.

FINAL PROJECT – TI 184833

ANALYSIS OF SPARE PART INVENTORY POLICY TO MACHINES AVAILABILITY AND THROUGHPUT USING DISCRETE EVENT SIMULATION APPROACH (CASE STUDY: PT STEEL PIPE INDUSTRY OF INDONESIA)

AHMED RAECKY BAIHAQY
NRP 02411540000009

SUPERVISOR
Nurhadi Siswanto, S.T., MSIE., Ph.D
NIP. 197005231996011001

CO SUPERVISOR
Effi Latiffianti, S.T., M. Sc.
NIP. 198304012014042001

DEPARTMENT OF INDUSTRIAL ENGINEERING
Faculty of Industrial Technology
Institut Teknologi Sepuluh Nopember
Surabaya 2019

APPROVAL SHEET

ANALYSIS OF SPARE PART INVENTORY POLICY TO MACHINES AVAILABILITY AND THROUGHPUT USING DISCRETE EVENT SIMULATION APPROACH (CASE STUDY: PT STEEL PIPE INDUSTRY OF INDONESIA)

FINAL PROJECT

Submitted as a Requisite to Achieve a Bachelor Degree from
Department of Industrial Engineering
Faculty of Industrial Technology
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia

Author
AHMED RAECKY BAIHAQY
NRP 02411540000009

Approved by:

Supervisor	Co-Supervisor
Nurhadi Siswanto, S.T., MSIE., Ph.D	**Effi Latiffianti, S.T., M.Sc.**
NIP. 197005231996011001	NIP. 198304012014042001

KEMENTERIAN RISET, TEKNOLOGI, DAN PENDIDIKAN TINGGI
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
FAKULTAS TEKNOLOGI INDUSTRI
DEPARTEMEN TEKNIK INDUSTRI

SURABAYA, JANUARY 2019

ANALYSIS OF SPARE PART INVENTORY POLICY TO MACHINES AVAILABILITY AND THROUGHPUT USING DISCRETE EVENT SIMULATION APPROACH (CASE STUDY: PT STEEL PIPE INDUSTRY OF INDONESIA)

Name	: Ahmed Raecky Baihaqy
NRP	: 02411540000009
Supervisor	: Nurhadi Siswanto, S.T., MSIE., Ph. D
Co-Supervisor	: Effi Latiffianti, S.T., M. Sc.

ABSTRACT

PT Steel Pipe Industry of Indonesia Tbk is the biggest steel pipe manufacturer in Indonesia. The production is supported by 6 units spread all over Indonesia. One of the units is Factory Unit 1 situated in SIER, Surabaya. PT Spindo Factory Unit 1 has capacity of 6,250 MTPY and this unit has 5 production lines. Currently, PT Spindo Unit 1 has problem in term of availability of its production line causing the throughput is not maximum. This will make the service level toward customer is declining. Turns out that one of the factors causing the declining availability is the availability of spare parts. Some of spare parts are unavailable when it is needed for repairing the failed machine causing the downtime is increasing, thus the availability will be decreasing as the consequences. Therefore, in this research writer tries to observe the effect of changing the spare part inventory policy to the availability and demand fulfillment as the key performance of this system. Currently, spare parts inventory in PT Spindo is *s,S*. The method used in this research is discrete event simulation because this method is able to overcome complexity due to variability as well as dependability within system. Based on the existing condition result based on simulation, it is obtained that the current availability is 0.9268 and 90.06% demand fulfilled. Using experimentation, obtained that the significant yet cost-efficient scenario is using *s,Q* policy where the both availability and percentage demand fulfillment are increasing whose values are 0.9370 and 91.61% respectively.

Keyword*: availability, demand fulfillment, spare parts, inventory policy, discrete event simulation*

(This page is intentionally left blank)

ACKNOWLEDGEMENT

All gratitude towards Almighty Allah for all the blessings and gifts so that the writer can complete final project with title of "Analysis of Spare Part Inventory Policy to Machines Availability and Throughput Using Discrete Event Simulation Approach (Case Study: PT Steel Pipe Industry of Indonesia)" well. The final project is one of the requirements to complete the final project and it is also the requirement to obtain the bachelor degree at Industrial Engineering Department, Institut Teknologi Sepuluh Nopember. During the accomplishment of this final project, writer wants to thank every parties who already helped, assisted, and supported the writer so that writer is able to complete this very well. All thanks are delivered to:

1. Nurhadi Siswanto, S.T., MSIE, Ph.D. as the head of Industrial Engineering Department as well as the supervisor and Effi Latiffianti, S.T., M.Sc. as co-supervisor of writer's final project for the assistances and advices during the completion of final project.
2. Mr. Mukhyidin as the vice head of Department of Technical and mentor from PT Steel Pipe Industry of Indonesia Unit 1 for the advice and guidance during final project completion and giving the writer the opportunity to do the research and internship as well.
3. Mr. Agung Prabowo and Mr. Heri Wasiyanto for all generosity and willingness to provide the data, guide the writer, as well as supporting writer during final project completion. Not forgetting Mr. Andy Praseno, Mr. Budi, and Mr. Feri for supporting writer in doing internship in PT Steel Pipe Industry of Indonesia Unit 1.
4. Prof. Ir. Budisantoso Wirjodirdjo, M.Eng. and Diesta Iva Maftuhah, S.T., M.T. as the reviewer in both final project proposal seminar and final defense for the corrections, advices, and suggestions to make this research becomes better in completion.
5. Yudha Andrian Saputra, S.T., MBA as the secretary of Industrial Engineering Department for the help and guidance.

6. Drs. Ec. Heristanto and Lilik Yuliastuti, S.E. as the beloved parents for the countless support and prayers for writer's success as well as Chintya Miranti Verdiana as the sister and Muhammad Sandy Irwansyah as the brother in-law for the support.
7. Industrial Engineering student fellow intake 2015, ICARUS, for all the great support during the college time and this final year. Hopefully you guys can do the great job also in finishing your final project later.
8. Der Administrator 2015 and 2016, the laboratory assistant of QMIPA Laboratory, for all supports, prayer, and helps during writer's completion on final project proposal. Thanks for all support and prayer during the completion of this final project
9. TA Squad 119, who is supporting each other to finish and complete the final project so that we can graduate in the same time very soon.
10. And other parties whom writer cannot mention all but very meaningful for writer.

By the completion of this final project, writer hopes that this will be helpful and beneficial for other parties who are going to conduct the similar research on reliability simulation and especially for PT Steel Pipe Industry of Indonesia Factory Unit 1 in decreasing the probability of low availability of machines so that able to increase its production throughput.

Surabaya, January 2019

Writer

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

In this chapter, the writer is going to explain about the problem background, problem formulation, objectives, benefits, limitation, assumption, and writing structure of this research.

1.1 Background of Problem

Currently, Indonesia is in the phase to develop its industries for the sake of realizing the national industry as the pillar and motor of national economics. This statement is explicitly written in *Rencana Induk Pembangunan Industri Nasional* (RIPIN) year 2015 – 2035. In its arrangement, RIPIN should consider some aspects which should be correlated and synergized to national industries development. Within RIPIN, there are 10 mainstay industry groups and one of them may include basic metal industry. The main commodities include in basic metal industry category consist of iron ore pellet, iron alloy, special-purpose steel, etc. The figure below shows ten groups of industry with the greatest export values in Indonesia for 2016.

Figure 1. 1 Ten Industry Groups with the Greatest Export Value in Indonesia year 2016 (www.kemenperin.go.id)

From figure above, it can be known that basic metal industry ranks in number three among the top ten in term of export value of industry in Indonesia. This thing is able to bring illustration that actually basic metal industry is one of the potential industrial groups in order to improve Indonesia's economic growth and support RIPIN realization. Besides export, there is also import value for these groups of industry shown by figure below.

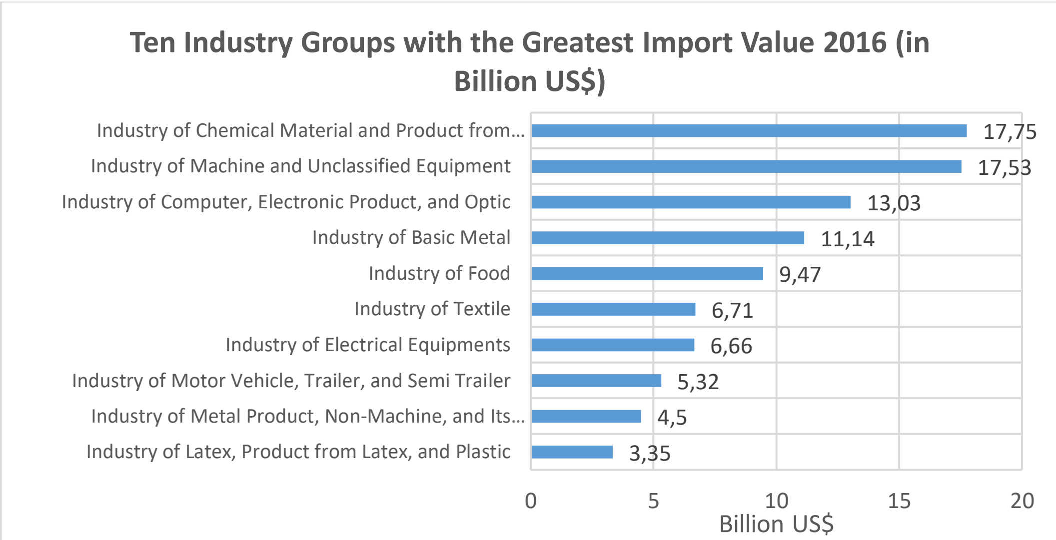

Figure 1. 2 Ten Industry Groups with the Greatest Import Value in Indonesia year 2016 (www.kemenperin.go.id)

Based on Figure 1.2 above, it can be comprehended that actually, in term of import value, for basic metal industry is still relatively high and ranks in number four in term of import value. From this fact, it can be somewhat concluded that Indonesia is still unable to fulfil the local demand for metal. The basic metal industry itself consists of a lot of commodities or products such as iron, steel, aluminum, zinc, nickel, and many more. The main and biggest commodity for this type of industry is iron and steel. The figure below shows the export and import value for both iron and steel in Indonesia during 2012 to 2016.

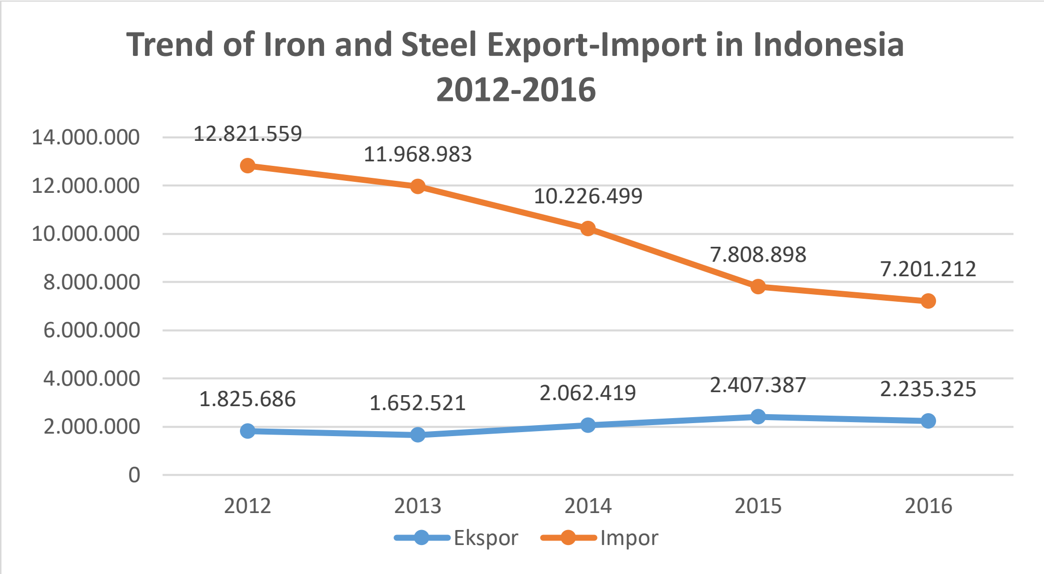

Figure 1. 3 Trend of Iron and Steel Export-Import in Indonesia 2012-2016 (www.kemenperin.go.id)

From Figure 1.3 above, it can be known the trend of both export and import for iron and steel commodities in Indonesia during 2012 to 2016 shown in thousand US$. According to figure above, it can be known that actually export rate for iron and steel is relatively lower compared to the import rate. However, the export value of iron and steel is somehow promising since there is positive trend of 8.12%. Still from the same figure, it can be known also that the import rate for iron and steel is higher than the export rate. But there is a negative trend for import of iron and steel which is 14.62%. This number is quite satisfying since Indonesia is in attempt to reduce the import rate for iron and steel for the sake of RIPIN 2016-2035 realization where Indonesia's industries is expected to be able to be independent and well-developed industries.

One of the remarkable companies in Indonesia that focuses in iron and steel manufacturing is PT Steel Pipe Industry of Indonesia Tbk (PT Spindo). PT Spindo is a company which manufactures various steel pipe or tube and other related products. PT Spindo was established in 1971 and operates seven factory units which spread all over Indonesia. One of PT Spindo factory unit is Unit I which is situated in Rungkut Industri I, Surabaya Industrial Estate Rungkut

(SIER), Surabaya. The main products of Unit I include straight welded steel pipe and other general steel products.

Production line in PT Spindo runs continuously for 24 hours per day and 7 days a week. By this running continuously production line, it is expected that PT Spindo is able to contribute in domestic demand fulfillment of iron and steel commodities. Moreover, it is supported by previous fact that in its operations, PT Spindo is supported by seven factory units to produce the throughput.

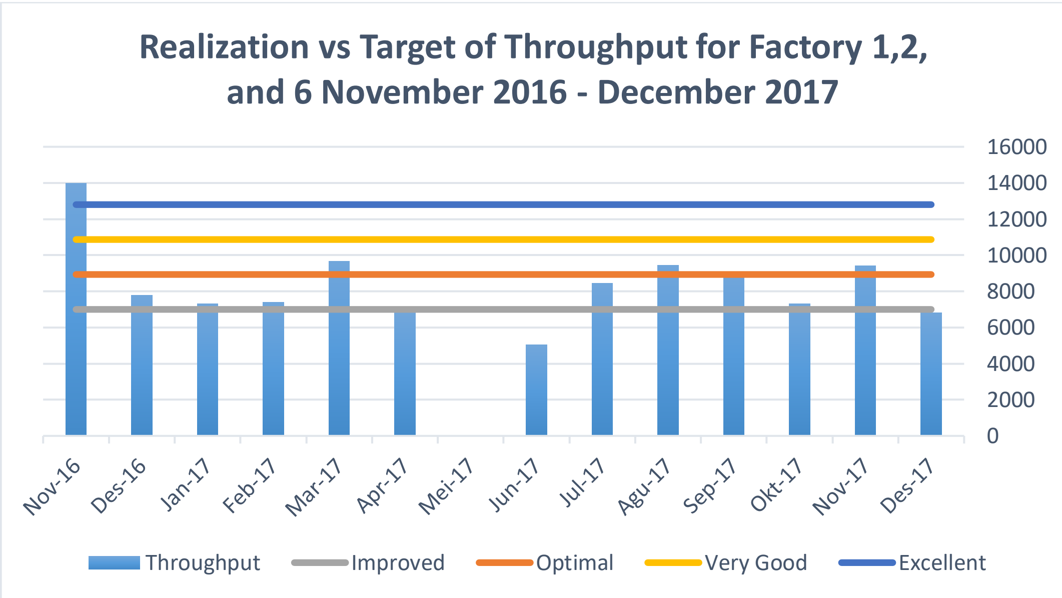

Figure 1. 4 Throughput KPI for Factory 1,2, and 6 November 2016 - December 2017 (PT. Spindo, 2018)

From Figure 1.4 above, it can be obtained the information of throughput of Factory 1,2, and 6 to the key performance indicator for throughput categorized into improved (above 7.000 tons), optimal (above 8.933 tons), very good (above 10.867 tons), and excellent (above 12.800 tons). It can be known that there was only one period where KPI achieved excellent rate (November 2016). Meanwhile almost rest of period fail to achieve optimal level for throughput KPI though in fact there were only three periods where optimal level is achieved.

By the fact that production line in PT Spindo which runs continuously, therefore it is expected that every machine within that production line has high availability rate. Availability is related to the uptime duration of a machine during operation and is a measurement of how frequent and how long a system or machine operates as it is and in a good condition (Barringer and Hotel, 1997). In industries which runs their production line continuously, availability is the most important and critical aspect moreover if the production aims to fulfil the market and customer demands.

The existence of failure in a system or machine is able to obstruct the production process, so it is probable that production target is failed to achieve. Therefore, the market demand will not be fulfilled as well which will have impact on decreasing service level of PT Spindo. Service level in an inventory control system is a probability where stock out does not happen when the demand arrives (Waters, 2003). Talking about the failure, it will relate to the downtime during production. Figure 1.5 below shows the downtime percentage during percentage over several periods. Please keep in mind that downtime percentage is defined as the downtime divided by total production time.

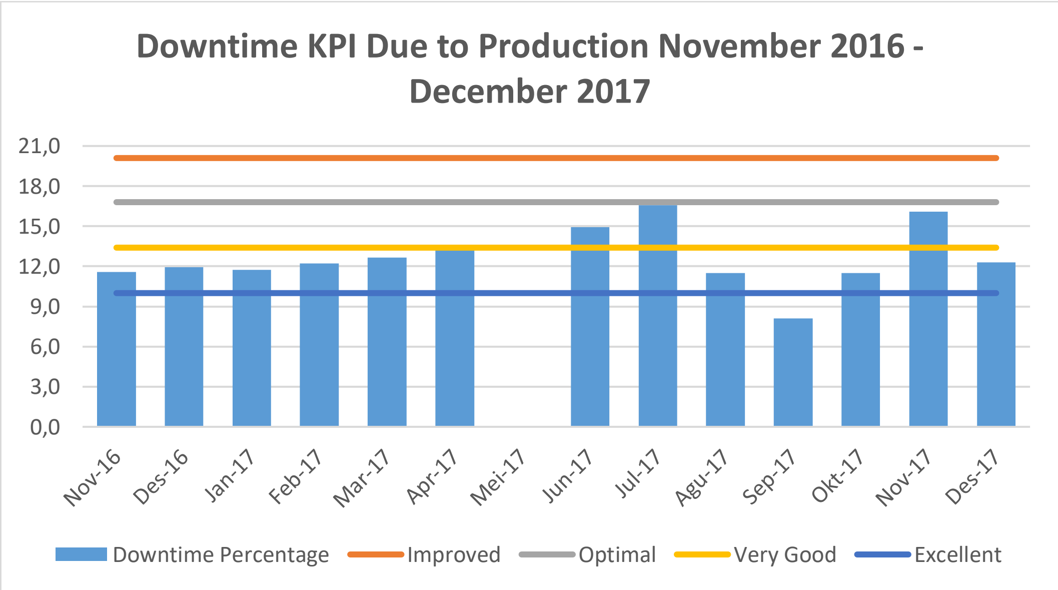

Figure 1. 5 Downtime KPI for Factory 1,2, and 6 November 2016 - December 2017 (PT. Spindo, 2018)

From Figure 1.5 above, it can be seen the comparison between the downtime to its KPI. The KPI is still divided into the same category which are improved (under

20%), optimal (under 16,8%), very good (under 13,4%), and excellent (under 10%). From figure above, it can be known that not all periods for downtime percentage are able to achieve KPI level of very good. And it can be seen that there is only one period which achieve excellent level where the downtime percentage is under 10% which is on September 2017. The downtime is indeed caused by the failure during the production process.

There are 5 functional production line at PT Spindo especially on Factory Unit 1. Each line has its own specification as well as the machines utilized and operated within that line. Actually, all production lines (milling) have similar process to mill the pipe but the machines may be different. R1 is one of the important production lines amongst them and it also has probability to fail for each machine within the line. The figure below shows the downtime of R1 for each machine as the downtime causes.

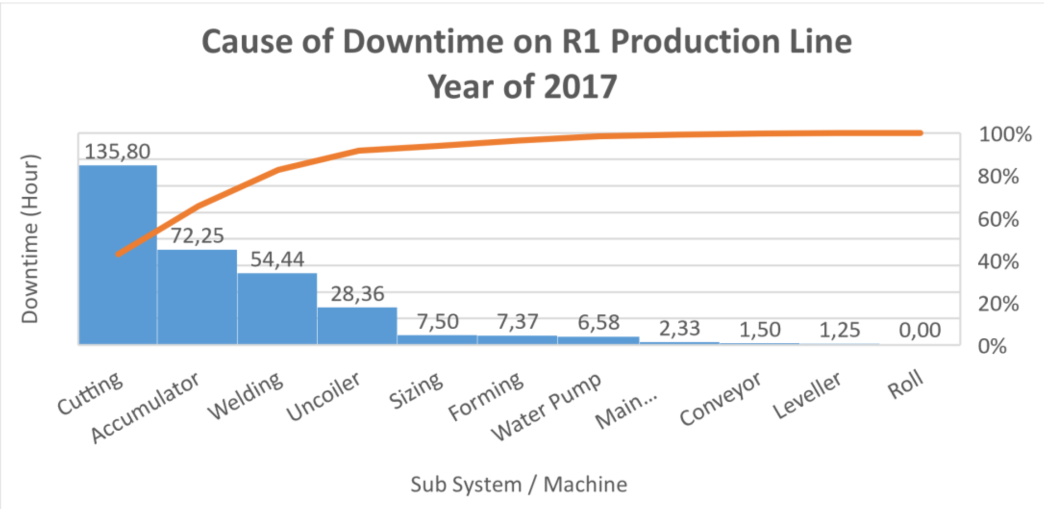

Figure 1. 6 Downtime Causes of R1 Production Line Year 2017 (PT Spindo, 2018)

From figure above, it can be obviously tracked that the cutting machine/sub system has the biggest portion in contributing the downtime on R1 followed by accumulator as well as the welding machine. Therefore, these subsystems should be checked regularly to ensure that the machine still work properly as it is expected.

In order to maintain the availability rate of a system and avoid the failure occurrence, the maintenance action is required. However, the failure occurrence is probabilistic or uncertain. It means, every machine as probability to fail in certain period of time. And if there is failure, the action can be in the form of spare part replacement. From this explanation it can be known that the maintenance frequency (which also related to how frequent the failure occurs) is closely related to the spare part inventory rate. Availability of spare part is expected to be high so that the machine can be repaired without waiting to procure the spare part.

The availability of spare part is related to the service level of spare part itself. If the spare part service level is high, it means whenever there is failure and a spare part is needed, said spare part is always available and ready to be taken and used. Actually, there is a problem in term of spare part inventory in PT Spindo. Mr. Mukhyidin (2018) as the vice head of Department of Technical said that there are two types of spare part inventory. The first one is consumable spare part which is provided by Department of Spare Part Storage (PBS) and repairable spare part made by maintenance workshop division by refurbishing the defect spare part due to failure. The problem is the consumable spare part is sometimes unavailable when it is needed for repair causing the downtime becomes longer

It is very urgent to repair the machine in a very short time due to the fact that production target should be achieved and since the production line is run continuously. If the failed machine is neglected, it will disturb the whole production process causing delay in production. Therefore, the solution to this problem is fixing the machine with whatever possible method. This is literally very unsafe both to the machine and the workers. The way they repair the machine is not following the standardized procedure, may cause the machine lifetime is decreasing as well.

From the fact elaborated above, it can be known that spare part inventory availability is critical in supporting the production process. The spare part itself is expected to be always available in case there is breakdown or failure. However, it is very difficult to predict when machine will fail accurately. Besides, maintenance action is various as well considering the policy and the period of execution which form a lot of combination. This will also consider the policy of spare part procurement, replenishment, and inventory control. There is relationship where the maintenance action is aimed to reduce the probability of a machine to fail. And if the spare part should be available in a huge amount, it will also have impact on the procurement cost as well as inventory cost which in advance will be great. Besides of that, both availability and spare part inventory is probabilistic or uncertain. One of methods which is suitable to accommodate uncertainty and interdependence as well as complexity is discrete event simulation. Benefits of using discrete event simulation which are flexibility in changing the system without interrupting the real one, instantly obtain the result, and able to overcome complexity due to interdependency and variability.

By this research, the writer is going to solve the problem of machine maintenance related to spare part inventory in Factory Unit I PT Spindo using discrete event simulation methods. This research is done by intention of increasing the availability of R1 production line compared to current availability as well as increasing production throughput so that the service level toward customer is kept high. This is done by changing the inventory spare parts parameter as well as trying to change spare part inventory policy by considering the annual inventory cost incurred to increase both availability and throughput.

1.2 Problem Formulation

Based on the background explained on sub chapter 1.1, so the problems which will be discussed in this research are as follow.

1. Doing analysis and evaluation on current reliability of system and subsystem in production line R1
2. Finding the best replenishment and inventory scenario and policy for spare part inventory so that the machine reliability can be maintained high.

1.3 Objectives

The objectives of this research that are going to achieve are as follow.

1. Analyzing and evaluating existing condition in term of current availability and current production throughput.
2. Predicting reliability and production throughput of PT Spindo on both existing and recommended improvement condition
3. Arranging and recommending the better spare part inventory level policy to keep the reliability of machine to be high.

1.4 Benefits

The benefits which can be obtained from this research are as follow.

1. As a basis of improvement of production process in term of increasing the throughput manufacturing
2. As a basis of improvement regarding the replenishment policy of spare part inventory such as EOQ and safety stock.

1.5 Limitations

The limitations of this research are as follow.

1. Observed object is PT Steel Pipe Industry of Indonesia Unit Factory I in Rungkut, Surabaya.
2. The system observed is production floor system as well as spare part warehouse system.
3. The focus of this research will be only on one production line which producing product of general pipes which is R1 due to the fact that R1 is one of the important lines that having relatively low availability.
4. Data taken for simulation input is only in range of 2 years.
5. The simulation model constructed consists only 3 levels (machines, equipment and components, and equipment's components).
6. The observed components or spare parts are only those which are procured by Department of PBS, not including the spare parts provided by workshop.
7. This research does not consider penalty cost of lost sales resulted from breakdown.

8. There will be no scenario of adding more machine due to high investment cost.
9. The process under observation excludes the post production process such as hydro testing, end facing, threading, and re-cutting.

1.6 Assumptions

Assumptions that will be used in this research are as follow.

1. There is no operational rule change on production system and reliability system during research time span.
2. The spare parts provided from workshop is always available thus can be neglected.
3. Operators to perform activities within production floor are assumed to be always available.
4. The raw material is always available to process.
5. Spare part unit cost is not affected by time value of money.

1.7 Writing Systematics

In this subchapter, will be explained about the research systematics which is going to be used.

CHAPTER 1 INTRODUCTION

This Chapter 1 will consist of the background of conducting the research as well as the formulated problem for this research. It will also be explained about the objectives, benefits, limitations, assumptions, and writing systematics of this research.

CHAPTER 2 LITERATURE REVIEW

In this Chapter 2, will consist of the theory and literature which is used for this research. The theory is going to be used as the basis in solving the problem and as the basic concept used in this research. Besides theory and literature, writer is also utilizing the previous researches as the references as well as comparison study materials, from final project, journal, and paper.

CHAPTER 3 RESEARCH METHODOLOGY

In this Chapter 3 will be explained about the methodology of the research. The methodology will be explained by a research flowchart representing the steps to be through during research as well as the detailed description of said flowchart.

CHAPTER 4 DATA GATHERING AND PROCESSING

In Chapter 4, will consist of the gathered data based on observation during research. Data collected can be in the form of primary or secondary data. All those gathered data will be processed according to the procedure explained in previous chapter.

CHAPTER 5 SIMULATION MODEL DEVELOPMENT

In Chapter 5 will be explained the construction and development of both conceptual and simulation model. These models will be verified and validated to assure the models are already able to represent the real system.

CHAPTER 6 RESULT AND EXPERIMENTATION ANALYSIS

In Chapter 6 will be shown the result of simulation and the experimented model based on proposed scenario. The output will be analyzed on experimented model to pick the best scenario or alternative.

CHAPTER 7 CONCLUSIONS AND SUGGESTIONS

In Chapter 7 will be stated the conclusions obtained from the research and the suggestions for the observation object and further research.

(This page is intentionally left blank)

CHAPTER 2
LITERATURE REVIEW

In this chapter, the writer will discuss and review some literatures that is used as the basis of this research.

2.1 Simulation

According to Schriber (1987), simulation is modelling of a process or system in such way that the model mimics the response of actual system to events that take place over time. Simulation modelling is one of the methods to analyze a complex system by making representation of research system (Altiok et al., 2007). The objectives of doing simulation is various as well starting from system improvement, cost and benefit analysis, sensitivity analysis, and many more. From simulation modelling, it is allowed and possible to do prediction, evaluation, and alternatives analysis without incurring cost and additional times to do alteration and interruption on real system.

2.1.1 Discrete Event Simulation

In general, according to Harrell et al. (2004) the simulation can be classified as follow.

- Static vs Dynamic
- Stochastic vs Deterministic
- Discrete vs Continuous

Discrete event simulation (DES) is a simulation method where that change happens at discrete points of time triggered by events. The examples of DES might include 1) the arrival of entity to a workstation, 2) failure of resource, 3) completion of activity, 4) end of shift, and 5) many more. Oppositely to DES, in continuous simulation the change in variable state is triggered by times so that it is called continuous change state variable. The example of continuous simulation is filling process of soda can or water gallon.

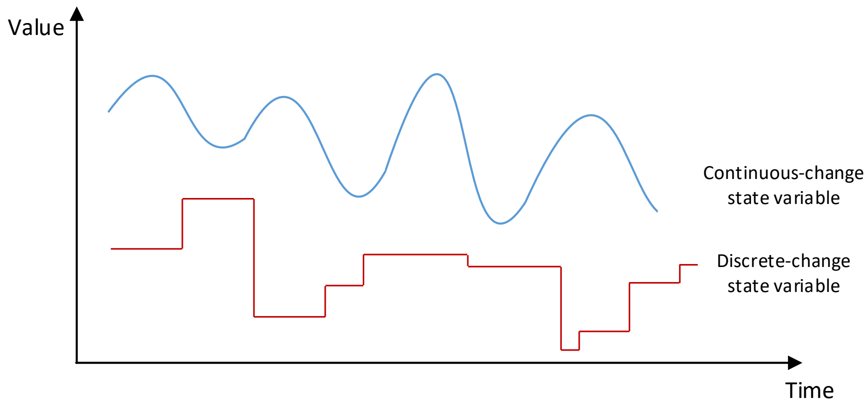

Figure 2. 1 Comparison of DES and Continuous Simulation in State Variable Change (Self processed from Harrell et al.,2004)

2.1.2 Advantage and Disadvantage of Simulation

There are some advantages as well as disadvantages when using simulation which are as follow (Harrell et al., 2004)

2.1.2.1 Advantage of Simulation

The advantages of using simulation might include as follow.

1. **Return of investment**. By doing simulation, decision maker is able to do cost analysis.
2. **Randomness concept**. Simulation is run based on randomness where every event is probable to occur. Random concept is based on data and is expected to reflect the real world.
3. **Anticipation**. By doing simulation, decision makers can avoid the potential risk by having alternative actions.

2.1.2.2 Disadvantage of Simulation

The disadvantages of using simulation might include as follow.

1. When the model is invalid (fail to reflect the real system), thus the simulation output is fail also to represent the policy implemented in real system.

2. Not all system has sufficient historical data. If this happens, it is required to collect the data by direct observation which consumes more time.
3. Since input parameter of simulation is random, simulation is required to be run several times to accommodate this randomness (concept of replication).

2.1.3 Problem Analysis and Information Collecting

Problem analysis is done with intention that the constructed model is able to answer and solve the problem of system. However, the modeler should look for information which is critical and potential to solve the problem. The information might include input parameter, performance measurement, relationship of parameter and variable, system rule, etc. The information then constructed as conceptual model such as logic flow diagram, hierarchy tree, activity flow diagram, and many more.

2.1.4 Data Collecting and Processing

Data collecting is required to estimate model of input parameter. Data can be obtained from interview, questionnaire, direct observation, and secondary data. Below is shown the type of data required in simulation (Harrel et al., 2004).

1. Structural Data

   This data is including object within the modeled system. Structural data consists of element of simulated system, such as entity, resources, and location.
2. Operational Data

   This data explain how system operates. Operational data consists of information regarding to where, when, and how activity or event occurs. Example of such data is route, schedule, downtime, resources allocation.
3. Numerical Data

Numerical data is all quantitative data of a system. Example of numerical data is capacity, arrival rate, activity duration, and time between failures.

Once the expected is obtained, the next step processing the data of input. The data should meet the requirement such as independent (randomness), homogeneity, and stationary (Harrell et al., 2004).

First one is independency test. Data is said independent each other if the value of one observation is not influenced by other value of another observation (Harrell et al., 2004). To perform this test, there are some methods which can be used such as scatter plot, autocorrelation test, and runs test (non-parametric test).

Second is homogeneity test. This kind of test is used to ensure that the data distribution is identical (Harrell et al., 2004). Homogeneity test is done to make sure that the data come from same population. One of way to do such test is by visually inspect the distribution of data to check whether the data has two modes. Data is nonhomogeneous if the distribution is change over time which also can be called nonstationary.

The next step is inputting the data into the model. There are some ways to input the data which are 1) directly input the collected data as the input, 2) fit the data to empirical distribution, and 3) fit the data to it to nature/theoretical distribution as it is recommended.

2.1.5 Model Construction

There are two types of model in simulation. First one is conceptual model e.g. flowchart, logic flow diagram, and activity flow diagram. The second one is simulation model. Such model can be constructed using computer program or simulation-dedicated software. The conceptual model is obtained from observing the real system and represents the system in a “thought” model. Once conceptual model is built, simulation model can be constructed according to conceptual model.

2.1.6 Model Verification

Verification is a process which is intended to ensure whether or not model is already constructed correctly by comparing the simulation model to conceptual model (Harrell et al., 2004). Verification can be performed by logical checking of model. Other methods of verification might include as follow.

- Reviewing model code
- Checking for reasonable output
- Watching and observing animation
- Using trace and debugging features

2.1.7 Model Validation

Besides verification, model is required to be validated. Validation is a process with intention of comparing whether or not model is already proper and representative enough to real system (Harrell et al., 2004). The validation is done by comparing either conceptual model or simulation model to real system. If constructed model is valid already, therefore automatically the performance measurement in the model will be more or less proper to implement in real system. The methods for validation are as follow.

- Watching and observing animation
- Comparing with real system
- Comparing with another model
- Conducting degeneracy and extreme condition test
- Checking for face validity
- Testing against historical data
- Performing sensitivity analysis

2.1.8 Simulation Output Analysis

It is known that the input of simulation is random, thus causing the output is also random and the performance measurement results based on the output is only estimation (not exact result). To overcome the randomness, it is necessary to run the simulation for several times. The number of experimental run or sample for simulation is called *replication* (Harrell et al., 2004). To determine how many n of replications, it is necessary to set the confidence interval to determine absolute error (e) between estimated mean and true mean which are unknown. To find confidence interval in this situation, point estimate is needed.

According to Harrell et al. (2004), point estimate is a single value estimate of a parameter of interest. Standard deviation is measuring the spread of data valies in the population relative to the mean. Point estimate for sample mean as well as standard deviation can be calculated as follow.

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{2.1}$$

where:

$\bar{x}$: point estimation of mean

x_i : value of i-th observation

n : sample size

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \tag{2.2}$$

where:

s : sample standard deviation

Actually point estimate gives only tiny information about how accurate the estimation is. Therefore interval estimation might be used to capture the range within which can have certain level of confidence that the true mean falls in said range (Harrell et al., 2004). The confidence interval estimation falls in the range of $\bar{x} \pm hw$ where hw is half-width or error which is obviously symmetrics. Half width can be calculated using formula below.

$$hw = \frac{(t_{n-1,\frac{\alpha}{2}}) \times s}{\sqrt{n}} \tag{2.3}$$

where:

hw : half width

$t_{n-1,\frac{\alpha}{2}}$: factor can be obtained from Student's *t* table

s : sample standard deviation

n : number of sample

2.2 System in Simulation

Of course, what is going to be simulated is a system. A system can be defined as the collection of elements that function together to achieve a desired and expected goal (Blachard, 1991 in Harrell et al.). The important point from this definition is that 1) system has multiple elements, 2) elements are interrelated each other, 3) has the goals or objectives to achieve.

2.2.1 Element of System

In system, there are said to be several elements. The elements of system consist of entities, activities, resources, and control.

a. Entities

Entities is decribed as items processed through system such as products, customers, etc. (Harrell et al., 2004). Entities can be differentiated in advance as human or animate (customers, patients, etc.), inanimate (parts, documents, etc.0 and intangible (email, etc.).

b. Activities

Activities are the tasks performed in the system that are directly or indirectly involved in entity processing (Harrell et al., 2004). Activities may classified as entity processing (inspection, fabrication, assembly, etc.), entity and resource movement (conveyor travel, etc.), and resource adjustments, maintenance, and repairs.

c. Resources

Resources are the things which processes the entities (Harrell et al., 2004). Inadequate resources may obstruct the entity processing. The resources can be categorized into human or animate (operators, cooks, doctors, etc.), inanimate (machine, tools, equipment), and intangible (information, power, etc.)

d. Controls

According to Harrell et al. (2004), controls dictate how, when, and where activities are performed and impose the order in system. Example of control such as routing sequences, production plans, work schedules, instruction sheets, etc.

2.2.2 System Complexity

It is said before that system consists of interrelated elements or components which work together. The way these elements work may trigger the complex interaction, causing the system is also complex. The system complexity is primarily the function of interdependencies and variability (Harrell et al., 2004).

2.2.3 System Variables

The system, indeed has parameter to measure the performance. This performance should be monitored to see how far or how close the system in achieving the desired goal in term of overall performance. There are three types of system variables which are decision variables, response variables, and state variables (Harrell et al., 2004).

a. Decision Variables

According to Harrell et al. (2004), decision variables is sometimes referred as independent variables where the changing the value of it will affect the behavior of system. Independent variable can be either controllable or uncontrollable. Controllable independent variable (or here is referred as decision variable) is the variable where the experimenter is able to change and control the value of said variable.

b. Response Variables

Response variables, or sometimes refer to output variables, is the measurement of system performance in regard to inputted decision variable (Harrell et al., 2004). Others may mention response variable as dependent variables since its value will depend on how system react to input from independent variables.

c. State Variables

State variables indicate the system performance at any specific point of time (Harrell et al., 2004). The example of state variable is status of machines or operators (busy, idle, fail), number of chairs occupied, queue length in any time, etc. Actually, state variables work the same way like response variable where it depends on decision variable.

2.3 Reliability

Assets' reliability is closely related to how good the performance of said assets. The reliability itself is related to how frequent the assets (in this context is machine) experience failures. Theoretically, the machine which rarely experiences failure will be said having high reliability.

2.3.1 Definition of Reliability

In formal definition, reliability is a probability of a product or assets will operate well for certain timespan and condition without experiencing failure (Elsayed, 2012). Other formal definition of reliability is the probability of an item or product that will perform the intended mission satisfactorily for stated time period when used according to certain condition (Dhillon, 2006). By this definition, it can be summarized that the key words of reliability may include 1) probability, 2) well functioned, 3) certain time span, and 4) certain condition. In other words, reliability is used as the success measurement of a system to function without any obstruction during lifespan. Mathematically, if there are n_s success components on t and n_f fail components in the same t, therefore machines reliability can be calculated by using below equation.

$$R(t) = \frac{n_s(t)}{n_s(t)+n_f(t)} = \frac{n_s(t)}{n_o} \qquad (2.4)$$

where:

$R(t)$: reliability of system at time of t

$n_s(t)$: number of success components at time of t

$n_f(t)$: number of fail components at time of t

n_o : number of components in system

As it is explained previously that reliability is probability. Thus, the reliability is a complement of failure. Thus, it can be expressed mathematically as well as follow.

$$R(t) + F(t) = 1 \tag{2.5}$$

where:

$R(t)$: system reliability at time of t

$F(t)$: system failure at time of t

The reliability term is also related to the hazard function. Hazard function can be defined as the limit of the failure rate as difference of t (Δt) approaches zero (Elsayed, 2012). Thus, hazard function or instantaneous failure rate can be formulated using equation below.

$$h(t) = \lim_{\Delta t \to 0} \frac{R(t) - R(t + \Delta t)}{\Delta t R(t)} = \frac{1}{R(t)}\left[-\frac{d}{dt}R(t)\right] = \frac{f(t)}{R(t)} \tag{2.6}$$

The concept of reliability also closely related to a concept called Bathtub Curve. This type of concept represents the failure behavior of various items in the function of time (Dhillon, 2006). The Bathtub Curve represents three regions which is region I, region II, and region III. The figure below shows the representation of Bathtub Curve

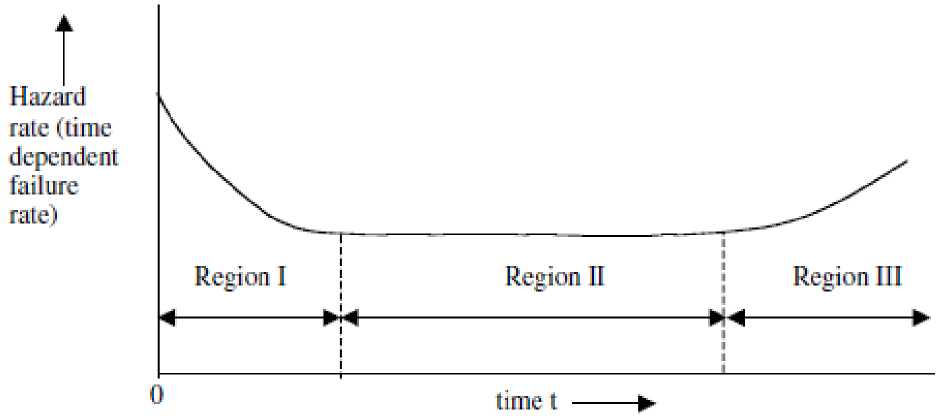

Figure 2. 2 Bathtub Curve (Dhillon, 2006)

Region I is called as burn-in region or infant mortality region. This region represents the high failure rate when the product is firstly utilized and then decreased until met the first point of region II. Region II is named as useful life period, where the hazard rate remains constant during this period until met the first point of region III. The region III is known as wear-out period where the hazard rate increases as time increases as well since the usage is more frequent.

2.3.2 Evaluating System Reliability

As it is known together that commonly, system is contructed by several components or aspects that work together to aim certain goal. In determining system reliability which consists of several subsystems or components, it is necessary to observe and look how those components are connected and arranged in such system.

2.3.2.1 Reliability Block Diagram

The way how to observe the connection and arrangement of components usually called as reliability block diagram or RBD (Elsayed. 2012). The block in RBD represents the component and will not show the detail of it. Once RBD is constructed already, the next thing to construct is the reliability graph. Reliability graph is a line which represents the blocks arrangement and the path on the graph (Elsayed, 2012). The arrangement of those components is various, can be in series arrangement, parallel arrangement, or even mixed arrangement (combination of series and parallel).

2.3.2.2 Series System

For a system whose components are arranged in series, if there are at least one out of *n* components is fail, then the whole system will be failed and stopped as well. Figure below is shong the RBD and reliability graph for components with series arrangement

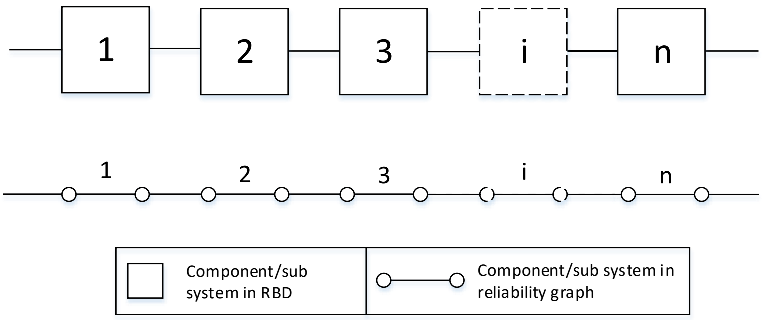

Figure 2. 3 RBD and Reliability Graph Series System

(Self-processed from Elsayed, 2012)

Taking Figure 2.2 as the explanation, if component 1 is fail so the whole system will fail since the first component which expected to function properly is fail already. However, if component 1 is success but component 2 or 3 is fail, the system is still said fail. For such system, so the system's reliability with *n* components arranged in series and work independently, can be calculated using equation below.

$$R_s = P(x_1) \times P(x_2) \times P(x_3) \times \ldots \times P(x_n) = \prod_{i=1}^{n} P(x_i) \quad (2.7)$$

where:

R_s : reliability of system where components are arranged in series

$P(x_i)$: probability of component *i* to work properly

2.3.2.3 Parallel System

For a system whose components are arranged in parallel, the system will be still able to function well and only if there is one out of *n* components is not fail. Because in parallel way, there are more paths that still allows to work properly if one or more path already fail (Elsayed, 2012). The figure below shows the RBD and reliability graph of parallel system.

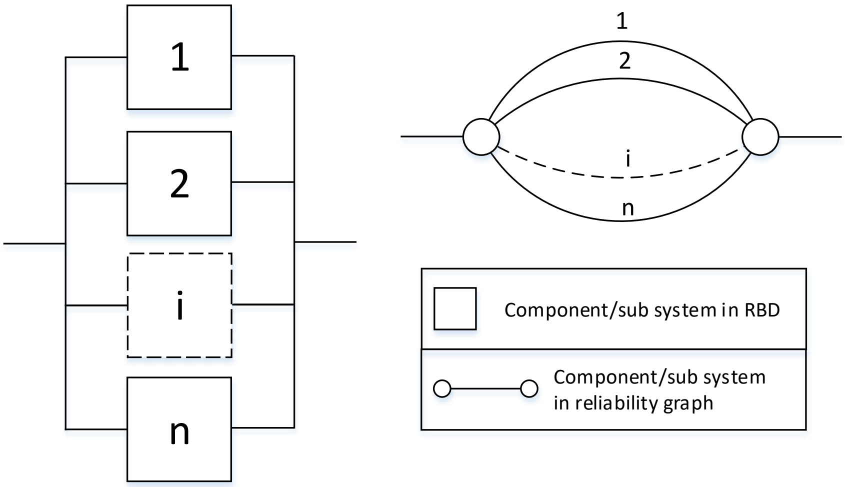

Figure 2. 4 RBD and Reliability Graph of Parallel System (Self-processed from Elsayed, 2012)

From Figure 2.3 it can be known that the components are arranged in such way so each component are parallel to each other. If only one component (suppose component 1) is fail, the system is still work properly. The system will still work properly if there are (n – 1) components are fail, leaving one success component. The system will be failed if all components are failed. For such system, the reliability of system with n components arranged in parallel way and each component works independently, can be calculated using equation below.

$$R_p = 1 - \left[\left(1 - P(x_1)\right)\left(1 - P(x_2)\right) \dots \left(1 - P(x_n)\right)\right] = 1 - \prod_{i=1}^{n}(1 - P(x_i)) \qquad (2.8)$$

where:

R_p : reliability of system where components are arranged in parallel

$P(x_i)$: probability of component i to work properly

2.3.2.4 Mixed Series and Complex System

Not only series or parallel system which implemented in a system whose reliability is going to calculate, but also mixed arrangement is possible as well. The figure below shows the example how the components are arranged in mixed arrangement where both series and parallel are combined.

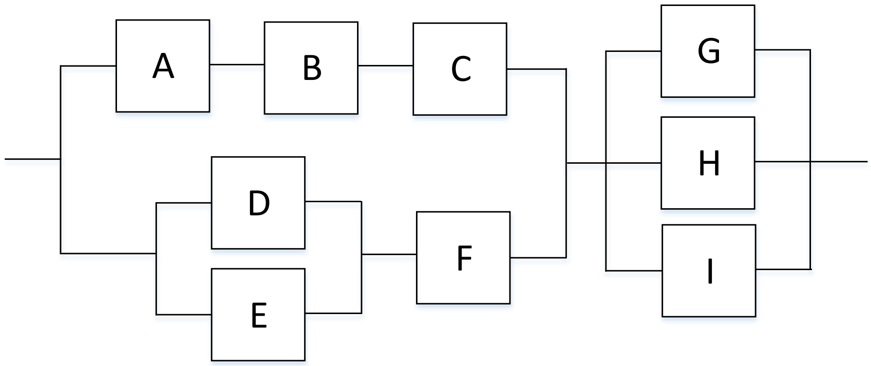

Figure 2. 5 Reliability Block Diagram of Mixed System (Self-processed from Elsayed, 2012)

If mixed arrangement of components is found (the components are arranged in such way so that there are series and parallel arrangement in one system), therefore the calculation of system's reliability can be done by breaking down the system according to the way components are arranged and then calculated using combination of equation (3) and (4). However, if the more complex system is found (where the model is difficult or almost impossible to model in series, parallel, series-parallel, parallel-series, etc), the way to calculate the system reliability is using decomposition, path set and cut set, event space, boolean truth table, reduction, path-tracing, and factoring algorithm method (Shooman, 1968).

2.4 Availability

Availability term is related to up time duration of machine during operation and is the measurement of how often and how long the system or machine operates as it is in good condition (Barringer and Hotel, 1997). Availability is also considered as one of the most important reliability performance measurement of system because it also considers failure rates as well as repair rates of system (Elsayed, 2012). The availability is determined by two aspects which are uptime and downtime. The problem in availability of system at least affected by three factors (Davidson, 1988) which are 1) increasing time to failure (TTF), 2) decreasing downtime due to repairment or scheduled maintenance, and 3) fulfillment of point 1 and 2 previously with as minimum as possible cost. According to Ireson (1996), there are three terms which often used in availability which are inherent, achieved, and operational availability.

2.4.1 Inherent Availability

The first one is *inherent availability*. This term is coming from maintenance personnel point of view. This only consider the corrective maintenance including time to repair or replace the failed components). This is the most commonly used availability concept which can be defined and expressed by using equation below.

$$A_i = MTBF/(MTBF + MTTR) \tag{2.9}$$

where:

A_i	: inherent availability
MTBF	: mean time between failure
MTTR	: mean time to repair

2.4.2 Achieved Availability

Second is the *achieved availability* which is coming from maintenance department point of view. Achieved availability may include both corrective and preventive maintenance. However, it does not include supply and administrative delays). This kind of availability can be expressed by equation below.

$$A_a = MTBM/(MTBM + MAMT) \tag{2.10}$$

where:

A_a	: achieved availability
MTBM	: mean time between corrective and preventive maintenance
MAMT	: mean active maintenance time

2.4.3 Operational Availability

And the third is *operational availability* which is coming from user point of view. Actually this is the most appropriate measurement of availabity since it considers a lot of aspects suct as direct time and indirect time in maintenance. This availability can be defined as equation below.

$$A_o = MTBM + RT/(MTBM + RT + MDT) \tag{2.11}$$

where:

A_o : achieved availability

MDT : mean down time

RT : ready time (operational cycle – (MTBM+MDT))

Another parameter to measure reliability is mean time to failure (MTTF). MTTF can be defined as expected time between to successive failures when the system is nonrepairable. If the system is repairable, it is considered to be MTBF (Elsayed, 2012). MTTF can be expressed by below equation.

$$MTTF = \int_0^\infty R(t)\, dt \tag{2.12}$$

where:

$MTTF$: mean time to failure

$R(t)$: reliability function of t

2.5 Maintenance

The machine which experience failure, indeed require a repairment or maintenance action. During maintenance or repairment, the downtime happens where the machine is uncable to do any activity caused by such failures. To prevent the freuqent downtime, therefore maintenance action is needed.

2.5.1 Definition of Maintenance

Maintenance is any kind of activity which is necessary to return the items, machines, or any assets to its good or expected state. Usually, maintenance action is done with intention of returning the machine to certain reliability level or as high as possible. The maintenance action actually incapable to restore the condition of machine as it is new.

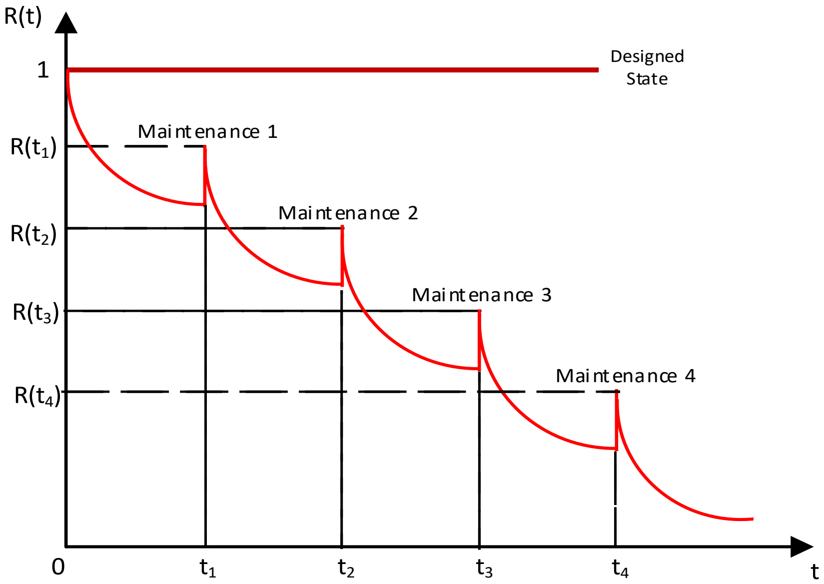

Figure 2. 6 Representation of Maintenance to Increase Reliability (Self-Documentation)

2.5.2 Maintenance Strategy

There are various maintenance strategies and adjusted to the necessity and the real condition. Some of well-known maintenace strategy may include below.

2.5.2.1 Corrective Maintenance

Corrective maintenace is a maintenance strategy where the action such as repairment or replacement is done right after the failure happened. So, this type of strategy is reactive since it need to wait until component is fail then it will repaired or replaced on order to restore the system reliability.

2.5.2.2 Preventive Maintenance

This strategy is against previous strategy. Preventive maintenance is a maintenance strategy which is intended to avoid sudden breakdown which will need further corrective action. This type of strategy appears as the solution to the higher cost when doing corrective maintenance due to breakdown. Usually, preventive maintenance is done periodically with certain frequency in order to make it cost effective.

2.5.2.3 Predictive Maintenance

Similarly to preventive maintenance, predictive maintenance involves detection of physical condition change as indication of failure thus will be directly maintained. Detection of failure indication can be done based on condition or statistics of the machine itself utilizing the data record.

In order to give better understanding regarding those three maintenance strategies above, the figure below shows the differentiation between corrective, preventive, and predictive (or condition based) maintenance.

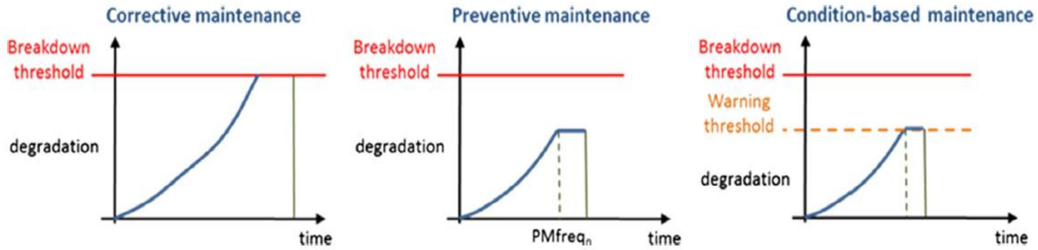

Figure 2. 7 Differentiation of Maintenance Strategies (Alrabghi et al., 2015)

Besides three maintenance strategies mentioned above, the other maintenance strategies might include risk based inspection (RBI), total productive maintenance (TPM), and reliability centered maintenance (RCM).

2.6 Throughput

Throughput generally can be defined as the number of units of output a company produces and sells over a period of time (Wilkinson, 2013). There is different between output and throughput. Where output means total production including scrap, grams, rejections, and stockpiled product, throughput is only the parts or product which is successfully produced, delivered, and accepted by customers (Steel, 2016). Therefore, by this understanding if a product is successfully manufactured but is not sold yet, it cannot be mentioned as throughput.

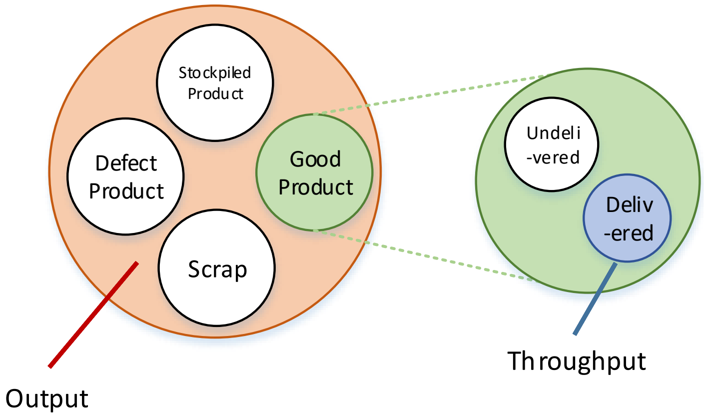

Figure 2. 8 Relationship between Output and Throughput
(Self-processed from Steel, 2016)

In calculating throughput, there are three variables involved which are:

1. Productive capacity
2. Productive processing time
3. Process yield

In some cases, manufacturers expect to reliably increase their throughput. According to Steel (2016), there are some ways to increase the throughput which shown as follow.

a. Eliminate throughput bottlenecks
b. Reduce the parts rejection rate
c. Improve employee training
d. Utilize factory automation features
e. Minimize physical prototyping where possible
f. Increase manufacturing safety

2.7 Spare Part

According to Indrajit et al. (2006), sparepart is the equipment or tools which support the goods procurement for necessity of equipments used in production process. Spare part can be classified as well into three categories based on function (Indrajit et al. 2006) which are as follow.

2.7.1 Consumable Parts

Consumable parts is the sparepart for regular usage, and the failure for this sparepart can be anytime. Thus, the inventory for this kind of sparepart should be planned very well that when this part is needed, it is always available and no need to wait for parts is procured.

2.7.2 Replacement Parts

This type of sparepart is usually used when overhaul (massive maintenance) happens. Overhaul is generally scheduled and planned as it is recommended. Replacement parts is usually accurately predicted in term of usage. Therefore, replacement parts are not stored in inventory for a very long time except for vital assets.

2.7.3 Insurance Parts

Insurance part is a sparepart which is rarely broken but still possible to break and will obstruct (and even stop) the operation and production process. Insurance part is usually large in size, expensive, and require long time to manufactured/made.

2.8 Sparepart Inventory Management

It is very important to manage the sparepart inventory. The decision to optimize the sparepart inventory control system is worthwile process that supports mainenance execution run smoothly (Short, n.d.). Once the sparepart is not available when it is required to perform maintenance, it will actually affect the availability since the time to repair (TTR) will be longer than it should be if sparepart is available. According to Short (n.d.), there are some methods to do in managing the inventory of sparepart.

2.8.1 ABC and XYZ Analysis

This method is done by classifying the sparepart into three classes of sparepart in term of its priority. This method is related to Pareto Principle or 80/20 Rule. Figure below shows the example of Pareto Chart of ABC Analysis.

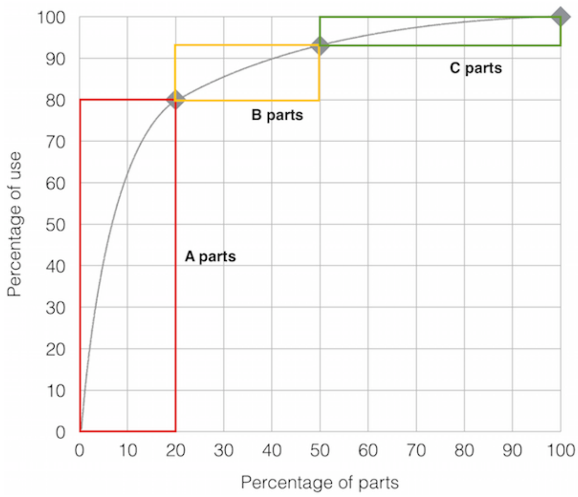

Figure 2. 9 Example of ABC Analysis Graph
(www.softwareadvice.com)

2.8.2 Sawtooth Diagram

For this method, it is necessary to establish some parameters regarding to sparepart inventory so that the volume remains balanced in the warehouse. It is necessary to establish the maximum inventory level as well as the reorder point by considering lead time too. Figure below shows the example of sawtooth diagram.

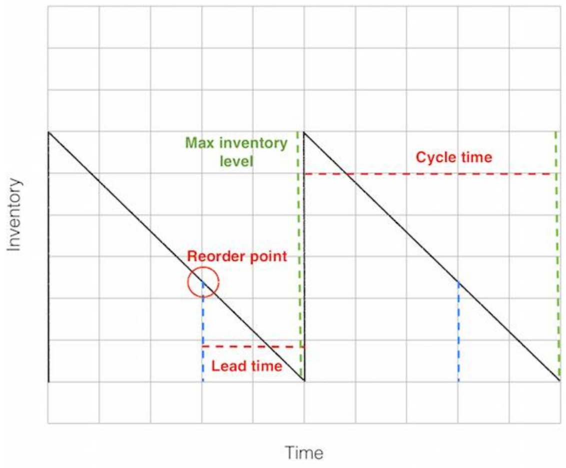

Figure 2. 10 Example of Sawtooth Diagram
(www.softwareadvice.com)

To determine the reorder point and economic order quantity (EOQ), it is necessary to know whether the inventory is reviewed periodically or continuously (perpetually). The reviewing method between periodical and continuous will be compared with some combination of parameters (Zahedi-Hosseini et al., 2017). Figure below shows the scenario of parameters combination in reviewing the spare part inventory.

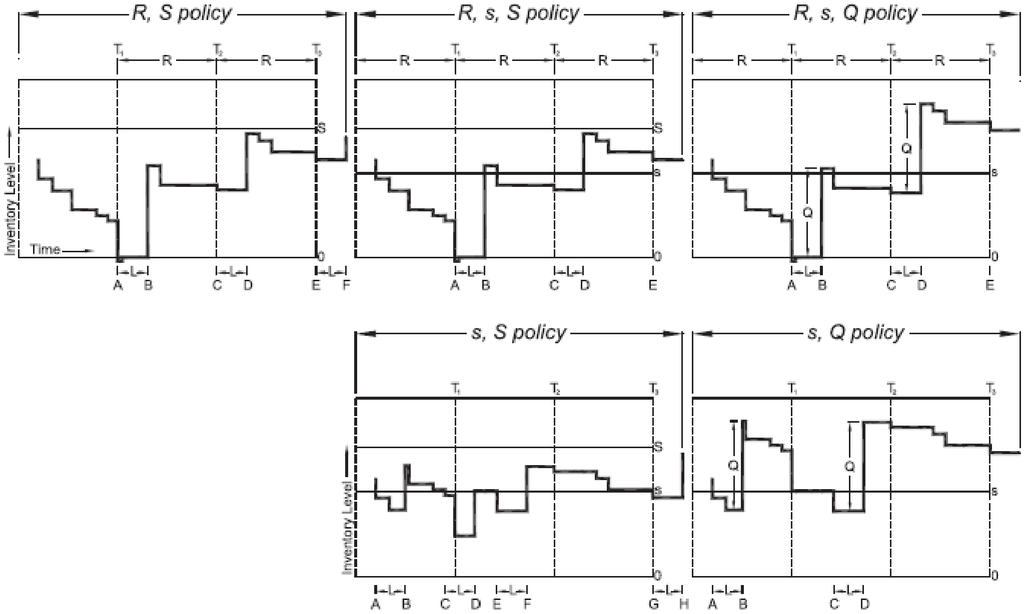

Figure 2. 11 Inventory Positions of Periodic and Continuous Review Inventory Policies (Zahedi-Hosseini et al., 2017)

2.8.2.1 R, S Policy

The inventory is reviewed periodically, where every *R* time unit which is the reviewing period, order is placed in order to increase the inventory level to *S* units.

2.8.2.2 R, s, S Policy

The inventory is reviewed periodically, where every *R* time unit order is placed to raise the inventory level to *S* units provided the inventory level has reached or below re-order level which is *s* units.

2.8.2.3 R, s, Q Policy

The inventory is reviewed periodically, where every *R* time unit order is placed in the amount of *Q* units provided the inventory level has reached or below re-order level (*s*).

2.8.2.4 s, S Policy

The inventory is reviewed continuously, where the order is placed to raise inventory level to *S* units when the stock is equal or fall below *s* units as reorder level.

2.8.2.5 s, Q Policy

The inventory is reviewed continuously, where the order is placed in the amount of *Q* units when the stock is equal or below reorder level *s* units.

It can be comprehended that *Q* is actually the economic order quantity (EOQ). Components of EOQ includes annual demand in units, purchasing cost per item, ordering cost per order, and annual holding cost as fraction of unit cost (Tersine, 1994) which can be formulated as follow.

$$EOQ = \sqrt{\frac{2CR}{PF}} \tag{2.13}$$

where:

EOQ : economic order quantity

C : ordering cost per order

R : annual demand in units

P : purchasing cost per unit

F : annual holding cost as fraction of unit cost

2.9 Research Position

It is necessary to find the position of this research in order to find the gap regarding to other previous researches. The table below shows the list of previous related researches.

Table 2. 1 List of Previous Related Researches

No	Title of Previous Researches	Authors	Year	Type	Observation Object
1	Joint optimisation of inspection maintenance and spare parts provisioning: a comparative study of inventory policies using simulation and survey data	Farhad Zahedi-Hosseini, Philip Scarf, Aris Syntetos	2017	Journal	Industrial Plant
2	A Discrete Event Simulation Model for Reliability Modelling of a Chemical Plant	Bikram Sharda, Scott J. Bury	2008	Proceedings	Chemical Plant
3	Simulation-based optimisation of maintenance systems: Industrialcase studies	Abdullah Alrabghi, Ashutosh Tiwari, Mark Savill	2017	Journal	Tyre Re-treading Factory and Petro-chemical Factory
4	Review of Simulation Approaches in Reliability and Availability Modelling	Meesala Srinivasa Rao, Vallayil N A Naikan	2016	Journal	-
5	A novel approach for modelling complex maintenance system using discrete event simulation	Abdullah Alrabghi, Ashutosh Tiwari	2016	Journal	-
6	*Analisis* Plant Reliability *pada Unit Pembuatan Urea dengan Pendekatan Simulasi*	Rahandi Nur Tegar Budiman	2006	Undergraduate Thesis	PT Petrokimia Gresik
7	*Perhitungan* plant reliability *dan pengendalian risiko di Pabrik Phonska* PT Petrokimia Gresik	IGP Raka Arthama	2006	Dissertation	PT Petrokimia Gresik
8	*Analisis Availabilitas dengan Mempertimbangkan* Inventory Sparepart *dan Penyangga Menggunakan Pendekatan Simulasi (Studi Kasus:* PT Petrowidada*)*	Nabila Yuraisyah Salsabila	2018	Undergraduate Thesis	PT Petrowidada

Table 2. 2 Comparing Previous Researches to This Research

	RESEARCH TITLE	METHODS AND CONDITION								OBJECTIVES										
		DES	Analytics or Optimization	Risk Assessment	Sparepart Inv. Mgmt.	Buffer Inventory	1-0 Equipment Status	Non 1-0 Eqpt. Status	RBD Analysis	Prod. Floor Reliability	Prod. Floor Availability	Critical Unit	Sparepart Inv. Policy	Maintenance Strgy	Risk Mitigation	Method Comparison	Buffer Inv. Policy	Calendar Days	Cost Optimization	Throughput Optimization
Previous Researches	Zahedi-Hosseni et al. (2017)	√	√		√								√	√					√	
	Sharda & Bury (2008)	√	√		√							√	√							√
	Alrabghi et al. (2017)	√	√			√								√					√	√
	Rao & Naikan (2016)	√									√					√				
	Alrabhi & Tiwari (2016)	√	√										√	√					√	
	Budiman, R. N. T. (2006)	√								√		√								
	Arthama, I. R. (2006)	√		√						√					√					
	Salsabila, N. Y. (2018)	√			√	√	√		√	√	√	√	√				√	√		
This Research		√			√			√	√	√	√	√	√							√

Plant reliability analysis had been done previously by considering the risk. On researched conducted by Budiman (2006), performed the risk score calculation as well as plant reliability calculation. While in the research performed by Arthama (2006), performed the risk mapping and the risk mitigation analysis. In these researches, there were no analysis on spare part inventory management yet.

The analysis for spare part inventory management started arise from research of Sharda & Bury (2008) by considering plant reliability analysis where the research was more focus on determining the most critical unit whose reliability is the lowest amongst other units within production floor. The unit which has the lowest reliability, later will be analyzed about its spare part inventory management. This research also considered the production lost minimization. Research performed by Zahedi-Hosseini et al. (2017) also considered the spare part inventory management. This research assigned some scenarios regarding to the inventory policy about lowest inventory level, EOQ, and determination of whether the inventory will be reviewed periodically (R) or continuously. Beside the inventory management policy, this research also performed the analysis about preventive maintenance (PM) frequency. The two policies will be combined and analyzed in attempt to find the most minimum cost incurred.

Research performed by Alrabghi et al. (2016) was about the brand-new approach about modelling complex maintenance system which used DES approach. Meanwhile, the research performed by Alrabghi et al. (2017) was about its implementation on industrial case by comparing the implementation on two different industries. The goal of this research is minimizing cost and maximizing the throughput by limiting some aspects such as the frequency of preventive maintenance, corrective maintenance, opportunistic maintenance, and condition-based maintenance. Both researches already used DES as the method.

In the other hand, the research performed by Rao & Naikan (2016) was about comparing the simulation methods on RAM (reliability, availability, and maintenance) analysis from literature review. From research conducted by Salsabila (2018), it already considered the sparepart inventory management and buffer inventory in order to maintain the availability and reliability of plant. Reliability block diagram (RBD) was used to model the complex system from level of processes arrangement until the level of how components are arranged for each machine. The goal of this research is determining the best scenario of both spare part inventory policy and buffer inventory to optimize the calendar days as the KPI. However, the system observed from this research only had two status of resources which are 1 (on) and 0 (fail).

Based on the previous researches, writer is planning to develop the analysis of plant reliability considering the optimum spare part inventory policy with non-1-0 equipment status (where the machine is possible to run although the indication of failure appears) in order to maximize production throughput, using RBD analysis and DES approach.

CHAPTER 3
RESEARCH METHODOLOGY

In this chapter, the writer is going to explain the methodology which will be used during research. Following subchapters are about the detailed explanation of flowchart provided above.

3.1 Study of System

The first thing to perform in this research is study of system and problem analysis. Problem should be analyzed in order to understand the goal and objective of constructing the model. The information should be firstly gathered in order to solve said problem. The information includes the element of system, variable of system, as well as the key performance indicator (KPI).

3.1.1 System Element

The element system, as it is known and explained previously, consists of entity, activity, resource, and control.

1. Entity that will be processed here is the raw material to make the steel pipe which is steel coil.
2. Activity here is the process of making the steel pipe. The production process is shown by the figure below. Pay attention that the production process is only takes place on R1 production line as main focus.
3. Resource which will be included in simulation model is the machine in R1 production line.
4. Control for this system is the production process flow as well as series parallel arrangement of the system.

3.1.2 System Variable

The variables of system to be modeled consist of the decision variable, response variable, and state variable. The decision variable is the spare part inventory procurement policy. The response variable is the production floor reliability measured by availability, and the production throughput. Meanwhile, the state variable is the machine status whether busy, idle, or fail.

3.1.3 Key Performance Indicator

Key performance indicator (KPI) is the measurement of system success in achieving the desired goals. In this research, the KPI of the system is the reliability which will be measured by availability and the production through put. Availability can be calculated using the concept of inherent availability where the equation can be seen on Chapter 2 which is equation 2.9.

Throughput generally can be defined as the number of units of output a company produces and sells over a period of time (Wikinson, 2013). In this context, the throughput may only be defined as the product which successfully manufactured over production time.

3.2 Data Collection and Processing

Data is needed as the input of simulation model in advance. The data here is categorized into three types which are structural, operational, and numerical.

1. Structural Data

   The structural data needed consist of the machine type, production process, and product type.
2. Operational Data

   Operational data here may include the production process flow, reliability system (arrangement of series or parallel), and inventory system for spare parts.
3. Numerical Data

   Numerical data required consist of the mean time between failure (MTBF), mean time to repair (MTTR), production capacity, current production target, production shift, and inventory policy in regard to the parameters.

Data is collected by several methods such as direct observation to the production floor, interviewing some related parties, as well as using secondary data. The data (especially the numerical) is still stochastic, such as MTTF and MTBF, which means it needs to perform distribution fitting for such data before being inputted into the model.

3.3 Designing Scenario

The scenario here is intended to be compared in advance relative to the existing system. The scenario to be experimented will only about the policy of the spare part inventory policy especially for the critical components.

3.4 Constructing Conceptual Model

The next procedure is constructing the conceptual model. The conceptual model here is about the reliability block diagram and logic flow diagram. The machines arrangement as well as its components arrangement will be modeled into RBD. Meanwhile logic flow diagram is constructed to model the production system and inventory system.

3.5 Validating Conceptual Model

Validating conceptual model is very necessary in order to ensure that constructed model is representing enough the real system already. Validating such model will be done by asking the related parties such as the manager of production to validate production system model, manager of technical to validate RBD, and manager of PBS to validate the spare part inventory model.

3.6 Constructing Simulation Model

Once the data has been fitted to the approximated or estimated distribution, then said data is ready to be input of simulation model. The model to simulate is constructed based on validated conceptual model. The model will be built based on DES method and using software of DES.

3.7 Calculating Number of Replication

Replication is needed to overcome the random result of simulation. The more replication, the more representing the simulation result is relative on the real system. If simulation is run only once (replication = 1), the result will not be representative enough to real system. Therefore, number of replications is mandatory to determine. The initial number of replication (n) should be set at first, and then based on result of running n replication, half width (hw) should be calculated. Half width can be calculated using equation 2.3 on previous chapter.

Once the hw is obtained, the next step is determining the desired hw by setting the absolute error (e) which can be calculated as follow.

$$hw' = hw \times e \tag{3.2}$$

where:

hw'	: desired half width

hw	: existing half width from simulation

e	: absolute error (%)

Following procedure is comparing the desired hw to existing hw from simulation. If hw < hw' (existing error is less than desired error), means that the previously determined number of replications is enough to run the simulation (Siswanto et al., 2018).

3.8 Verifying and Validating Simulation Model

Besides conceptual model, simulation model is compulsory to be verified and validated. The verification process of simulation model can be either by using debugging features of software (checking the syntax error) or animation (checking the semantic error). The verification process is done to ensure that the model is already built right.

The validation process is performed to check whether or not writer already build the right model. Validation is done by comparing the result of simulation with n replication to the result obtained from the real system using inferential statistics. If both systems do not show significant different, it means that the simulation model is already valid and able to represent real system.

3.9 Experimentation

After the simulation model is valid, the simulation can be run. For both existing condition and scenario. Experimentation can be done by executing the simulation based on proposed scenario.

3.10 Output Analysis

Output analysis is done by comparing the result of simulation for each scenario in term of key performance indicator. In this step, the better scenario which causes significant different relative to existing system will be taken and analyzed. However, if the KPI is not achieved yet another scenario will be proposed which is predicted to be able to achieve the desired KPI level.

3.11 Conclusions and Suggestions

The writer will deliver the conclusion of the research regarding to the best result of scenario including the inventory parameter suggested to implement to increase the reliability thus throughput can be increased as well. Besides conclusion, some suggestion regarding to the further research and for the observation object will be delivered and explained.

(This page is intentionally left blank)

CHAPTER 4
DATA COLLECTION AND PROCESSING

In this chapter, the writer is going to explain the description of observation object, collected data, and processed data. The data is collected is secondary data from company documentation as well as primary data from direct observation and interview. The data is processed by doing filtering, sorting, and fitting data to closest distribution as the input of simulation.

4.1 Data Collection

In this section, will be explained the collected data required for this research. As it was stated on previous chapter, there are 3 types of data which are going to be used which are structural data, operational data, and numerical data. Each type of data collected will be shown below.

4.1.1 Structural Data

According to Harrell (2004), structural data involve all of the objects in the system to be modeled including elements as entities, resources, and locations. In this research, the structural data may include product or output of production process which is, of course, steel pipe as well as the machine type (which also covers the equipment within the machine) and the spare part required for maintenance action for each equipment.

4.1.1.1 Machine and Equipment

Machine used for the production process is categorized as the structural data since it technically plays a role as resource and level 1 in RBD. Within the machine, there are some supporting equipment (sub system of machine) that play a role as level 2 in RBD. There are at last 7 identified machines within production line R1. Those machines are uncoiler, accumulator, forming, welding, sizing, cutting, and conveyor.

4.1.1.2 Spare Part of Equipment

Data of spare part is very important for this research. Therefore, identifying the spare part requirement (type and quantity required) is necessary to do. However, during data collection not all equipment's spare parts are identified. Therefore, the writer only shows the data of spare part for certain equipment which is found.

There are 16 identified spare part for uncoiler machine, 49 identified spare part for accumulator, 16 identified spare parts used for forming machine, 3 spare parts identified used for sizing machine, 43 identified spare parts for welding machine and 137 identified spare parts needed to repair cutting machine. However, there is no identified spare parts used to repair or maintain conveyor machine.

4.1.2 Operational Data

Operational data actually explains how the system operates and consists of all logical or behavioral information about the system such as routings, schedules, downtime behavior, and resource allocation (Harrell, 2004). In this research, the operational data may include the production process flow of R1 line, reliability system, and inventory system policy.

4.1.2.1 Production Process Flow of R1 Line

In this section, will be explained how the flow of production process within R1 line. The figure below shows the production process flow within R1 line specifically.

The production line in PT Spindo runs continuously for 24 hours a day and mostly 7 days a week. Figure above is telling us about how the processes occur within the R1 line to process steel coil until steel pipe is manufactured. The first thing, the steel coil should be installed into uncoiler to be uncoiled and the coil itself will be pulled away by accumulator as the place to accumulate the steel coil. The coil, afterwards, will be formed into a tube within forming machine before it is welded in welding machine. Once it is already welded, the pipe size will be adjusted in sizing process. Afterwards, the WIP pipes will be cut into pieces with the length of 6 meters each in cutting machine which use cold saw mechanism. The last is the pipe will be entering conveyor and kicker and will be inspected by inspector to check whether or not the pipe is good and meet specification.

4.1.2.2 Reliability System of R1 Line

Actually, the reliability system within R1 line follows series arrangement. According to the interview with some parties in Department of Technical of PT Spindo, they stated that almost all equipment's' failure causing the line to fail as well thus the line should be stopped at that time to be repaired as immediate as possible.

However, both Department of Technical Head and Section Head in Department of Production agree that sometimes the line is still able to run though there is a failure. And they agree as well that it may cause the capacity of production line to decrease thus the production rate cannot be optimized. But, both of them cannot tell and predict how significant the production capacity is decreased. In this research, assumed that the capacity will fall to 50% of ideal capacity if this happens.

4.1.2.3 Failure Combination of Production Line

It is necessary to get the operational data for failure combination related to production line. Referring to Salsabila (2018), there will be five combination included in this research and those will be explained as follow. Please take note that the failure will follow preemptive rule where the obstructed production process due to failure will be done whenever failure is done.

1. Combination 1: Failure outside Production Time

   In this combination, the failure does not occur in production time, therefore the production time is not affected by the failure time.

2. Combination 2: Production inside Failure

   In this combination, the failure does occur before production is even started and the failure is finished far after production process is finished.

3. Combination 3: Failure Before and in the Middle of Production

   In this combination, the failure occurs before production and will be finished in the middle of production.

4. Combination 4: Failure in the Middle and After Production

   In this combination, the failure occurs in the middle of production process and still occurs though production is done.

5. Combination 5: Failure inside Production

   In this combination, the failure occurs and finish in the middle of production process. Figure below shows how combination 5 is.

For additional information, when the status of production line is 0.5 thus the total production time is not affected. Because, the production is still run although the system actually fails. Thus, the total production time will be simply by deducting T_2 with T_1.

4.1.2.4 Spare Part Inventory System Policy

The spare part inventory system in PT Spindo follows *s,S* policy where *s* denotes as minimum inventory level and *S* denotes the maximum inventory level. In this case, the minimum inventory level is represented by reorder point (ROP). ROP defines the time when it is necessary to reorder the spare part represented by particular level of inventory. The inventory review itself follow continuous review system where the inventory is checked at least once a day and maximum three times a day.

In PT Spindo, there are at least four parameters of inventory which are minimum stock, safety stock (SS), reorder point (ROP), and maximum stock.

4.1.3 Numerical Data

Numerical data is the data which is able to provides quantitative information about the system under observation such as arrival rates, interarrival time, capacity, processing time, time between failures, etc (Harrell et al., 2004). The numerical data which are going to be shown in this section include the production throughput and approached demand, production capacity, and inventory parameter value. The mean time to failure (MTTF) and mean time to repair (MTTR) will not be shown here. However, it will be shown in data processing as the final result.

4.1.3.1 Production Throughput and Approached Demand

The production throughput here is shown in term of tonnage and piece of pipes. Instead of using tonnage or kilogram as the input of model later on, the demand is approached in unit of piece of pipe by finding the average weight of pipe. The data is approached using total output in kilogram divided by piece of pipe.

4.1.3.2 Production Capacity

The Section Head of Department of Production said that the capacity is in term of production line capacity not in term of each machine capacity within the line. The production line capacity is approached using the data of production throughput in pieces divided by working time assuming the product is homogenous with the weight defined previously.

4.1.3.3 Inventory Parameter Value

The inventory parameter value that will be shown here is the minimum stock or will be represented as ROP (*s*) and maximum level of stock denotes as *S*. It is assumed that the parameter value does not change over time (constant) since in reality, the value may fluctuate depend on the average usage of spare part. The delivery lead time of spare parts vary as well.

4.1.3.4 Inventory Cost

In this section, will be shown the data of cost related to inventory cost. The inventory cost is determined by some components such as unit cost, ordering cost, as well as holding cost.

The ordering cost here is assumed to be Rp300,000 per order since it is also assumed that the order placed is always domestic order. Meanwhile, fraction holding cost is assumed to be 20% per unit cost per year. If it is converted into daily basis, it will be 0.05% per unit cost per day.

4.2 Data Processing

In this section, collected data previously will be processed by fitting the data to closest theorical distribution as well as probability calculation. The result of data processing later will be used as the input of simulation model.

4.2.1 Distribution Fitting of MTTF and MTTR

Weibull Distribution is used to represent the random behavior of time between failure. Besides, Erlang Distribution is chosen to model random behavior of time to repair. Weibull Distribution is one of the most suitable distribution to model random behavior in time between failure (Siswanto et al., 2018) meanwhile Erlang Distribution is one of distribution which is suitable to model time to repair (Siswanto et al., 2018).

4.2.2 Selecting Spare Part

In this research, observing all identified spare parts is not necessarily important. Therefore, the system will be bounded by selecting the most impactful spare part in maintenance action. According to data served on Figure 1.6, it can be seen that the most critical machines in R1 are cutting, accumulator, and welding. Therefore, it is necessary to take most attention on these machines and not neglecting other machines since the other may also have impact on determining when the line fails. The spare part selection is done using Pareto Chart by finding

20% of spare parts which have impact on 80% of total usage. The selection itself takes place on each machine.

Summarizing the selected spare parts, there are 26 spare parts under observation for the whole R1 system.

4.2.3 Spare Part Requirement Probability

According to the data collected from 2017 to 2018, it is necessary to find the probability of failure occurrence to require particular spare parts.

4.2.4 Probability of Half Capacity for Each Machine

In this section the, probability of each machine within R1 line to have capacity of 50% (assumed value) will be calculated. The probability is being generalized for all equipment within machine.

4.2.5 Distribution of Demand

It is important to find the distribution of demand for pipe as the input of simulation. This is done because the demand is stochastic thus needs to be fitted to closest distribution. According to Choy and Cheong (n.d.), the stochastic demand can be approximated using normal distribution.

(This page is intentionally left blank)

CHAPTER 5
SIMULATION MODEL DEVELOPMENT

In this chapter, will be explained the process in constructing and developing simulation model starting from conceptual model construction, simulation model construction, verification, and validation. There will be several sub models constructed which are failure sub model, spare part inventory sub model, and production sub model.

5.1 Conceptual Model

In this subchapter, the writer is going to show the process and result in constructing and developing conceptual model.

5.1.1 Failure Sub Model

In this section, will be shown the developed conceptual model of failure sub model which consists of reliability block diagram (RBD) and logic flow diagram.

5.1.1.1 Reliability Block Diagram

In this section, the writer will show the conceptual modelling of production line system in term of reliability block diagram. The way how to observe the connection and arrangement of components usually called as reliability block diagram or RBD (Elsayed. 2012).

All machines within R1 line are arranged in series arrangement. This is causing the system will fail whenever at least one of machine is fail. From RBD of production line which represent the level 1 RBD, the next will be constructed the level 2 RBD showing the RBD for each equipment within machine in R1.

5.1.1.2 Failure Logic Flow Diagram

Besides RBD, logic flow diagram is also used to model the failure in production line R1. It tells about the logic starts from when the failure occurs, needing spare part, and repaired

5.1.1.3 Series Arrangement Logic Flow Diagram

The next logic flow diagram to be shown is series arrangement in RBD. The diagram tells how the RBD of series system works.

5.1.2 Spare Part Inventory Sub Model

In this section, it will be shown and explained the conceptual model for spare part inventory sub model. As it is stated previously that the spare part inventory system in PT Spindo follows continuous review with *s*, *S* parameter where *s* denotes minimum inventory level or ROP in this research and *S* as maximum inventory level. The order is placed whenever inventory level falls on or below ROP.

5.1.3 Production Sub Model

In this section, explained the conceptual model of production sub model. The production lines at PT Spindo run continuously 24 hours a day and mostly 7 days a week. The writer here constructs the production sub model with consideration of failure combination explained on sub chapter 4.2.2.3. The writer here uses conceptual model of Salsabila (2018) as the reference.

5.2 Simulation Model

In this section, will be shown the simulation model of this research. As it is stated previously that this research will use discrete event simulation as the method, dedicated software for discrete event simulation methodology called ARENA will be utilized. In this software, will be constructed the simulation model based on the conceptual model that writer had constructed in the previous section. The simulation will be run in non-terminating rule. Therefore, there will be warm up period which is set into 7 days. Thus, the result during that warm up period will be discarded. The simulation model will be shown as well as explained as follow.

5.2.1 Failure Simulation Sub Model

In this section, will be shown the simulation model for failure sub model explained before. The simulation model is constructed based on conceptual model of failure

5.2.2 Spare Part Inventory Simulation Sub Model

In this section, will be shown and explained the way of modelling the spare part inventory in simulation. Spare part inventory should be modeled into simulation model to correspond the required spare part to conduct repair to the availability of the spare part itself.

5.2.3 Production Simulation Sub Model

In this section, will be shown and explained the way how to model the production system into simulation model. Modelling the production system is core of this research. Because the intention of this research is to improve the production throughput. The model here will start from the demand of product. Afterwards, the demand will be processed into the production line according to the processes within. Then, will be ended in the final product checking such as product acceptance rate as well as check whether or not the output classified as lost sales.

5.3 Verification

Verification is the important step in simulation modelling. Verification, is the process to determine whether the model operates as intended or at least it runs correctly (Harrell, 2004). In a simple way verification is concerned in building the model right by comparing the simulation model to corresponding conceptual model (Banks et al., 2001). In this step, two types of verification will be performed which are verification of syntax error and verification of semantic error.

5.3.1 Verification of Syntax Error

Verifying syntax error is intended to check whether or not there is error in coding or building the input of modules in ARENA using debug feature available on the software. And proven that there is no error on model.

5.3.2 Verification of Semantic Error

Verification of semantic error is intended to trace the error in term of logic to follow based on conceptual model. The animation feature provided by ARENA will be used to conduct verification of semantic error. There are some things to be verified in term of semantic error such as RBD logic, inventory control, and production system.

5.4 Number of Replication

Simulation has characteristic of random input random output (RIRO). Therefore, running simulation only once is not sufficient to represent the real system since it means only representing one sample. Thus, it is necessary to run the simulation for several times. That is why replication is needed. Without replication, simulation output is unable to form an estimation interval (Siswanto et al., 2017). The number of how many times simulation model should be run must be calculated anyway.

In determining the number of replications needed, used percentage of demand fulfillment as the parameter since it is able to represent the system performance as a whole. First of all, the writer here determines 10 as the initial number of replications.

After obtaining resultof simulation, the next step is determining the desired half width (*hw*). From simulation report, it is obtained that the *hw* of total throughput is 3.19%. In this research, it is expected that the *hw* will not be exceeding 5% of existing total throughput which will be calculated.

Calculation shows us that the 10 replication is enough since the hw is less than hw'. However, writer is interested in finding how many replications is exactly needed to be run.

From calculation performed, it can be known that actually 4 replications are already enough to reach the desired half width. However, 10 replications are taken anyway to run the simulation since it will only take 3 minutes to run and get better and more representative result.

5.5 Validation

Validation is the last step in building simulation model. The validation is the process to determine whether or not the model is meaningful and accurate representation of the real system (Hoover and Perry, 1990 in Harrell et al., 2004). In other word, validation is the process to check whether we already build the right model. Validation is done to ensure that the constructed model is already representing the real system. In validation, comparing output of simulation and real system is necessary. Because the samples are independent, *Student's t* hypothesis test is used to compare average of simulation output to real system. The parameter used as validation is still the same with determining number of replications which is demand fulfillment percentage. The hypothesis for validation is formulated below.

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

As the input of calculation using Data Analysis in Microsoft Excel, the writer states that hypothesized mean difference is 0, error (α) is 5% and degree of freedom (*df*) is 18 thus obtained *t-test* value is 2.101.

From the calculation performed, it can be known that the *t Stat* value is -1.5379. This value will be compared to *t Critical two tail* as follow.

$$-t\ Critical < t\ Stat < t\ Critical$$

$$-2.101 < -1.5379 < 2.101$$

$$Do\ not\ reject\ H_0$$

Comparison above showing us that *t Stat* is still in the range bounded by *t Critical*. Besides, known that the *p value* is 0.1415 which is greater than 0.05 as error level. By this finding, it can be concluded that writer should not reject null hypothesis thus the simulation model is already valid and able to represent the real existing system.

CHAPTER 6
RESULT AND EXPERIMENTATION ANALYSIS

In this chapter, will be explained about the existing condition of system, experimentation by designing scenario, analysis of scenarios, as well as sensitivity analysis.

6.1 Existing Condition

In this section, will be explained the existing condition result based on the simulation model.

6.1.1 Simulation Result on Availability and Demand Fulfillment

In the existing condition of PT Spindo, the inventory is reviewed continuously with parameter of minimum and maximum level (*s*,*S*). The spare parts will be ordered from supplier whenever the stock level falls on *s* or below *s*. The line itself has probability to have half capacity of the ideal capacity. This occurs when the production line fails but the line still able to run. Spare parts should be available to overcome the failure occurrence. When the spare part is not available when needed, another additional time due to lead time delay is added causing the downtime is increased thus has impact on lowering percentage demand fulfillment.

Based on simulation result, obtained the availability of R1 as well as the percentage of demand fulfillment as the performance parameter of system. The availability of R1 is obtained by comparing the repair/down time of R1 to the total observation time. Meanwhile, percentage demand fulfillment is obtained by comparing throughput with demand since the demand itself is stochastic. The table below is showing the recapitulation of simulation result.

From table above, it can be seen that the average availability of R1 production line is 0.9268. Meanwhile the average percentage of demand fulfilled is 90.06%. This numbers are still able to be improved using some scenarios that will be later explained in the next section of this chapter.

6.1.2 Simulation Result on Spare Parts Inventory

In this section, writer will analyze and explain the simulation result on spare parts inventory. As it is explained before, the system used in the spare parts inventory is *s*,*S* policy.

In the initial condition, there are some spare parts whose current stock is zero. That is the reason why the simulation should be run using warm up period for 7 days lead time on average. In running simulation model, simulation model is run for 3 years in order to cover larger time bucket. Besides, it is expected to get more knowledge and information by running the simulation model for longer time.

It can be known that the requirement of each spare part is different. Since the simulation is only run for one replication, thus running for 10 replications is needed to get better comprehension. The writer will use parameter of spare part availability to measure the readiness of spare parts when it is needed.

6.2 Experimentation

In this section, experiment will be conducted by constructing some scenarios intended to find which scenario that is said better compared to the existing system. Here, chosen 4 spare parts to be basis of making scenarios based in writer’s idea. Besides, if it is found that the result is insignificant another scenario will be proposed anyway by changing the parameters of all spare parts as well as altering the inventory policy.

Using the scenario basis, will be constructed the possible scenarios to be executed and obtained 19 scenarios. Following will be discussed about the experimentation result and explanation about the scenarios.

6.3 Inventory Cost Calculation

In this section, calculation regarding inventory cost on selected scenario is going to be performed. From previous subchapter, it can be known that there are 3 scenarios which has significant effect in term of increasing the availability and demand fulfillment. After that, it is necessary to calculate the cost incurred to inventory as the impact on changing the inventory policy as the scenario. In this research, formulated the inventory cost as follow.

$$TIC = OC + PC + HC \tag{6.1}$$

where:

TIC : total inventory cost

OC : ordering cost

PC : purchasing cost

HC : holding cost

In this research, it is attempted to calculate the inventory cost for 3 years where 3 years used as time bucket as it is used on section 6.1.2 to check the inventory level. Here the the inventory cost for the existing condition, scenario 17, scenario 18, and scenario 19 will be calculated.

Based on calculation, it can be known that the total inventory cost of existing condition during 3 years assuming only observing 26 spare parts are Rp 126,034,490. Obtained that the total inventory cost for scenario 17 is increasing significantly from existing. Adding Rp 63,522,381 becomes Rp 189,556,872. For scenario 18 known that the total inventory cost is increasing around Rp 5,668,600 from existing cost so that the inventory becomes Rp131,703,090. According to calculation performed, it can be known that the total inventory cost for scenario 19 is increasing around Rp 15,288,800 from existing cost so that the inventory becomes Rp 141,323,304.

6.4 Analysis

In this section, the writer will do analysis based on existing simulation model and improvement scenarios. The things to be analyzed might include the existing condition, effect on changing inventory policy, total inventory cost, and selected scenarios.

6.4.1 Analysis of Existing Condition

Currently, PT Spindo has 4 operating production lines and one of them is Mill R1. All machines within production line is arranged in series arrangement. If at least one machine within line fails, it will have a great impact on the whole line system so that the line should be shut down. However, it is very possible for a line to still run whenever experience failure. But the production capacity will be decreased as the consequences. Therefore, the repair will take place in the same time when production is still running..

Increasing downtime due to spare part unavailability will have on impact on demand fulfillment. It is expected that lost sales should be as low as possible. The line availability should be high in order to achieve that goal. So, the availability of spare parts itself should be high as well to support this goal.

Based on simulation result, it is obtained that the average availability of production line R1 is 0.9268 and the average percentage of demand fulfillment is 90.06%. Availability is the critical component in a production line. Downtime has impact on delayed production. Delayed production will cause the demand fulfillment will be decreased as well, therefore the lost sales will be bigger.

6.4.2 Analysis of Inventory Policy Alteration Impact

Scenario of altering inventory policy is conducted based on the reason that some spare parts availability is low which will have impact on lowering availability and demand fulfillment. It is expected that all spare parts will have availability of 1 means that spare parts are always available when it is needed. Based on simulation result, there are actually some spare parts which has availability less than 1. However, there are 4 spare parts which has the lowest availability.

Here, the inventory parameter of these spare parts which will changed especially on its ROP and maximum level.

By changing the inventory parameter of spare parts one by one, it can be found that actually both line availability and demand fulfillment is increased quite much compared to existing condition . However, it is found that changing only one spare part inventory parameter is not that significant to increase availability and demand fulfillment. Until combining 4 spare parts altogether, writer is still unable to get the significant different in term of result.

Therefore, by considering all spare parts it might be better to consider all spare parts in making scenario. Besides, this fact may be caused by the random behavior on system especially on the failure arrival. Writer also think that this might be caused by the simulation characteristic which is random input random output (RIRO).

The other inventory policy might be tried here. Writer is interested to find the impact if the *s*,*Q* policy is implemented here. EOQ is obtained based on annual demand. The scenario's result is significant but still lower than previous scenario. Thus, writer tries to increase the *s* by 50% maintaining the *Q* value. By this scenario, significant result is obtained where the availability is 0.9407 (exactly same to scenario 17) and the demand fulfillment is the highest which are 92.1%.

6.4.3 Analysis of Total Inventory Cost

Changing inventory policy always have impact on the total inventory cost. Inventory policy has their own benefits and disbenefits. For example *s,Q* policy. This policy actually will decrease the number of orders placed that will decrease the ordering cost as well. However, since the amount to order is always constant it will have significant impact on the purchasing cost and also holding cost since units in warehouse might be high. In this section, will be analyzed the impact of changing inventory policy to total inventory cost. Please be aware that the total inventory cost analyzed here is during 3 years.

The current inventory cost is the lowest among all which is around Rp 126,000,000. And the highest total inventory cost is scenario which almost reach Rp 190,000,000. Both scenario 18 and scenario 19 is slightly increasing from existing condition in term of total cost. By so far, in term of total cost scenario 18 has the lowest total cost among scenarios.

The existing condition has the highest ordering cost. It is caused by the fact that in the existing condition, orders are frequently placed during 3 years since the gap between minimum and maximum level of inventory for some spare parts are so narrow. This makes every single usage of particular spare parts will end up on reordering the spare part. Other scenarios have lower ordering cost means that the ordering frequency is decreased significantly. The lowest ordering cost is from scenario 18 means that ordering frequency is lowest here.

In term of purchasing cost, found that existing condition is very cost efficient because the quantity purchased in single order is not too big since the gap between *s* and *S* (gap) is not too big. Meanwhile all scenarios have greater purchasing cost as the consequence of both increasing the inventory gap and constant quantity order. In term of purchasing cost, the scenario 18 is the lowest and scenario 17 is the highest among scenarios.

Existing condition has lower holding cost compared to other scenarios. It means that the amount of spare part to carry during 3 years is not too many so that the holding cost is not high. The highest holding cost is on scenario 17. Increasing both *s* and *S* causes the number of spare parts kept in the warehouse is increasing significantly so that no wonder that holding cost is increasing significantly. Among scenarios, in term of holding cost still scenario 18 is the best since it has the lowest holding cost. From all explanations above, it can be intuitively concluded that from 3 scenarios above chosen that scenario 18 has the lowest total inventory cost.

6.4.4 Analysis of Selected Scenarios

In this section writer will do analysis on selected scenarios. Based on experimentation done before, writer will do analysis in order to find the best scenario to be chosen. Table below shows the summary of experimentation result.

Table 6. 1 Summary of Experimentation Result

Scenario	Availability	Demand Fulfillment	Change
1	0.9300	90.86%	Insignificant
2	0.9288	90.83%	Insignificant
3	0.9300	90.09%	Insignificant
4	0.9288	90.86%	Insignificant
5	0.9288	90.83%	Insignificant
6	0.9300	90.09%	Insignificant
7	0.9300	90.86%	Insignificant
8	0.9288	90.06%	Insignificant
9	0.9288	90.83%	Insignificant
10	0.9300	90.09%	Insignificant
11	0.9300	90.06%	Insignificant
12	0.9288	90.83%	Insignificant
13	0.9300	90.09%	Insignificant
14	0.9268	90.06%	Insignificant
15	0.9268	90.06%	Insignificant
16	0.9363	90.92%	Insignificant
17	0.9407	91.74%	Significant
18	0.9370	91.61%	Significant
19	0.9407	92.1%	Significant

According to table above, it explains that changing only one spare part parameter will not have significant impact. This may be caused by random behavior on the other subsystem that may be uncontrollable. Thus, it is tried to combine the spare part parameter. However, until changing four spare parts' parameter altogether the result still insignificant. Therefore, the writer tries to change parameter of all spare parts by increasing the *s*. Changing *s* by increasing it to certain percentage results significant increase. Unfortunately, the inventory cost incurred on this scenario is increased significantly as well.

Writer is also interested to find the result of changing the whole inventory policy to *s*,*Q*. Besides writer also tries to increase the *s* in this policy by increasing it to certain value Both scenarios are resulting the significant difference in term of availability and demand fulfillment increase. Both scenarios also result slightly increasing inventory cost compared to current cost. However, scenario 17 will have result that almost the same to scenario 19. There is tradeoff between maximizing the performance metrics of availability and demand fulfillment, and minimizing the total inventory cost. Thus, writer is interested in finding how significant the cost increased to the increasement of availability and demand fulfillment.

Here, finding the margin between existing condition and scenarios in term of availability, demand fulfillment, and inventory cost is substantial. Since the result of availability and demand fulfillment is considered to be annual, therefore the total inventory cost should be yearly as well. Assuming that the annual total inventory cost can be obtained dividing total inventory cost by 3, thus will be obtained the total inventory cost for every condition. Table below shows the summary of calculating the margin cost and margin availability.

Table 6. 2 Inventory Cost Incurred to Increase Availability

Condition	Annual TIC	A	Margin Cost	Margin (A)	Cost to Increase
Existing	Rp 42,011,497	0.9268			
S17	Rp 63,185,624	0.9407	Rp 21,174,127	1.39%	Rp 15,233,185
S18	Rp 43,901,030	0.937	Rp 1,889,533	1.02%	Rp 1,852,484
S19	Rp 47,107,768	0.9407	Rp 5,096,271	1.39%	Rp 3,666,382

From table above, writer tries to calculate the margin cost and margin of availability in order to be able to find the inventory cost incurred to increase certain level of availability. To compare among scenario, calculation of the effort in term of cost to increase 1% of availability is performed. For example, to increase 1% of availability in scenario 17, the inventory cost will be increasing Rp 15,233,185 and so on. Besides availability, it is necessary to calculate the inventory cost incurred to increase the demand fulfillment. Table below shows the calculation of it.

Table 6. 3 Inventory Cost Incurred to Increase Demand Fulfillment

Condition	Annual TIC	DF	Margin Cost	Margin (D)	Cost to Increase
Existing	Rp 42,011,497	90.06%			
S17	Rp 63,185,624	91.74%	Rp 21,174,127	1.68%	Rp 12,603,647
S18	Rp 43,901,030	91.61%	Rp 1,889,533	1.55%	Rp 1,219,054
S19	Rp 47,107,768	92.10%	Rp 5,096,271	2.04%	Rp 2,498,172

Table above contains the same information but for demand fulfillment. For example, to increase 1% percent of demand fulfillment the inventory cost will be increasing Rp 1,219,054 per year in scenario 18. The figure below is summarizing the result of calculating the increased inventory cost to increase 1% of both availability and demand fulfillment.

In conclusion, the scenario 18 will incur the least margin inventory cost and this scenario will increase the availability to 0.937 and 91.61% demand is fulfilled. In contrast, scenario 19 will incur more inventory cost but the availability will reach at maximum which is 0.9406 and 92.1% demand will be fulfilled. Scenario 18 may be the best if company is minimizing cost-oriented meanwhile scenario 19 is the best only if company is maximizing performance-oriented. So far, assume that company is more focus on cost minimization, so scenario 18 is chosen.

6.5 Sensitivity Analysis

Sensitivity analysis is done to predict the robustness of system that is simulated to the change of uncontrollable variable. In this section, writer will do analysis of sensitivity caused by delay lead time and initial stock of spare part to the availability and demand fulfillment. Besides, it will also be observed the impact on unit cost to overall inventory cost. The sensitivity analysis will take place on chosen scenario which is scenario 18.

6.5.1 Sensitivity Analysis on Delay Lead Time

Delay lead time is the time needed to ship the order of spare part. In this sensitivity analysis, writer will try to change the delay lead time using certain circumstances.

The relationship of both availability and demand fulfillment to change of lead time is linear. Increasing the lead time will make availability will decrease so that the demand fulfillment will decrease as well. The relationship itself has negative trend. Increasing one parameter will decrease other parameter as consequence. Concluded that lead time is the sensitive variable on respect to availability and demand fulfillment. Thus, the delivery lead time should be controlled in the attempt to keep the availability high and more demand is fulfilled.

6.5.2 Sensitivity Analysis on Spare Part Initial Stock

The next sensitivity analysis is about initial stock of spare part. It is known that some spare parts inventory is zero in the beginning time of simulation and others are non-zero. In this sensitivity analysis, writer will do some changes on initial stock related to *s*.

The relationship between initial stock of spare parts to availability and demand fulfillment is not linear. There are some inconsistencies on the result making it non-linear. This is can be caused by the random behavior of the MTTF and MTTR. Therefore, concluded that availability and demand is not sensitive to initial stock of spare part.

6.5.3 Sensitivity Analysis on Unit Cost

Unit cost is determining almost all component in the inventory cost. Intuitively, increasing unit cost may of course causing inventory cost to be increased. In this analysis, writer wants to check and validate this statement and examine the relationship. Here writer will do some changes regarding to the unit cost using some conditions.

It is proven that increasing unit cost will have consequence of increasing total inventory above. The relationship between the unit cost and total inventory cost is linear represented by a straight line. Therefore, the total inventory cost is sensitive to unit cost.

CHAPTER 7
CONCLUSIONS AND SUGGESTIONS

In this chapter, will be explained the obtained conclusions of this research and suggestions from writer regarding the possible future research.

7.1 Conclusions

Based on the result of this research, obtained some conclusions shown as follow.

1. Based on existing condition result from simulation model, it can be known that the availability of R1 production line is 0.9268. Meanwhile, the percentage of demand fulfilled in this existing condition is 90.06%. Looking at these values, it is still possible to increase the availability expecting the demand fulfilled will be increased as well.
2. In term of spare part availability, not all spare parts are having high availability. There are 4 spare parts with lowest availability which are SP 400923, 410107, 412019, and 402583 with availability of 0.9694, 0.9576, 0.9737, and 0.9219 respectively. These spare parts will be used as basis in constructing improvement scenario.
3. The availability of production line will be done by changing the inventory parameter of spare parts especially 4 spare parts aforementioned. Parameter changed includes s which is ROP and S maximum inventory level. Found that changing only one spare part parameter is insignificant, writer tries to combine the spare part scenario. Until changing 4 spare parts' parameter, the result is still insignificant. Thus writer tries to change all spare parts s,S where obtained significant result when s is increased 80% and S is doubled from new s. The availability obtained from this scenario is 0.9407 and 91.74% demand fulfilled. Changing policy to s,Q is also proven resulting significant result.

4. Total inventory cost for existing condition is Rp 126,034,490. Resulting 3 significant scenarios, it is necessary to calculate inventory cost incurred from scenarios. Calculated for 3 years the inventory cost of scenario 17, scenario 18, and scenario 19 are Rp 189,556,827; Rp 131,703,090; and Rp 141,323,304 consecutively.
5. Based on experimentation and considering both inventory cost incurred and performance metrics obtained that scenario of using *s*,*Q* is the best. In this scenario, to increase 1% of availability the inventory cost incurred will be increased only Rp 1,852,484 per year. Meanwhile, to increase 1% percentage of demand fulfilled the inventory cost will only increase Rp 1,219,054 per year. By this scenario, obtained that the availability will be increased to 0.9370 and demand fulfilled will be increased to 91.61%. This scenario is good if the company is cost oriented. If company is performance oriented, scenario 19 (*s*,*Q* where *s* increased 50%) will be the best scenario.
6. According to sensitivity analysis, the performance (availability and demand fulfillment) will be decreased when the delivery lead time of spare part is increasing. The performance even worse than existing condition when the lead time is increased to 50%. Therefore, availability and demand fulfillment are sensitive to lead time. In contrast, availability and demand fulfillment are not sensitive to the initial stock of spare part. Both of them are having non-linear relationship. The inventory cost is sensitive to unit cost and having straight linear relationship. Managing both lead time and unit cost is very essential to maintain the performance of the system.

7.2 Suggestions

Here are some suggestions or recommendations from writer for the sake of future potential research.

1. It is suggested to also consider the inventory stockout cost, maintenance cost, penalty cost as the consequences of lost sales.

2. Writer suggests to get more detail and complete data in order to get better and more robust model. Therefore, the result can be more representative and make sense.
3. It suggested to observed the whole system of factory instead only observing a system of one production line to get more comprehension on the whole system of PT Spindo.
4. Detailing the type of product produced instead of generalizing the product along with its specification.
5. Conduct advanced research including other maintenance policy such as preventive maintenance and predictive maintenance on current observation object in order to get more significant result of availability and demand fulfillment.

(This page is intentionally left blank)

REFERENCES

Alrabghi, A. and Tiwari, A. (2016) 'A novel approach for modelling complex maintenance systems using discrete event simulation', *Reliability Engineering and System Safety*. Elsevier, 154, pp. 160–170. doi: 10.1016/j.ress.2016.06.003.

Alrabghi, A., Tiwari, A. and Savill, M. (2017) 'Simulation-based optimisation of maintenance systems : Industrial case studies', *Journal of Manufacturing Systems*. The Society of Manufacturing Engineers, 44, pp. 191–206. doi: 10.1016/j.jmsy.2017.05.008.

Altiok, T. & Melamed, B., 2007. *Simulation Modeling and Analysis with Arena.* New Jersey: Elsevier.

Arthama, I. R., 2006. Dissertation. *Perhitungan Plant Reliablity dan Pengendalian Risiko di Pabrik Phonska PT Petrokimia Gresik.*

Barringer, H. P. and Hotel, H. 1997. 'Availability , Reliability , Maintainability , and Capability'.

Budiman, R. N. T., 2006. Undergraduate Thesis. *Analisis Plant Reliability pada Unit Pembuatan Urea dengan Pendekatan Simulasi*

Choy, M. and Cheong, M. L. F. n.d. *Identification of Demand through Statistical Distribution Modeling for Imporved Demand Forecasting*. Singapore Management University. Singapore

Davidson, J. 1988, *The Reliability of Mechanical Systems* , Mechanical Engineering Publications Limited for The Institution of Mechanical Engineers, London.

Elsayed, E.A. 2012. *Reliability Engineering 2nd Edition*. John Wiley. USA

Harrel, C., Gosh, B. K. & Bowden, R. O., 2004. *Simulation Using Promodel.* 2nd ed. California: Mc. Graw Hill.

Indrajit, R.E., Djokopranoto, R. (2006). *Manajemen Persediaan*. Grasindo

Ireson, W. Grant, Clyde F. Coombs, Jr., Richard Y. Moss 1996, *Handbook of Reliability Engineering and Management, 2nd edition*, McGraw-Hill.

Kemenperin.go.id. (2018). Perkembangan Ekspor Kelompok Hasil Industri. [online] Available on : http://kemenperin.go.id/statistik/kelompok.php?ekspor=1 [diakses 20 Agustus 2018].

Kemenperin.go.id. (2018). Perkembangan Impor Kelompok Industri Logam Dasar. [online] Available on: http://www.kemenperin.go.id/statistik/subsektor.php?kode=202024&ekspor= [diakses 20 Agustus 2018].

Kementrian Perindustrian Indonesia, 2015. *Rencana Induk Pembangunan Industri Nasional 2015 - 2035*, Jakarta: Pusat Komunikasi Publik Kementrian Perindustrian Indonesia.

PT Spindo. 2018. Company Data Documentation

PT Spindo. 2017. Annual Report. *Marking The Precision Business*.

Rao, M. S. and Naikan, V. N. A. (2016) 'Review of Simulation Approaches in Reliability and Availability Modeling', 12(4), pp. 369–388.

Salsabila, N. Y., 2018. Undergraduate Thesis. *Analisis Availabilitas dengan Mempertimbangkan Inventory Sparepart dan Penyangga menggunakan Pendekatan Simulasi (Studi Kasus: PT Petrowidada)*

Sharda, B. & Bury, S. J., 2008. A Discrete Event Simulation Model for Reliability Modelling of A Chemical Plant. *Proceeding of the 2008 Winter Simulation Conference.*

Short, T. (n.d.). *How to Optimize Your Spare Parts Inventory Control System*. [online] Software Advice. Available at: https://www.softwareadvice.com/resources/optimize-inventory-control-system/ [Accessed 7 Oct. 2018].

Siswanto, N., Latiffianti, E., Wiratno, S.E., 2017. *Simulasi Sistem Diskrit Implementasi dengan Software Arena*. ITS Tekno Sains

Steel, M. (2016). *6 Effective Ways to Improve Manufacturing Throughput*. [online] Marlinwire.com. Available at: https://www.marlinwire.com/blog/improve-manufacturing-throughput [Accessed 6 Oct. 2018].

Tersine, R.J. (1994). *Principles of Inventory and Materials Management Fourth Edition*. Prentice Hall

Waters, D., 2003. *Inventory Control and Demand Management.* 2nd ed. India: Wiley.

Wilkinson, J. (2018). *Throughput Definition | Throughput Variables* • The Strategic CFO. [online] The Strategic CFO. Available at: https://strategiccfo.com/throughput/ [Accessed 6 Oct. 2018].

Zahedi-hosseini, F., Scarf, P. and Syntetos, A. (2017) 'Joint optimisation of inspection maintenance and spare parts provisioning : a comparative study of inventory policies using simulation and survey data', *Reliability Engineering and System Safety*. Elsevier Ltd, 168(March), pp. 306–316. doi: 10.1016/j.ress.2017.03.007.

(This page is intentionally left blank)

APPENDIXES

Appendix 1: Spare Part Inventory Level of Existing Condition

Day	Spare Part Inventory Level																									
	SP 400889	SP 400923	SP 401040	SP 407797	SP 100159	SP 401107	SP 410107	SP 404205	SP 404206	SP 404213	SP 404211	SP 404247	SP 414407	SP 401565	SP 412019	SP 412095	SP 401896	SP 404314	SP 402583	SP 413703	SP 413260	SP 405189	SP 403265	SP 403244	SP 406898	SP 414477
1	2	1	3	3	15	3	1	18	4	0	13	4	65	2	0	0	1	1	1	0	1	33	1	2	65	17
2	2	1	3	3	15	3	1	18	4	0	13	4	65	2	0	0	1	1	1	0	1	33	1	2	65	17
3	2	1	3	3	15	3	1	18	4	0	13	4	65	2	0	0	1	1	1	0	1	33	1	2	65	17
4	2	1	3	3	15	3	1	18	4	0	13	4	65	2	0	0	1	1	1	0	1	33	1	2	65	17
5	2	1	3	3	15	3	1	18	4	0	13	4	65	2	0	0	1	1	1	0	1	33	1	2	65	17
6	2	1	3	3	10	3	1	18	4	0	13	4	65	2	0	0	1	1	1	0	1	33	1	2	65	17
7	2	1	3	3	10	3	1	18	4	0	13	4	65	2	0	0	1	1	1	0	1	33	1	2	65	17
8	2	1	3	3	10	3	1	18	4	0	13	4	65	2	0	0	1	1	1	0	1	33	1	2	65	17
9	2	0	6	4	157	6	2	42	26	22	36	4	28	2	8	24	4	2	0	1	4	74	2	2	65	56
10	2	0	6	4	157	6	2	42	26	22	36	4	28	2	8	24	4	2	0	1	4	74	2	2	65	56
11	2	0	6	4	157	6	2	42	26	22	36	4	28	2	8	24	4	2	0	1	4	74	2	2	65	56
12	2	0	6	4	157	6	2	42	26	22	36	4	28	2	8	24	4	2	0	1	4	74	2	2	65	56
13	2	0	6	4	157	6	2	42	26	22	36	4	28	2	8	24	4	2	0	1	4	74	2	2	65	56
14	2	0	6	4	157	6	2	42	26	22	36	4	28	2	8	24	4	2	0	1	4	74	2	2	65	56
15	2	3	6	4	157	6	2	42	26	22	36	4	124	2	8	24	4	2	3	2	4	74	2	2	65	56
16	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
17	2	3	6	4	157	6	2	42	26	22	36	4	124	4	3	24	4	2	3	2	4	74	2	2	65	56
18	2	3	6	4	157	6	2	42	26	22	36	4	124	4	3	24	4	2	3	2	4	74	2	2	65	56
19	2	3	6	4	157	6	2	42	26	22	36	4	124	4	3	24	4	2	3	2	4	74	2	2	65	56
20	2	3	6	4	157	6	2	42	26	22	36	4	124	4	3	24	4	2	3	2	4	74	2	2	65	56
21	2	3	6	4	157	6	2	42	26	22	36	4	124	4	3	24	4	2	3	2	4	74	2	2	65	56
22	2	3	6	4	157	6	2	42	26	22	36	4	124	4	3	24	4	2	3	2	4	74	2	2	65	56

Day	Spare Part Inventory Level																									
	SP 400889	SP 400923	SP 401040	SP 407797	SP 100159	SP 401107	SP 410107	SP 404205	SP 404206	SP 404213	SP 404211	SP 404247	SP 414407	SP 401565	SP 412019	SP 412095	SP 401896	SP 404314	SP 402583	SP 413703	SP 413260	SP 405189	SP 403265	SP 403244	SP 406898	SP 414477
23	2	0	4	4	157	6	2	42	26	22	36	4	124	4	3	24	4	2	0	2	4	74	2	2	65	56
24	2	0	4	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	0	2	4	74	2	2	65	56
25	2	0	4	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	0	2	4	74	2	2	65	56
26	2	0	4	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	0	2	4	74	2	2	65	56
27	2	0	4	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	0	2	4	74	2	2	65	56
28	2	0	4	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	0	2	4	74	2	2	65	56
29	2	0	4	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	0	2	4	74	2	2	65	56
30	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
31	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	1	4	2	3	2	4	74	2	2	65	56
32	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	1	4	2	3	2	4	74	2	2	65	56
33	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	1	4	2	3	2	4	74	2	2	65	56
34	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	1	4	2	3	2	4	74	2	2	65	56
35	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	1	4	2	3	2	4	74	2	2	65	56
36	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	1	4	2	3	2	4	74	2	2	65	56
37	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	1	4	2	3	2	4	74	2	2	65	56
38	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
39	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
40	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
41	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
42	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
43	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
44	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
45	2	0	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
46	2	0	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
47	2	0	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
48	2	0	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
49	2	0	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
50	2	0	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56

Day	Spare Part Inventory Level																								
	SP 400889	SP 400923	SP 401040	SP 407797	SP 100159	SP 401107	SP 410107	SP 404205	SP 404206	SP 404213	SP 404211	SP 404247	SP 414407	SP 401565	SP 412019	SP 412095	SP 401896	SP 404314	SP 402583	SP 413703	SP 413260	SP 405189	SP 403265	SP 403244	SP 406898	SP 414477
51	2	0	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
52	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
53	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
54	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
55	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
56	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
57	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
58	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
59	2	3	6	2	157	6	2	42	26	22	36	4	124	4	8	24	2	2	3	2	4	74	2	2	65	56
60	2	3	6	2	157	6	2	42	26	22	36	4	124	4	8	24	2	2	3	2	4	74	2	2	65	56
61	2	3	6	2	157	6	2	42	26	22	36	4	124	4	8	24	2	2	3	2	4	74	2	2	65	56
62	2	3	6	2	157	6	2	42	26	22	36	4	124	4	8	24	2	2	3	2	4	74	2	2	65	56
63	2	3	6	2	157	6	2	42	26	22	36	4	124	4	8	24	2	2	3	2	4	74	2	2	65	56
64	2	3	6	2	157	6	2	42	26	22	36	4	124	4	8	24	2	2	3	2	4	74	2	2	65	56
65	2	3	6	2	157	6	2	42	26	22	36	4	124	4	8	24	2	2	3	2	4	74	2	2	65	56
66	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
67	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	0	2	4	74	2	2	65	56
68	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	0	2	4	74	2	2	65	56
69	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	0	2	4	74	2	2	65	56
70	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	0	2	4	74	2	2	65	56
71	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	0	2	4	74	2	2	65	56
72	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	3	2	0	2	4	74	2	2	65	56
73	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	3	2	0	2	4	74	2	2	65	56
74	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	3	2	3	2	4	74	2	2	65	56
75	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	3	2	3	2	4	74	2	2	65	56
76	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	3	2	3	2	4	74	2	2	65	56
77	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	3	2	3	2	4	74	2	2	65	56
78	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	3	2	3	2	4	74	2	2	65	56

Day	Spare Part Inventory Level																									
	SP 400889	SP 400923	SP 401040	SP 407797	SP 100159	SP 401107	SP 410107	SP 404205	SP 404206	SP 404213	SP 404211	SP 404247	SP 414407	SP 401565	SP 412019	SP 412095	SP 401896	SP 404314	SP 402583	SP 413703	SP 413260	SP 405189	SP 403265	SP 403244	SP 406898	SP 414477
79	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
80	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
81	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
82	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
83	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
84	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
85	2	3	6	4	157	6	2	42	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
86	2	3	6	4	157	6	2	37	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
87	2	3	6	4	157	6	2	37	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
88	2	3	6	4	157	6	2	37	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
89	2	3	6	4	157	6	2	37	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
90	2	3	6	4	157	6	2	37	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
91	2	3	6	4	157	6	2	37	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
92	2	3	6	4	157	6	2	37	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
93	2	3	6	4	157	6	2	37	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
94	2	3	6	4	157	6	2	37	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
95	2	3	6	4	157	6	2	37	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
96	2	3	6	4	157	6	2	37	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
97	2	3	6	4	157	6	2	37	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
98	2	3	6	4	157	6	2	37	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
99	2	3	6	4	157	6	2	37	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56
100	2	3	6	4	157	6	2	37	26	22	36	4	124	4	8	24	4	2	3	2	4	74	2	2	65	56

Appendix 2: Spare Part Inventory Level of Scenario 19

Day	SP 400923	SP 410107	SP 412019	SP 402583
1	1	1	0	1
2	1	1	0	1
3	1	1	0	1
4	1	1	0	1
5	1	1	0	1
6	1	1	0	1
7	1	1	0	1
8	1	1	0	1
9	5	23	135	18
10	5	23	135	18
11	5	23	135	18
12	5	23	135	18
13	5	23	135	18
14	5	23	135	18
15	5	23	135	18
16	5	23	135	18
17	5	23	130	18
18	5	23	130	18
19	5	23	130	18
20	5	23	130	18
21	5	23	130	18
22	5	23	130	18
23	2	23	130	15
24	2	23	130	15
25	2	23	130	15
26	2	23	130	15
27	2	23	130	15
28	2	23	130	15
29	2	23	130	15
30	9	23	130	15
31	9	23	130	15
32	9	23	130	15
33	9	23	130	15
34	9	23	130	15
35	9	23	130	15
36	9	23	130	15
37	9	23	130	15
38	9	23	130	15
39	9	23	130	15
40	9	23	130	15
41	9	23	130	15
42	9	23	130	15
43	9	23	130	15
44	9	23	130	15
45	6	23	130	15
46	6	23	130	15
47	6	23	130	15
48	6	23	130	15
49	6	23	130	15

Day	SP 400923	SP 410107	SP 412019	SP 402583
50	6	23	130	15
51	6	23	130	15
52	6	23	130	15
53	6	23	130	15
54	6	23	130	15
55	6	23	130	15
56	6	23	130	15
57	6	23	130	15
58	6	23	130	15
59	6	23	130	15
60	6	23	130	15
61	6	23	130	15
62	6	23	130	15
63	6	23	130	15
64	6	23	130	15
65	6	23	130	15
66	6	23	130	15
67	6	23	130	12
68	6	23	130	12
69	6	23	130	12
70	6	23	130	12
71	6	23	130	12
72	6	23	130	12
73	6	23	130	12
74	6	23	130	12
75	6	23	130	12
76	6	23	130	12
77	6	23	130	12
78	6	23	130	12
79	6	23	130	12
80	6	23	130	12
81	6	23	130	12
82	6	23	130	12
83	6	23	130	12
84	6	23	130	12
85	6	23	130	12
86	6	23	130	12
87	6	23	130	12
88	6	23	130	12
89	6	23	130	12
90	6	23	130	12
91	6	23	130	12
92	6	23	130	12
93	6	23	130	12
94	6	23	130	12
95	6	23	130	12
96	6	23	130	12
97	6	23	130	12
98	6	23	130	12

Day	SP 400923	SP 410107	SP 412019	SP 402583
99	6	23	130	12
100	6	23	130	12
101	6	23	130	12
102	6	23	130	12
103	6	23	130	12
104	6	23	130	12
105	6	23	130	12
106	6	23	130	12
107	6	23	130	12
108	6	23	130	12
109	6	23	130	12
110	6	23	130	12
111	6	23	130	12
112	6	23	130	12
113	6	23	130	12
114	6	23	130	12
115	6	23	130	12
116	6	23	130	12
117	6	23	130	12
118	6	23	130	12
119	6	23	130	12
120	6	23	130	12
121	6	23	130	12
122	6	23	130	12
123	6	23	130	12
124	6	23	130	12
125	6	23	130	12
126	6	23	130	12
127	6	23	130	12
128	6	23	130	12
129	6	23	130	12
130	6	23	130	12
131	6	23	130	12
132	6	23	130	12
133	6	23	130	12
134	6	23	130	12
135	6	23	130	12
136	6	23	130	12
137	6	23	130	12
138	6	23	130	12
139	6	23	130	12
140	6	23	130	12
141	6	23	130	12
142	6	23	130	12
143	6	23	130	12
144	6	23	130	12
145	6	23	130	12
146	6	23	130	12
147	6	23	130	12

Appendix 3: Spare Part Inventory Level of Scenario 18

Day	SP 400923	SP 410107	SP 412019	SP 402583
1	1	1	0	1
2	1	1	0	1
3	1	1	0	1
4	1	1	0	1
5	1	1	0	1
6	1	1	0	1
7	1	1	0	1
8	1	1	0	1
9	5	23	135	18
10	5	23	135	18
11	5	23	135	18
12	5	23	135	18
13	5	23	135	18
14	5	23	135	18
15	5	23	135	18
16	5	23	135	18
17	5	23	130	18
18	5	23	130	18
19	5	23	130	18
20	5	23	130	18
21	5	23	130	18
22	5	23	130	18
23	2	23	130	15
24	2	23	130	15
25	2	23	130	15
26	2	23	130	15
27	2	23	130	15
28	2	23	130	15
29	2	23	130	15
30	2	23	130	15
31	2	23	130	15
32	2	23	130	15
33	2	23	130	15
34	2	23	130	15
35	2	23	130	15
36	2	23	130	15
37	2	23	130	15
38	2	23	130	15
39	2	23	130	15
40	2	23	130	15
41	2	23	130	15
42	2	23	130	15
43	2	23	130	15
44	2	23	130	15
45	2	23	130	15
46	2	23	130	15
47	2	23	130	15
48	2	23	130	15
49	2	23	130	15

Day	SP 400923	SP 410107	SP 412019	SP 402583
50	2	23	130	15
51	2	23	130	15
52	6	23	130	15
53	6	23	130	15
54	6	23	130	15
55	6	23	130	15
56	6	23	130	15
57	6	23	130	15
58	6	23	130	15
59	6	23	130	15
60	6	23	130	15
61	6	23	130	15
62	6	23	130	15
63	6	23	130	15
64	6	23	130	15
65	6	23	130	15
66	6	23	130	15
67	4	23	130	15
68	4	23	130	15
69	4	23	130	15
70	4	23	130	15
71	4	23	130	15
72	4	23	130	15
73	4	23	130	15
74	4	23	130	15
75	4	23	130	15
76	4	23	130	15
77	4	23	130	15
78	4	23	130	15
79	4	23	130	15
80	4	23	130	15
81	4	23	130	15
82	4	23	130	15
83	4	23	130	15
84	4	23	130	15
85	4	23	130	15
86	4	23	130	15
87	4	23	130	15
88	4	23	130	15
89	2	23	130	15
90	2	23	130	15
91	2	23	130	15
92	2	23	130	15
93	2	23	130	15
94	2	23	130	15
95	2	23	130	15
96	2	23	130	15
97	2	23	130	15
98	2	23	130	15

Day	SP 400923	SP 410107	SP 412019	SP 402583
99	2	23	130	15
100	2	23	130	15
101	2	23	130	15
102	2	23	130	15
103	2	23	130	15
104	2	23	130	15
105	2	23	130	15
106	2	23	130	15
107	2	23	130	15
108	2	23	125	15
109	2	23	125	15
110	2	23	125	15
111	2	23	125	15
112	2	23	125	15
113	2	23	125	15
114	2	23	125	15
115	2	23	125	15
116	2	23	125	15
117	2	23	125	15
118	2	23	125	15
119	2	23	125	15
120	2	23	125	15
121	2	23	125	15
122	2	23	125	15
123	2	23	125	15
124	2	23	125	15
125	2	23	125	15
126	2	23	125	15
127	2	23	125	15
128	2	23	117	15
129	2	23	117	15
130	2	23	117	15
131	2	23	117	15
132	2	23	117	15
133	2	23	117	15
134	2	23	117	15
135	2	23	117	15
136	2	23	117	15
137	2	23	117	15
138	2	23	112	15
139	2	23	112	15
140	2	23	112	15
141	2	23	112	15
142	2	23	112	15
143	2	23	112	15
144	2	23	112	15
145	2	23	112	15
146	2	23	112	15
147	2	23	112	15

Appendix 4: Calculating Daily Holding Cost

Day	SP 400889	Daily HC	SP 400923	Daily HC	SP 401040	Daily HC	SP 407797	Daily HC	SP 100159	Daily HC	SP 401107	Daily HC	SP 410107	Daily HC	SP 404205	Daily HC	SP 404206	Daily HC	SP 404213	Daily HC
1	2	Rp 235.62	1	Rp 486.58	3	Rp 41.10	3	Rp 49.81	15	Rp 218.63	3	Rp 30	1	Rp 7	18	Rp 247	4	Rp 64	0	Rp -
2	2	Rp 235.62	1	Rp 486.58	3	Rp 41.10	3	Rp 49.81	15	Rp 218.63	3	Rp 30	1	Rp 7	18	Rp 247	4	Rp 64	0	Rp -
3	2	Rp 235.62	1	Rp 486.58	3	Rp 41.10	3	Rp 49.81	15	Rp 218.63	3	Rp 30	1	Rp 7	18	Rp 247	4	Rp 64	0	Rp -
4	2	Rp 235.62	1	Rp 486.58	3	Rp 41.10	3	Rp 49.81	15	Rp 218.63	3	Rp 30	1	Rp 7	18	Rp 247	4	Rp 64	0	Rp -
5	2	Rp 235.62	1	Rp 486.58	3	Rp 41.10	3	Rp 49.81	15	Rp 218.63	3	Rp 30	1	Rp 7	18	Rp 247	4	Rp 64	0	Rp -
6	2	Rp 235.62	1	Rp 486.58	3	Rp 41.10	3	Rp 49.81	10	Rp 145.75	3	Rp 30	1	Rp 7	18	Rp 247	4	Rp 64	0	Rp -
7	2	Rp 235.62	1	Rp 486.58	3	Rp 41.10	3	Rp 49.81	10	Rp 145.75	3	Rp 30	1	Rp 7	18	Rp 247	4	Rp 64	0	Rp -
8	2	Rp 235.62	1	Rp 486.58	3	Rp 41.10	3	Rp 49.81	10	Rp 145.75	3	Rp 30	1	Rp 7	18	Rp 247	4	Rp 64	0	Rp -
9	2	Rp 235.62	0	Rp -	6	Rp 82.19	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
10	2	Rp 235.62	0	Rp -	6	Rp 82.19	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
11	2	Rp 235.62	0	Rp -	6	Rp 82.19	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
12	2	Rp 235.62	0	Rp -	6	Rp 82.19	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
13	2	Rp 235.62	0	Rp -	6	Rp 82.19	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
14	2	Rp 235.62	0	Rp -	6	Rp 82.19	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
15	2	Rp 235.62	3	Rp 1,459.73	6	Rp 82.19	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
16	2	Rp 235.62	3	Rp 1,459.73	6	Rp 82.19	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
17	2	Rp 235.62	3	Rp 1,459.73	6	Rp 82.19	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
18	2	Rp 235.62	3	Rp 1,459.73	6	Rp 82.19	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
19	2	Rp 235.62	3	Rp 1,459.73	6	Rp 82.19	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
20	2	Rp 235.62	3	Rp 1,459.73	6	Rp 82.19	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
21	2	Rp 235.62	3	Rp 1,459.73	6	Rp 82.19	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
22	2	Rp 235.62	3	Rp 1,459.73	6	Rp 82.19	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
23	2	Rp 235.62	0	Rp -	4	Rp 54.79	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
24	2	Rp 235.62	0	Rp -	4	Rp 54.79	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
25	2	Rp 235.62	0	Rp -	4	Rp 54.79	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
26	2	Rp 235.62	0	Rp -	4	Rp 54.79	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
27	2	Rp 235.62	0	Rp -	4	Rp 54.79	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482
28	2	Rp 235.62	0	Rp -	4	Rp 54.79	4	Rp 66.41	157	Rp 2,288.33	6	Rp 61	2	Rp 14	42	Rp 575	26	Rp 413	22	Rp 482

Day	SP 404211	Daily HC	SP 404247	Daily HC	SP 414407	Daily HC	SP 401565	Daily HC	SP 412019	Daily HC	SP 412095	Daily HC	SP 401896	Daily HC	SP 404314	Daily HC	SP 402583	Daily HC
1	13	Rp 413	4	Rp 3	65	Rp 14	2	Rp 16	0	Rp -	0	Rp -	1	Rp 245.48	1	Rp 4,706.85	1	Rp 63.01
2	13	Rp 413	4	Rp 3	65	Rp 14	2	Rp 16	0	Rp -	0	Rp -	1	Rp 245.48	1	Rp 4,706.85	1	Rp 63.01
3	13	Rp 413	4	Rp 3	65	Rp 14	2	Rp 16	0	Rp -	0	Rp -	1	Rp 245.48	1	Rp 4,706.85	1	Rp 63.01
4	13	Rp 413	4	Rp 3	65	Rp 14	2	Rp 16	0	Rp -	0	Rp -	1	Rp 245.48	1	Rp 4,706.85	1	Rp 63.01
5	13	Rp 413	4	Rp 3	65	Rp 14	2	Rp 16	0	Rp -	0	Rp -	1	Rp 245.48	1	Rp 4,706.85	1	Rp 63.01
6	13	Rp 413	4	Rp 3	65	Rp 14	2	Rp 16	0	Rp -	0	Rp -	1	Rp 245.48	1	Rp 4,706.85	1	Rp 63.01
7	13	Rp 413	4	Rp 3	65	Rp 14	2	Rp 16	0	Rp -	0	Rp -	1	Rp 245.48	1	Rp 4,706.85	1	Rp 63.01
8	13	Rp 413	4	Rp 3	65	Rp 14	2	Rp 16	0	Rp -	0	Rp -	1	Rp 245.48	1	Rp 4,706.85	1	Rp 63.01
9	36	Rp 1,144	4	Rp 3	28	Rp 6	2	Rp 16	8	Rp 7	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	0	Rp -
10	36	Rp 1,144	4	Rp 3	28	Rp 6	2	Rp 16	8	Rp 7	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	0	Rp -
11	36	Rp 1,144	4	Rp 3	28	Rp 6	2	Rp 16	8	Rp 7	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	0	Rp -
12	36	Rp 1,144	4	Rp 3	28	Rp 6	2	Rp 16	8	Rp 7	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	0	Rp -
13	36	Rp 1,144	4	Rp 3	28	Rp 6	2	Rp 16	8	Rp 7	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	0	Rp -
14	36	Rp 1,144	4	Rp 3	28	Rp 6	2	Rp 16	8	Rp 7	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	0	Rp -
15	36	Rp 1,144	4	Rp 3	124	Rp 27	2	Rp 16	8	Rp 7	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	3	Rp 189.04
16	36	Rp 1,144	4	Rp 3	124	Rp 27	4	Rp 33	8	Rp 7	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	3	Rp 189.04
17	36	Rp 1,144	4	Rp 3	124	Rp 27	4	Rp 33	3	Rp 2	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	3	Rp 189.04
18	36	Rp 1,144	4	Rp 3	124	Rp 27	4	Rp 33	3	Rp 2	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	3	Rp 189.04
19	36	Rp 1,144	4	Rp 3	124	Rp 27	4	Rp 33	3	Rp 2	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	3	Rp 189.04
20	36	Rp 1,144	4	Rp 3	124	Rp 27	4	Rp 33	3	Rp 2	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	3	Rp 189.04
21	36	Rp 1,144	4	Rp 3	124	Rp 27	4	Rp 33	3	Rp 2	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	3	Rp 189.04
22	36	Rp 1,144	4	Rp 3	124	Rp 27	4	Rp 33	3	Rp 2	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	3	Rp 189.04
23	36	Rp 1,144	4	Rp 3	124	Rp 27	4	Rp 33	3	Rp 2	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	0	Rp -
24	36	Rp 1,144	4	Rp 3	124	Rp 27	4	Rp 33	8	Rp 7	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	0	Rp -
25	36	Rp 1,144	4	Rp 3	124	Rp 27	4	Rp 33	8	Rp 7	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	0	Rp -
26	36	Rp 1,144	4	Rp 3	124	Rp 27	4	Rp 33	8	Rp 7	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	0	Rp -
27	36	Rp 1,144	4	Rp 3	124	Rp 27	4	Rp 33	8	Rp 7	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	0	Rp -
28	36	Rp 1,144	4	Rp 3	124	Rp 27	4	Rp 33	8	Rp 7	24	Rp 20	4	Rp 981.92	2	Rp 9,413.70	0	Rp -

Day	SP 413703	Daily HC	SP 413260	Daily HC	SP 405189	Daily HC	SP 403265	Daily HC	SP 403244	Daily HC	SP 406898	Daily HC	SP 414477	Daily HC
1	0	Rp -	1	Rp 30.14	33	Rp 994.52	1	Rp 0.66	2	Rp 1.32	65	Rp 993.70	17	Rp 46.58
2	0	Rp -	1	Rp 30.14	33	Rp 994.52	1	Rp 0.66	2	Rp 1.32	65	Rp 993.70	17	Rp 46.58
3	0	Rp -	1	Rp 30.14	33	Rp 994.52	1	Rp 0.66	2	Rp 1.32	65	Rp 993.70	17	Rp 46.58
4	0	Rp -	1	Rp 30.14	33	Rp 994.52	1	Rp 0.66	2	Rp 1.32	65	Rp 993.70	17	Rp 46.58
5	0	Rp -	1	Rp 30.14	33	Rp 994.52	1	Rp 0.66	2	Rp 1.32	65	Rp 993.70	17	Rp 46.58
6	0	Rp -	1	Rp 30.14	33	Rp 994.52	1	Rp 0.66	2	Rp 1.32	65	Rp 993.70	17	Rp 46.58
7	0	Rp -	1	Rp 30.14	33	Rp 994.52	1	Rp 0.66	2	Rp 1.32	65	Rp 993.70	17	Rp 46.58
8	0	Rp -	1	Rp 30.14	33	Rp 994.52	1	Rp 0.66	2	Rp 1.32	65	Rp 993.70	17	Rp 46.58
9	1	Rp 79.45	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
10	1	Rp 79.45	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
11	1	Rp 79.45	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
12	1	Rp 79.45	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
13	1	Rp 79.45	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
14	1	Rp 79.45	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
15	2	Rp 158.90	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
16	2	Rp 158.90	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
17	2	Rp 158.90	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
18	2	Rp 158.90	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
19	2	Rp 158.90	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
20	2	Rp 158.90	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
21	2	Rp 158.90	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
22	2	Rp 158.90	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
23	2	Rp 158.90	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
24	2	Rp 158.90	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
25	2	Rp 158.90	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
26	2	Rp 158.90	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
27	2	Rp 158.90	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42
28	2	Rp 158.90	4	Rp 120.55	74	Rp 2,230.14	2	Rp 1.32	2	Rp 1.32	65	Rp 993.70	56	Rp 153.42

(This page is intentionally left blank)

AUTHOR'S BIOGRAPHY

The author is named Ahmed Raecky Baihaqy and was born on March 14,1997. During studies, the author had attended elementary school in SDN Kandangan I /121/ Surabaya , junior high school in SMP Negeri 3 Surabaya, and senior high school in SMA Negeri 5 Surabaya. Afterwards, the author got bachelor degree in Department of Industrial Engineering, Institut Teknologi Sepuluh Nopember after attending the college for 7 semesters.

During college life, the author not only focuses on academic matters but also has experience on non academic things. The author was a staff of IE Fair Division, Himpunan Mahasiswa Teknik Industri (HMTI) ITS for 1 year and was an active volunteer at ITS International Office for 3 semesters and now is a passive volunteer. The author also had experienced in being a committee in some events such as IE Games 12th Edition, INCHALL 2017, Global Competencies Workshop, and CommTECH.

The author was also active as the laboraroty assistant of Quantitative Modelling and Industrial Policy Analysis (QMIPA) Laboratory, Industrial Engineering Department on both odd and even semester 2017/2018, and being the assistant coordinator at the same lab on odd semester 2018/2019. The author also ever be a trainer at ARENA Training 2018 where ARENA is the discrete event simulation software. During college as well, the author ever got the award such as 4th place in Industrial Challenge (INCHALL) 2018 held by HMTI ITS which is an international scale competition in industrial engineering field. Should any questions and need of further information regarding to this research, you may contact the author via email baihaqy.ahmed@gmail.com.