp 75,577,161,563. Visually, the result of total cost, service level, and end inventory is depicted in figure 4.21-4.23. The overall simulation results are depicted in table 4.35.

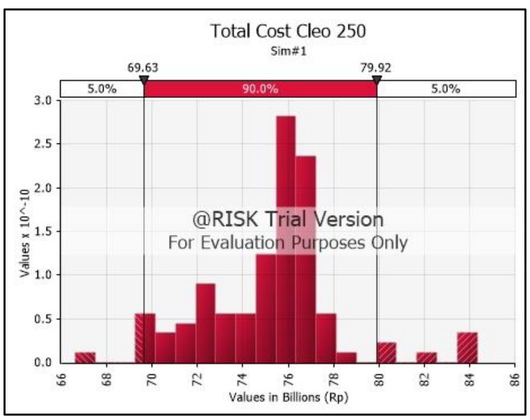

Figure 4.22 Total Cost 1A

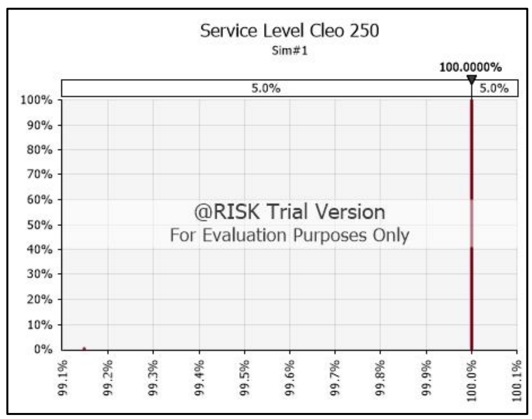

Figure 4.21. Service Level 1A

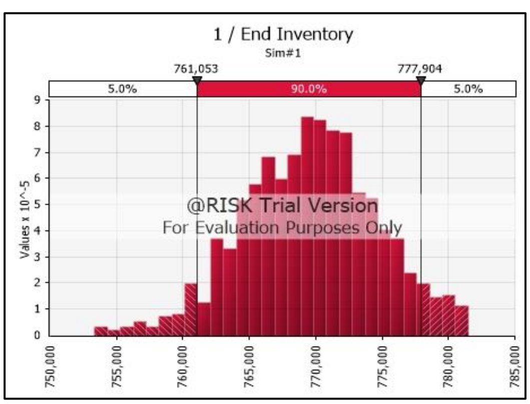

Figure 4.23 End Inventory 1A

Table 4.35 Total Cost and Service Level Recapitulation of Existing Policy

Product	Total Cost	Service Level
1A	Rp 75,577,161,563	99.998%
2B	Rp 25,106,421,491	99.875%
3C	Rp 9,638,811,060	99.999%
4D	Rp 41,002,165,584	99.997%
5E	Rp 59,758,201,688	99.999%
6F	Rp 37,974,918,706	99.999%
7G	Rp 121,773,502,164	100.000%
8H	Rp 60,665,107,437	99.996%
9I	Rp 6,448,881,723	99.715%
10J	Rp 2,363,052,735	99.994%
11K	Rp 536,865,215	100.000%
12L	Rp 2,529,246,451	99.947%
13M	Rp 2,191,814,179	100.000%
14N	Rp 761,780,524	99.979%
15O	Rp 1,986,335,528	99.980%
16P	Rp 3,913,718,801	99.964%
17Q	Rp 5,466,290,144	99.991%
18R	Rp 4,566,233,605	100.000%
19S	Rp 1,345,797,753	99.877%
20T	Rp 813,127,333	99.999%
21U	Rp 4,808,110,840	99.998%
22V	Rp 1,456,381,768	100.000%
23W	Rp 411,037,879	98.291%
24X	Rp 4,111,080,686	99.893%
25Y	Rp 1,171,105,445	99.624%
26Z	Rp 3,127,155,290	99.889%
27A	Rp 880,087,514	100.000%

4.7 Experimentation

The experimentation is conducted by examining two models which are (s, S) and modified (s, Q) where the Q uses the algorithm of Fixed Order Interval. Below is the explanation of steps and algorithms as well as the results in each of the models.

4.7.1 Continuous Review (s, S)

Comparing to the existing model, the continuous review (s, S) model has a difference in the quantity to be ordered as it highly depends on the condition of end inventory and the quantity will vary over time. Besides that, as the existing condition mechanism does not consist of how to calculate the minimum stock (s), the continuous review (s, S) model also includes the determination of minimum stock given the service level target is 99.5%. Furthermore, where a product has seasonality in the year, the parameters will also change according to its seasonality condition. Below are some differences in inventory policy compared to the existing model.

1. Initial Inventory

The initial inventory on this policy is assumed to be the maximum level of inventory (S).

2. Safety Stock

Comparing to the existing system which has unclear reason upon the minimum stock, the safety stock in this model follows the formula of safety stock mentioned in the table 2.2 with demand and lead time uncertainty. The safety stock must accommodate the demand during lead time.

3. Ordering Quantity

The ordering quantity varies along the year as it depends to the number of inventories at the reorder point. The ordering quantity to order until the inventory reaches the maximum (S).

Table 4.36 and 4.37 below is the depiction of some parameters input and output on the simulation of both product that has no seasonality and product that has seasonality.

Table 4.36 Continuous Review (s, S) Inventory Parameters of 1A

Inventory Parameters 1A	
Demand	Norm (12158,5198)
Average Demand/Month	370,120
Lead Time	Norm (24,6)
Safety Stock	$SS = 2.58 \times \sqrt{(12158^2 \times 6^2) + (24 \times 5198^2)} = 228{,}113\ FU$ $SS = \frac{228{,}113}{370{,}120} \times 30 = 18.5\ Days\ of\ Inventory\ (DOI)$
s	$s = (12{,}158 \times 24) + 228{,}113 = 523{,}557\ FU$ $s = \frac{523{,}557}{370{,}120} \times 30 = 42.4\ Days\ of\ Inventory$
Q	$Q = \sqrt{\frac{2 \times 12{,}158 \times 366{,}490}{(2{,}238/365)}} = 38{,}121\ FU$
S	$S = 523{,}5571 + 38{,}121 = 561{,}678\ FU$ $S = \frac{561{,}678}{370{,}120} \times 30 = 45.5\ Days\ of\ Inventory$

Table 4.37 Continuous Review (s, S) Inventory Parameters of 5E

Inventory Parameters 5E	
Demand T1	Norm (5689,3881)
Demand T2	Norm (7949,4141)
Average Demand/Month	209,167 FU
Average Demand T1	210,000
Average Demand T2	208,333
Lead Time	Norm (27,4)
Safety Stock T1	$SS = 2.58 \times \sqrt{(5689^2 \times 4^2) + (27 \times 3881^2)} = 83{,}962\ FU$ $SS = \frac{83{,}962}{209{,}167} \times 30 = 12\ Days\ of\ Inventory\ (DOI)$
Safety Stock T2	$SS = 2.58 \times \sqrt{(7949^2 \times 4^2) + (27 \times 41411^2)} = 107{,}230\ FU$ $SS = \frac{107{,}230}{209{,}167} \times 30 = 15.4\ Days\ of\ Inventory\ (DOI)$
s T1	$s = (5{,}689 \times 27) + 83{,}962 = 241{,}849\ FU$ $s = \frac{241{,}849}{209{,}167} \times 30 = 34.7\ Days\ of\ Inventory$
s T2	$s = (7{,}949 \times 27) + 107{,}230 = 265{,}116\ FU$ $s = \frac{265{,}116}{209{,}167} \times 30 = 38\ Days\ of\ Inventory$

Inventory Parameters 5E	
Q T1	$Q = \sqrt{\dfrac{2 \times 5{,}689 \times 366{,}490}{(4{,}652/365)}} = 12{,}738\ FU$
Q T2	$Q = \sqrt{\dfrac{2 \times 7{,}949 \times 366{,}490}{(4{,}652/365)}} = 15{,}181\ FU$
S T1	$S = 241{,}849 + 12{,}738 = 254{,}586\ FU$ $S = \dfrac{254{,}586}{210{,}000} \times 30 = 36.5\ Days\ of\ Inventory$
S T2	$S = 265{,}116 + 15{,}181 = 280{,}297\ FU$ $S = \dfrac{280{,}297}{208{,}333} \times 30 = 40.2\ Days\ of\ Inventory$

According to the table 4.36 and 4.37 above, there are two kinds of inventory policy that can occur in this research, namely the inventory policy for a product with seasonality and an inventory policy for a product with no seasonality. For the inventory policy of a product with no seasonality, there is only single inventory policy for each parameter – single safety stock, minimum inventory, ordering quantity, and maximum inventory. Meanwhile, the inventory policy for a product with seasonality will be changing along the year with the number of changes depends on the seasonality that each product has according to the previous analysis. For a product with two seasonality such as 5E, two inventory policies that must be applied – two safety stock, minimum inventory, ordering quantity, and maximum inventory. The objective of having such policy is to increase the accuracy and efficacy of inventory policy as the data with different seasons might have a different data pattern and distribution. The parameters of each inventory policy can also be modified later in scenario analysis to see the local optimum inventory parameters in each of the products. Table 4.38 below is the recapitulation of cost and service level.

Table 4.38 Simulation Result of Continuous Review (s, S)

Product	Total Cost	Service Level
1A	Rp 54,106,170,000.00	87.30%
2B	Rp 18,371,692,000.00	84.17%
3C	Rp 6,839,004,600.00	85.68%
4D	Rp 32,442,232,000.00	88.92%
5E	Rp 43,233,448,000.00	74.86%
6F	Rp 28,663,100,000.00	85.75%
7G	Rp 93,679,748,000.00	81.57%
8H	Rp 41,301,920,000.00	78.53%
9I	Rp 5,205,428,400.00	90.83%
10J	Rp 1,909,452,000.00	94.51%
11K	Rp 531,311,220.00	99.72%
12L	Rp 2,084,999,000.00	96.35%
13M	Rp 2,142,780,600.00	99.69%
14N	Rp 630,513,060.00	98.24%
15O	Rp 1,436,267,600.00	89.33%
16P	Rp 2,972,872,200.00	94.92%
17Q	Rp 4,570,915,600.00	94.08%
18R	Rp 3,577,395,800.00	93.12%
19S	Rp 897,603,940.00	90.65%
20T	Rp 504,272,700.00	88.78%
21U	Rp 4,011,090,200.00	91.95%
22V	Rp 1,486,793,200.00	95.91%
23W	Rp 328,358,240.00	93.02%
24X	Rp 3,331,991,200.00	81.00%
25Y	Rp 1,035,743,200.00	90.61%
26Z	Rp 2,974,007,400.00	98.95%
27A	Rp 822,277,620.00	99.84%

4.7.2 Fixed-Order-Interval (FOI)

Comparing to the existing model, the FOI model has a difference in the quantity to be ordered or called as Q. In this model, the quantity to be ordered also varies between times as it depends on the ending inventory during the reorder level. Below are the summary differences between FOI and the existing model.

1. Initial Inventory

The initial inventory (January) on this policy is equal with the Q (FOI) as the order in the last year (December) which is equal to Q is projected to be received in the beginning of the January.

2. Safety Stock

Comparing to the existing system which has unclear reason upon the minimum stock, the safety stock in this model follows the formula of safety stock mentioned in the table 2.2 with demand and lead time uncertainty.

3. Ordering Quantity

The ordering quantity in this model is described at formula 2.8 in chapter two. Table 4.39 and 4.40 below is the depiction of some parameters input and output on the simulation of both product that has no seasonality and product that has seasonality.

Table 4.39 Fixed-Order-Interval-Inventory Parameters of 1A

Inventory Parameters 1A	
Demand	Norm (12158,5198)
Average Demand/Month	370,120
Lead Time	Norm (24,6)
Safety Stock	$SS = 2.58 \times \sqrt{(12158^2 \times 6^2) + (24 \times 5198^2)} = 228{,}113\ FU$ $SS = \frac{228{,}113}{370{,}120} \times 30 = 18.5\ Days\ of\ Inventory\ (DOI)$
s	$s = (12{,}158 \times 24) + 228{,}115 = 523{,}557\ FU$ $s = \frac{523{,}557}{370{,}120} \times 30 = 42.4\ DOI$
Q	$Q = Average\ Demand\ (DOI) \times (30 + LT) + s - A$ $Q = (\frac{12158}{370{,}120} \times 30) \times (30 + 24) + 42.4 = 95.9\ DOI - A$

Table 4.40 Fixed-Order-Interval-Inventory Parameters of 5E

Inventory Parameters 5E	
Demand T1	Norm (5689,3881)
Demand T2	Norm (7949,4141)
Average Demand/Month	209,167 FU
Average Demand T1	210,000
Average Demand T2	208,333
Lead Time	Norm (27,4)
Safety Stock T1	$SS = 2.58 \times \sqrt{(5689^2 \times 4^2) + (27 \times 3881^2)} = 83{,}962\ FU$ $SS = \frac{83{,}962}{209{,}167} \times 30 = 12\ Days\ of\ Inventory\ (DOI)$
Safety Stock T2	$SS = 2.58 \times \sqrt{(7949^2 \times 4^2) + (27 \times 41411^2)} = 107{,}230\ FU$ $SS = \frac{107{,}230}{209{,}167} \times 30 = 15.4\ Days\ of\ Inventory\ (DOI)$
s T1	$s = (5{,}689 \times 27) + 83{,}962 = 241{,}849\ FU$ $s = \frac{241{,}849}{209{,}167} \times 30 = 34.7\ Days\ of\ Inventory$
s T2	$s = (7{,}949 \times 27) + 107{,}230 = 265{,}116\ FU$ $s = \frac{265{,}116}{209{,}167} \times 30 = 38\ Days\ of\ Inventory$
Q T1	$Q = Average\ Demand\ (DOI) \times (30 + LT) + s - A$ $Q = (\frac{5689}{209{,}167} \times 30) \times (30 + 24) + 34.6 = 81.6\ DOI - A$
Q T2	$Q = Average\ Demand\ (DOI) \times (30 + LT) + s - A$ $Q = (\frac{7949}{209{,}167} \times 30) \times (30 + 24) + 47 = 113.1\ DOI - A$

Table 4.41 Simulation Result of Fixed-Order-Interval (FOI)

Product	Total Cost	Service Level
1A	Rp 69,443,226,000.00	100.00%
2B	Rp 21,680,784,000.00	99.80%
3C	Rp 8,993,486,000.00	100.00%
4D	Rp 41,909,306,000.00	100.00%
5E	Rp 63,732,544,000.00	100.00%
6F	Rp 35,877,790,267.97	99.96%
7G	Rp 131,185,400,000.00	99.95%
8H	Rp 58,023,270,000.00	99.99%
9I	Rp 5,806,845,400.00	99.90%
10J	Rp 2,283,034,600.00	99.99%
11K	Rp 627,919,020.00	100.00%
12L	Rp 2,286,692,108.29	97.71%
13M	Rp 1,882,746,200.00	100.00%
14N	Rp 700,209,820.00	99.94%
15O	Rp 1,781,593,400.00	100.00%
16P	Rp 3,865,048,800.00	99.99%
17Q	Rp 5,426,866,800.00	99.95%
18R	Rp 4,269,985,000.00	100.00%
19S	Rp 1,199,062,200.00	98.04%
20T	Rp 743,106,380.00	99.53%
21U	Rp 4,776,931,200.00	100.00%
22V	Rp 1,709,486,200.00	100.00%
23W	Rp 458,146,380.00	99.45%
24X	Rp 4,227,115,600.00	100.00%
25Y	Rp 1,339,648,000.00	99.90%
26Z	Rp 2,965,002,800.00	100.00%
27A	Rp 1,171,795,600.00	99.98%

4.8 Scenario Analysis

In this section, scenario analysis will be carried out. The scenario analysis is conducted to compare each of the inventory policy which are existing policy, FOI, and continuous review (s, S). Firstly, the comparison is conducted to eliminate the policy which has a service level below 99.5%. After that, a normalization and weighting process is conducted to find the best inventory policy by considering the total cost and service level. Below is the formula of both two aspects.

$$TC\ Normalization = \frac{(TC\ Max - Result)}{(TC\ Max - TC\ Min)} \tag{4.31}$$

$$SL\ Normalization = \frac{(Result - SL\ Min)}{(SL\ Max - SL\ Min)} \tag{4.32}$$

$$Weight = 0.7 \times TC\ Norm + 0.3 \times SL\ Norm \tag{4.33}$$

In total cost normalization, the way to calculate is by subtracting the maximum value of the total cost with the total cost result from the simulation and divide it by the total cost interval. All those costs are only the cost for accepted policy, a policy that has more than 99.5% service level. In this scope, the higher the result of total cost, the lower the result of normalization and vice versa. This is suitable with the initial objective to choose the lowest possible cost.

In service level normalization, the way to calculate it is by subtracting the result of the simulation with the minimum service level, then divide it with the service level interval. Same as the total cost, it is only applicable for the accepted strategy, a strategy that has more than 99.5% service level. In this scope, the higher the result of total cost, the higher the result of normalization.

Ultimately, the result of both total cost and service level normalization is aggregated in the weighting to see the best possible inventory policy. The result of weight scoring, 0.7 and 0.3, is due to the priority of the firm to focus on cost minimization while still serving the customer at the targeted service level. As a sample, table 4.42 below is the summary of scenario analysis of product 1A.

Table 4.42 Scenario Analysis of Product 1A

Scenario	Min T1	Max or Q T1[1]	TC		SL	Status	TC Norm	SL Norm	Weight
Existing	52.5	90.0	Rp	75,687,122,000	100.00%	Accept	0.24	0.99	0.47
FOI	42.4	95.9	Rp	69,443,226,000	100.00%	Accept	0.67	1.00	0.77
(s, S)	42.4	45.5	Rp	54,106,170,000	87.30%	Reject	-	-	-
(s, S) 1	42.4	50.0	Rp	58,224,960,000	92.23%	Reject	-	-	-
(s, S) 2	42.4	60.0	Rp	63,127,652,000	97.98%	Reject	-	-	-
(s, S) 3	42.4	65.0	Rp	64,057,190,000	99.18%	Reject	-	-	-
(s, S) 4	40.0	72.0	Rp	58,490,068,000	96.62%	Reject	-	-	-
(s, S) 5	40.0	75.0	Rp	58,447,374,000	97.78%	Reject	-	-	-
(s, S) 6	42.4	78.0	Rp	58,273,762,000	99.23%	Reject	-	-	-
(s, S) 7	42.4	70.0	Rp	64,563,512,000	99.63%	Accept	1.00	-	0.70
(s, S) 8	40.0	80.0	Rp	79,198,546,000	100.00%	Accept	-	1.00	0.30
(s, S) 9	45.0	75.0	Rp	65,764,954,000	99.93%	Accept	0.93	0.82	0.90
(s, S) 10[2]	**45.0**	**78.0**	**Rp**	**65,714,364,000**	**99.98%**	**Chosen**	**0.94**	**0.96**	**0.94**

1) Max is applied for s, S while Q is applied for FOI and existing policy
2) Blue-shaded row is the chosen strategy based on the highest weighting score

According to table 4.42 above, the chosen strategy for product 1A is strategy (s, S) 10 due to its highest score of weighting – considering both the scoring system of total cost and service level. As can be seen, the normalization of both total cost and service level is conducted only for those who have service level above 99.5% or started from the seventh strategy of (s, S). As the company will have the capacity to use continuous review inventory control, the FOI model is only used as a benchmark by compare it to the continuous review and the existing model. As a result, there a cost saving for about Rp 10 million for this product comparing to the existing model. This method of scoring system is carried out to all the products to find the best inventory policy. Table 4.43 until 4.68 below is the summary of the scenario analysis for each of the products.

4.9 Sensitivity Testing

In this section, sensitivity testing will be carried out to see how the observed variables change when the uncertainty variables are fluctuating. The sensitivity testing is conducted only to the chosen strategy mentioned in the previous section.

4.9.1 Demand Sensitivity

The sensitivity of demand is carried out to see how the effect of demand changes to the total cost and service level is. There are eight conditions to be observed, which are the existing condition and the change with the percentage of 25%, 50%, 125%, 150%, 175%, 200%, 250%, 300% relative to the initial condition. Table 4.69 below is the result example of demand sensitivity of product 1A.

Table 4.43 Demand Sensitivity of Product 1A

Demand	Total Cost	Service Level
25%	Rp 16,526,880,000.00	100.000%
50%	Rp 33,417,260,000.00	100.000%
0%	Rp 65,714,364,000.00	99.984%
125%	Rp 86,962,844,000.00	99.992%
150%	Rp 101,151,627,000.00	99.990%
175%	Rp 123,470,104,000.00	99.987%
200%	Rp 134,456,728,000.00	99.897%
250%	Rp 174,873,988,000.00	99.989%
300%	Rp 199,143,092,000.00	99.990%

To see the effect of demand sensitivity holistically, figure 4.24 below represents the demand sensitivity testing some of the products which have relatively high value. The reason of only selecting the product with relatively high value is merely due to better data visualization reason as adding a product with low value would not be appeared in the graph clearly as the y axis magnitude is dominated with high value products.

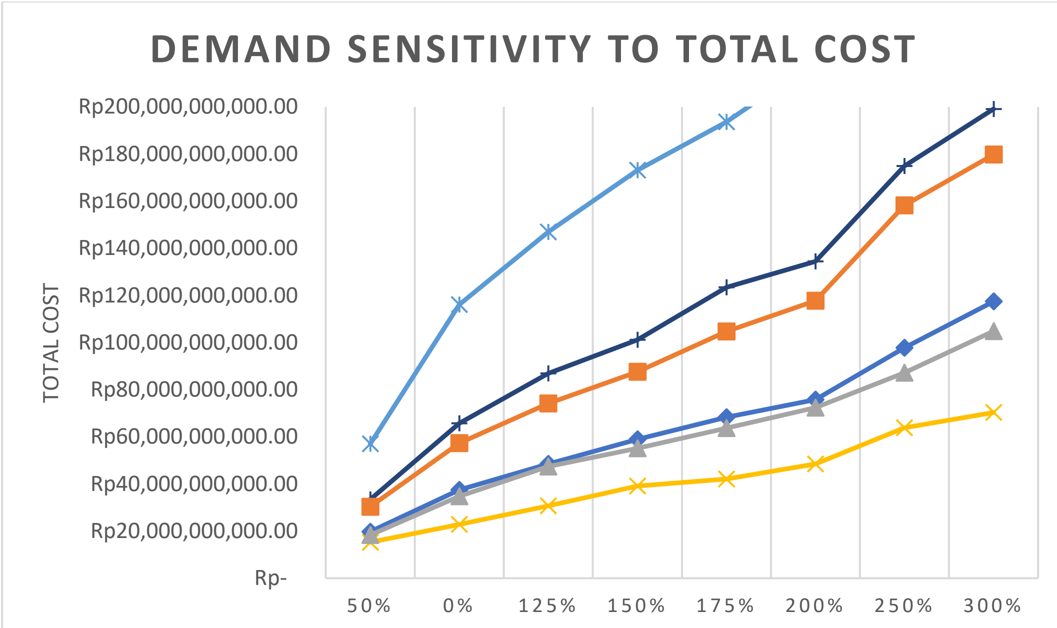

Figure 4.24 Effect of Demand Changes to Total Cost

Besides the effect of demand change to the total cost, another aspect to consider is the effect to the service level. With the same chosen products as the figure above, figure 4.25 below represents the effect of demand change to the service level.

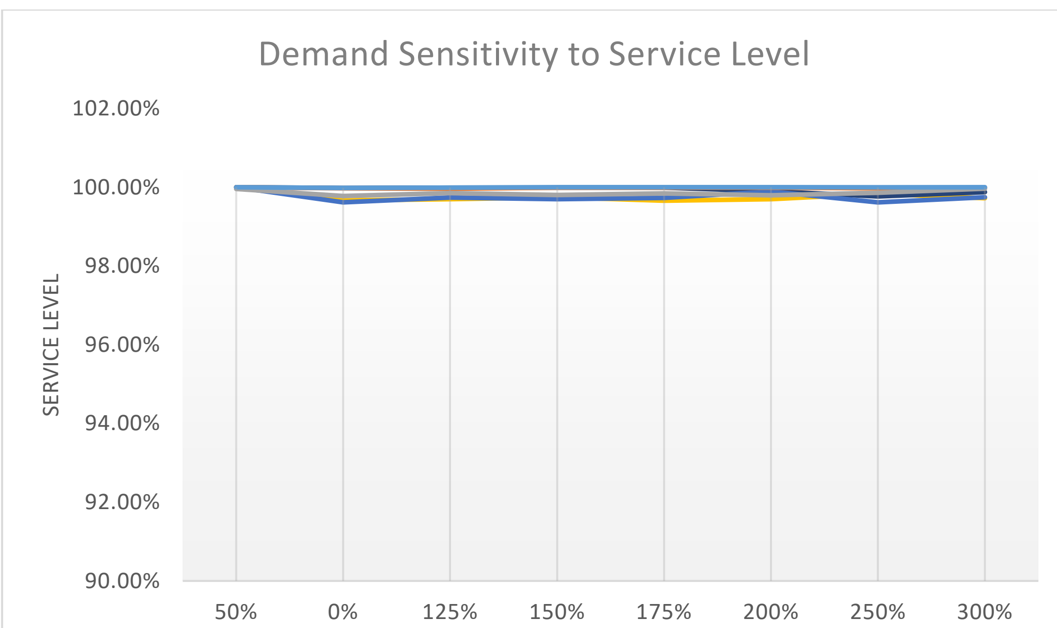

Figure 4.25 Effect of Demand Changes to Service Level

4.9.2 Lead Time Sensitivity

Asides from the sensitivity of demand, lead time is another uncertain variable that also need to be tested. There are seven conditions to be tested, which are the existing condition and the change with the percentage of 25%, 50%, 125%, 150%, 175%, 200% relative to the initial condition. Table 4.70 represents the example of lead time sensitivity result of product 1A while figure 4.26 represents the effect of demand changes of several sample products to see the effect of lead time sensitivity clearly.

Table 4.44 Lead Time Sensitivity of Product 1A

LT	Total Cost		Service Level
25%	Rp	64,582,590,000.00	100.00%
50%	Rp	64,062,280,000.00	100.00%
0%	Rp	65,714,364,000.00	99.98%
125%	Rp	69,635,050,000.00	99.81%
150%	Rp	69,736,270,000.00	98.38%
175%	Rp	70,863,000,000.00	96.53%
200%	Rp	70,573,180,000.00	94.33%

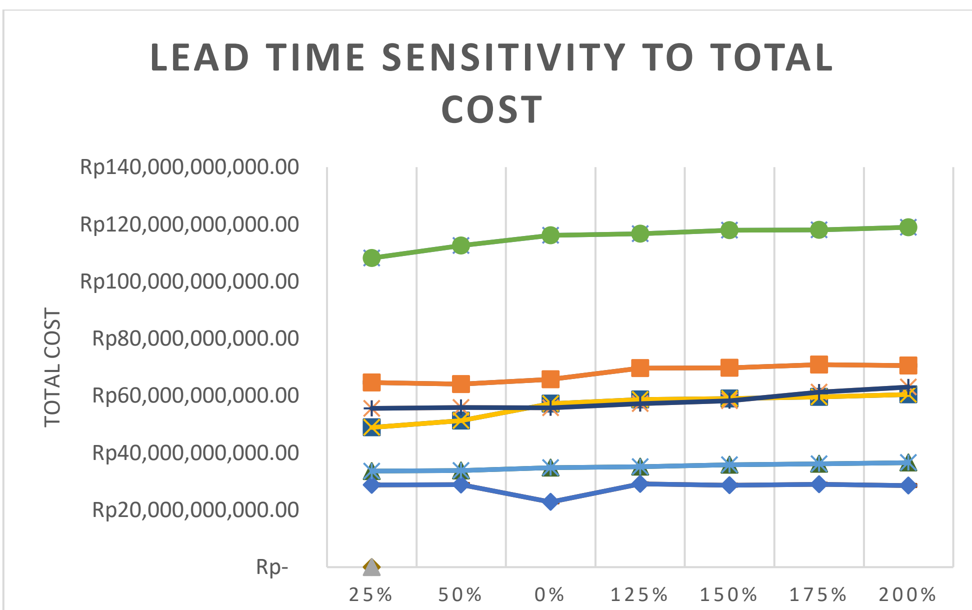

Figure 4.26 Effect of Lead Time Changes to Total Cost

Besides the effect of lead time sensitivity to the total cost, the effect to the lead time is also observed. Figure 4.27 below represents the effect of lead time changes to the service level.

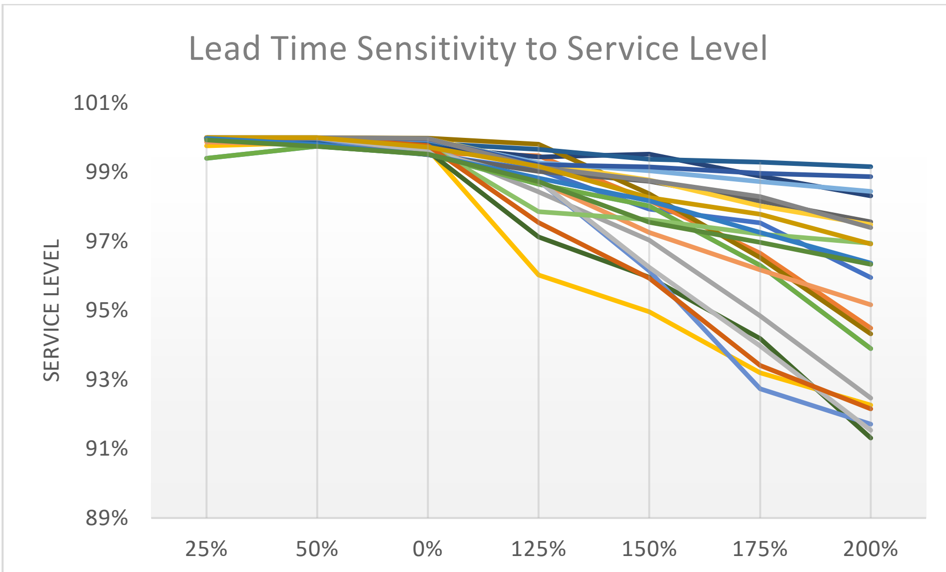

Figure 4.27 Effect of Lead Time Changes to Service Level

4.9.3 Two Way Sensitivity

In this section, the effect of demand and lead time change is combined to see the overall impact on total cost and service level. The data and visualization of change can be seen in table 4.45 and figure 4.28 below.

Table 4.45 Demand and Lead Time Sensitivity

%Change in Demand & Lead Time	Total Cost	Service Level
25%	16,526,880,000.00	100.00%
50%	33,417,260,000.00	100.00%
0%	65,714,364,000.00	99.98%
125%	86,962,844,000.00	99.81%
150%	101,151,627,000.00	98.38%
175%	123,470,104,000.00	96.53%
200%	134,456,728,000.00	94.33%

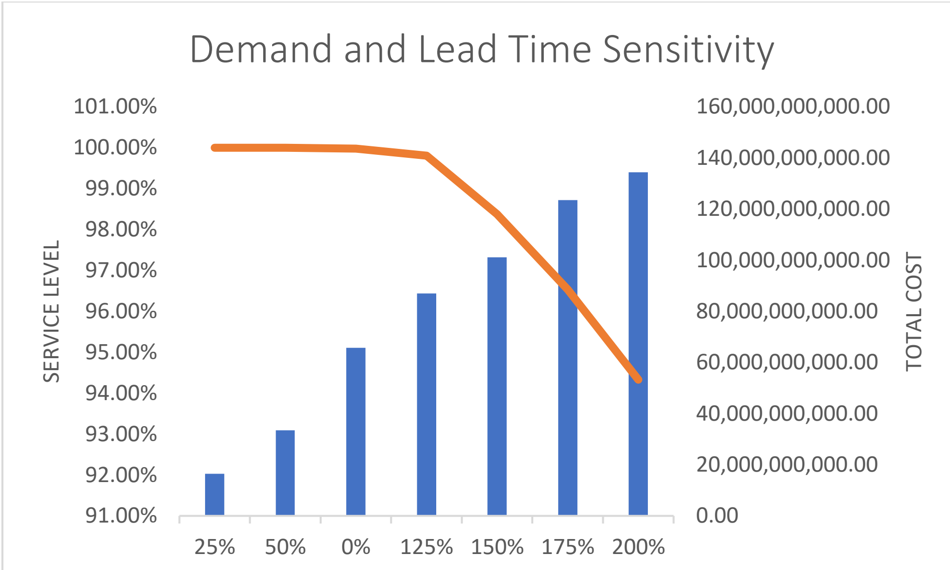

Figure 4.28 Demand and Lead Time Sensitivity

According to the figure 4.28 above, the only parameter that matters is the lead time since the change in demand does not affect the service level as can be seen in figure 4.25. In this case, the company is suggested to set the minimum service level where the suppliers lead time reliability is problematic to ensure that they can still meet the targeted service level, in the very worst scenario. As an example, when the actual targeted service level is 99.5% and the worst targeted service level is 95%, it means that the company can still accept the delay of lead time not more than 75% relative to the initial lead time. This is due to when the lead time increases more than 75% of the actual lead time, the company may not achieve the worst targeted service level of 95%. This decision is helpful to decide the metrics of supplier selection to ensure that they can still comply with the targeted service level.

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CHAPTER 5
ANALYSIS AND INTERPRETATION

In this chapter, an analysis of both the material requirement planning system and inventory policy will be explained. The analysis of the material requirement planning system comprises the difference between the actual and suggested system while the analysis of the inventory policy comprises the analysis of existing policy until the sensitivity testing of chosen policy.

5.1 Analysis of Material Requirement Planning System

The development of a material requirement planning system has to objective to create a more robust and efficient inventory and procurement control. This is due to a lot of manual calculations performed by the workers, causing not only a long time to process the data but also a calculation that is prone to mistake. Therefore, the digitalization of the material requirement planning system is proposed.

The proposed digitalized MRP system consists of four main sections, namely master data, BOM, demand management, and planning & monitoring along with the interconnection between each and another section. The master data consists of all data needed for procurement calculation including, but not limited to, stock, in-transit, OS PO, demand forecast, and lead time. Out of all the data existing in the master data section, three data will be continuously updated daily which are stock, in-transit, and OS PO thus resulting in a higher size of data storage. These data will be then integrated into the other section. Besides the master data, another section is BOM, consisting of the material's structure as well as its conversion rate. The BOM will be then integrated to demand management to explode the finished goods demand to the lower level of material in each of the finished goods. Finally, the previous three sections will be later integrated with planning and monitoring in order to capture each of the important parameters and to see how many quantities that the firm has to order along with its scheduling system with a real-time monitoring system.

The development of the MRP system is not only comprising of the software requirement document explained in chapter four, as an Excel model is also developed. The development of the Excel model has a function to not only give an actual depiction of business process and how the data should be presented along with its practical algorithm, since the firm needs to soon move to a system that is more efficient in the calculation without compromising its quality of inventory control model. The Excel model consists of the same content as what the software requirement software presents, including the master data update function, BOM conversion, and practical material monitoring system that is capable to control the inventory.

As the timeframe of the MRP system is still under development phase, rigorous impact assessment on time-processing savings, data accuracy, and other necessary effect is hard to be done. Therefore, a design of usability testing is developed to equip the firm with metrics of how the quality of the proposed system is. The usability testing consists of two main parts, namely the practical questionnaire using the Standard Usability Scale (SUS) and the feedback form. Generally, SUS has been widely implemented to assess perceived usability. The SUS acts as quantitative measures of how the quality of the software is, given all the requirements and function developed that was presented in software requirement documents. Two main directionalities will be under the SUS questionnaire. Firstly, for the odd-numbered question, the higher scores are better. Secondly, for even-numbered items, lower scores indicate a better user experience. Hence, the formula presented in chapter four has two ways of calculating direction, where the odd number will act as a positive number and the even number will act as a negative number – subtracted from the maximum raw value of five. Asides from the SUS questionnaire, the feedback form has a function to internalize what the users feel about the software and gaining their possible pain points when using the software. The feedback form is highly important as it will be accommodating and emphasizing users’ voices, giving the software developer more insight about what is lacking in the developed system.

5.2 Analysis on Existing Inventory Policy

In this section, there are three inventory policies to be analyzed, namely the existing inventory policy, fixed-order interval, and continuous review (s, S) system. Each of those inventory policies has its own advantages and weaknesses. In this section, an analysis of each of the inventory policy will be carried out using Monte Carlo simulation to see which one is the best for the firm according to several predetermined criteria.

The first policy to be analyzed is indeed the existing inventory policy applied by the firm. Currently, the company implements a conventional (s, Q) inventory control system where Q unit will be purchased whenever the inventory reaches the reorder level or minimum level of inventory. The current reorder level applied by the firm is 52.5 Days of Inventory (DOI) while the ordering quantity (Q) is around 90 days. However, there is a possibility that the company order when the inventory is still above the minimum level of 52.5 DOI as a subjective judgment from the workers is still widely implemented in a way to open the replenishment. After communicating with the material's planner, usually, the planner will order with the quantity of Q when the inventory level is around 45 to 60 DOI. As the fixed minimum inventory level is not exact, an average between 45 to 60 DOI is used to simulate the existing inventory policy which is equal to 52.5 DOI. Doing this method of calculation is necessary as the minimum inventory level in the Monte Carlo simulation has to be exact.

Besides the inclusion of subjectivity from the workers during the replenishment cycle, the clarity of where the minimum DOI and ordering quantity are formed are also questionable. This is due to the absence of rigorous mathematical study to determine the inventory parameters for each product and plant. Furthermore, the existing reorder level and ordering quantity applied uniformly to all kinds of products in the observed plant. This is indeed problematic as different materials might have different behavior and pattern in demand and lead time – signifying the importance of having a unique inventory policy for each of the products within the plant. This is due to a different material might have different demand and lead time's average and standard deviation which require a uniqueness in each of the inventory policy.

However, amidst several pointed weaknesses earlier, the existing inventory policy has a strong point on the service level side. After doing Monte Carlo simulation for the existing inventory policy, the recapitulation of service level of the existing inventory policy is recapitulated in the figure below.

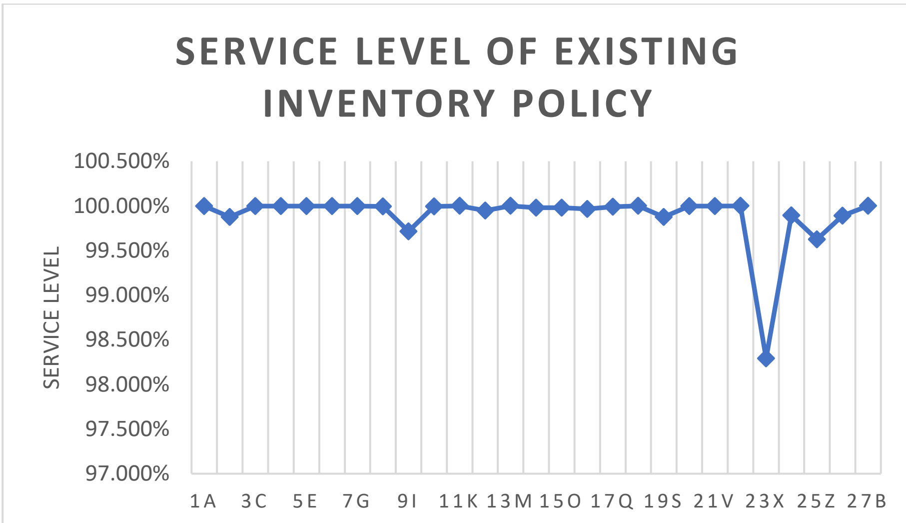

Figure 5.1 Service Level of Existing Inventory Policy

According to figure 5.1 above, the service level of the existing inventory policy is around 98.5 – 100%. While the expected service level of the company is above 99.5%, almost all products are fulfilling the service level requirement. However, the firm's problem is not located to the service level, but more into the amount of inventory they have which is also related to the total cost. The root cause of this problem is due to the absence of maximum inventory level measurement and target, as the present Key Performance Indicators (KPI) is only to measure the minimum stock level. Therefore, the workers have no drive to carefully manage the maximum inventory level as their main objective is only to play safe above the minimum level. Given this fact, an assessment of the maximum inventory level is necessary to be conducted to make sure that the inventory of the firm is still within an acceptable limit. This study will be summarized in the next section where the improved inventory policy more likely focuses on how to reduce the inventory level while still maintaining adequate service level.

5.3 Analysis of Improved Inventory Policy Alternatives

In this section, two inventory policy alternatives will be assessed, namely the Fixed-Order-Interval (FOI) and Continuous Review (s, S). These two scenarios will be assessed in the scope of their associated cost and service level. Initially, there should be an inventory policy that is below the service level target. However, when the total cost signifies a promising amount of savings, a scenario analysis of the chosen inventory policy will be carried out.

Firstly, a continuous review model (s, S) is tested. In this method, an order quantity to maximum inventory (S) will be placed whenever the inventory reaches the minimum inventory (s). The ordering quantity will vary across replenishments as the ordering quantity should investigate the condition of inventory. However, this method needs a supporting system that is capable to control the inventory in real-time as the inventory parameters need to be updated continuously. Generally, this method produces a lower total cost compared to another inventory control model. However, there is one adjustment of a continuous review that should be highlighted as there is a rule of thumb that the firm can only order a material after 30 days of previous replenishment. This rule should be accommodated in the model to create a more realistic approximation on this model.

Secondly, the FOI inventory control model is also tested. In this method, orders must be placed at fixed time intervals which in this case is on a monthly basis. This approach is quite different from (s, Q) approach in which the order size generally comes fixed between each cycle. The usage of this policy is usually due to the policy coming from the supplier that might encourage to order at a fixed interval. The advantage of using this policy is more into the easiness of implementation as it does not require hassles to control the inventory in real-time. However, as this paper aims to develop a tool for continuous review inventory control as it is generally creates more cost savings, the FOI inventory control model is only used as a benchmark to see the correspondence total cost and service level. This method should only be considered if the total cost is lower than both continuous review (s, S) and the existing inventory control model while still maintaining the targeted service level.

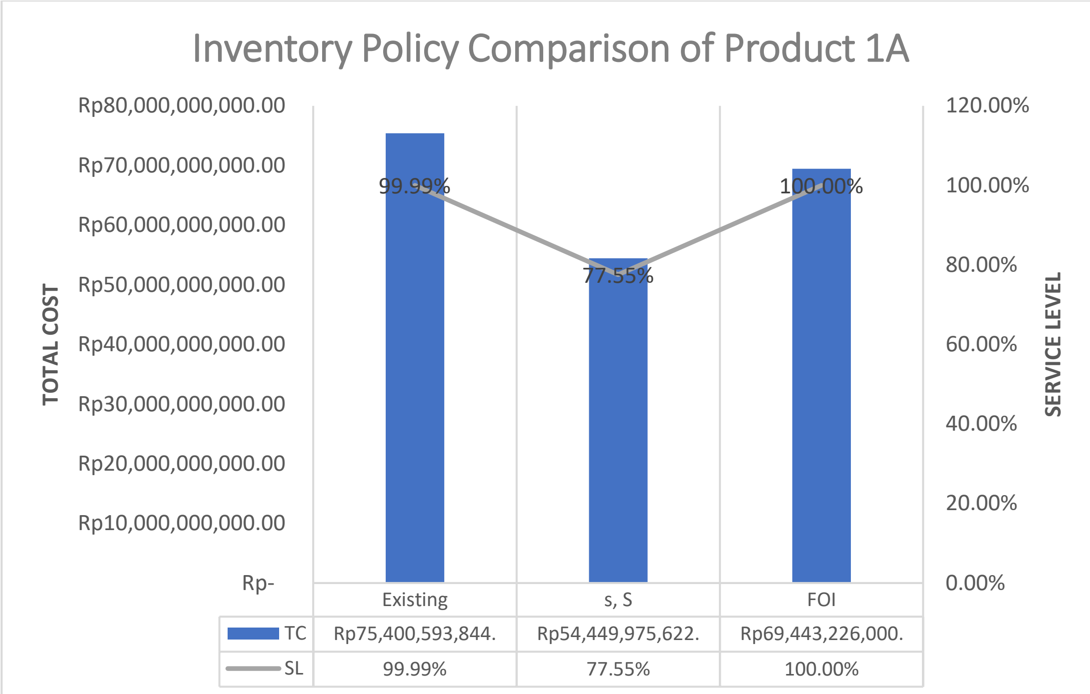

Figure 5.2 Comparison of Total Cost and Service Level of Product 1A

Figure 5.2 above represents the comparison of inventory policy on total cost and service level of product 1A. The reason behind choosing one random product is due to the uniform pattern of total cost and service level in each type of the inventory policy, where the continuous review (s, S) generally produces the lowest service level and total cost while the FOI generally produces the highest service level and the with an acceptable total cost. Seeing this pattern, one main key takeaway should be carried out, where the FOI and continuous review (s, S) can be competing later when the service level is all above the threshold of 99.5%. As the service level of (s, S) is not yet meeting the target, scenario testing and analysis should be carried out until the continuous review (s, S) reaches the minimum service level 99.5%. After which, the comparison could be conducted which will compare both the total cost and service level between the continuous review (s, S), FOI, and the existing condition. The decision to choose the best inventory policy will be explained in the next section under the scenario testing and analysis.

5.4 Scenario Analysis of Inventory Policy

In this part, a comparison between several inventory policies is conducted. There are four inventory policies to be compared which are the existing inventory policy, FOI, continuous review (s, S), and the chosen continuous review (s, S) after scenario testing. As the sample of assessment, the inventory policy comparison of product 6F is carried out.

In scenario analysis, two main steps should be taken. Firstly, creating several scenarios for the continuous review (s, S) inventory policy and its impact on the total cost and service level is needed to create a list of possible inventory policy options. Secondly, any policy which results in the service level below 99.5% should be eliminated as it is below the firm's target. Thirdly, after having the list of inventory policies above 99.5%, normalization and weighting are conducted. The normalization and weighting aim to take the most critical impact parameters, total cost, and service level, into account thus resulting in the best inventory policy after considering both parameters. Figure 5.3 is the illustration of inventory policy comparison between the existing condition, FOI, (s, S), and (s, S) scenario six as the sample. The depiction of scenario six is to show that there is an impact on total cost and service level when the inventory parameters are changed.

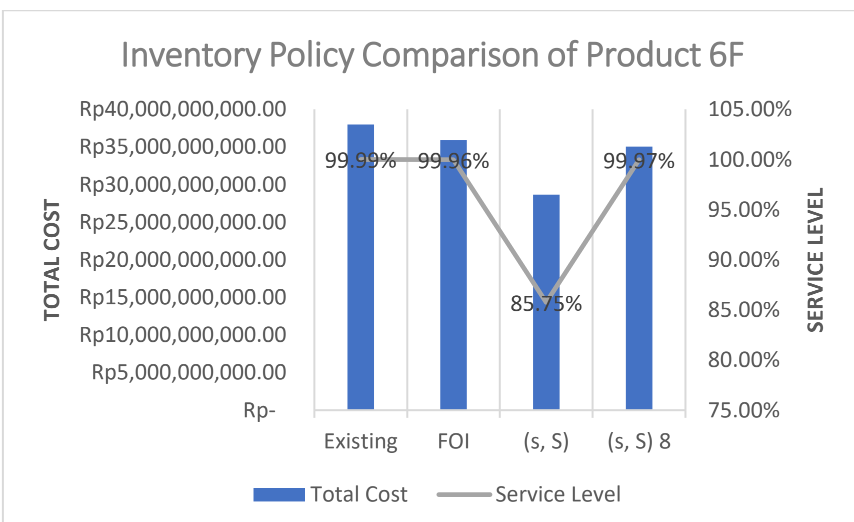

Figure 5.3 Inventory Policy Comparison of Product 6F

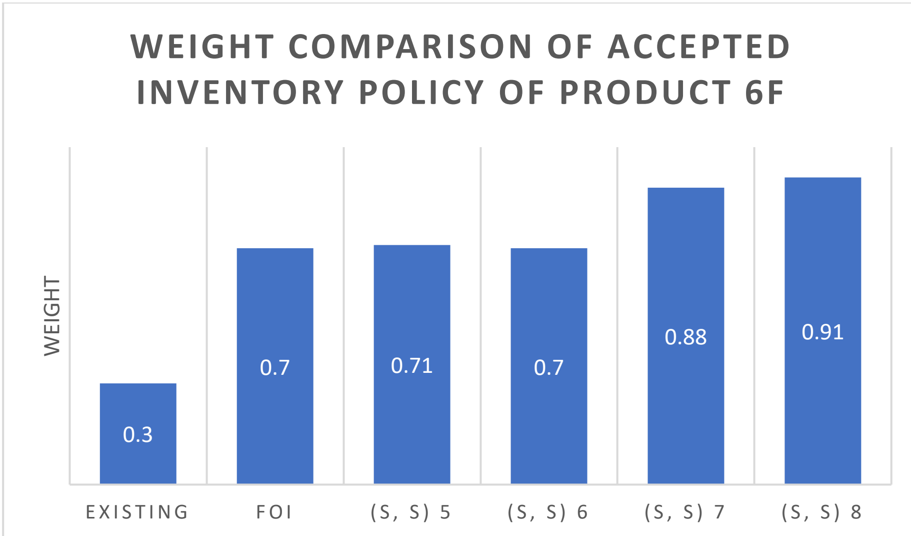

Figure 5.4 Weight Comparison of Product 6F

Figure 5.4 above is the visualization of scenario testing of product 6F where the full result can be seen in table 4.38. While figure 5.3 only represents the total cost and service level sample, figure 5.4 represents the final result of the process which consists of the value of total weight in each of the inventory policies. However, figure 5.4 represents only for inventory policies which service level is above 99.5% because the other else does not meet the service level minimum requirement. The methodology of finding the total weight can be seen in the formula 4.30 – 4.32. After doing the calculation, the best inventory policy among the list available for product 6F is into the inventory policy of continuous review (s, S) scenario 8. This is due to the highest result of weighting (0.91) compare to other possible inventory policies after taking the total cost and service level into account. The chosen inventory policy for this product is the inventory policy with the minimum value of 45 DOI and the maximum value in 80 DOI which results in the total cost of 35,049,706,000 rupiahs and 99.97 service level. The process of doing inventory policy selection is conducted similarly in each of the products to find the best possible inventory policy from the available given options. The best inventory policy in this research is under the assumption of local optimum, as the methodology carried out to select the inventory policy is based on a simulation, not an optimization.

Table 5.1 Recapitulation of Total Cost Performance

CODE	Chosen Policy	Total Cost Existing		Total Cost Improvement		Savings	
1A	(s, S) 10	Rp	75,687,122,000	Rp	65,714,364,000	Rp	9,972,758,000
2B	FOI	Rp	25,106,421,491	Rp	21,670,784,000	Rp	3,435,637,491
3C	(s, S) 7	Rp	9,638,811,060	Rp	8,302,011,800	Rp	1,336,799,260
4D	(s, S) 7	Rp	41,002,165,584	Rp	37,486,502,000	Rp	3,515,663,584
5E	(s, S) 9	Rp	59,758,201,688	Rp	57,255,304,000	Rp	2,502,897,688
6F	(s, S) 8	Rp	37,974,918,706	Rp	35,049,706,000	Rp	2,925,212,706
7G	(s, S) 7	Rp	121,773,502,164	Rp	116,068,580,000	Rp	5,704,922,164
8H	(s, S) 9	Rp	60,665,107,437	Rp	55,789,967,500	Rp	4,875,139,937
9I	FOI	Rp	6,448,881,723	Rp	5,806,945,400	Rp	641,936,323
10J	(s, S) 6	Rp	2,363,052,735	Rp	2,100,236,000	Rp	262,816,735
11K	(s, S) 5	Rp	536,865,215	Rp	537,755,300	Rp	-
12L	(s, S) 6	Rp	2,529,246,451	Rp	2,285,379,400	Rp	243,867,051
13M	FOI	Rp	2,191,814,179	Rp	1,882,746,200	Rp	309,067,979
14N	(s, S) 7	Rp	761,780,524	Rp	660,601,940	Rp	101,178,584
15O	(s, S) 2	Rp	1,986,335,528	Rp	1,634,686,400	Rp	351,649,128
16P	(s, S) 6	Rp	3,913,718,801	Rp	3,091,795,000	Rp	821,923,801
17Q	(s, S) 8	Rp	5,466,290,144	Rp	5,280,619,200	Rp	185,670,944
18R	(s, S) 3	Rp	4,566,233,605	Rp	3,255,701,667	Rp	1,310,531,938
19S	(s, S) 6	Rp	1,345,797,753	Rp	1,160,455,400	Rp	185,342,353
20T	(s, S) 3	Rp	813,127,333	Rp	662,020,180	Rp	151,107,153
21V	FOI	Rp	4,808,110,840	Rp	4,476,931,200	Rp	331,179,640
22W	Existing	Rp	1,456,381,768	Rp	1,456,381,768	Rp	-
23X	(s, S) 10	Rp	411,037,879	Rp	366,721,680	Rp	44,316,199
24Y	(s, S) 8	Rp	4,111,080,686	Rp	4,113,896,200	Rp	-
25Z	Existing	Rp	1,171,105,445	Rp	1,171,105,445	Rp	-
26A	(s, S) 5	Rp	3,127,155,290	Rp	2,503,640,166	Rp	623,515,124
27B	(s, S) 5	Rp	880,087,514	Rp	611,277,340	Rp	268,810,174
Cost Savings						**Rp**	**40,101,943,956**

According to table 5.1 above, the total cost savings after implementing the proposed inventory policy is around 40 billion rupiahs. The achievement of this cost savings is under the scenario where all products are successfully achieving the service level target, above 99.5%. After conducting the simulation, all products have a service level above the target with an average of 99.78%. Therefore, the inventory cost savings is acceptable as it can reduce the total cost while still maintaining a proper service level. Ultimately, 21 products should follow continuous review (s, S), 4 products should follow FOI, and 2 products should hold the existing inventory policy as it has been optimal.

5.5 Sensitivity Analysis of Improved Inventory Policy

Sensitivity testing is conducted to see the impact of changes of uncertain variables, which in this case are demand and lead time, to the observed inventory parameters which are total cost and service level.

5.5.1 Demand Sensitivity Analysis

Firstly, the uncertain variable to be tested is demand. The demand sensitivity is conducted by modifying its value to 25%, 50%, 125%, 150%, 175%, 200%, 250%, 300% relative to the initial condition. Below is the illustration of demand changes to the cost.

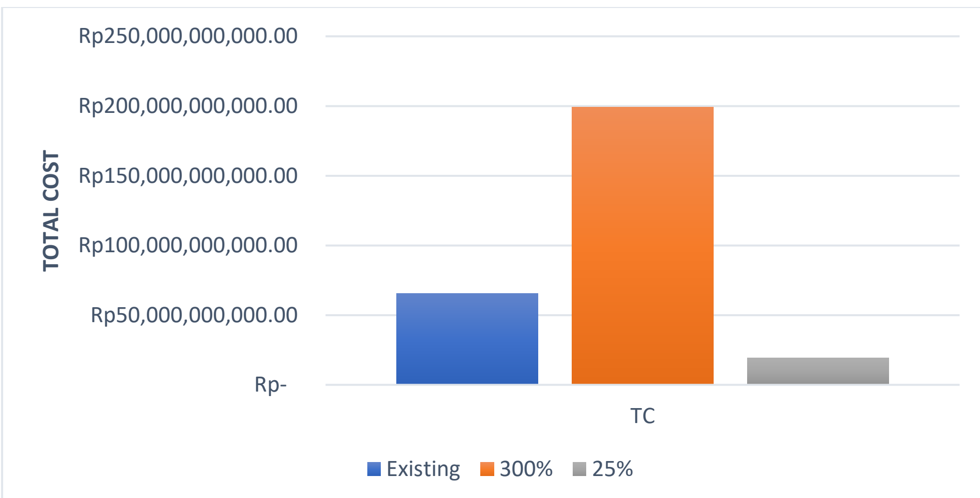

Figure 5.5 Demand Changes Effect to Cost of Product 1A

According to figure 5.4, the higher the demand change, the higher the total cost will be, and vice versa. As depicted in the figure above the total cost rise from around 64 million rupiahs to 199 million rupiah – approximately three times higher of cost escalation. This is indeed due to the requirement to buy more materials in response to the growing demand. This condition of total cost change applies uniformly to all the products which mean that if any product experiences demand increase, the total cost will also be increasing and so does the opposite.

Asides from the total cost, demand changes will also be impacting the service level and average inventory. The illustration of this statement is depicted in the figure below.

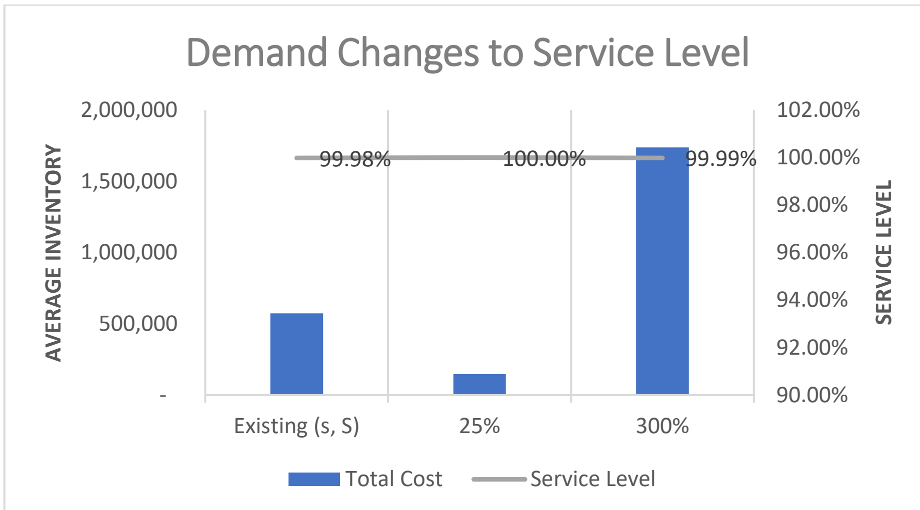

Figure 5.6 Effect of Demand Changes to Service Level of Product 1A

According to figure 5.6 above, there is no significant effect between the demand difference and the service level. It means that regardless of the demand change, the inventory policy can still perform in achieving the targeted service level. This is due to a mechanism to order is depending on the Days of Inventory (DOI) of the product. However, the demand changes affect the average inventory as when the demand increases, the average inventory also increases. To give clearer depiction, below is the formula of Days of Inventory and its relation to ordering quantity.

$$Ordering\ Quantity\ = \frac{(S - DOI)}{30} \times\ Monthly\ Demand_n \tag{5.1}$$

According to the above formula, the ordering quantity is not fixed. When the monthly demand decreases, the ordering quantity decreases and vice versa. Therefore, regardless of the demand changes, the inventory policy suggests an ordering quantity relative to the needs of present business, thus performing more robust inventory policy.

5.5.2 Lead Time Sensitivity Analysis

In the lead time sensitivity, two aspects are observed to see how the effect of lead time change to the total cost and service level. There are seven conditions to be tested, which are the initial condition and the change with the percentage of 25%, 50%, 125%, 150%, 175%, 200% relative to the initial condition.

Firstly, the result of lead time changes has no significant effect on the total cost as can be seen in figure 4.25. This is happening because there is no significant trigger for additional purchases or buying more materials as it is only under the factors of delay in receiving the materials. In this case, the demand still can be served with the buffer when the lead time is longer than the initial state. This phenomenon is happening in all the products; thus, the synthesis is undeniably valid.

Secondly, the effect of lead time on the service level is also observed. In this case, there is a negative relationship between the lead time increase and the service level. When the lead time increases, the service level decreases – can be seen in figure 4.26. The reason behind this is due to the longer arrival of ordered materials which create a delay to satisfy the customer needs. However, after doing the simulation, the demand escalation up to 200% relative to the initial state, the service level of the company still above 90% in all products. In this case, when the suppliers inform the firm that they have an issue on their production, the lead time up to two times compared to the initial state will be reducing the service level to around 90% in average.

Comparing to the condition of demand changes, the lead time changes does not give significant pressure to aware for the firm, as there is no significant effect to the total cost and the effect to the service level is still, somehow, relatively acceptable under the very worst circumstances as the service level is all above 90%. However, as the company has a target to maintain 99.5% service level as the minimum – KPI of the Supply Chain division, having a good supplier relationship is always the key in order to transparently monitor their performance throughout the year thus reducing the likelihood of bad circumstances.

5.6 Analysis of Seasonality Identification

In this section, the impact of seasonality identification will be explained. Unlike the other usual method in creating generalized inventory policy throughout the year, this paper also focuses on seasonality identification to produce more accurate and better inventory control. The reason behind this is due to the existence of demand pattern uniqueness throughout the year, meaning that some months could have different data pattern compare to the other months. To accommodate this phenomenon, Fourier transformation is conducted to measure the existence of seasonality throughout the year. The reasons of seasonality could be due to various reasons, including special days such as Muslim special days Eid al- Fitr, summer reasoning, and others.

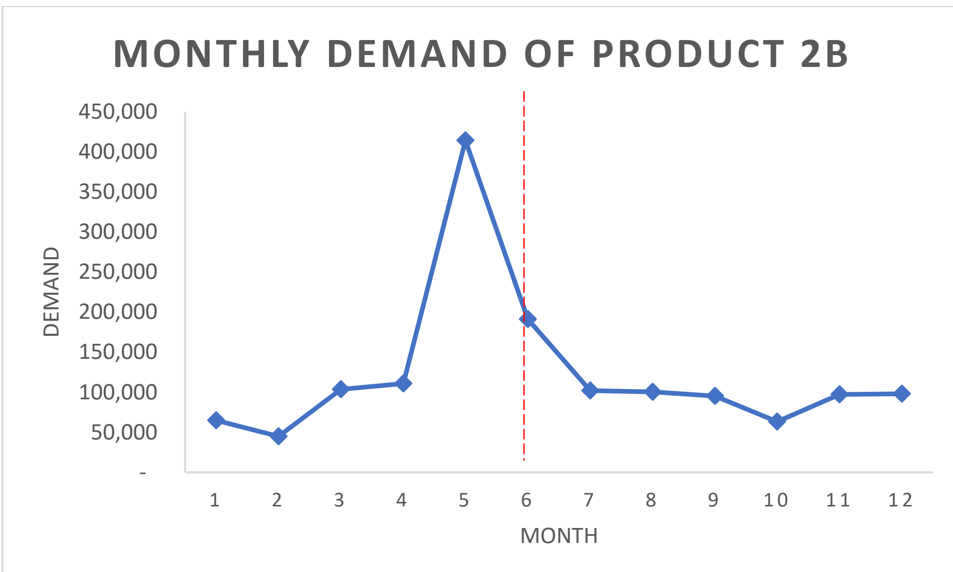

Figure 5.7 Monthly Demand of Sample with Two Seasonal Difference

As a sample of analysis, product 2B with two seasonal difference in a year is chosen with the demand pattern shown in figure 5.7. Visually, this seasonality cannot easily be detected therefore the software helps to capture the seasonality more accurately. But, according to the result of Fourier transformation using R software using two years historical data, the seasonality is repeated every six months, which means that the demand between Jan-2019 to Jun-2019 formed one seasonality and Jul-2019 to Dec-19 formed another seasonality.

Table 5.2 Seasonality Impact Assessment of Product 2B

Scenario	Min T1	Min T1	Max T1	Max T2	TC	SL	Weight
FOI	**52.6**	**103.4**	**29.9**	**79.4**	**Rp 21,680,784,000.00**	**99.80%**	**0.87**
FOI 1	52.6	103.4	52.6	103.4	Rp 21,432,370,864.00	96.35%	-
FOI 2	29.9	79.4	29.9	79.4	Rp 26,705,911,106.00	100%	0.3

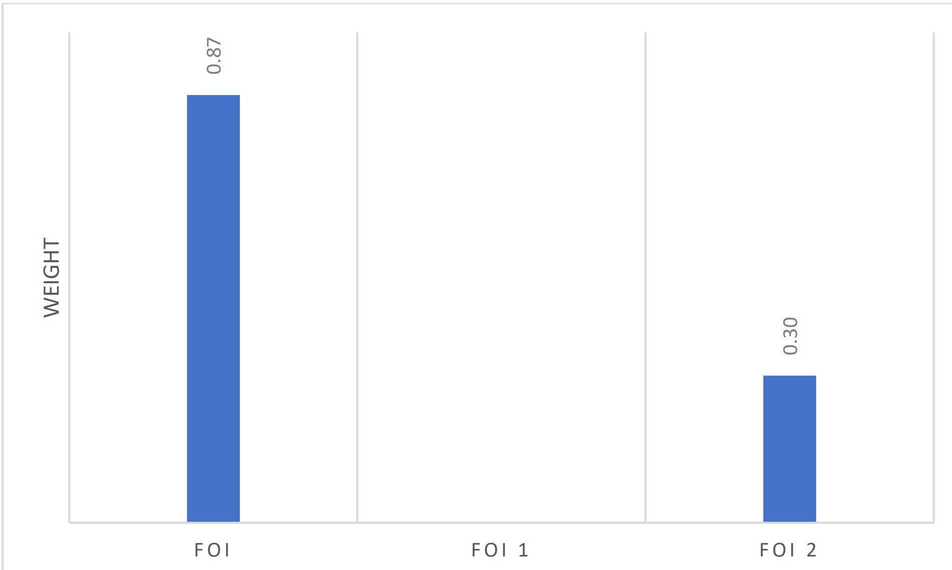

Figure 5.8 Weight Result of Product 2B for Seasonality Assessment

Table 5.2 is the recapitulation of scenario testing to measure the impact of seasonality identification. Across all seasonality that has been built earlier, the existing FOI, FOI 1, and FOI 2 are the best scenario to measure the impact of seasonality identification. While FOI 1 and FOI 2 implements generalized inventory policy throughout the year, the actual FOI implements a unique inventory policy as the value of minimum inventory in T1 (52.6) is different with T2 (29.9) as well as the difference in ordering quantity and producing the highest weight as can be seen in figure 5.8. This can be happening due to a significantly higher average demand and standard deviation in season one due to Eid al-Fitr happening in June 2019, resulting in a higher minimum inventory level or reorder point, and ordering quantity. This phenomenon is not only happening on product 2B per se, as all the product with seasonality requires unique or different inventory policy throughout the year to produce the best result.

CHAPTER 6
CONCLUSIONS AND SUGGESTIONS

This chapter provides the conclusion and recommendation for future research.

6.1 Conclusion

Several conclusions can be derived from this research are as follows.

1. The development of the material requirement planning system comprises four mains sections, namely master data, bill of material, demand management, and planning & monitoring. The system development is documented in software requirement specifications which will be given to the software developer for execution purposes. Besides that, the development of the Excel model MRP system is also executed as a prototype as well as acting better tools to improve the existing system.
2. There are three possible inventory policy alternatives, namely the continuous review (s, S), Fixed-Order-Interval (FOI), and the existing inventory policy. Several parameters used during the calculation including, but not limited to, Safety Stock (SS), minimum inventory or reorder level (s), maximum inventory level (S), and ordering quantity (Q) – all mentioned in the formula 2.2 – 2.8.
3. To gain the objective of total cost minimization while still maintaining the targeted service level, implementation of 21 continuous review (s, S), 4 Fixed-Order-Interval (FOI), and maintaining 2 existing inventory policy across 27 observed finished goods should be carried out. By implementing this, the firm can reduce the total cost up to around 40 billion IDR while still maintaining the service level above the target.
4. The seasonality identification brings an impact on the performance of inventory policy compared to using generalized yearly inventory policy for the products which have seasonality during the year – resulting in a higher total weight score under the scenario analysis.

5. Uncertain variables changes might affect the performance of inventory policy. In demand sensitivity, an increase in demand will increase the total cost but does not affect the service level due to the DOI system that the inventory policy has. In lead time sensitivity, an increase in lead time will result in a decrease in service level but has no significant effect on the total cost. The contrary effect also applies which means a decrease in demand will also result in a decrease in total cost.

6.2 Suggestion

Several suggestions for future research are mentioned as follows.

1. The improvement of inventory policy should consider warehouse capacity, shipment capacity, and the occurrence of manual rounding and adjustments.
2. The improvement of inventory policy should also consider promotional events that might affect the quantity to be ordered by the firm.
3. A study to assess suppliers' reliability on product quality and lead time is necessary to measure the risk associated with the replenishment scheme.

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AUTHOR'S PROFILE

Muhammad Afif Purwandi is an undergraduate student majoring in Industrial and Systems Engineering at ITS. During his college years, he has successfully championed many breakthrough-based competitions and MUN including, but not limited to, Think Efficiency by Shell and Asia Pacific Model United Nations Conference in Australia. Due to his notable achievements, he was awarded as **The Most Outstanding Student of ITS**, **Young Leaders for Indonesia by McKinsey & Company** Wave 11, and **Indonesia's 3rd Most Outstanding Student** by The Ministry of Research, Technology, and Higher Education in 2019.

His previous professional experience as a Supply Chain Intern at one of the largest bottled water company in Indonesia has equipped him with strong knowledge in Supply Chain. He worked on an inventory policy excellence project which is projected to save ~40 billion IDR annually while also preparing procurement digitalization initiative – reported directly to the country's Supply Chain Director and PPIC Manager. Besides that, he had a downstream operation experience too during his internship at DHL Supply Chain. He worked under the plant's Senior Manager to develop green warehousing initiatives with ~120 million IDR projected yearly cost savings while preserving the environment.

Besides his genuine interest in operations, he is also interested in business and strategy. He believes that having a complete package of both business and operations acumen would equip him with a strong capability to solve any complex problem. He was the Project Consultant of Gojek, assisted directly by McKinsey consultants. He advised Gojek's VP of Marketing and her team to develop a go-to-market strategy for their new product. Through this experience, he has developed his ability to digest potential merchants' problems and translate them into business opportunities. He can be contacted through email afifpurwandi@gmail.com or through his LinkedIn at https://www.linkedin.com/in/afifpurwandi/.