IMPLEMENTATION OF PREVENTIVE MAINTENANCE SYSTEM IN AUTO MACHINE TOY ASSEMBLY TO INCREASE MACHINE RELIABILITY IN TOY MANUFACTURING COMPANY

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THESES ADVISOR
RECOMMENDATION LETTER

This thesis entitled **“Implementation of preventive Maintenance System in Auto Machine Toy Assembly to Increase Machine Reliability in Toy Manufacturing Company”** prepared and submitted by **Valentina Novita Bere** in partial fulfillment of the requirements for the degree of Bachelor Degree in the Faculty of Engineering has been reviewed and found to have satisfied the requirements for a thesis fit to be examined. I therefore recommend this thesis for Oral Defense.

Cikarang, Indonesia, 31st January, 2017

Anastasia Lidya Maukar, ST., MSc., MMT.

DECLARATION OF ORIGINALITY

I declare that this thesis, entitled **"Implementation of Preventive Maintenance System in Auto Machine Toy Assembly to Increase Reliability of Machine in Toy Manufacturing Company"** is, to the best of my knowledge and belief, an original piece of work that has not been submitted, either in whole or in part, to another university to obtain a degree.

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ABSTRACT

During the production process, machine performance can be seen from the data of machine downtime. Machine with greater number of downtime is the machine that has a low reliability. The objectives of this study are to identify the components which activate dowtown machine and to propose the shcedule of preventive maintenance. The data was taken in Toy assembly area (TA) of toy manufacturing company in Jababeka and observation was used to collect the data. To develop preventive maintenance schedule in order to get the interval time of machine failure based on target of reliability, several steps which are analyzing the current data based on the types of components, calculating Time to Repair (TTR), time to failure (TTF), mean time to repair (MTTR) and mean time to failure (MTTF) were used. The calculation of each component is based on the failure distribution that fit for the components failure data. After implementing the preventive maintenance, the result of the calculation in the proposed condition shows that all the component can achieve the target of reliability 80% with the average reliability of each component increase by 50.7%. In addition, through the implementation of preventive maintenance,cost of maintenance reduces by 21% on average, production loss can be eliminated and downtime reduces by 9% on average.

Keywords: Preventive maintenance, Reliability, Failure distribution, TTF, TTR, MTTF, MTTR.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF THERMINOLOGIES

Breakdown machine	:	condition when the machine cannot operate due to the failure of the component
Downtime machine	:	time during the machine can not operate caused by failure of a component of machine
MTTF	:	The average time between two failures.
MTTR	:	The average time needed to repair a failed components or machine.
Preventive Maintenance	:	a maintenance system with scheduled downtime which is usually periodical based on the interval time
Reliability	:	is the probability that an item will perform a required function under stated condition for a stated period of time
TTF	:	Time to failure is the duration from one failure to the next failure.
TTR	:	Time to repair is the time from the machine or component start to repair until finish.

CHAPTER I
INTRODUCTION

1.1 Problem Background

Machine performance is the one of important aspect in production process that should be optimized in order to support the productivity in line production. Every machine in line production should run optimally. The performance of machine can be shown from the downtime machine that occurred during production time. Maintenance can be assigned as the all appropriated action in order to keep equipment or bring it back to a given condition (Dillhon, 2002). In order to support the optimization of machine performance, there is an action to maintain the performance of the machine, which is to plan the schedule for the machine maintenance based on the duration time of downtime machine. This action is usually called preventive maintenance. Preventive maintenance is a system to develop schedule of machine downtime which occurred in machine or component of machine (Ebeling, 1997).

PT. OPQ is a toy manufacturing company which produces many types of toy. Production process in PT. OPQ is defined into several stages. These stages are Rotocast, Molding, Torso Assembly (TA), Rooting and Pack out. Every process in each stage affects the process of the other stage. The process should follow the sequence, so if there are some problems in the Rotocast it will delay the process in the next stage. Every process in each stage has been plot in time scheduled in order to make sure that the products are available based on the customer demand. So, every process in each stage should follow the schedule.

There is a project to optimize line production especially to increase machine performance in Torso Assembly area, so this research will concern in Torso Assembly area. Torso Assembly (TA) is the area or stage which the material or part from molding will be assembled become toy’s body and toy’s accessories. There are several production lines in TA classified based on the type of machine or tools used for assembly process. Almost of the assembly process in TA is done by the machine.

Therefore, the machine should be running well during the production process. The important aspect that must be considered in this process is machine performance.

There is one line production called Auto line that consists of 4 auto machines. This line runs automatically by the machine. Based on the downtime report of this auto machine in the last six months, the percentage of downtime was 55% of total production period. From initial observation, auto machine in line 2 had the highest number of downtime. It means the machine in auto line 2 is the most frequently failure production process. Machine downtime can stop production process because this machine will be repaired. When the process production in this line stops, it will cause low achievement of targeted output. If the output of that day is not achieved because of the machine breakdown, there is an overtime to fulfill the production target that should be achieved. To solve this problem, the machine should have preventive schedule in order to avoid the downtime machine during production time and also to increase the reliability of machine.

1.2 Problem Statement

Based on the problem background, the problem statements of this research are as follows;

1. Which components did activate the downtime machine occurred frequently in machine Auto 2?
2. How does the company determine schedule preventive maintenance on machine Auto 2 to increase reliability of machine and reduce maintenance cost?

1.3 Research Objective

The objectives of this report are:

1. To identify the critical components which affect machine downtime.
2. To determine the interval of preventive maintenance schedule in order to increase machine reliability and reduce maintenance cost.

1.4 Scope

1. The data observed was the one from January 2016 until July 2016.
2. Downtime machine began from the machine start to repair until the repairing component is done.
3. This observation started from August 2016 until December 2016.

1.5 Assumption

1. All the auto machine is identical machine that has same function.
2. There is no price increase of machine components.
3. Availability of spare parts.
4. The skill of all mechanics in order to repair the component and change the component is alike.

1.6 Research Outline

Chapter I Introduction

This chapter consists of the explanation of problem background, problem identification, research objective, scope and assumption during the observation was conducted.

Chapter II Literature Study

This chapter presents the theory of maintenance, types of maintenance, theory of reliability, maintainability and several distributions to create preventive maintenance.

Chapter III Research Methodology

This chapter explains the whole process of research. It presents the initial observation to collect the information of the process production in PT.OPQ, and the method how to solve the problems. They are shown in research framework and research flowchart.

Chapter IV Data Analysis

This chapter provides information about how the data collected is identified. Furthermore, it contains analysis of data that has been collected in previous chapter. All the calculation is done on this chapter. All the data is analyzed based on the method of reliability machine that has been explained in chapter two. The proper schedule of preventive maintenance created from the result of calculation and analyst data is also available in this chapter.

Chapter V Conclusion and Recommendation

This chapter presents the conclusion of the whole research process. The result and improvement is explained in this chapter. Recommendation for future research is presented in this chapter as well.

CHAPTER II
LITERATURE STUDY

2.1 Definition of Maintenance

Maintenance is an activity to maintain and repaire the machine and tools in order to get a good condition of production process using machine and to make the process can run well. Maintenance can be assigned as the all appropriated action in order to keep equipment or bring it back to a given condition (Dillhon, 2002). Maintenance is a combination of each action done to maintain a machine or tools in production process or to repaire the machine or tools in order to get the good condition of the machine or tools (James, 1998). According to Assuari (2008) there are several purposes to conduct machine maintenance:

- The capability of production to achieve the target as production planning.
- Keep the quality of process production so there is no distraction during the production process.
- To reduce number of consuming and inventory of capital investment that out of limit during the duration that already planned by the company.
- To achieve the lowest maintenance cost, through conduct the effective way to maintain the machine.

2.2 Types of Maintenance

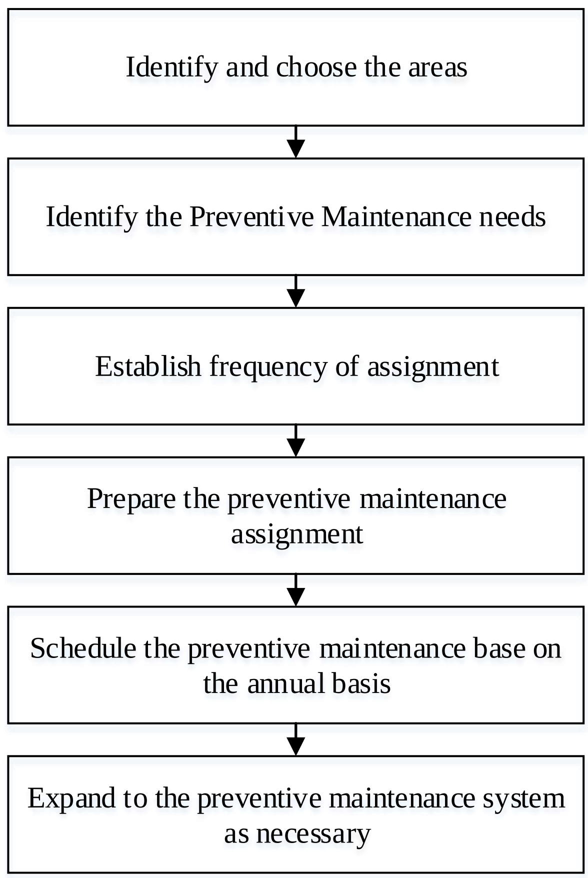
According to Dillhon (2002), there are two types of maintenance. They are preventive maintenance and corrective maintenance. These types of maintenance are described below:

2.2.1 Preventive Maintenance

Preventive maintenance is a simple method to ensure machine reliability and the efficiency of process production in line manufacturing. Preventive maintenance is the maintenance conducted based on the planed intervals of time. The purpose of preventive maintenance is to maintain the machine in optimum working condition to prevent any unplanned downtime due to breakdown which occurs at the critical point in time to fulfill the most important customers order. Preventive maintenance can include measuring and checking component as well as the replacement of various components. According to Dillhon (2002), preventive maintenance consists of seven elements which are:

1. Inspection: this activity is conducted periodically in order to define the equipment or machine service ability through comparing several condition of machine such as physical condition, electrical condition, mechanical condition, etc., feature to the expectation of standards.
2. Servicing: this activity is conducted periodically in order to clean the machine, give the lubricant to the machine or component, preservation, etc., in order to avoid the failure that might occure in that machine or equipment.
3. Calibration: this activity is conducted periodically in order to define the specific value of equipment by comparing with the standard.
4. Testing: activity of testing the equipment is conducted periodically in order to define the ability to service and find degradation of electrical.
5. Alignment: it is to conduct the changes to an equipment or component in machine in order to achieve the optimum performance.
6. Adjustment: this activity is to adjust specific variable equipment of material in order to optimize the performance.
7. Installation: this is the activity to replace component of machine base on the component using full life in order to maintain the system tolerance.

In order to create an effective preventive maintenance system, there are some important things that should be available. They are, equipment's historical records, recommendations of manufacturer, skill of mechanic, manual services, support from management, and information of failure. There are several steps involved in order to develop the preventive maintenance. They are shown in the figure 2.1 below.



Source: Dhillon, 2002, P.59

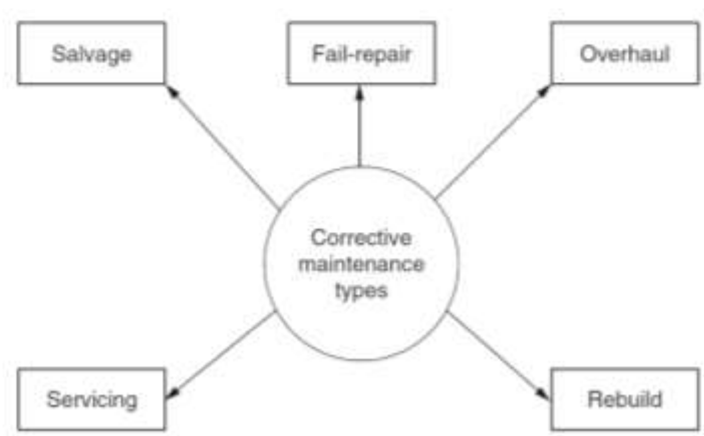
Figure 2.1 Six Steps of Preventive Maintenance

2.2.2 Corrective Maintenance or Breakdown Maintenance

Corrective maintenance is an activity to repair the breakdown machine so the machine can run well as the standard of machine operation. Corrective maintenance or breakdown maintenance is the maintenance activity conducted after the failure exists where the machine cannot function properly (Dhillon, 2002). Corrective maintenance is not just about repairing machine but also to know the cause of machine breakdown and the way to solve or fix the root cause of machine breakdown. In order to avoid the repeat breakdown machine, there are several stratigies as the alternative to face that condition:

- Change the production process
- Change design or construction or material from the component that activate breakdown machine.
- Change with the new machine.
- Fix the preventive maintenance procedure.
- Considere changing the operation process, and conduct the training for operators about how to operate the machine in the right way.
- Reduce the capacity per load for the machine.

Furtheremore, there are 5 major categories of Corrective maintenance. They are shown on the figure 2.3 below.



Source: Dhillon, 2002, P.73

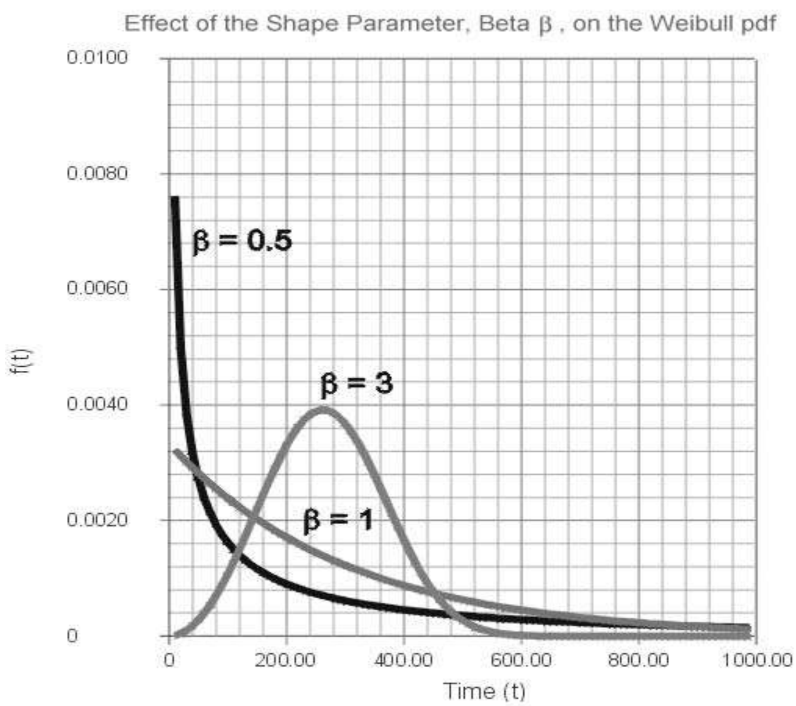
Figure 2.2 Types of Corrective Maintenance

2.3 Failure Distribution

In order to increase the reliability of machine and calculate the machine reliability theory of reliability is used. There are several types of failure distribution and here are the failure distribution used to calculate the machine reliability:

2.3.1 Weibull Distribution

Weibul distribution is the common distribution used in the reliability calculation. Generally this distribution is used in the mechanic component or component of machine. There are two parameters used in this distribution which are θ which is called scale parameter and β called shape parameter.



Source: Dhillon, 2002, P.25

Figure 2.3 Weibull Distribution

In this distribution, the parameter which can define the failure rate from the data of failure is shape parameter. Table 2.1 below shows the value changed from the parameter shape;

Table 2. 1 Shape Parameter (β) values of Weibull Distribution

Values	Failure rate
$0< \beta <1$	Decreasing Failure Rate (DFR)
$\beta =1$	Constant Failure Rate (CFR)
	Exponential Distribution
$1< \beta <2$	Increasing Failure Rate (IFR)
	Concave-shaped curve
$\beta =2$	Linier Failure Rate (LFR)
	Rayleigh Distribution
$\beta >2$	Increasing Failure Rate (IFR)
	Convex-shaped curve
$3\leq \beta \leq 4$	Increasing Failure Rate (IFR)
	Symmetric-shaped curve
	Normal Distribution

Here are the functions in Weibull distribution that will be used in the calculation:

Probability Density Function

$$f(t) = \frac{\beta}{\theta}\left(\frac{t}{\theta}\right)^{\beta-1} e^{\left(\frac{t}{\theta}\right)^{\beta}} \tag{2-1}$$

Cumulative Distribution Function

$$F(t) = 1 - e^{-\left(\frac{t}{\theta}\right)^{\beta}} \tag{2-2}$$

Reliability Function

$$R(t) = e^{-(\frac{t}{\theta})^{\beta}} \tag{2-3}$$

Failure Rate Function

$$\lambda(t) = \frac{\beta}{\theta}\left(\frac{t}{\theta}\right)^{\beta-1} \tag{2-4}$$

Mean Time to Failure in Weibull Distribution

$$MTTF = (\theta)(\Gamma)\left(1 + \frac{1}{\beta}\right) \tag{2-5}$$

$$\Gamma(x) = (x - 1)\Gamma(x - 1) \tag{2-6}$$

Which $\Gamma(x)$ = Gamma Function

Variance

$$\sigma^2 = (\theta)^2 \left\{\Gamma\left(1+\frac{2}{\beta}\right) - \left[\Gamma\left(1+\frac{1}{\beta}\right)\right]^2\right\} \quad (2\text{-}7)$$

Where:

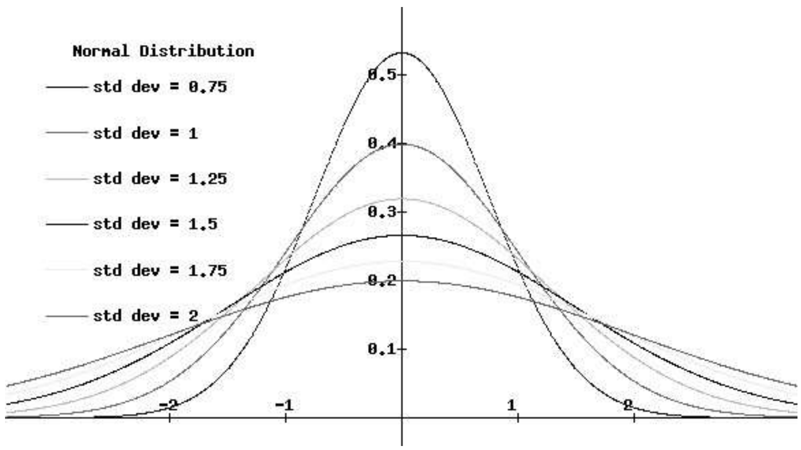
β = shape parameter

θ = scale parameter

e = exponential

2.3.2 Normal Distribution

This distribution is used in wear engine phenomena. There are two parameters used in Normal distribution which are mean (μ) and standard deviation (σ).



Source: Dhillon, 2002, P.26

Figure 2.4 Normal Distribution

Below is the function that will be used in calculating data which fit with Normal distribution:

Probability Density Function

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{\left[\frac{(t-\mu)^2}{2\sigma^2}\right]} \quad (2\text{-}8)$$

for -∞ < t < ∞, which t = time

Cumulative Distribution Function

$$F(t) = \Phi\left(\frac{t-\mu}{\sigma}\right) \quad (2\text{-}9)$$

Reliability Function

$$R(t) = 1 - F(t) \quad (2\text{-}10)$$

Failure Rate Function

$$\lambda(t) = \frac{\Phi\left(\frac{t-\mu}{\sigma}\right)}{\sigma R(t)} \quad (2\text{-}11)$$

Mean Time To Failure in Normal Distribution

$$MTTF = \mu \quad (2\text{-}12)$$

Where

σ = Standard deviation

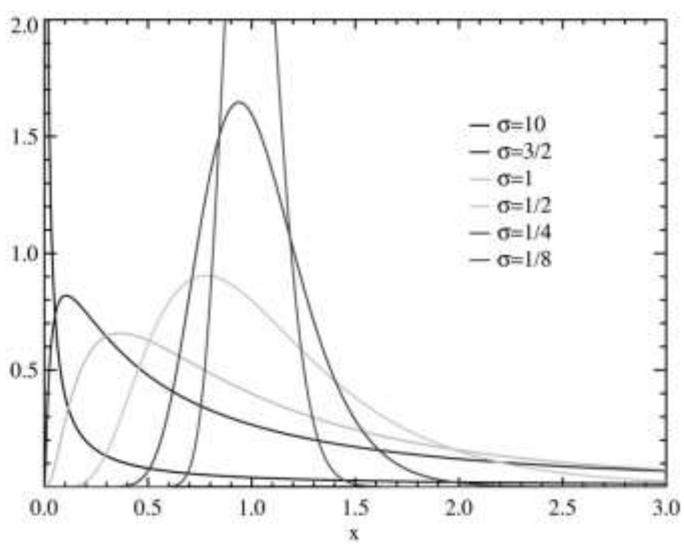
μ = Mean

t = Time

Φ = Normal distribution

2.3.3 Lognormal Distribution

Lognormal distribution also has two parameters which are parameter s called shape parameter and t_{med} which is called location parameter. This distribution is almost similar with the weibull distribution because lognormal distribution has several shapes.



Source: Dhillon, 2002, P.27

Figure 2.5 Lognormal Distribution

Below are the functions that will be used in the calculation of data that fit with Lognormal distribution:

Probability Density Function

$$f(t) = \frac{1}{st\sqrt{2\pi}} e^{\left[\frac{1}{2s^2}\left(ln\frac{t}{tmed}\right)^2\right]} \qquad (2\text{-}14)$$

for t ≥ 0

Cumulative Distribution Function

$$F(t) = \Phi\left[\frac{1}{s}\ln\frac{\mathrm{t}}{\mathrm{tmed}}\right] \qquad (2\text{-}13)$$

Reliability Function

$$R(t) = 1 - F(t) \qquad (2\text{-}14)$$

Failure Rate Function

$$\lambda(\mathrm{t}) = \frac{\Phi\left(\frac{1}{s}ln\frac{t}{tmed}\right)}{stR(t)} \qquad (2\text{-}15)$$

Mean Time To Failure in Lognormal Distribution

$$MTTF\ = tmed.e^{\left(\frac{s^2}{2}\right)} \qquad (2\text{-}16)$$

Variance

$$\sigma^2 = {t_{med}}^2 e^{s^2}\left\lfloor e^{s^2} - 1\right\rfloor \qquad (2\text{-}17)$$

Where

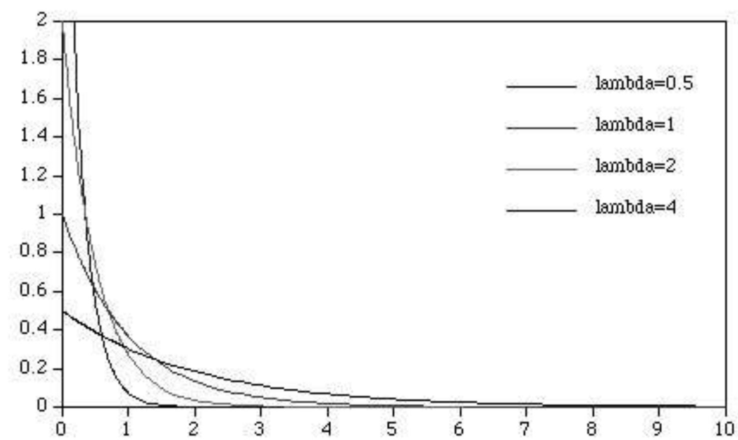
s = Scale

t_{-med} = Median

Φ = Normal distribution

2.3.4 Exponential Distribution

Exponential distribution is used to calculate reliability of failure distribution which has constant failure. This distribution has constant failure rate of time which is easy to be analyzed. Parameter of this distribution is λ that refers to the mean time of failure.



Source: Dhillon, 2002, P.24

Figure 2.6 Exponential Distribution

Here are the functions used to calculate the data which fit for exponential distribution:

Probability Density Function

$$f(t) = \lambda e^{(-\lambda . t)} \qquad (2\text{-}18)$$

Cumulative Distribution Function

$$F(t) = 1 - e^{(-\lambda . t)} \qquad (2\text{-}19)$$

Reliability Function

$$R(t) = e^{(-\lambda . t)} \qquad (2\text{-}20)$$

Failure Rate Function

$$\lambda(t) = \frac{f(t)}{R(t)} = \lambda \qquad (2\text{-}21)$$

Mean Time To Failure in Exponential Distribution

$$MTTF = \frac{1}{\lambda} \qquad (2\text{-}23)$$

Variance (σ^2) and standard deviation (σ)

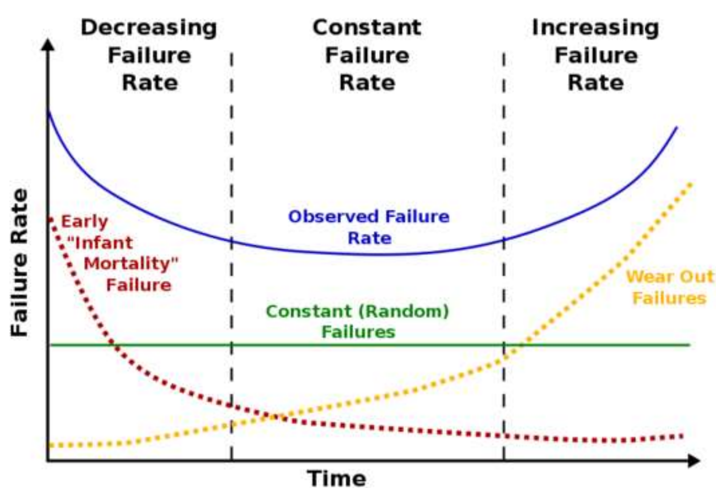
$$\sigma^2 = \frac{1}{\lambda^2} \qquad (2\text{-}24)$$

$$\sigma = \frac{1}{\lambda} \qquad (2\text{-}25)$$

2.4 Failure Rate or Hazard Rate Function

Pattern of machine or equipment age can be seen from the failure rate of that machine or component. Failure rate of the machine which occurred in t is the probability for the component failure on the next interval of time that has been set which component is in the good condition in the beginning of interval time that will be the conditional probability. Notation of failure rate is λ or R (t). The useful life of the machine can be categorized into three big groups of period which are:

- ✓ Decreasing Failure Rate
- ✓ Constant Failure Rate
- ✓ Increasing Failure Rate



Source: Wikipedia.org

Figure 2.7 Bathtub Curve

2.5 Probability Density Function

In the even that X is the continuous random variable pronounced as failure time of system from aggregate sum of failure time, furthermore has a consistent distribution function of fx at every point in the real axis the fx is said to be an element of the variable x density opportunities. If X can be a genuine value (x>0) in the interim time of t, then it meet following requirements.

$fx(t) \geq 0$, for $t \geq 0$ (2-26)

Then,

$$\int_0^t f_x(t)dt = 1 \quad (2\text{-}27)$$

Where

t = time

f (x) = probability density function

Based on the explanation before the breakdown characteristic of various equipments is not always same. Indeed, even the breakdown normal for indistinguishable equipment may not be the same in the event that is done under various conditions.

2.6 Reliability Function

Reliability is the likelihood that an item will perform a bound function under specified condition for a stated period of time (Alain, 1991). Reliability of machine has impact to the production performance. Machine with high reliability will produce high number of product based on the target or more than that without any problems of the machine. Generally reliability discipline consists of several areas of activities such as (Alain, 1991):

- ✓ System failure analysis
- ✓ Operational or observed reliability
- ✓ Reliability data bases
- ✓ Reliability tests
- ✓ Predicted reliability
- ✓ Method to predicted reliability and safety
- ✓ Reliability and quality assurance.

This can be obtained by using this equation λ (t) = - $\frac{1}{R\ (t)}\ x\ \frac{dR\ (t)}{dt}$ so the formula is below:

$$-\lambda\ (t)dt = \frac{1}{R\ (t)}.dR\ (t) \qquad (2\text{-}28)$$

Integrating both side of equation above over the time interval (0,t), below is the formula:

$$-\int_0^t \lambda\ (t)dt = \int_1^{R(t)} \frac{1}{R\ (t)}\ dR\ (t) \qquad (2\text{-}29)$$

Because at t= 0, and R (t) = 1. Evaluating the right hand side of equation above:

In R (t) = -$\int_0^t d\ (t)\ dt$ (2-30)

Thus, from equation the general expression for reliability function is:

$$R\ (t) = \ e^{-\int_0^t \lambda\ (t)dt} \qquad (2\text{-}31)$$

Where

R = reliability function

t = time

λ = failure rate (sometimes referred to as hazard rate)

Equation above can be used to obtain the reliability of an item when its times to failure follow any time continuous probability distribution.

2.7 Mean Time to Failure

Mean time to failure (MTTF) is the average time from one failure to the next failure. This is an important reliability measure and it can be obtained by using the following three formulas:

$$MTTF = \int_0^\infty R\ (t)dt \qquad (2\text{-}32)$$

Or

$$MTTF = \int_0^{\infty} t\, f\,(t)dt \tag{2-33}$$

Or

$$MTTF = lim_{s-0}\, R\,(s) \tag{2-34}$$

Where s is the Laplace transform variable, MTTF is the mean time to failure, and R is the Laplace transform of the reliability function R (t). In this research, the calculation of MTTF uses the formulas based on the type of failure distribution. Here are the formulas used to calculate MTTF of each component based on the type of failure distribution.

Weibull distribution

$$MTTF\ = (\theta)(\Gamma)\left(1 + \frac{1}{\beta}\right) \tag{2-35}$$

$$\Gamma(\mathrm{x}) = (\mathrm{x} - 1)\Gamma(\mathrm{x} - 1) \tag{2-36}$$

Which Γ(x) = Gamma Function

Normal distribution

$$MTTF\ = \mu \tag{2-37}$$

Lognormal distribution

$$MTTF\ = tmed.\, e^{\left(\frac{s^2}{2}\right)} \tag{2-38}$$

Exponential distribution

$$MTTF\ = \frac{1}{\lambda} \tag{2-39}$$

Where

R = reliability function

t = time

λ = failure rate (sometimes referred to as hazard rate)

2.8 Mean Time to Repair

Mean time to repair or MTTR is the average time needed to repair the machine. In this research the MTTR is calculated based on the time to repair data of each machine or components. MTTR is calculated in order to measure the mechanic ability to change the component or repair the machine. Statistical software that will fit the time to repair of the components with each type failure distribution is used in this calculation. After that, the data will be analyzed using statistical software to find the mean time to repair each component.

2.9 Determine Preventive Maintenance Interval

After all the calculation have been done, preventive maintenance can be conducted based on the components interval time of failure. Maintenance is often related with the cost of maintenance, because maintenance that is too often will lead to the big cost of that company must spend for maintenance (Mulyono et al, 2009). In order to define the interval of maintenance time, the first thing that should be calculated is the cost. There are several reasons to calculate the maintenance cost, these reasons are to set the maintenance cost drivers, to prepare budget in order to conduct the maintenance, control cost of maintenance, and improve the productivity in line production. There are two types of maintenance cost that will be calculated in this research which are corrective maintenance cost and preventive maintenance cost. Below is the formula used to calculate that optimum maintenance cost;

$$C(t) = \frac{C_p + C_f . H(t)}{t} \tag{2-40}$$

Where

C(t) = Cost per unit of time

Cp = Cost of preventive maintenance

Cf = Cost of corrective maintenance

H(t) = Cumulative hazard function in the interval of t

Cp = component price + (replacement time (hours) x salary of mechanic per hours) + (production capacity x replacement time x loss of production per doll head)

Cf = component price + (downtime (hours) x salary of mechanic per hours) + (Production capacity x downtime x loss of production per doll head)

After all the calculations have been done, the interval of preventive maintenance can be defined based on the objective of the research. If the research have the purpose to reduce the maintenance cost, the interval can be define based on the minimum cost However, if the research purpose is to increase the reliability, the interval time of maintenance can be defined based on the number of reliability target that should be achieved.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Theoretical Framework

Below is the theoretical framework of this research:

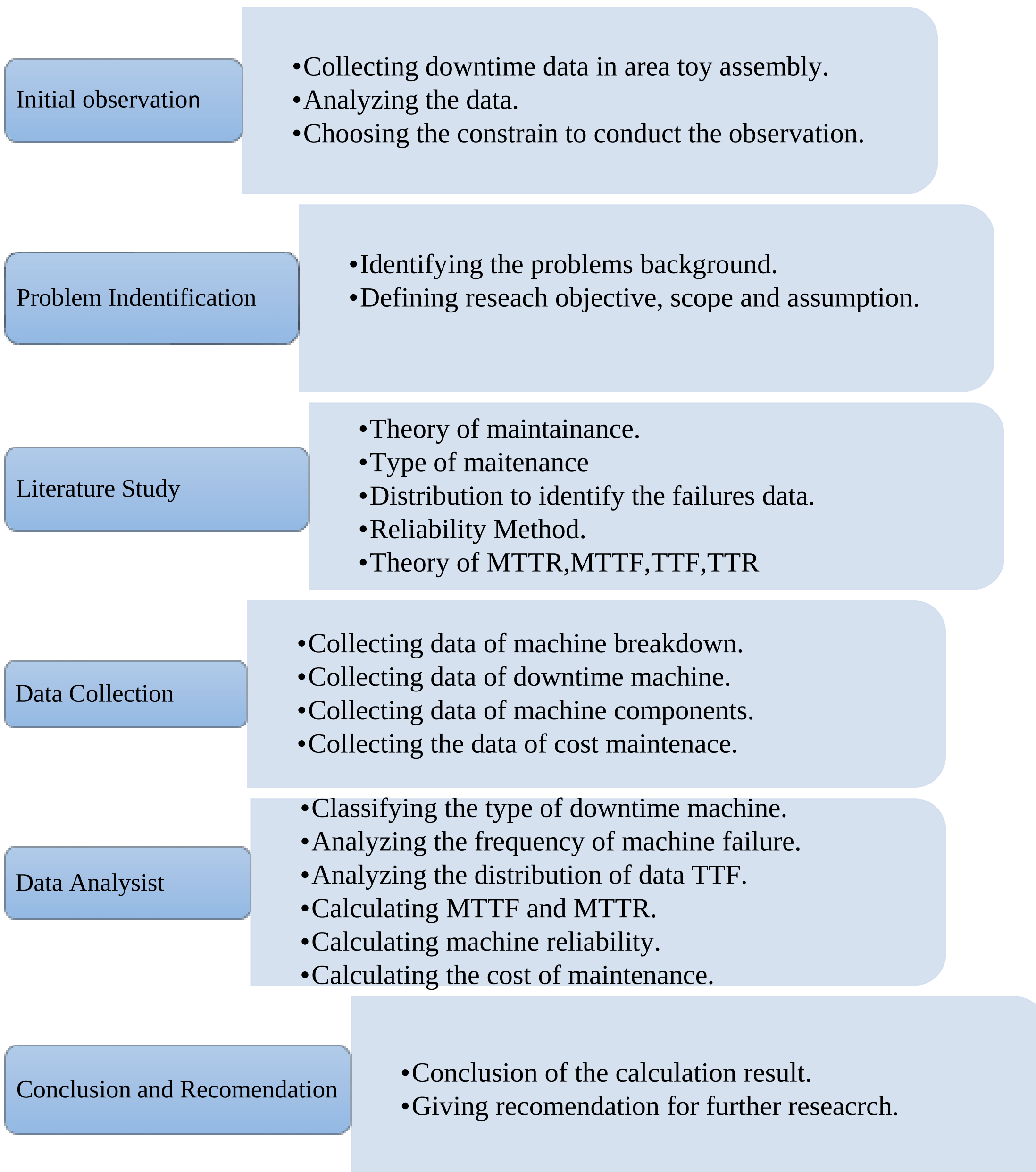


Figure 3.1 Theoretical Framework

3.1.1 Initial observation

This is the first step to start this research. In this step, the current condition was observed by collecting all the information about production process in Toy Assembly area. Data needed to be analyzed in this research is downtime data in area TA, data of machine in area TA, data of component price, data of maintenance cost, and also capacity of auto machine in TA area. All the information needed to do the research was also collected as the initial observation.

3.1.2 Problem Identification

In this stage, the problems have been found through the data analysis of current system. Then the next step is to determine the reseaarch objectives that should be achieved through this research. Limitation and assumption of the research was also defined in this stage. Based on the initial observation there were several machines in TA area, and this research just focus to the most high failure rate of machine that belong to Auto machine. There are also several assumptions of this observation in order to ensure that all the process of this observation can be done well.

3.1.3 Literature Study

The theoretical studies about machine maintenance were reviewed in this stage. In order to create the preventive maintenance, there are several methods that can be used. Reliability of machine was used to define and assign the schedule of preventive maintenance. Data analysis and data calculation is based on the type of failure distribution. The formula used to calculate the data based on the failure distribution types is available in this chapter.

3.1.4 Data collection

This is the stage to collect data needed for scheduling the preventive maintenance in Auto machine 2. The first data was downtime machine data recorded from January

2016 until July 2016. Downtime data was needed to analyze the failure rate of machine, and the duration between failures in order to estimate the time of machine failure. The component of machine was also needed to classify the schedule based on the priority of component function and price. Data about the components needed in this research were, component price, component function, and average time to repair the component that have been standardize from the company. The other data such as mechanic fee or salary, machine capacity in one hour, duration of working time, and price of product produced by machine Auto 2 were collected as well.

3.1.5 Data Analysis

All data that had been collected was analyzed in this step. Data analysis of downtime machine and finding the most frequent failure component of machine was done in this step. Furthermore, ccalculation of TTF, TTR, MTTF, MTTR, reliability of machine and cost of maintenance was explained in this chapter. After calculating TTF of each component, all the data TTF was analyzed using the statistical software in order to fit the data with type of failure distribution. Then the next step was calculating MTTF and Reliability of each component based on the type of failure distribution of the data. Maintenance cost in the current condition and proposed condition was also calculated in this step. The comparison of current and proposed condition based on the reliability calculation, maintenance cost calculation and time to repair in current and proposed calculation was done in this step as well.

3.1.6 Conclusion and Recommendation.

The result and evaluation of this research is shown in this step. The conclusion of this research based on the calculation in the previous chapter is summarized in this step. The recommendation for the future research is given in this step as well.

3.2 Research Framework

Below is the research framework that shows the steps to do this research. Every step to do this report should be set systematically in order to solve research problems.

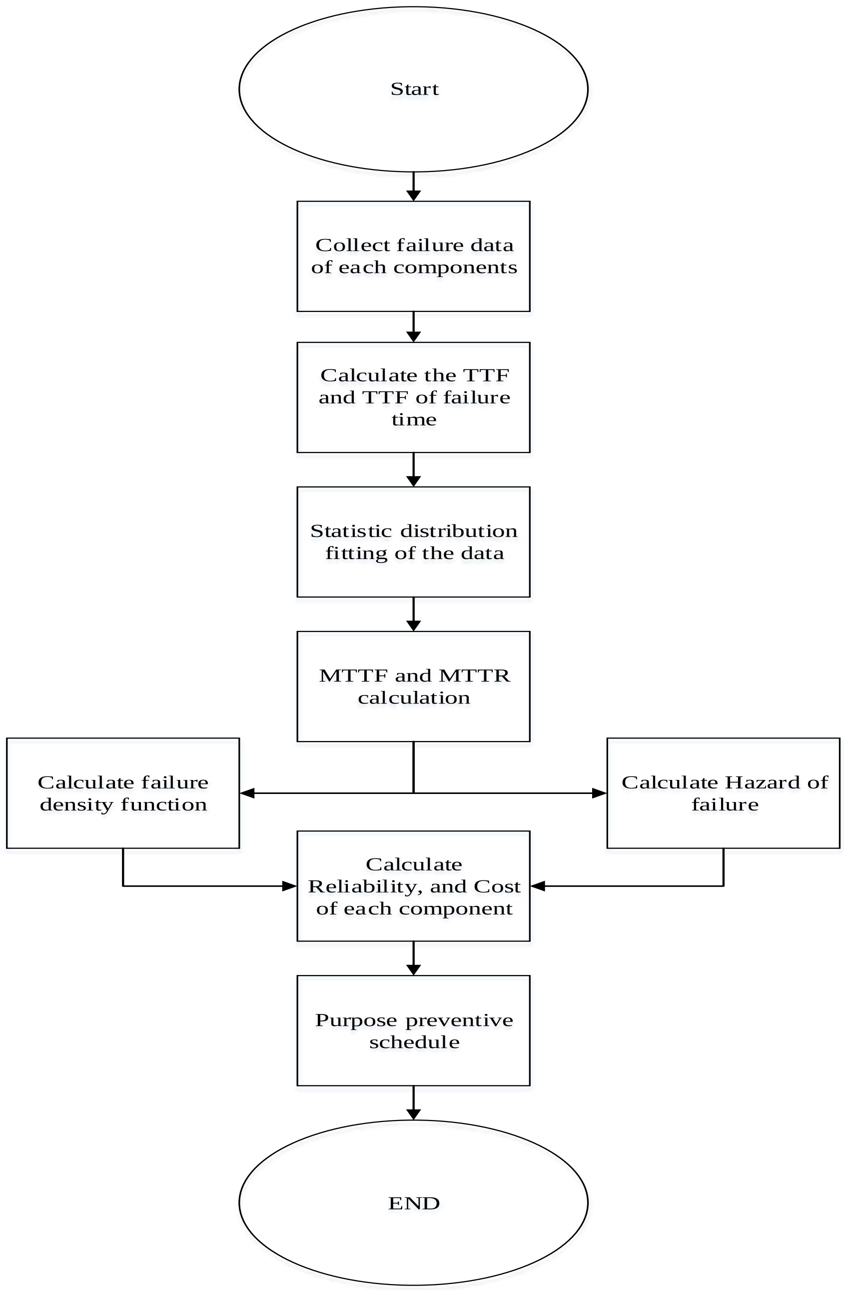


Figure 3.2 Research Framework

Figure 3.2 above shows research framework. This research starts with collecting the data of failure time of each component. After the data have been collected, the calculation can be started. The data calculation is started by calculating TTF and TTR based on the time failure of each component. The next step is doing the statistic distribution fitting using computer software. TTF data is input in the software and the software is analyzed the data based on the several distributions. These distributions are normal distribution, lognormal distribution, Weibull distribution and exponential distribution.

After all the data have been analyzed, the next step is choosing the distribution that has greater value of index of fit. MTTF calculation was done using software based on the distribution that has been chosen. The next step is calculating the current reliability based on the type of data distribution. Based on the current condition it should be improved so the purpose reliability is calculated. Before calculating reliability of each machine, the data calculation that should be done is failure density function of each component. Failure density function is also calculated based on the type of data distribution that has been chosen. Failure density function is used in reliability calculation and hazard of failure calculation. After that the reliability of each component is calculated also based on the distribution type. The proposed reliability is 80%, so each component will have reliability of 80% after implementing preventive maintenance.

After getting the current and proposed reliability, calculating the cost of preventive maintenance is done. Finally, scheduling the preventive maintenance based on the average time of failure chosen to achieve the target reliability which is proposed.

CHAPTER IV
DATA COLLECTION AND ANALYSIS

In this chapter, all the data required to this research is calculated and analyzed using the method that has been defined to achieve the research objective.

4.1 Current Condition Analysis

Auto machine 2 is one of the auto machines in Toy Assembly area (TA). The process of this machine is to assemble all the molded part becomes toy's body. All the assemblying process in the line production is done by this machine. Thus, machine performance is the important thing that should be well maintained in order to support the process production in this area.

Downtime machine is the condition when the machine stop running because of component failures during operation time that must be repaired by the mechanic or replaced the component with the new one. Downtime machine and machine breakdown are the factor that should be controllable in order to maintain the process production and also to keep the reliability of machine. Based on the monthly report of downtime machine that occurred TA area, Auto machine 2 has high percentage of downtime machine.

The percentage of downtime machine that occurred in Auto machine 2 is 55% of production time. Based on the total downtime in and total production during six months the percentage of downtime can be calculated as follows:

Production time during six months = 3600

Total downtime in six months = 1965

$$\frac{1965\,h}{3600\,h}\;x\;100 = 55\;\%$$

This condition has a big impact to the productivity of production floor. Every time when the machine breakdown, it will cause to downtime machine and this condition will impact to loss of production in the production process, and increase maintenance cost. So in order to solve this problem, the analysis of the machine failures was done in order to define the critical failure component which caused to recurrence of failures in machine.

4.1.2 Identify Component failure

Machine breakdown is caused by some critical failures components of the machine. Auto machine 2 has function to assemble every molded parts of toy's body in TA area. Based on the downtime report of Toy Assembly area there are several component that caused downtime machine frequently. Auto machine 2 has twelve components, and based on the analysis in the initial observation, there are six critical failure components which have highest number of downtime then the other. Figure below shows the frequency of failure based on the component in Auto machine 2 during January 2016 until July 2016.

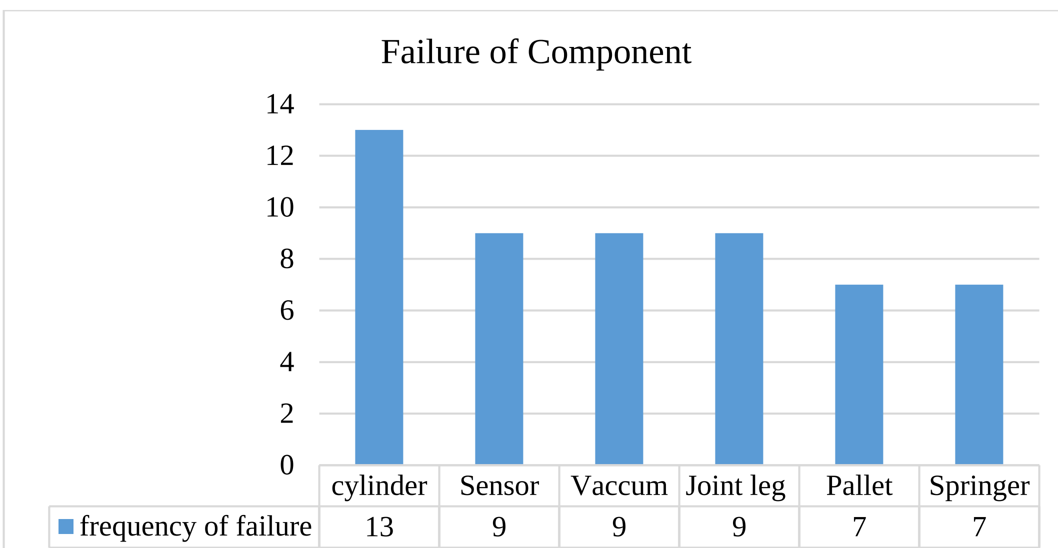


Figure 4.1 Failures of Components

Figure 4.1 above shows that cylinder is a component that has the highest frequency of failure. During six months, cylinder failed for 13 times and the other five also have high frequency of failure. These critical components should be analyzed in order to develop the preventive maintenance system of each component. Here are the root causes of machine failure on each component.

Table 4.1 Root Cause of Machine Breakdown

Critical Component	Root Cause	Failure Occurrence	Action
Cylinder	Unloaded Cylinder, broken cylinder	13	replace with the new component
Vacuum	Ripped Vacuum caused by the vacuum taking the materials that have heavy weight, rubber- made vacuum.	9	replace with the new component
Sensor	Broken wires, and sensor is not working.	9	replace with the new component
Joint leg	Join leg failed caused by broken joint leg, some failure occurred caused by the joint leg is not located in the right position.	9	Setting position of joint leg and replace with the new component
Pallet	Broken pallet caused by pallet which is not located in the center. These failures can be caused by the mechanic setting.	7	Cleaning roller pallet, setting position and replace with the new component
Springer	Broken springer and bending springer.	7	replace with the new component

Table 4.1 above shows the root cause of the failures caused by each component. Based on the analysis above, causes of failures in machine auto 2 can be define in to three factor which are material, man and method. Material refers to the quality of machine which has effect to the performance and failure frequency of the component itself. Man refers to the mechanic that repairs or setts the machine. The ability of mechanic to sett the machine or repair the component has impact to the failure of the component or machine. The other one is method that mechanic use to set the component in the machine. Method used must be based on the manual book of the machine itself. The table also shows some failure caused by the mechanic because they did not use the right method to set the component.

Failure data of each component will be analyzed based on the distribution failure and calculation of mean time to failure of each component to estimate time to conduct preventive maintenance of each component. Table 4.1 below shows downtime data of each components based on the report that has been collected during six months.

Table 4.2 Downtime of Components

Component	Downtime (h)
Sensor	5.25
cylinder	5.05
Vacuum	3.35
Springer	2.05
Joint leg	1.55
Pallet	1.35

Table 4.1 above provides information about the total downtime for each component during six months period (January 2017 – July 2016). Based on the downtime data, Sensor had highest downtime with total downtime in the last six month is 5.25 hours. Cylinder was on the second position which has high number of total downtime and Pallet was the least one. These six components are the critical failure components in Auto Machine 2 with high number of downtime than the other components. Thus, these component were chosen to be analyzed in this research. Figure 4.2 below shows the Pareto diagram of downtime machine during six months period starting from January 2016- March 2017, based on the each component in Auto machine 2.

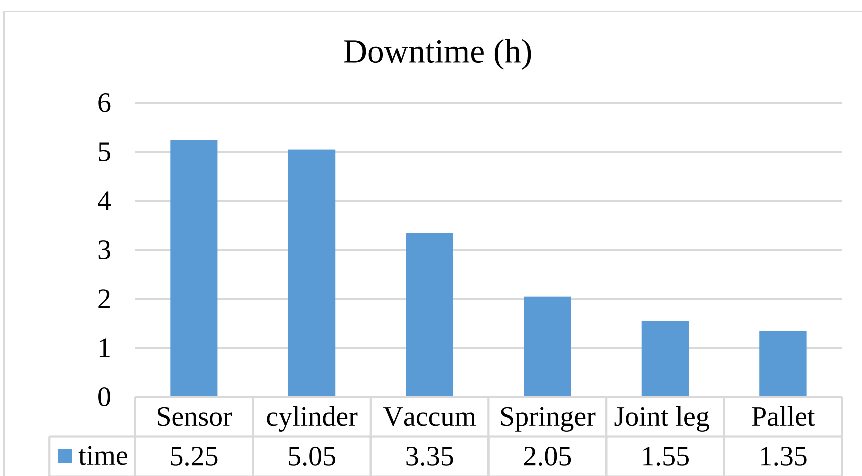


Figure 4.2 Components Downtime

These components will be analyzed based on the time failure and data calculation in order to develop the preventive maintenance system to these components. It has been mentioned before that there are six components that will be analyzed in this research. Below is the explanation of the function of each component which has impact on production process when the failure occurred in these components. The detail pictures of each component are available on appendix 3:

- Cylinder

  Cylinder is the component that has a function to move every part from the current position or current point to the assembled point. When the cylinder fails, the assembly process fails as well.
- Sensor

  Sensor is the component that has function to detect every sequence of process in order to make the process run properly. So this component also plays the important role in assembly process.
- Vacuum

  This component has a function to take the part from the current potion in order to move the part to the assembly point.
- Springer

  Springer is the component that has a function to support the process in joining leg.
- Joint Leg

  In joint leg process, there are two parts which are lower leg and upper leg. Joint leg will press both parts become toy's leg.
- Pallet

  Pallet is the component to place toy's body. Pallet has a function to move the parts from current position to the assembly point.

4.1.3 Component Failure data

In order to estimate the time to conduct the preventive, the failure data of component is needed. Ccomponent failures data in the last six months will be used in this research. Failure occurrence in Auto machine 2 based on the each component is shown in the following table.

Table 4.3 Failure time of Cylinder

No	Date	Component	Repair time	
			Start	Finish
1	2/16/2016	Cylinder	23:30	23:45
2	3/4/2016	Cylinder	14:10	14:25
3	3/14/2016	Cylinder	9:30	10:00
4	3/21/2016	Cylinder	7:30	8:10
5	4/8/2016	Cylinder	5:30	5:45
6	4/20/2016	Cylinder	18:00	18:30
7	4/30/2016	Cylinder	19:00	19:30
8	5/16/2016	Cylinder	23:15	23:25
9	5/30/2016	Cylinder	20:40	21:00
10	6/8/2016	Cylinder	19:40	20:00
11	6/22/2016	Cylinder	5:00	5:40
12	7/12/2016	Cylinder	4:45	4:55
13	7/27/2016	Cylinder	13:30	15:00

Table 4.3 above shows Cylinder failure data. During the last six months, a total failure of cylinder was 13 times. This component had highest number of downtime than the other component.

Table 4.4 Failure time of Vacuum

No	Date	component	Repair Time	
			Start	Finish
1	3/21/2016	Vacuum	19:00	19:30
2	4/18/2016	Vacuum	1:30	1:40
3	5/17/2016	Vacuum	3:00	3:30
4	5/31/2016	Vacuum	23:50	0:10
5	6/21/2016	Vacuum	22:55	23:30
6	6/28/2016	Vacuum	23:00	23:30
7	7/14/2016	Vacuum	16:00	16:15
8	7/21/2016	Vacuum	8:20	8:35

Table 4.4 above shows the Vacuum failure data during six months. Vacuum had 9 times failure during the last eight months. Vacuum is the component in Auto machine 2 that has function to take the part from nest to join with the other parts. These times, data will be calculated in the next section in order to develop the preventive maintenance schedule of this component.

Table 4.5 Failure time of Sensor

No	Date	Component	Repair time	
			Start	Finish
1	01/08/16	Sensor	4:00	4:20
2	02/04/16	Sensor	1:00	1:45
3	02/10/16	Sensor	7:20	9:00
4	02/24/16	Sensor	19:40	20:05
5	03/07/16	Sensor	20:40	21:50
6	05/02/16	Sensor	3:00	3:10
7	05/11/16	Sensor	7:20	7:25
8	06/27/16	Sensor	16:10	16:25
9	07/23/16	Sensor	22:40	23:15

Table 4.5 above shows the data of failure time that occurred due to sensor. Total failure time was 6 hours. During January until August, failure occurrence of sensor was 9 times.

Table 4.6 Failure Time of Join Leg

No	Date	Component	Repair time	
			Start	Finish
1	02/04/16	Joint Leg	15:10	15:20
2	02/10/16	Joint Leg	4:30	4:40
3	03/01/16	Joint Leg	20:30	20:35
4	03/16/16	Joint Leg	17:50	18:10
5	03/30/16	Joint Leg	10:00	10:15
6	04/20/16	Joint Leg	11:30	11:40
7	05/09/16	Joint Leg	21:00	21:20
8	05/16/16	Joint Leg	20:00	20:15
9	05/25/16	Joint Leg	4:55	5:05

Table 4.6 above is the table data of failures time occurred in Auto machine 2 caused by Join leg. Join leg is the component that has function to press leg in order to join leg to toy's body. Total failure time of join leg during eight month is 1.5 hours.

Table 4.7 Failure Time of Pallet

No	Date	Component	Repair time	
			Start	Finish
1	3/17/2016	Pallet	18:00	18:25
2	4/19/2016	Pallet	17:00	17:10
3	5/13/2016	Pallet	3:00	3:10
4	5/20/2016	Pallet	13:40	13:50
5	5/30/2016	Pallet	14:50	15:00
6	6/10/2016	Pallet	22:00	22:15
7	6/28/2016	Pallet	16:10	16:25

Table 4.7 above provides information about time failures of Pallet. Pallet is the component in Auto machine 2 that has function to move the part in order to join the part of toy. Total time failure of pallet was 1.35 hours.

Table 4.8 Failure Time of Springer

No	Date	Component	Repair time	
			Start	Finish
1	2/5/2016	Springer	8:00	8:10
2	2/17/2016	Springer	20:20	20:40
3	4/20/2016	Springer	1:00	1:20
4	5/4/2016	Springer	4:05	4:15
5	5/30/2016	Springer	2:00	2:15
6	6/8/2016	Springer	16:30	17:10
7	7/13/2016	Springer	2:30	2:40

Table 4.8 above is the table data of failure time of springer. Springer has a function to support to join leg process. During the operation time from January until August springer had failure in process for 7 times. Total time failure occurred in Auto machine 2 which was caused by springer failure was 2.05 hours.

4.2 Downtime and Time to Failure of Components

After all the data has been collected and in order to design the preventive maintenance schedule for those components, the first step that should be done is calculating the time to failure (TTF) and time to repair (TTR). TTF and TTR will be used to calculate the average time of component failure and average time the mechanic repair the components.

4.2.1 TTF and TTR calculation of Cylinder

Based on the data of time failure, TTF and TTR will be calculated. Table 4.8 below provides information about the time to failure and time to repair of Cylinder.

Table 4.9 Cylinder's TTF and TTR Calculation

No	Date	Component	Repair time		TTR	TTF (h)
			Start	Finish		
1	2/16/2016	Cylinder	23:30	23:45	0:15	-
2	3/4/2016	Cylinder	14:10	14:25	0:15	374.42
3	3/14/2016	Cylinder	9:30	10:00	0:30	187.08
4	3/21/2016	Cylinder	7:30	8:10	0:40	165.5
5	4/8/2016	Cylinder	5:30	5:45	0:15	381.33
6	4/20/2016	Cylinder	18:00	18:30	0:30	264.25
7	4/30/2016	Cylinder	19:00	19:30	0:30	240.5
8	5/16/2016	Cylinder	23:15	23:25	0:10	291.75
9	5/30/2016	Cylinder	20:40	21:00	0:20	309.25
10	6/8/2016	Cylinder	19:40	20:00	0:20	214.67
11	6/22/2016	Cylinder	5:00	5:40	0:40	297
12	7/12/2016	Cylinder	4:45	4:55	0:10	359.08
13	7/27/2016	Cylinder	13:30	15:00	1:30	344.58

Below is the example of TTF and TTR calculation:

Machine failure occurred on March, 4th 2016. The failure was at 14:10 until 14:25. The previous failure occured on 16th February 2016. The failure started from 23:30 until 23:45. The range of both failures is 16 days. Operating time is 24 hours per day and there are three shifts per day.

The TTF can be calculated as follows:

2/16/2016 (23:45) - 3/4/2016 (14:10) = 15 working days and 19 hours

TTF= (15 days x 24 hours) + 19 = 374.32

The duration from the failure which occurs until the mechanic finished repairing it is called TTR. Thus, the example of the failure on TTR that occurred on 4th March is 23:30- 23.45= 0:15 hours.

4.2.2 TTF and TTR Calculation of Vacuum

Table 4.10 below shows the data calculation of TTR and TTF of failure that occurred in Auto machine 2 and which was caused by Vacuum.

Table 4.10 Vacuum's TTR and TTF Calculation

No	Date	component	REPAIR TIME		TTR	TTF (h)
			Start	Finish		
1	3/21/2016	Vacuum	19:00	19:30	0:30	-
2	4/18/2016	Vacuum	1:30	1:40	0:10	558
3	5/17/2016	Vacuum	3:00	3:30	0:30	578
4	5/31/2016	Vacuum	23:50	0:10	0:20	332
5	6/21/2016	Vacuum	22:55	23:30	0:35	455
6	6/28/2016	Vacuum	23:00	23:30	0:30	168
7	7/14/2016	Vacuum	16:00	16:15	0:15	305
8	7/21/2016	Vacuum	8:20	8:35	0:15	205
9	7/26/2016	Vacuum	23:20	23:35	0:15	135

It can clearly be seen that failure that occured on 18th April 2016 was at 1:30. The last or the previous failure took place on 21th March 2016. TTF of both failures can be calculated as follows;

3/21/2016 (19:30) - 4/18/2016 (1:30) = 23 working days and 6 hours

TTF = (23 days x 24 hours) + 6 = 558 hours

Time to repair (TTR) is the duration that mechanic takes to repair the component so the TTR in each failure can be calculated using the time when the failure start until the machine can be operated again. For example, failure that occurred on 21st of March started from 19:00 until 19:30 and time to repair the component that mechanic spent was 30 minutes. Thus, the TTR of this failure is 30 minutes or 0.3 hours.

4.2.3 TTF and TTR Calculation of Sensor

Table 4.11 below shows the result of TTR and TTF calculation based on the failure time which occurred in Auto machine 2 and which was caused by sensor.

Table 4.11 Sensor's TTR and TTF Calculation

No	Date	Component	Repair time		TTR	TTF (h)
			Start	Finish		
1	01/08/16	Sensor	4:00	4:20	0:20	
2	02/04/16	Sensor	1:00	1:45	0:45	572
3	02/10/16	Sensor	7:20	9:00	1:40	127
4	02/24/16	Sensor	19:40	20:05	0:25	307
5	03/07/16	Sensor	20:40	21:50	1:10	265
6	05/02/16	Sensor	3:00	3:10	0:10	1109
7	05/11/16	Sensor	7:20	7:25	0:05	172
8	06/27/16	Sensor	16:10	16:25	0:15	993
9	07/23/16	Sensor	22:40	23:15	0:35	534

For example, it can be clearly seen that failure occurred on 8th January 2016 at 4:00 until 4:20 and 4th February 2016 at 1:00 until 1:45. TTF of both failures can be calculated as follows:

01/08/2016 (4:20) – 02/04/2016 (1:00) = 23 working days and 20 hours

TTF = (23 days x 24 hours) + 20 hours = 572 Hours

The example for calculation of TTR is taken from failure that occurred in 8th January. The Failure started at 4:00 and the mechanic finished repairing the component. Thus, the TTR of this failure is 20 minutes or 0.2 hours.

4.2.4 TTF and TTR Calculation of Join Leg

Table 4.12 below shows the result of TTR and TTF calculation of Join leg. This calculation is based on the time failure of Join leg.

Table 4.12 Join Leg's TTR and TTF Calculation

No	Date	Component	Repair time		TTR	TTF
			Start	Finish		
1	02/04/16	Joint Leg	15:10	15:20	0:10	
2	02/10/16	Joint Leg	4:30	4:40	0:10	109
3	03/01/16	Joint Leg	20:30	20:35	0:05	443
4	03/16/16	Joint Leg	17:50	18:10	0:20	309
5	03/30/16	Joint Leg	10:00	10:15	0:15	280
6	04/20/16	Joint Leg	11:30	11:40	0:10	457
7	05/09/16	Joint Leg	21:00	21:20	0:20	370
8	05/16/16	Joint Leg	20:00	20:15	0:15	143
9	05/25/16	Joint Leg	4:55	5:05	0:10	201

The objective of TTF Calculation is to know the duration between failures that occurred during the operation time. For example failure that occur in 4^{th} February 2016 and 10^{th} February 2016. TTF of both failures can be calculated as follows:

02/04/2016 (15:20) – 02/10/2016 (4:30) = 4 working days and 13 hours

TTF = (4 days x 24 hours) + 13 hours = 109 hours

4.2.5 TTF and TTR Calculation of Pallet

Table 4.13 below presents the result of TTF and TTR calculation based on the failure time which occurred in Auto machine 2 and which was caused by Pallet. This calculation is based on the failure data of pallet that has been recorded during the operation time in six month started from January 2016 until July 2016.

Table 4.13 Pallet's TTR and TTF Calculation

No	Date	Component	Repair time		TTR	TTF
			Start	Finish		
1	03/17/16	Pallet	18:00	18:25	0:25	
2	04/19/16	Pallet	17:00	17:10	0:10	647
3	05/13/16	Pallet	3:00	3:10	0:10	466
4	05/20/16	Pallet	13:40	13:50	0:10	137
5	05/30/16	Pallet	14:50	15:00	0:10	193
6	06/10/16	Pallet	22:00	22:15	0:15	270
7	06/28/16	Pallet	16:10	16:25	0:15	378

For instance, failure took place on 17th March at 18:00 and on 19th April at 17:00. Below is the TTF calculation of both failures;

03/17/2017 (18:25) – 04/19/2016 (17:00) = 26 working days and 23 hours

TTF = (26 days x 24 hours) + 23 hours = 647

TTR or time to repair is calculated from the machine starting to repair at 17:00 until it finished at 18:25. Thus, TTR of failure occurred on 19 April 2016 is 25 minutes.

4.2.6 TTR and TTF Calculation of Springer

Table 4.14 below shows the result of TTF and TTR calculation based on the failure time of Springer.

Table 4.14 Springer's TTR and TTF Calculation

No	Date	Component	Repair time		TTR	TTF
			Start	Finish		
1	2/5/2016	Springer	8:00	8:10	0:10	
2	2/17/2016	Springer	20:20	20:40	0:20	197
3	4/20/2016	Springer	1:00	1:20	0:20	845
4	5/4/2016	Springer	4:05	4:15	0:10	316
5	5/30/2016	Springer	2:00	2:15	0:15	574
6	6/8/2016	Springer	16:30	17:10	0:40	230
7	7/13/2016	Springer	2:30	2:40	0:10	729

Time to failure is calculated as the initial data that will be used to create preventive maintenance schedule of the component. Based on the result above here is the example of TTF calculation in order to get the TTF number. Failure occurred on 5th February 2016 at 8:00 and failure took place on 17th February 2016. The duration between both failures is 8 working days and 5 hours. Thus, the total time to failure between both failures in hours is 197 hours.

TTR can be calculated starting from the mechanic begins to repair the component until the fixing up finishes. For example, failure that occurred on 5th February started from 8:00 until 8:10 means that the time to repair the component is 10 minutes or 0.16 hours.

4.3 MTTF and Reliability of Component

Mean time to failure (MTTF) is the average time from one failure to the next failure. After TTF has been calculated, the next step is to calculate MTTF. Preventive maintenance will be scheduled based on mean time to failure of each component. As a result, before the component fails, the preventive maintenance should be conducted. TTF will be analyzed based on goodness of fit test. The objective of analysis of goodness index of fit test is to determine which distribution should be chosen.

In this research the testing statistical software is used. The data will test in the goodness fit testing by comparing the value of coefficient correlation. The distribution that should be chosen in this test is the distribution with the greater number of coefficient correlation or r value. After the distribution has been defined, the next step is calculating the MTTF. The data will be calculated based on the distribution type such as Normal distribution, Lognormal distribution, Weibull distribution and Exponential distribution. MTTF of each component will be calculated using statistical software. On the other hand, there are also formula that can be used to calculate MTTF manually.

Reliability of machine has impact on the production performance. Machine with high reliability will produce high number of product based on the target or more than that without any problems of the machine. Preventive maintenance aims to reduce downtime machine and increase machine reliability. The target of reliability that should be achieved in this research is 80%. Reliability of each component will be calculated based on the type of distribution that fit with failure time data of each component and the parameters or each distribution. There is also another data calculation used to calculate the component reliability. Cumulative distribution function is needed as the one of variables to calculate reliability of each component. Thus, here are the detail calculation of MTTF and reliability of each components;

4.3.1 Cylinder

As it has been explanation above that MTTF will be calculated based on the type of failure distribution. In order to know which type of the data is distributed, there is goodness of fit test of the data from TTF. This test will be done using statistical software in computer. The figure below shows the result of the goodness fit test:

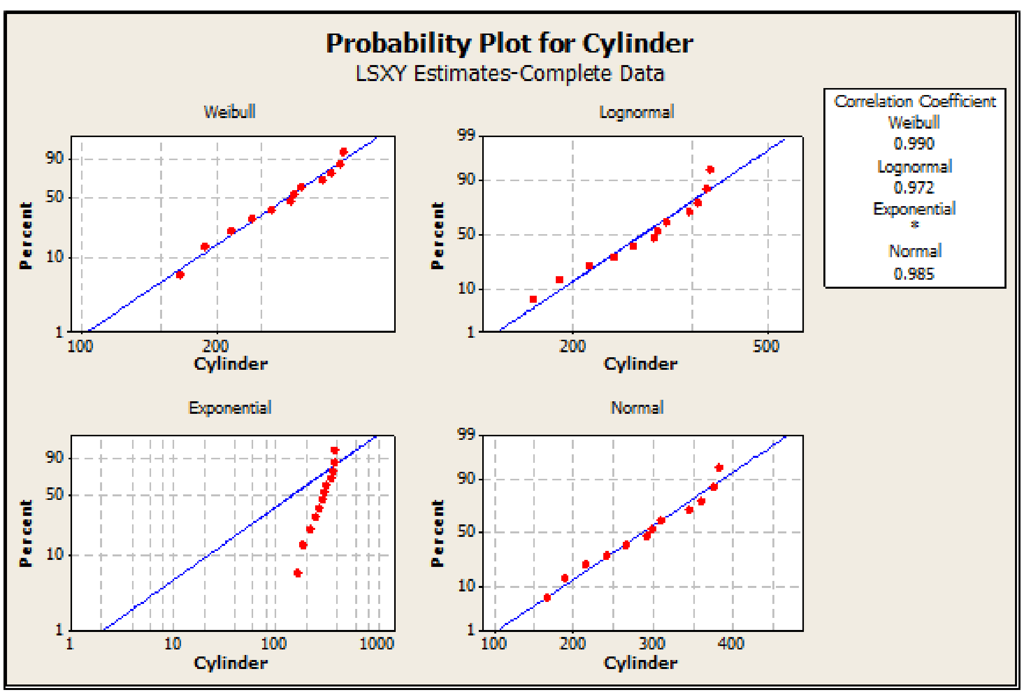


Figure 4.3 Goodness of Fit for Cylinder

The figure 4.3 above presents that distribution that has greater coefficient of correlation is Weibull distribution. The next step is calculating MTTF using Weilbull distribution. This calculation was also done by the same statistical software. The following is the result of the calculation;

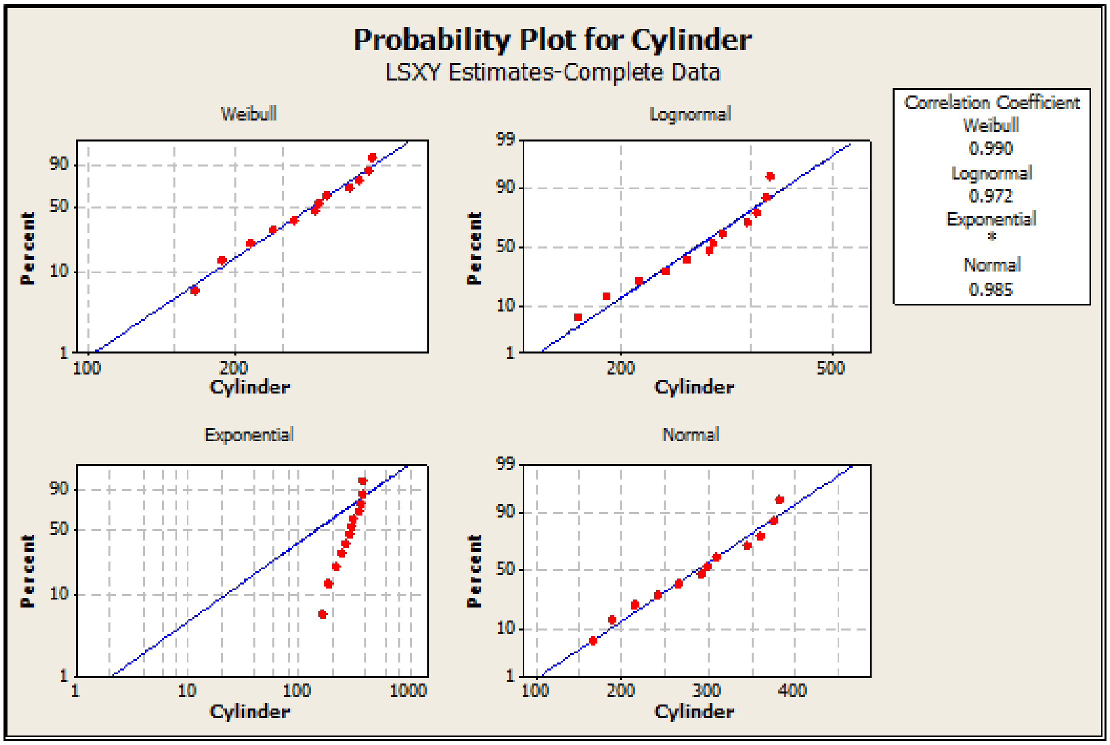


Figure 4.4 Parametric test of Cylinder

Parameter β = 4.151

Parameter θ = 314.167

It can be clearly seen that MTTF of Cylinder is t = 385.366 hours or equal to 16 days. It means that every 16 days after operation, Cylinder should be replaced in order to prevent machine failure. Reliability of this Cylinder also can be calculated when t = 385.366 as follows:

$$R(t) = e^{-(\frac{t}{\theta})^{\beta}} \quad (4\text{-}1)$$

R (385.366) = 52%

4.3.2 Vacuum

MTTF of vacuum is calculated based on the TTF data that has been calculated before. This calculation was done using computer software analysis based on the distribution of TTF data. Before calculating MTTF, step which should be done is knowing the distribution of the data.

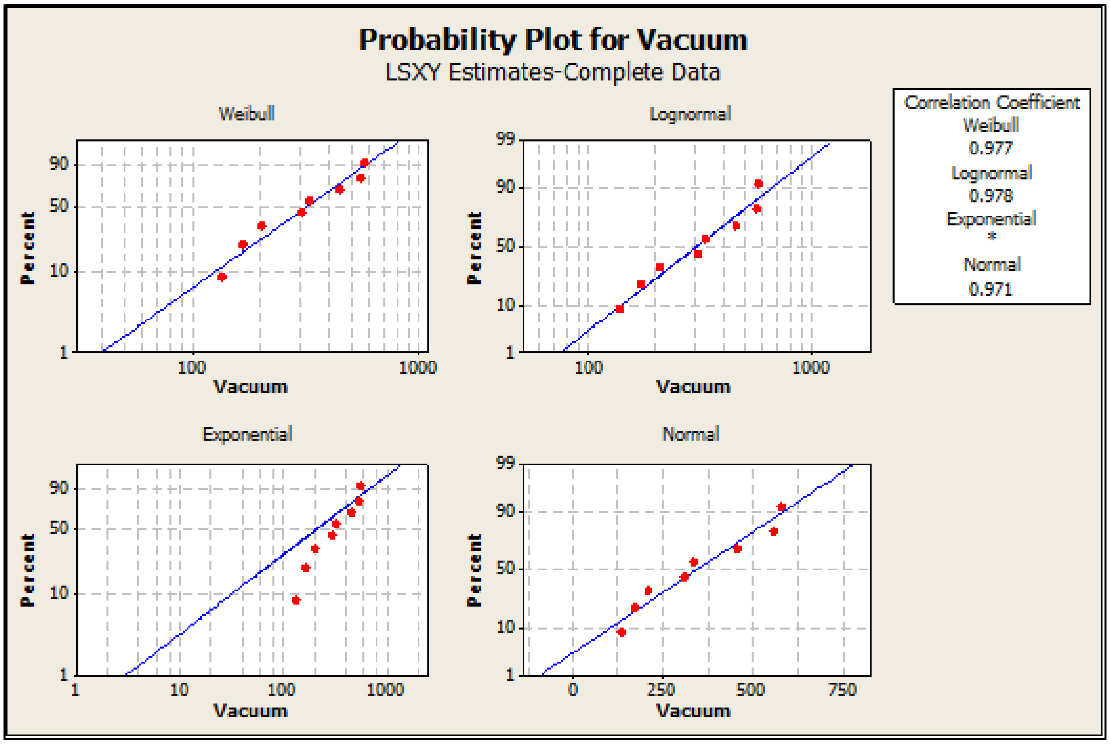


Figure 4.5 Goodness of Fit for Vacuum

Figure 4.5 above is the result of distribution analysis using statistical software. The result above provides information that the distribution that has greater coefficient of correlation was Lognormal distribution. Consequently, Lognormal distribution is chosen in order to calculate the MTTF in the next step. Here is the result of the statistical analysis to find the MTTF of Vacuum and the parameters of the calculation.

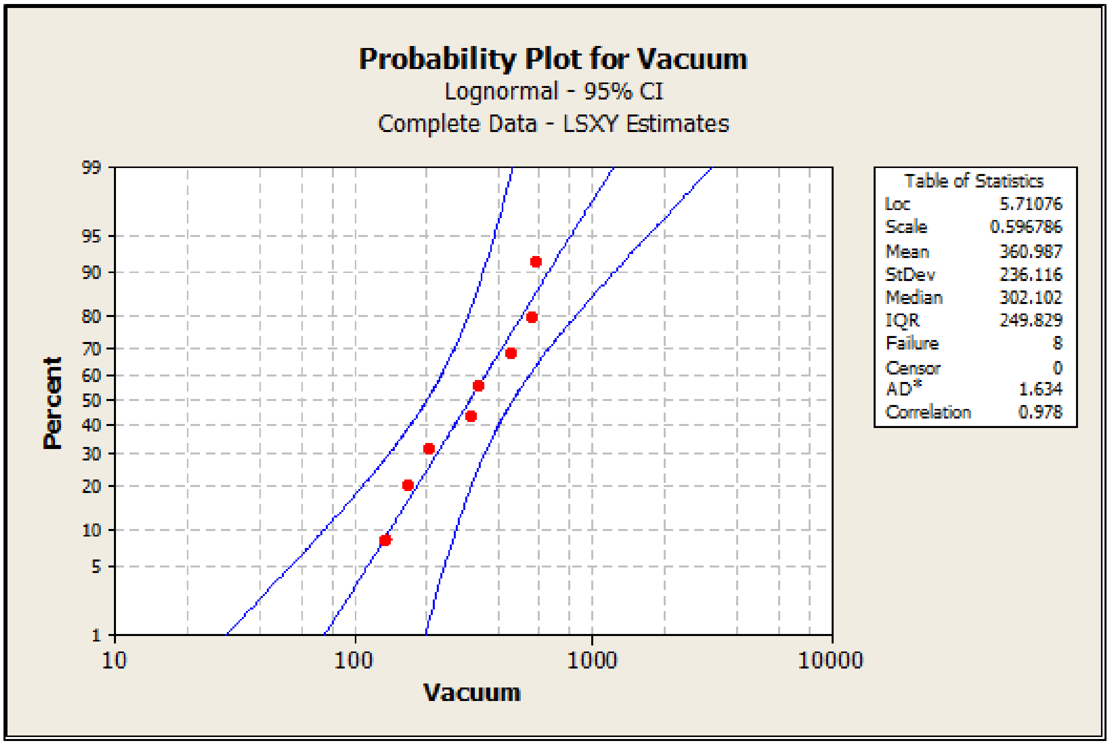


Figure 4.6 Parametric of Vacuum

Parameter s = 0.596

Parameter t-med = 302.102

MTTF can also be calculated manually using formulas based on the each type of distribution. Calculation below is the MTTF calculation of Vacuum based on the Lognormal distribution.

$$MTTF \ = tmed\ x\ e^{\left(\frac{s^2}{2}\right)} \tag{4-2}$$

$$MTTF = 302.102x\ e^{\frac{0.596^2}{2}} = 360.987$$

MTTF of Vacuum is 360.987 hours or equal to 15 days. Therefore, in order to prevent the failure, the preventive maintenance should be conducted before that time. These two parameters will be used to calculate the reliability of Vacuum. After the MTTF has been found and the parameter has been defined, the reliability of machine can be calculated as follows:

$$R\ (t) = 1 - \ \Phi\ [(\ln t/tmed)/s] \qquad (4\text{-}3)$$

R (360.987) = 38 %

4.3.4 Sensor

Goodness of fit is the steps to fit the data to several distributions in order to know which distribution that most fit with the data. This step leads to calculating the MTTF of components and to find parameters of calculating reliability of component. The distribution with greater coefficient of correlation will be chosen on the next calculation.

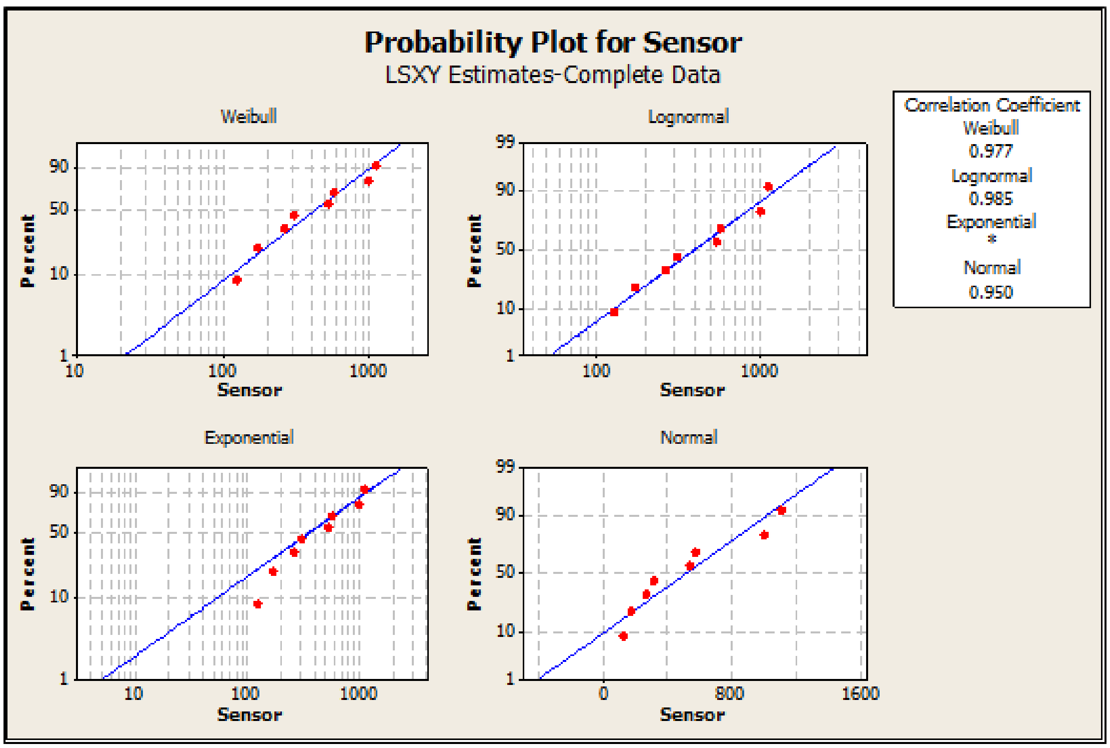


Figure 4.7 Goodness of Fit for Sensor

Figure 4.7 above is the result of statistical software analysis of fitting the data to the type of distribution. Based on the result of analysis above, the distribution chosen is Lognormal distribution. Therefore, MTTF of sensor will be calculated based on lognormal distribution formulas and analysis. In this research, MTTF will be calculated using statistical software. The result of the software analysis is presented below;

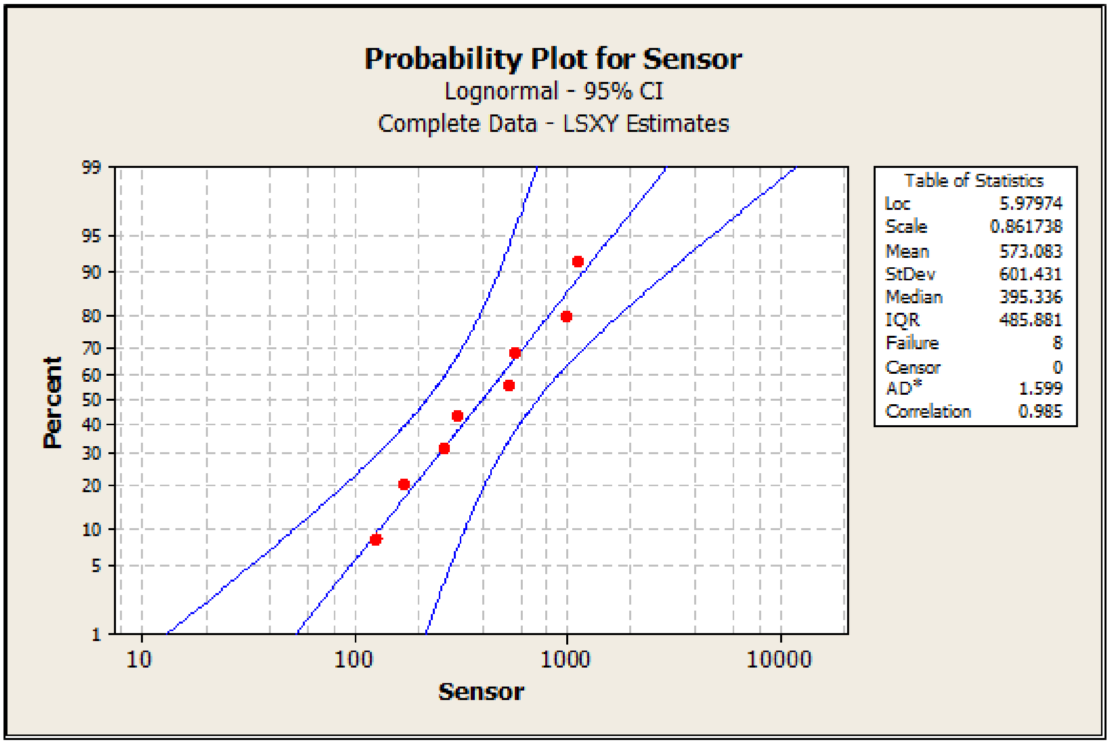


Figure 4.8 Parametric of Sensor

Parameter s = 0.861

Parameter t-med =395.336

$$MTTF \ = tmed\ x\ e^{\left(\frac{s^2}{2}\right)} \qquad (4\text{-}5)$$

$$MTTF\ = 396.336\ x\ e^{\frac{0.861^2}{2}} = 573.083$$

The result of MTTF of sensor is 573.083 hours and to prevent the failure, the preventive maintenance should be conducted before MTTF hours. Furtheremore, based on the data of MTTF and the parameters, reliability of sensor in the current condition can be calculated as follows:

$$R\ (t) = 1 - \ \Phi\ [(\ln t/tmed)/s] \qquad (4\text{-}6)$$

R (573.083) = 33%

4.3.5 Joint Leg

To calculate MTTF of Joint leg, there is one step that should be done before. The step is fitting the data to several types of distribution failure using goodness of fit test. This test will be done by statistical software. The result of the test is presented below:

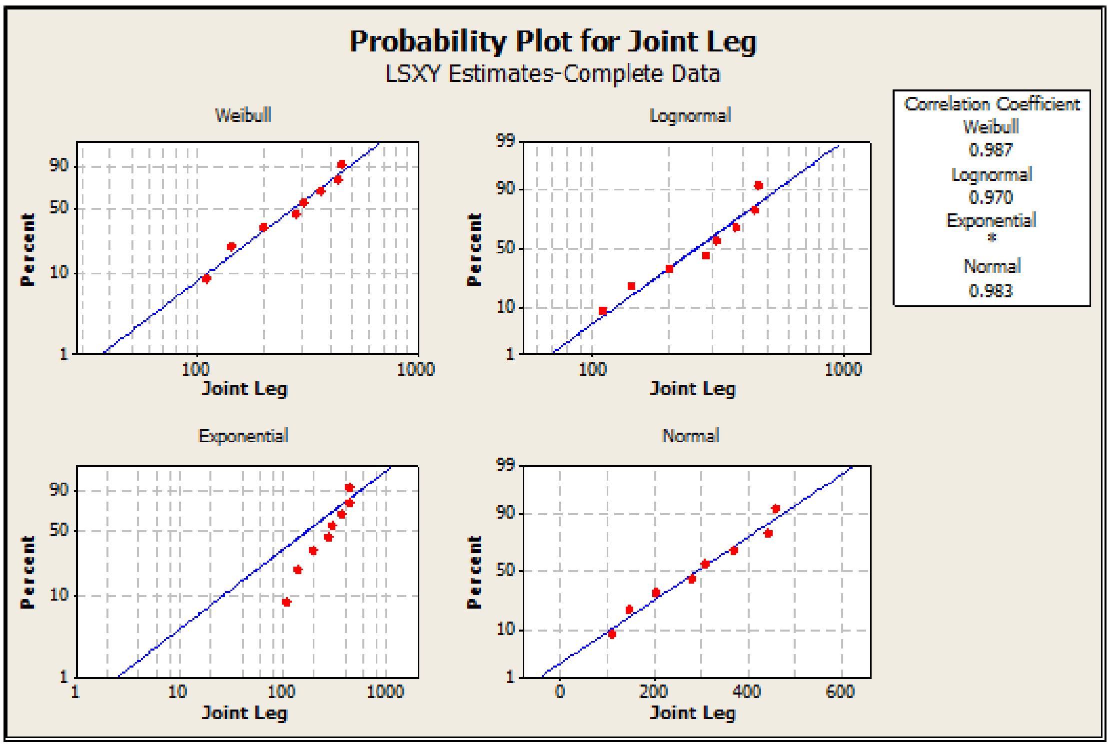


Figure 4.9 Goodness of Fit for Join Leg

The figure 4.9 above clearly shows that the distribution that has greater coefficient of correlation is Weibul distribution. Therefore, to calculate the MTTF and reliability of joint leg, Weibul distribution formulas will be used.

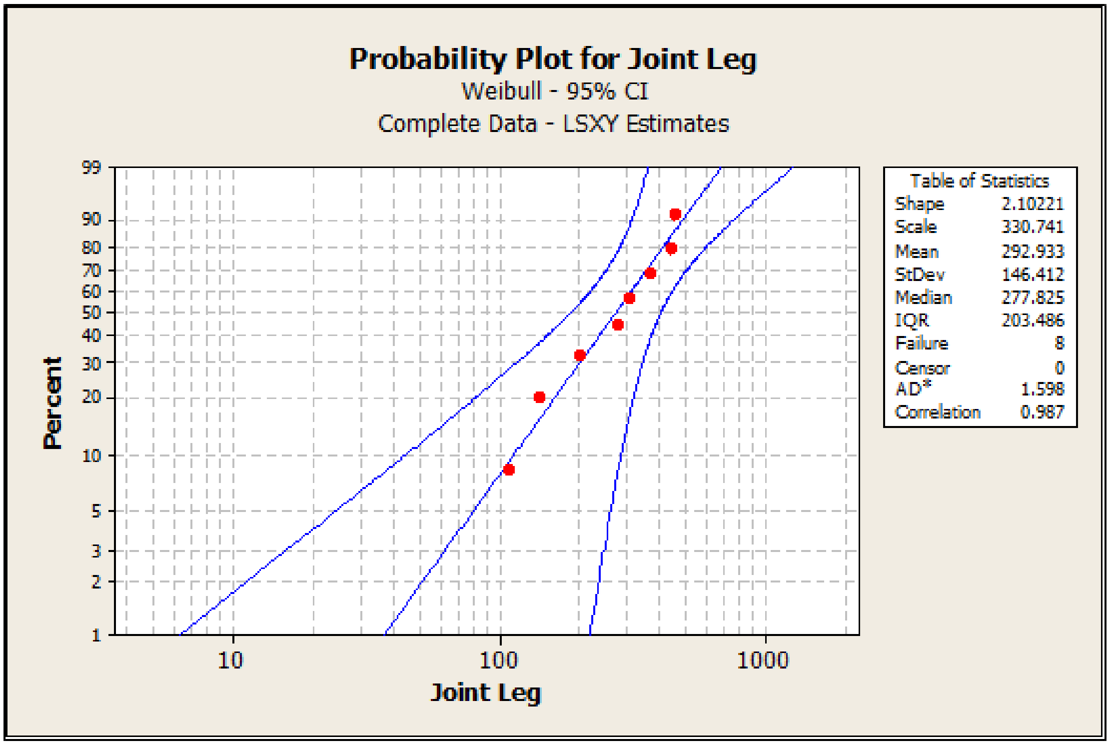


Figure 4.10 Parametric of Join Leg

Parameter β = 2.10

Parameter θ = 330.741

It can be clearly seen on Figure 4.10 above that MTTF of Joint leg is 292.922 hours. It means that Joint leg will fail again when passing the operation during 292.933 hours. To avoid component failure that will cause to downtime machine, the preventive maintenance should be done before that time. Reliability of Joint leg can be calculated using the parameters and MTTF has been found as follows:

$$R(t) = e^{-(\frac{t}{\theta})^{\beta}} \quad (4\text{-}7)$$

R (292.933) = 46%

4.3.6 Pallet

MTTF is calculated in order to know the average time from one failure to the next failure of the component. TTF data of pallet is used to calculate the MTTF in this section. Before calculate the MTTF of pallet, the data of TTF should be test using Goodness of fit test in order to know the distribution type of the data. Goodness of fit test is done used statistical software.

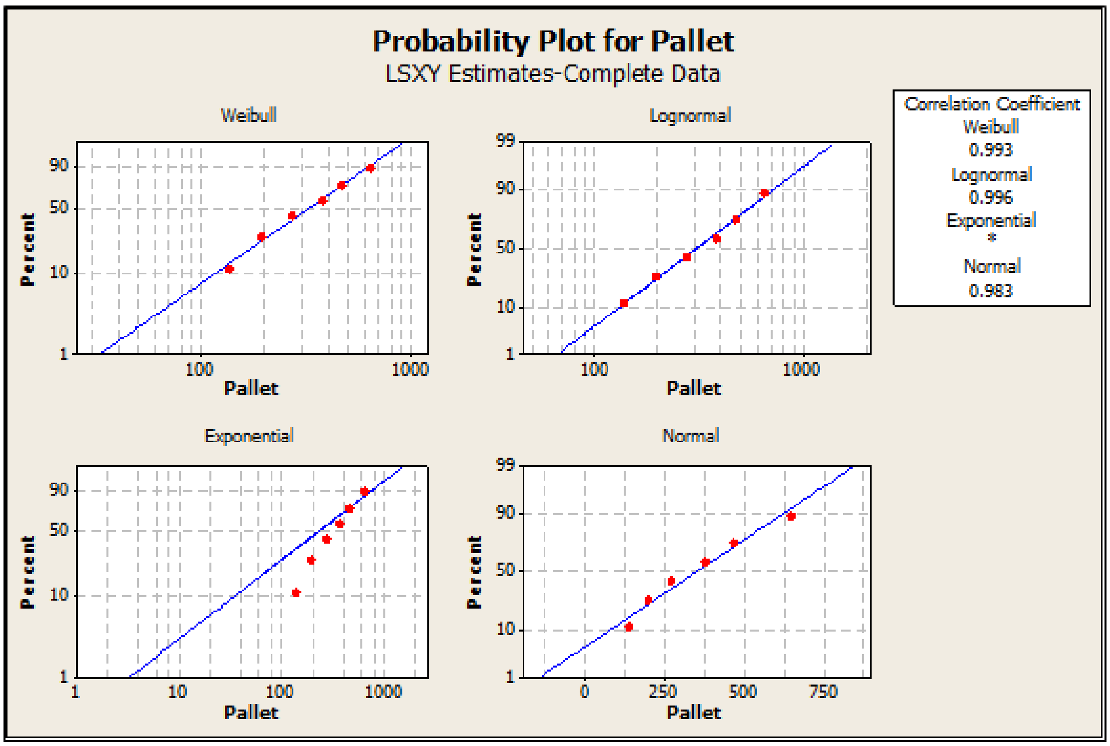


Figure 4.11 Goodness of Fit for Pallet

The result of statistical fitting on the figure 4.11 above clearly shows that the distribution which has greater coefficient of correlation is lognormal distribution. Therefore, MTTF of pallet will be calculated based on the formula in lognormal distribution. In this research MTTF will be calculated using statistical software. After the distribution of data has been defined, the next step is calculating MTTF of Pallet.

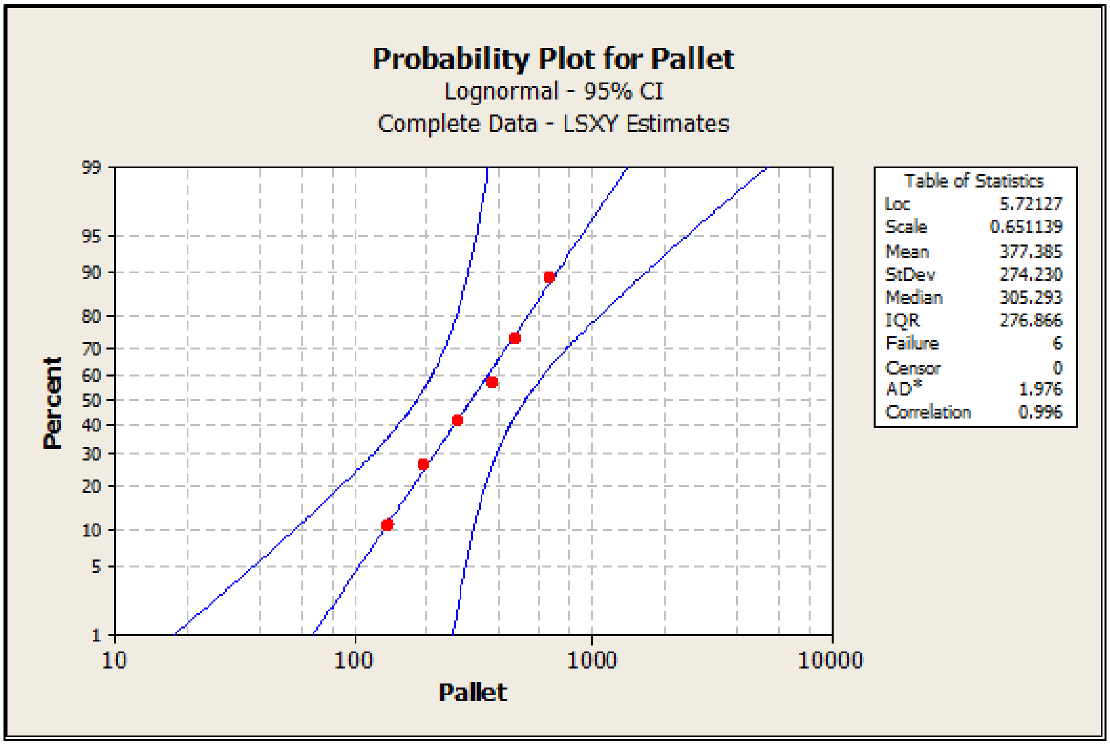


Figure 4.12 Parametric of Pallet

Parameter s = 0.651

Parameter t-med = 305.293

$$MTTF \ = tmed \ x \ e^{\left(\frac{s^2}{2}\right)} \qquad (4\text{-}8)$$

$$MTTF = 305.293 \ x \ e^{\frac{0.651^2}{2}} = 377.385$$

The result above shows that MTTF of pallet is 377.385 hours which equals to 16 days. So after 16 days operating, the component has probability to fail during the operation. Failure of the component will result in stoping the production time that is called as downtime and to avoid downtime machine caused by pallet, the preventive maintenance should be conducted before MTTF time. Based on the average time of failure that has been calculated above, reliability of Pallet can also be calculated as follows:

$$R\ (t) = 1 - \ \Phi\ [(\ln t/tmed)/s] \qquad (4\text{-}9)$$

R (377.385) = 37%

4.3.7 Springer

In order to calculate MTTF of springer, the TTF data that have been calculated should be analyzed using statistical software to fit the data with one type of failure distributions. There are four types of failure distribution which are Weibull distribution, Lognormal distribution, and Exponential distributions.

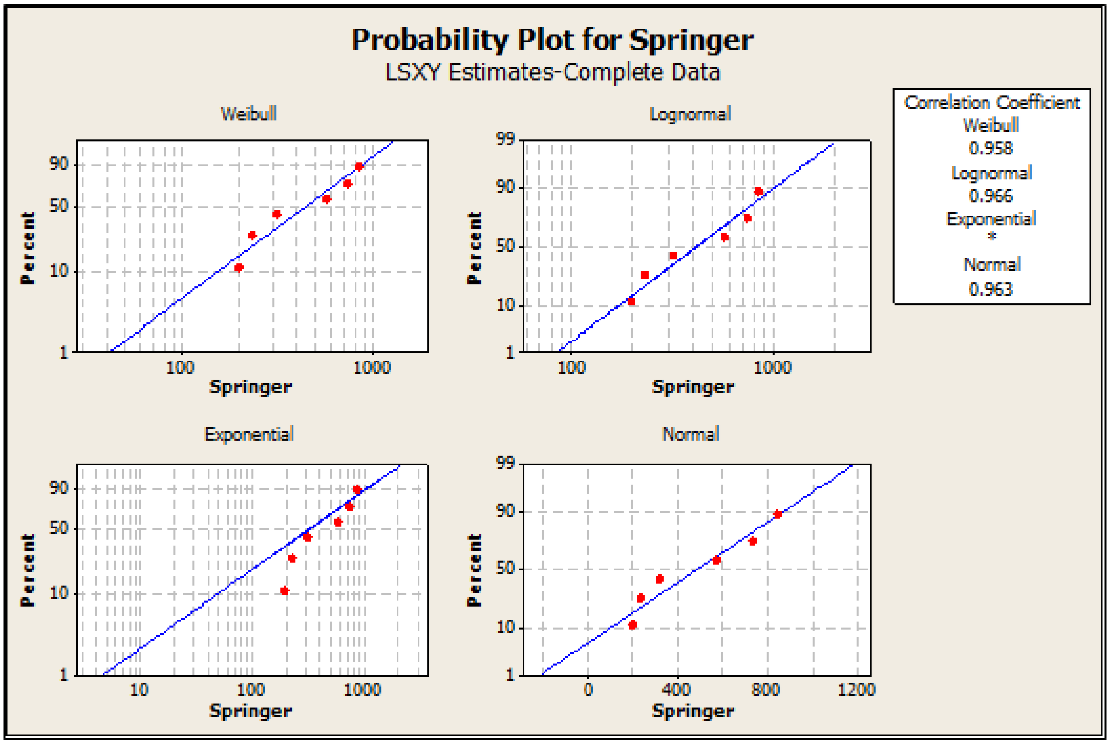


Figure 4.13 Goodness of Fit for Springer

Figure 4.14 above is the result of statistical fitting using goodness fit test of failure distribution. Distribution that has greater coefficient of correlation is the good distribution that was chosen to calculate the future calculation of springer. So the result shows that Lognormal distribution is more suitable with the failure data of springer. MTTF of springer will be calculated using the same software based on the Lognormal distribution.

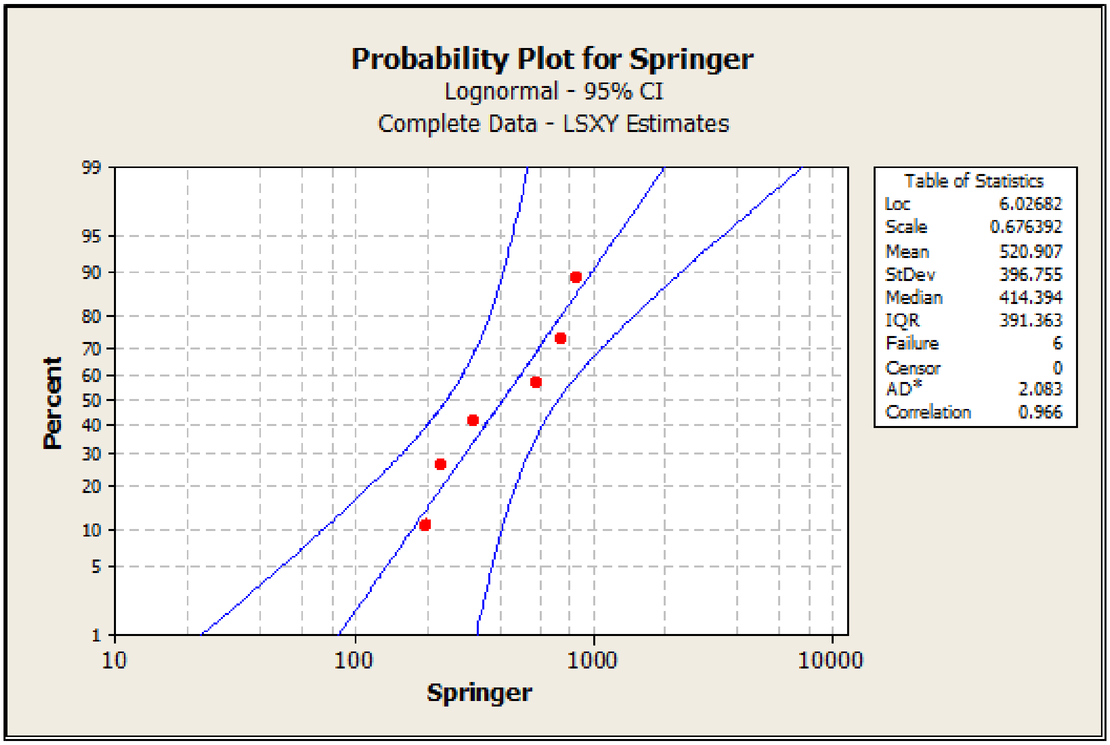


Figure 4.14 Parametric of Springer

Parameter s = 0.676

Parameter t-med = 414.394

$$MTTF \ = tmed \ x \ e^{\left(\frac{s^2}{2}\right)} \qquad (4\text{-}10)$$

$$MTTF = 414.394 \ x \ e^{\frac{0.676^2}{2}} = 520.907$$

The calculation above clearly shows that mean time to failure of springer is 520.907 hours. It means that every 520.90, the component should have preventive maintenance. To know the reliability of Springer, the parameter and MTTF the calculation can be done as it is presented here:

$$R \ (t) = 1 - \ \Phi \ [(\ln t / tmed)/s] \qquad (4\text{-}11)$$

R (520.907) = 37%

4.4 MTTR Calculation

Mean time to repair (MTTR) is needed in order to know the duration the operator takes to repair or replace a component. Based on the time to repair that has been calculated in the previous sub chapter, in this stage the data is input on statistical software in order to calculate the MTTR of each component. The steps to calculate MTTR is similar to the calculation of MTTF. The detail result of software analysis and calculation can be seen in the Appendix 2.

Table 4.15 MTTR of Components

Component	Distribution	Parameter	MTTR
Cylinder	Lognormal	s = 0.4	0.24
		t-med = 0.21	
Vacuum	Weibull	β = 2.6	0.22
		θ = 0.24	
Sensor	Lognormal	β = 0.9	0.56
		θ = 0.35	
Join Leg	Weibull	β = 2.6	0.12
		θ = 0.14	
Pallet	Lognormal	s = 0.34	0.13
		t-med = 0.12	
Springer	Lognormal	s= 0.53	0.18
		t-med = 0.15	

Table 4.15 above shows the summary of software calculation of MTTR. It can be clearly seen that the component that has greater time to repair is sensor. Data of MTTR above will be used to calculate cost of maintenance and to measure the mechanic ability to repair the components.

4.5 Calculation of Maintenance Cost

Cost is the important thing which is always one of the considerations in every aspect of business process. This research aims to implement maintenance system in production line in order to increase reliability of machine. Productivity of machine can be seen by the output of machine that can achieve the target with the lowest cost of production. Therefore, the objectives of this section is to know the cost of maintenance. There are two types of maintenance which are corrective maintenance and preventive maintenance. Cost calculation of maintenance is calculated to know how much the company should spend in this maintenance system. In order to calculate the maintenance cost, here are several data used in calculation;

- Machine capacity per hour is 180 toys.
- Mechanic fee per hour IDR 18,000
- Product price IDR 12,500
- Component prices as follows:

Table 4.16 Components Price

Component	Price (IDR)
Cylinder	678,000
Vacuum	524,000
Sensor	827,000
Join Leg	559,000
Pallet	549,000
Springer	913,000

Maintenance fee in amount of IDR 18,000 is computed from the mechanic salary in one hour. Production capacity is the number of product that should be produced by Auto machine 2 per hour during production process. Production loss is calculated from the prices per product multipled by the downtime of each component.

4.5.1 Corrective Maintenance Cost (Cf)

Corrective maintenance cost is the cost of maintenance that occurs when component fails during the production process. Corrective maintenance cost can be calculated using Equation (4-1) below.

$$Cf = d + (c\ x\ a) + (e\ xc\ x\ b) \qquad (4\text{-}12)$$

Where:

a = mechanic fee per hour

b = cost of production loss

c = downtime (hours)

d = component price/unit
e = production capacity

Table 4.17 Corrective Maintenance Cost Calculation

Component	Maintenance Fee	Component Price (IDR)	Production Capacity	Downtime (h)	Prod Loss (IDR)	Cf (IDR)
Cylinder	18,000	678,000	180	0.24	3,000	811,920
Vacuum	18,000	524,000	180	0.22	2,750	636,860
Sensor	18,000	827,000	180	0.56	7,000	1,542,680
Joint Leg	18,000	559,000	180	0.12	1,500	593,560
Pallet	18,000	549,000	180	0.13	1,625	589,365
Springer	18,000	913,000	180	0.18	2,250	989,140

This is the calculation example of corrective maintenance cost for cylinder. Mechanic fee to replace the cylinder in one hour is a=IDR 18,000, cost of production loss caused by downtime is b= IDR 3,000, price of cylinder per unit is d= IDR 678,000 and the capacity of machine auto 2 is e=180 products in one hour. Based on the downtime report in six month the average downtime that occurred in cylinder is c=0.24 h. Thus, considering the equation 4-12 and these information, cost of corrective maintenance for cylinder can be calculated as follows:

$$Cf = 678{,}000 + (0.24 x\ 6{,}000) + (180\ x 0.24 x\ 3{,}000) = IDR\ 811{,}920$$

4.5.2 Preventive Maintenance Cost (Cp)

Preventive maintenance cost is the cost needed to replace the component before the time to failure of the components. Cost of component based on the preventive maintenance can be calculated using the formula below:

$$Cp = a + (b\ x\ c) + (e\ x\ b\ x\ d) \qquad (4\text{-}13)$$

Where;

a = Price of component

b = Preventive time

c = Mechanic fee

d = Cost of production loss

e = production capacity

Table 4.18 below shows the result of preventive maintenance cost calculation of each component:

Table 4.18 Preventive Maintenance Cost Calculation

Component	Preventive Time (h)	Component Price (IDR)	Maintenance Fee (IDR)	Production Capacity	Cp (IDR)
Cylinder	0.3	678,000	18,000	180	683454
Vacuum	0.2	524,000	18,000	180	527636
Sensor	0.4	827,000	18,000	180	834272
Joint Leg	0.12	559,000	18,000	180	561181.6
Pallet	0.12	549,000	18,000	180	551181.6
Springer	0.14	913,000	18,000	180	915545.2

Table 4.18 above shows the calculation of preventive maintenance cost that will be proposed for the preventive maintenance system. In the purposed condition, the preventive maintenance will be conducted during shift change time in order to eliminate production loss. Consequently, there is no production loss cost in preventive maintenance cost calculation. The calculation example of preventive maintenance cost for cylinder is described here. Cylinder price per unit is a= IDR 678,000, preventive maintenance will be done by the mechanic based on the standard time given by the company which is 0.3 h for the cylinder. Mechanic fee in one hour is IDR 6,000 and the capacity of machine auto 2 is 180 products per hour. Considering the equation 4-13, preventive maintenance cost of cylinder can be calculated as follows:

$$Cp = 678{,}000 + (0.3\ x\ 6{,}000) + (180\ x\ 0.3) = IDR\ 679{,}854$$

4.6 Component Replacement Interval

After the reliability of each component has been calculated, the interval of component replacement is calculated in this section. In order to achieve the target of average reliability which is 80%, there is simulation of preventive maintenance of each component.

Reliability of machine has impact on the production performance. Machine with high reliability will produce high number of product based on the target or more than that without any problems of the machine. Preventive maintenance aims to reduce downtime machine and increase machine reliability. The target of reliability that should be achieved in this research is 80%. Reliability of each component will be calculated based on the type of distribution that fit with failure time data of each component and the parameters or each distribution. There is also another data calculation used to calculate the component reliability. Cumulative distribution function is needed as the one of variables to calculate reliability of each component.

4.6.1 Cylinder

The next step after calculating the MTTF and reliability of each component is simulating replacement time to know which interval of time can achieved reliability 80%. Here is the interval replacement time of cylinder in 285 hours.

Table 4.19 Replacement Interval Time of Cylinder

t(i)	f	F	Reliability	H(t)	Cost (IDR)
210	0.004	0.17	83%	0.17	3,912
220	0.005	0.20	79%	0.20	3,845
230	0.007	0.24	76%	0.24	3,819
240	0.008	0.28	72%	0.28	3,795
250	0.009	0.321	0.679	0.321	3,784
260	0.011	0.366	0.634	0.366	3,773
270	0.014	0.413	0.587	0.413	3,764
285	0.19	0.487	0.523	0.487	3,754

Parameter β = 4.151

Parameter θ = 314.167

- Probability Density Function

$$f(t) = \frac{\beta}{\theta}\left(\frac{t}{\theta}\right)^{\beta-1} e^{\left(\frac{t}{\theta}\right)^{\beta}} \quad (4\text{-}14)$$

$$f(210) = \frac{4.151}{314.167}\left(\frac{210}{314.167}\right)^{4.151-1} e^{\left(\frac{210}{314.167}\right)^{4.151}} = 0.004$$

- Cumulative Distribution Function

$$F(t) = 1 - e^{-\left(\frac{t}{\theta}\right)^{\beta}} \quad (4\text{-}15)$$

$$F(210) = 1 - e^{-\left(\frac{210}{314.167}\right)^{4.151}} = 0.17$$

- Reliability Function

$$R(t) = e^{-(\frac{t}{\theta})^{\beta}} \quad (4\text{-}16)$$

$$R(210) = e^{-\left(\frac{210}{314.167}\right)^{4.151}} = 0.83$$

- Cost per unit of time

$$C(t) = \frac{Cp+(Cf \text{ x } H(t))}{t} \quad (4\text{-}17)$$

$$C(t) = \frac{IDR\ 683{,}454 + (IDR 811{,}920 \text{ x } 0.17)}{210} = IDR\ 3{,}912$$

The simulation table above, it is clearly seen that Cylinder can achieve 80% of reliability with time of replacement is 210 hours. The cost of per toy of time is also calculated as the consideration for the company to compare with the initial cost. Figure 4.15 below shows the curve of reliability of cylinder with the cost per toy each time.

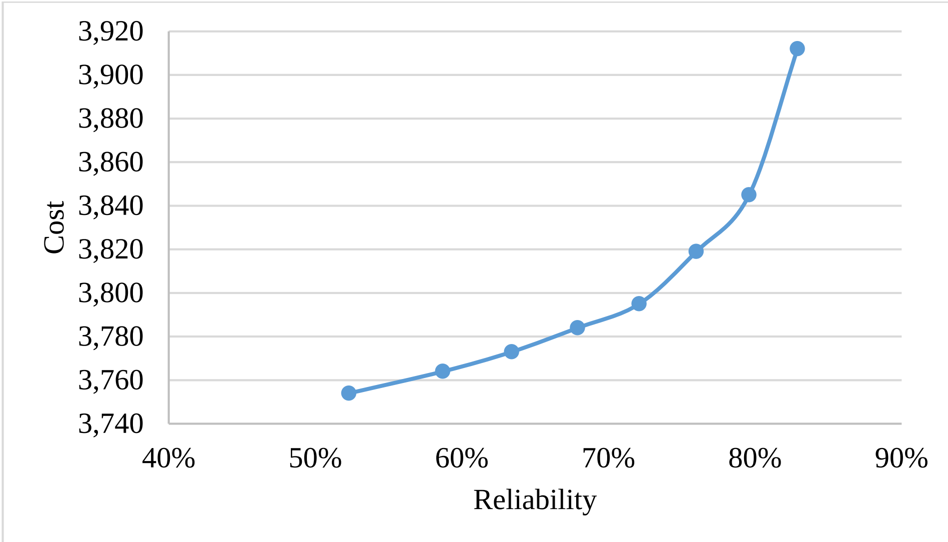


Figure 4.15 Reliability of Cylinder

4.6.2 Vacuum

Calculation of replacement interval of Vacuum is based on the type of distribution that failure time data of Vacuum fit to. From the result of Goodness fit test, failure data of Vacuum fit with lognormal distribution. Table 4.20 below shows the result of the calculation;

Table 4.20 Replacement Interval Time of Vacuum

t(i)	f	F	Reliability	H(t)	Cost (IDR)
180	0.002	0.19	81%	0.19	3,604
200	0.002	0.24	76%	0.24	3,402
220	0.002	0.30	70%	0.30	3,267
240	0.002	0.35	65%	0.35	3,127
260	0.002	0.40	60%	0.40	3,009
280	0.002	0.45	55%	0.45	2,908
300	0.002	0.50	50%	0.50	2,820
320	0.002	0.54	46%	0.54	2,724
340	0.002	0.58	42%	0.58	2,638
360	0.002	0.62	38%	0.62	2,562

Parameter s = 0.596

Parameter t-med = 302.102

- Probability Density Function

$$f(t) = \frac{1}{st\sqrt{2\pi}} e^{\left[\frac{1}{2s^2}\left(ln\frac{t}{tmed}\right)^2\right]} \quad (4\text{-}18)$$

$$f(180) = \frac{1}{236.1\sqrt{2x\,3.14}} e^{\left[\frac{1}{2x0.596^2}\left(ln\frac{180}{302.102}\right)^2\right]} = 0.002$$

- Cumulative Distribution Function

$$F(t) = \Phi\left[\frac{1}{\mathrm{s}}\ln\frac{\mathrm{t}}{\mathrm{tmed}}\right] \quad (4\text{-}19)$$

$$F(108) = \Phi\left[\frac{1}{0.596}\ln\frac{180}{302.102}\right] = 0.19$$

- Reliability Function

$$R(t) = 1 - F(t) \quad (4\text{-}20)$$

$$R(t) = 1 - 0.19 = 0.81$$

- Cost per unit of time

$$C(t) = \frac{Cp + (Cf \text{ x } H(t))}{t} \quad (4\text{-}21)$$

$$C(t) = \frac{IDR\ 527{,}636 + (IDR\ 636{,}860 \text{ x } 0.19)}{180} = IDR\ 3{,}604$$

Currently reliability of Vacuum is 38% with MTTF 360 hours. This component should increase the reliability in order to reduce downtime of machines and achieved the target of average reliability. The target of reliability that should be achieved is at least 80%. From the calculation above, Vacuum can achieve the target of reliability when t = 180 hours. Therefore, preventive maintenance to replace vacuum in machine auto 2 is conducted every 180 hours after the vacuum finished operating. Figure 4.16 below shows the curve considering reliability and cost of each cycle time of replacement interval;

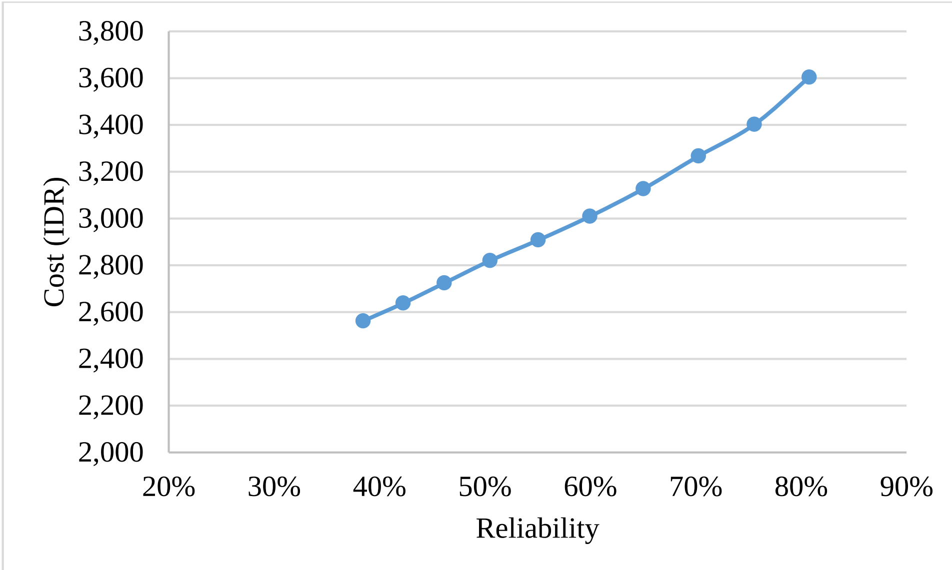


Figure 4.16 Reliability of Vacuum

4.6.3 Sensor

Replacement interval calculation of the component is done in order to know when the component should be replaced based on the target of reliability that should be achieved. This calculation is based on the distribution type that fit with failure data of the Sensor. Based on the statistical failure data, Sensor is fit with Lognormal distribution. Table 4.21 below is the result of the calculation of simulation interval time to replacement of sensor.

Table 4.21 Replacement Interval Time of Sensor

t(i)	f	F	Reliability	H(t)	Cost
180	0.001	0.18	82%	0.18	6,178
240	0.0007	0.28	72%	0.28	5,276
300	0.0006	0.37	63%	0.37	4,684
360	0.0006	0.46	54%	0.46	4,289
420	0.0006	0.53	47%	0.53	3,933
480	0.0006	0.59	41%	0.59	3,634
540	0.0007	0.64	36%	0.64	3,373
573	0.0007	0.67	33%	0.67	3,260

Parameter s = 0.86

Parameter t-med = 395.33

- Probability Density Function

$$f(t) = \frac{1}{st\sqrt{2\pi}} e^{\left[\frac{1}{2s^2}\left(ln\frac{t}{tmed}\right)^2\right]} \quad (4\text{-}22)$$

$$f(180) = \frac{1}{601.4\sqrt{2x\ 3.14}} e^{\left[\frac{1}{2x0.86^2}\left(ln\frac{180}{395.33}\right)^2\right]} = 0.001$$

- Cumulative Distribution Function

$$F(t) = \Phi\left[\frac{1}{\mathrm{s}}\ln\frac{\mathrm{t}}{\mathrm{tmed}}\right] \quad (4\text{-}23)$$

$$F(180) = \Phi\left[\frac{1}{0.86}\ln\frac{180}{395.33}\right] = 0.18$$

- Reliability Function

$$R(t) = 1 - F(t) \quad (4\text{-}24)$$

$$R(180) = 1 - 0.18 = 0.82$$

- Cost per unit of time

$$C(t) = \frac{Cp + (Cf \text{ x } H(t))}{t} \quad (4\text{-}25)$$

$$C(t) = \frac{IDR\ 834{,}272 + (IDR\ 1{,}542{,}680 \text{ x } 0.18)}{180} = IDR\ 6{,}178$$

From the calculation above, sensor can achieved the target reliability with MTTF 180 hours. So in order to increase sensor reliability, the preventive maintenance should replace the sensor every 180 hours after operating time. Figure 4.17 below shows the curve of reliability of the machine with the cost of production of the time.

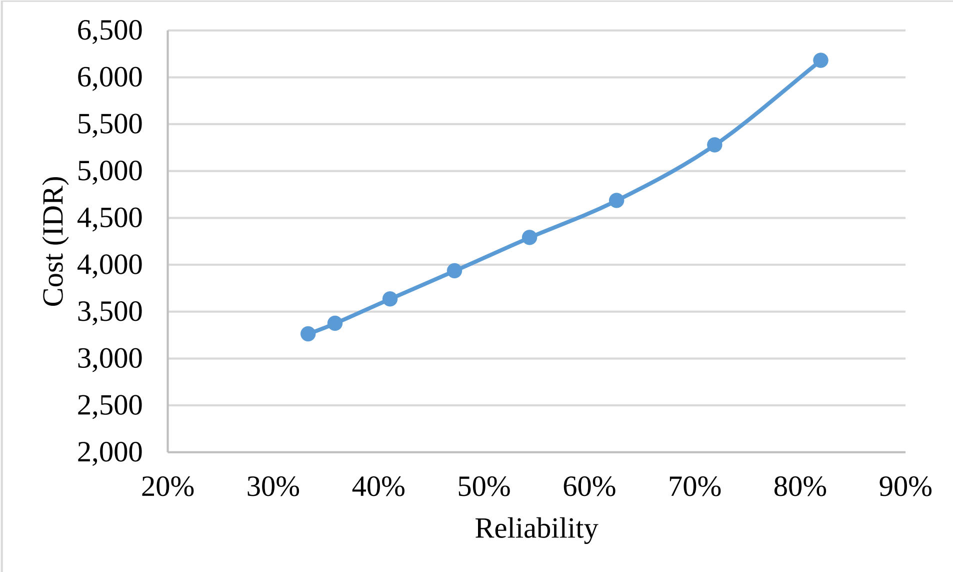


Figure 4.17 Reliability of Sensor

4.6.4 Joint Leg

After the current MTTF and reliability has been calculated, the next step is to calculate the interval replacement of Joint leg. Before starting this calculation, the important thing that should be known is type of distribution used in this calculation. Considering the statistical fitting to failure type of distribution, data failure time of Join leg is fit to Weibull distribution. After the calculation, below is the result of replacement interval calculation with the simulation of interval replacement;

Table 4.22 Replacement Interval Time of Joint Leg

t(i)	f	F	Reliability	H (t)	Cost (IDR)
160	0.004	0.059	80%	0.059	3,726
180	0.004	0.094	76%	0.094	3,428
200	0.005	0.142	71%	0.142	3,227
220	0.006	0.204	65%	0.204	3,101
240	0.007	0.279	60%	0.279	3,028
260	0.009	0.366	55%	0.366	2,994
280	0.011	0.462	49%	0.462	2,984
292	0.012	0.522	46%	0.522	2,983

Parameter β=2.10

Parameter θ= 330.741

- Probability Density Function

$$f(t) = \frac{\beta}{\theta}\left(\frac{t}{\theta}\right)^{\beta-1} e^{\left(\frac{t}{\theta}\right)^{\beta}} \qquad (4\text{-}26)$$

$$f(160) = \frac{2.10}{330.741}\left(\frac{160}{330.741}\right)^{2.10-1} e^{\left(\frac{160}{330.741}\right)^{2.10}} = 0.004$$

- Cumulative Distribution Function

$$F(t) = 1 - e^{-\left(\frac{t}{\theta}\right)^{\beta}} \qquad (4\text{-}27)$$

$$F(160) = 1 - e^{-\left(\frac{180}{330.741}\right)^{2.10}} = 0.059$$

- Reliability Function

$$R(t) = e^{-(\frac{t}{\theta})^{\beta}} \qquad (4\text{-}28)$$

$$R(160) = e^{-\left(\frac{180}{330.741}\right)^{2.10}} = 0.80$$

- Cost per unit of time

$$C(t) = \frac{Cp + (Cf \text{ x } H(t))}{t} \qquad (4\text{-}29)$$

$$C(t) = \frac{IDR\ 5611{,}181.6 + (IDR\ 593{,}560 \text{ x } 0.059)}{160} = IDR\ 3{,}726$$

The calculation above clearly shows that Joint leg can achieve the average reliability in 80% with t = 160 hours. It means that every 160 hours after the operation, this component should be replaced in order to maintain the reliability of that component and machine. The curve of reliability that with cost of product per time cycle is presented in this following figure.

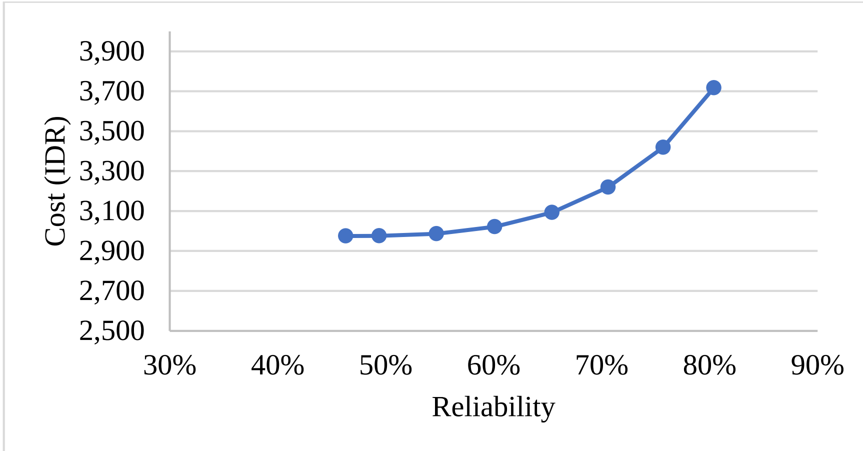


Figure 4.18 Reliability of Join Leg

4.6.5 Pallet

Considering the reliability of Pallet in current condition which has not achieved the reliability target, in this step, there is a simulation replacement interval calculation in order to find the time to conduct the preventive maintenance based on the average reliability that should be achieved. From the result of goodness fit test, the data failure time of Pallet is fit for lognormal distribution. Therefore, this calculation will be done based on the lognormal distribution formulas. Table Pallet 4.23 below is the result of calculation of maintenance interval calculation of Pallet.

Table 4.23 Replacement Interval Time of Pallet

t(i)	f	F	Reliability	H(t)	Cost (IDR)
160	0.002	0.16	84%	0.16	4,034
200	0.002	0.26	74%	0.26	3,522
240	0.002	0.36	64%	0.36	3,181
280	0.001	0.45	55%	0.45	2,916
320	0.001	0.5	50%	0.5	2,643
360	0.002	0.6	40%	0.6	2,513
377	0.002	0.63	37%	0.63	2,477

Parameter s = 0.65

Parameter t_{med} = 305.29

- Probability Density Function

$$f(t) = \frac{1}{st\sqrt{2\pi}} e^{\left[\frac{1}{2s^2}\left(ln\frac{t}{tmed}\right)^2\right]} \quad (4\text{-}30)$$

$$f(160) = \frac{1}{274.23\sqrt{2x3.14}} e^{\left[\frac{1}{2x0,65^2}\left(ln\frac{160}{305.29}\right)^2\right]} = 0.02$$

- Cumulative Distribution Function

$$F(t) = \Phi\left[\frac{1}{s}\ln\frac{t}{tmed}\right] \quad (4\text{-}31)$$

$$F(160) = \Phi\left[\frac{1}{0.65}\ln\frac{160}{305.29}\right] = 0.16$$

- Reliability Function

$$R(t) = 1 - F(t) \quad (4\text{-}32)$$

$$R(160) = 0.84$$

- Cost per unit of time

$$C(t) = \frac{Cp + (Cf \text{ x } H(t))}{t} \quad (4\text{-}33)$$

$$C(t) = \frac{IDR\ 551{,}181.6 + (IDR\ 589{,}365 \text{ x } 0.16)}{160} = IDR\ 4{,}034$$

The current Pallet condition has reliability 37% with t = 377 hours. From the calculation above Pallet can achieve average reliability if the preventive maintenance is conducted every 160 hours after operation. Figure 4.19 below shows the curve of reliability with cost of toy per time.

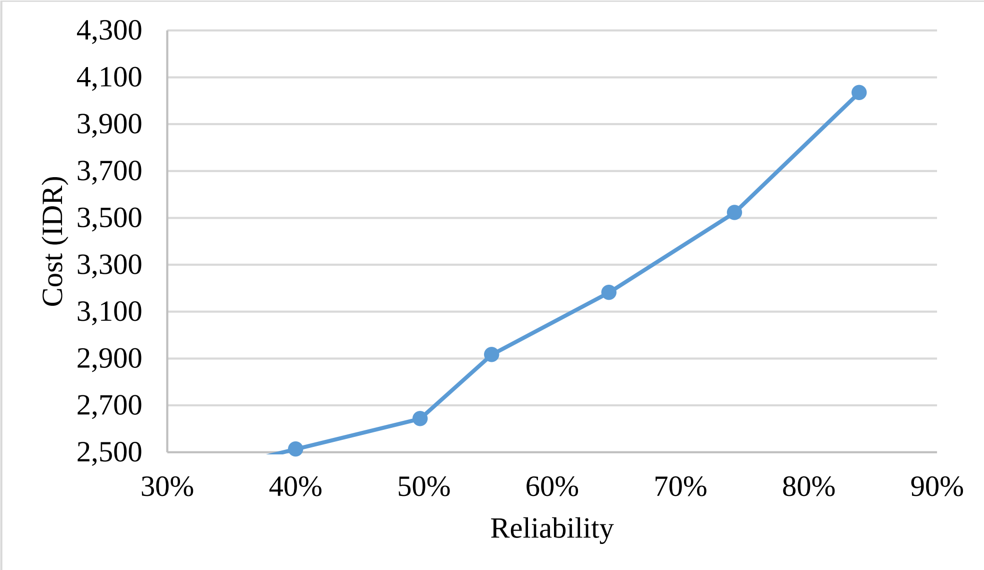


Figure 4.19 Reliability of Pallet

4.6.6 Springer

In the current condition Springer has 37% reliability with t = 521 hours. This condition should be improved to increase the reliability of Springer. Here is the calculation of interval time of preventive maintenance in order to know when the preventive maintenance should be conducted in order to achieve the target of reliability that should achieve.

Table 4.25 Replacement Interval Time of Springer

t(i)	F	F	Reliability	H(t)	Cost
220	0.002	0.17	83%	0.17	4,927
260	0.001	0.25	75%	0.25	4,472
300	0.001	0.32	68%	0.32	4,107
340	0.001	0.38	62%	0.38	3,798
380	0.001	0.45	55%	0.45	3,581
420	0.001	0.51	49%	0.51	3,381
460	0.001	0.56	44%	0.56	3,194
500	0.001	0.61	39%	0.61	3,038
521	0.001	0.63	37%	0.63	2,953

Parameter s = 0.67

Parameter t-med = 414.39

- Probability Density Function

$$f(t) = \frac{1}{st\sqrt{2\pi}} e^{\left[\frac{1}{2s^2}\left(ln\frac{t}{tmed}\right)^2\right]} \quad (4\text{-}34)$$

$$f(220) = \frac{1}{396.75\sqrt{2x3.14}} e^{\left[\frac{1}{2x0,67^2}\left(ln\frac{220}{414.39}\right)^2\right]} = 0.02$$

- Cumulative Distribution Function

$$F(t) = \Phi\left[\frac{1}{s}\ln\frac{\text{t}}{\text{tmed}}\right] \quad (4\text{-}35)$$

$$F(220) = \Phi\left[\frac{1}{0.67}\ln\frac{220}{414.39}\right] = 0.17$$

- Reliability Function

$$R(t) = 1 - F(t) \quad (4\text{-}36)$$

$$R(220) = 0.83$$

- Cost per unit of time

$$C(t) = \frac{Cp + (Cf \text{ x } H(t))}{t} \quad (4\text{-}37)$$

$$C(t) = \frac{IDR\ 915{,}545 + (IDR\ 989{,}140 \text{ x } 0.17)}{220} = IDR\ 4{,}927$$

The calculation above shows that Springer can achieve the target of reliability when the preventive maintenance is conducted every 220 hours after operating. When t = 220, Springer can achieve reliability in 83%. Table 4.22 above also shows the cost of toy per time. In this case, cost toy per time based on the reliability that should be achieved is IDR 4,917. Figure 4.20 below shows the curve of reliability of springer with cost per cycle time.

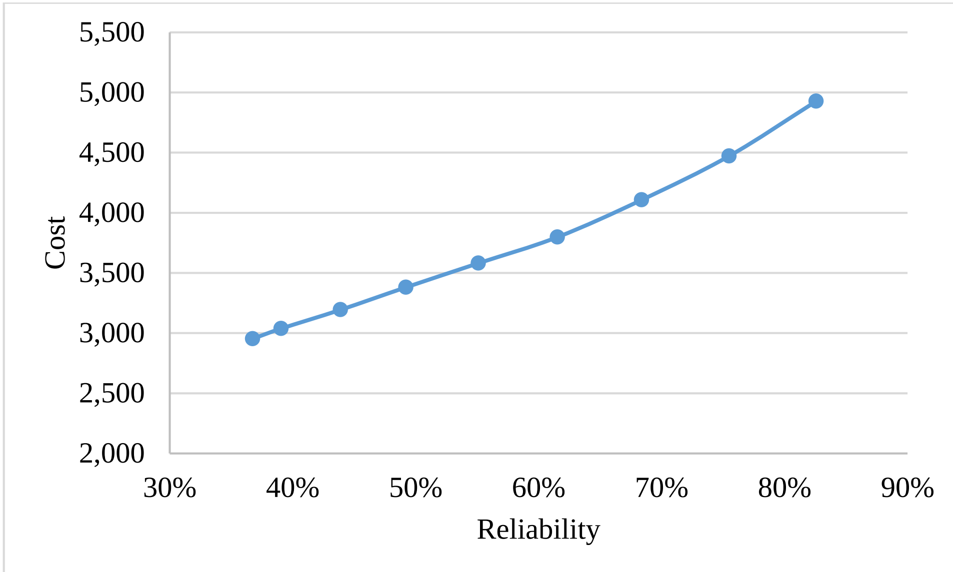


Figure 4.20 Reliability of Springer

4.7 Analysis Current and Proposed Condition

Current condition is the condition of the component before implementing an improvement. In order to know the effectiveness of the improvement there is comparison between current and after improving conditions. This research proposes the preventive maintenance as the improvement of current condition. After all the analysis and calculation of data on the current condition and get the proposed condition, here is the comparison of both conditions. The period of the comparison as the proposed condition is August 2016 until December 2016.

4.7.1 MTTR Comparison

MTTR or mean time to repair is the average time needed to repair the component. Time to repair (TTR) is calculated using the duration of mechanic work for repairing the component. The longer time to repair will result in higher production loss. Thus, MTTR is calculated from the average of TTR based on the report of downtime in the last six months. Downtime of machine in current condition is longer because of there is waiting time for the mechanic to repair the component. For example, when the machine breakdown and the operators need to call the mechanic to repair, time from the machine breakdown until the mechanic come to repair the machine is called waiting time. Hence, in order to eliminate waiting time, the preventive maintenance is proposed in this research. Figure 4.21 below shows the comparison of MTTF in the current condition with proposed condition.

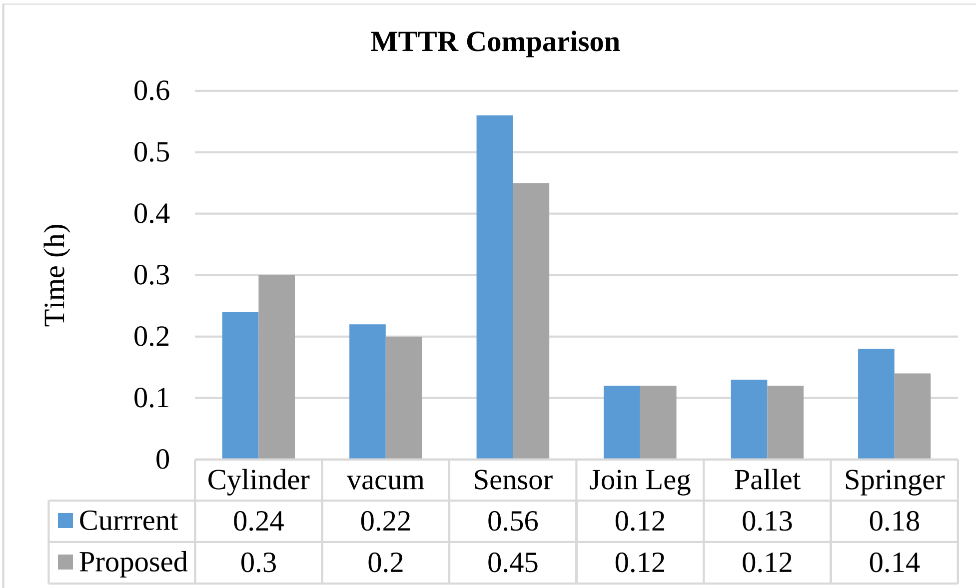


Figure 4.21 MTTR Comparison

The average of MTTR in the current condition of each component is 0.24 hours, and the average MTTR in proposed condition is 0.22 hours. With this result, the percentage of MTTR reduction can be calculated as follows:

$$\frac{0.24 - 0.22}{0.22} x\ 100 = 9\%$$

Based on the Figure 4.21 and calculation above, the average of MTTR can decrease by 9% for each component. In the proposed condition the activities of maintenance have been scheduled so the mechanic will do the preventive maintenance based on the schedule and duration to repair the components. Thus, there is no waiting time and the production loss can reduce in the condition as well.

4.7.2 Reliability Comparison

Machine performance in the production line can be measured from the percentage of reliability of that machine itself. In this research, the target reliability that should be achieved by all components is 80%. Based on the data analysis of current condition, there are six components that have a higher frequency of failure. To support the production performance of machine Auto 2, these components should have preventive maintenances to reduce the number of failure frequency. By implementing the preventive maintenance, the average the reliability of each component increase by 50.7%. Figure 4.22 below shows the comparison of reliability current condition with the proposed condition of each component.

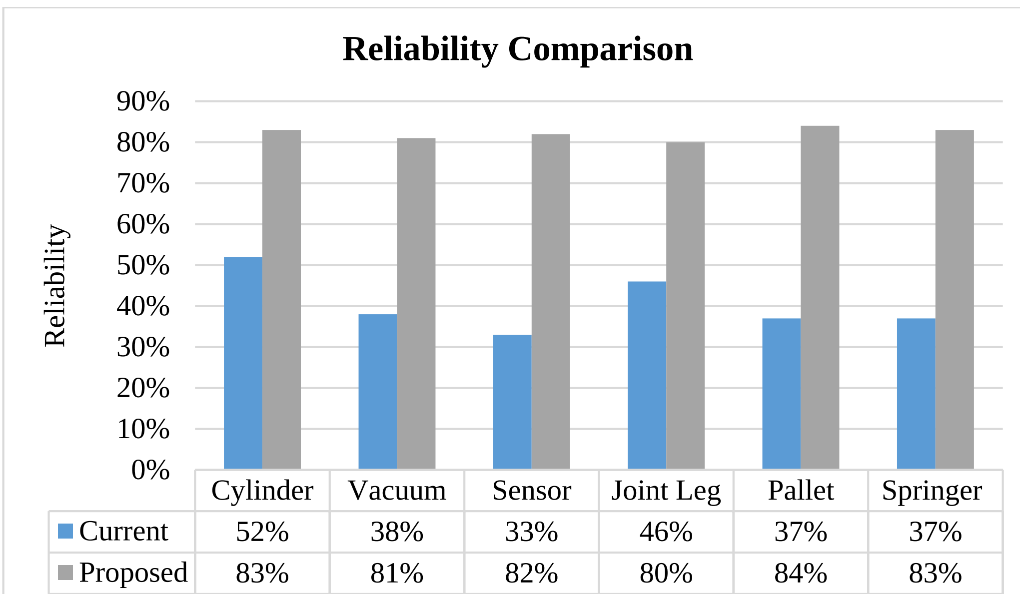


Figure 4.22 Reliability Comparison

The average reliability of all components in current condition is 41%, while in the proposed condition the average of reliability of all components is 82%. The percentage of the increase can be calculated as follows:

$$\frac{0.82 - 0.41}{0.82} x\ 100 = 50.7\%$$

4.7.3 Cost Comparison

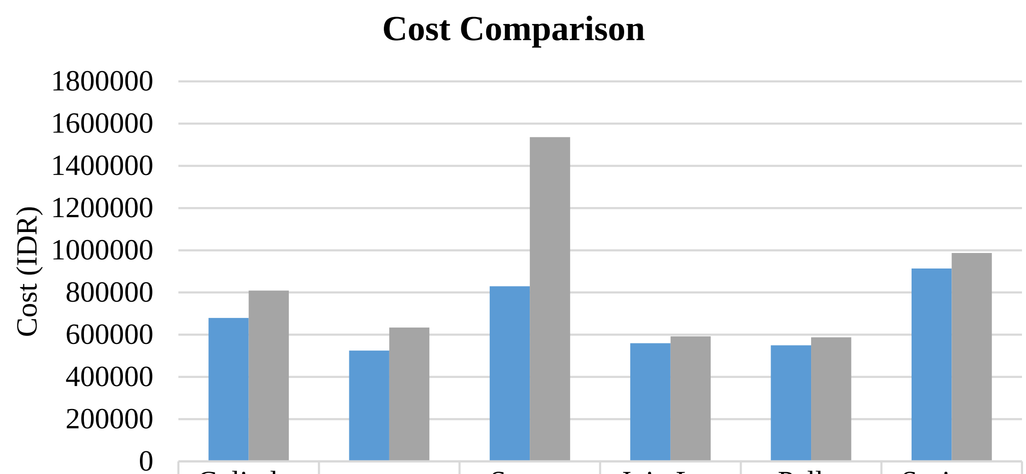
Cost is an important thing which is always one of the considerations in every activity in the company and the preventive maintenance is the right way to reduce machine breakdown of machine and increase the machine reliability. Every second in production process has the cost. Consequently, by implementing preventive maintenance, waiting time to repair the component can be eliminated. Table 4.23 below shows the maintenance cost comparison before implementing the preventive maintenance and after implementing preventive maintenance in machine Auto 2.

Table 4.26 Cost Comparison

Component	Proposed (IDR)	Current (IDR)	Saving (IDR)
Cylinder	683454	809,040	811,920
Vacuum	527636	634,220	636,860
Sensor	834272	1,535,960	1,542,680
Join Leg	561181.6	592,120	593,560
Pallet	551181.6	587,805	589,365
Springer	915545.2	986,980	989,140
		Average	181,709

Table 4.24 above shows the comparison of maintenance cost in the current and proposed condition. It can be clearly seen that by implementing the preventive maintenance, company can save maintenance cost around IDR 181,709 in the average. In the percentage, the maintenance cost can be reduced by 21% in the average for each maintenance activity of each component.

The cost difference between current and purposed condition is presented in Figure 4.23 below.



	Cylinder	vacum	Sensor	Join Leg	Pallet	Springer
Purpose	679854	525236	829472	559741.6	549741.6	913865.2
Current	809040	634220	1535960	592120	587805	986980

Figure 4.23 Cost Comparisons between Proposed and Current Condition

4.8 Scheduling Preventive Maintenance for the Next 3 Months (Jan- March 2017)

Scheduling time to conduct preventive maintenance is based on the interval time to replace the component with the average reliability is 80%. Replacement interval time of each component has been calculated in the previous sub chapter. After all the calculation is done, here is the scheduling preventive maintenance for the next 3 months start from January 2017 until March 2017.

In order to reduce the production loss, preventive maintenance will be conducted during the time of shift changes. The duration time of shift changes that can be used to conduct the preventive maintenance is changing shift from shift 2 to shift 3. The duration is 1 hour and 30 minutes. This duration can be spent to repair all the components. Thus, there is no production process that should be stopped because of maintenance activities. Table 4.24 below shows the result of the time interval of replacement.

Table 4.27 MTTF Data of each Component

Component	MTTF(day)	Start	Duration	Finish
Joint Leg	7	15:45	0:07	15:52
Pallet	7	15:45	0:10	15:55
Springer	9	15:45	0:08	15:53
Cylinder	9	15:45	0:18	16:03
Vacuum	8	15:45	0:12	15:57
Sensor	8	15:45	0:24	16:09

Table 4.24 above shows that there are some components that have same number of MTTF. It means that the preventive maintenance of these components can be done in one day. This maintenance activity will be done by one mechanic. Below is the scheduling of preventive maintenance that has been plot into calendar 2017.

JANUARY 2017

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

28 : Lunar New Year

FEBRUARY 2017

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28				

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

28: Nyepi 8: All Components

Cylinder and Springer
Vacuum and Sensor
Joint leg and Pallet
All Components

The preventive maintenance for each component for the next months will be conducted based on the schedule above. By Implementing the schedule, it is expected that there is no unwanted breakdown machine or unscheduled downtime of machine. After the preventive maintenance have been plotted on the date in calendar base on the MTTF of each component, here is the calculation of maintenance cost for the next 3 months. This calculation is based on the preventive maintenance cost that has been calculated before. Table 4.26 below show the maintenance cost used to calculate the total maintenance cost during the 3 months (January 2017-March 2017).

Table 4.28 Preventive Maintenance Cost of Each Component

Component	Maintenance Cost (IDR)
Cylinder	683,454
Vacuum	527,636
Sensor	834,272
Joint Leg	561,181.6
Pallet	551,181.6
Springer	915,545.2

Table 4.27 below shows the total cost of maintenance cost from January 2017 until March 2017.

Table 4.29 Preventive Maintenance Cost for Jan 2017 – March 2017

Months	Components		Cost
January	Cylinder and Springer	2	3,161,998.40
	Vacuum and Sensor	3	4,031,724
	Joint leg and Pallet	3	3,391,089.60
February	Cylinder and Springer	3	4,742,997.60
	Vacuum and Sensor	3	4,031,724
	Joint leg and Pallet	3	3,391,089.60
March	Cylinder and Springer	2	3,161,998.40
	Vacuum and Sensor	2	2,687,816
	Joint leg and Pallet	2	2,260,726.40
	All components	1	3,983,270.40
Total cost in 3 months			**34,844,434.4**

Based on the result of calculation above, the company should spend IDR 34,844,343 for maintenance cost for all components in 3 months. This calculation is based on the total maintenance frequency during 3 months starting from January 2017 until March 2017. For example, in January preventive maintenance for Cylinder and springer is conducted for 2 times. The detail of the calculationis as follows;

Maintenance cost for cylinder in one time is IDR 684,454 and maintenance cost for Springer in one time is IDR 915,545. Each maintenance cost has included mechanic cost for 1 hour for each component so the total maintenance cost for both components will be reduced by IDR 6,000 because the company just need less than one hour to repair or replace both components. In January, preventive maintenance that should be conducted for both components is 2 times. So the preventive maintenance of cylinder and springer in January is

[(IDR 684,454 + IDR 915,545) – IDR 18,000] x 2 = IDR 3,161,998.40

This calculation is used to calculate the preventive maintenance cost of the other components for the next months.

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

After all the calculation and analysis of the data have been done, here are the conclusions of the all the result:

- Machine Auto 2 consists of 12 components in which each has function to assemble toy's body. Based on the report of downtime that occurred in machine auto 2, there are 6 components that have high number of downtime and failure during the last six month starts from January 2016 until July 2016. These critical components that frequently occurred in machine auto 2 are Cylinder, Vacuum, Sensor, Joint Leg, Pallet and Springer.
- In order to determine the preventive maintenance schedule, there are some calculations that should be done, such as calculate the TTF and TTR of each component, calculate MTTF and MTTR of component and calculate the reliability of each component based on the MTTF of each component. In the proposed condition, the average reliability of components increased by 50.7%. The entire component can achieve the target of reliability set by the company that all the components should have reliability 80%. On the other side, by implementing the preventive maintenance in machine Auto 2, the cost of maintenance also reduce from the current condition. Through implanting the preventive maintenance, waiting time and production loss can be eliminated from the maintenance cost.

5.2 Recommendation

Due to the limitation of time and source in this research there are some recommendations which might be benefecial for the further research and suggestion for the company to increase the productivity.

- In order to get the proper data of downtime machine, the data should be recorded based on the types of component which is complete with the time of failure and duration of mechanic taken to repair the machine.
- The other suggestion for future research is to develop the algorithm for integrating the real production schedule and preventive maintenance schedule.
- In order to optimize preventive maintenance for the future research to concern with machine lifetime
- The company is suggested to conduct the training for the mechanic in order to increase the ability of the mechanic to set the machine to avoid any failure or breakdown machine caused by the setting of machine.

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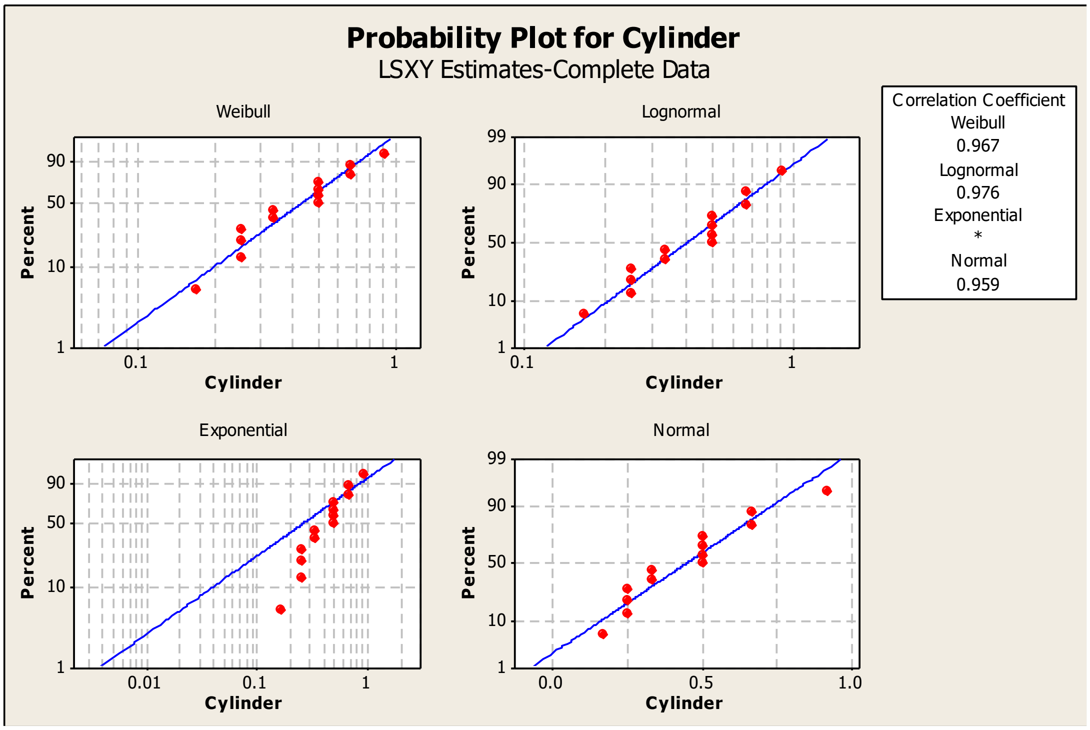
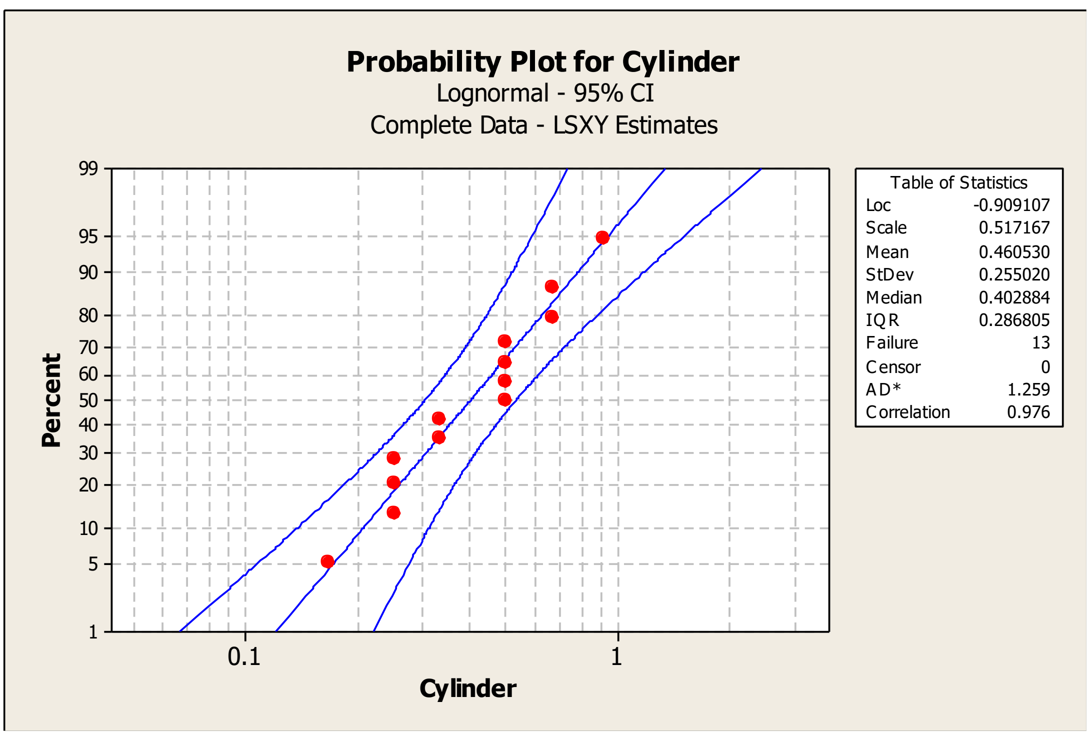
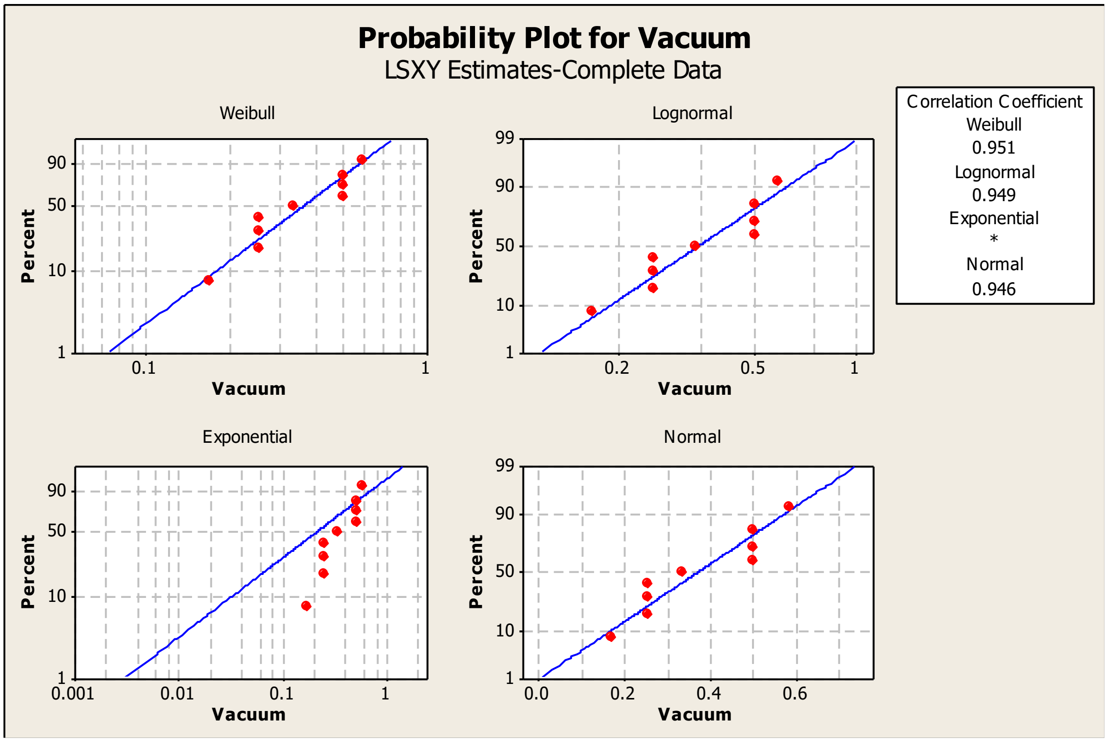
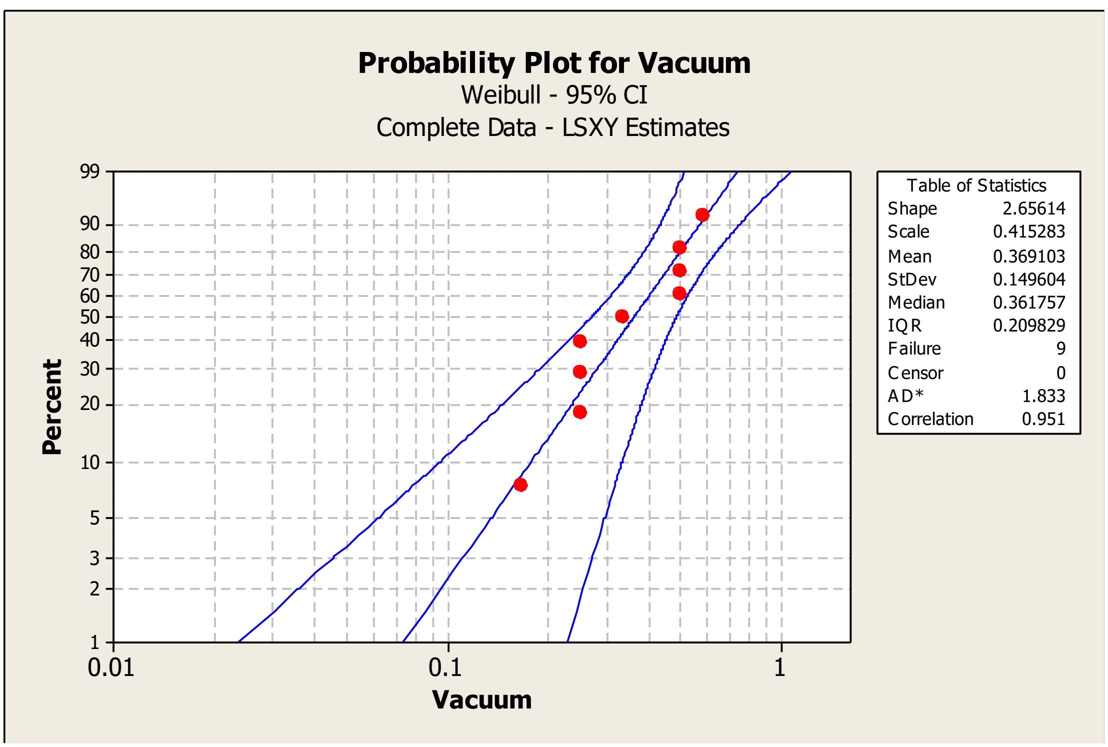
APPENDIX

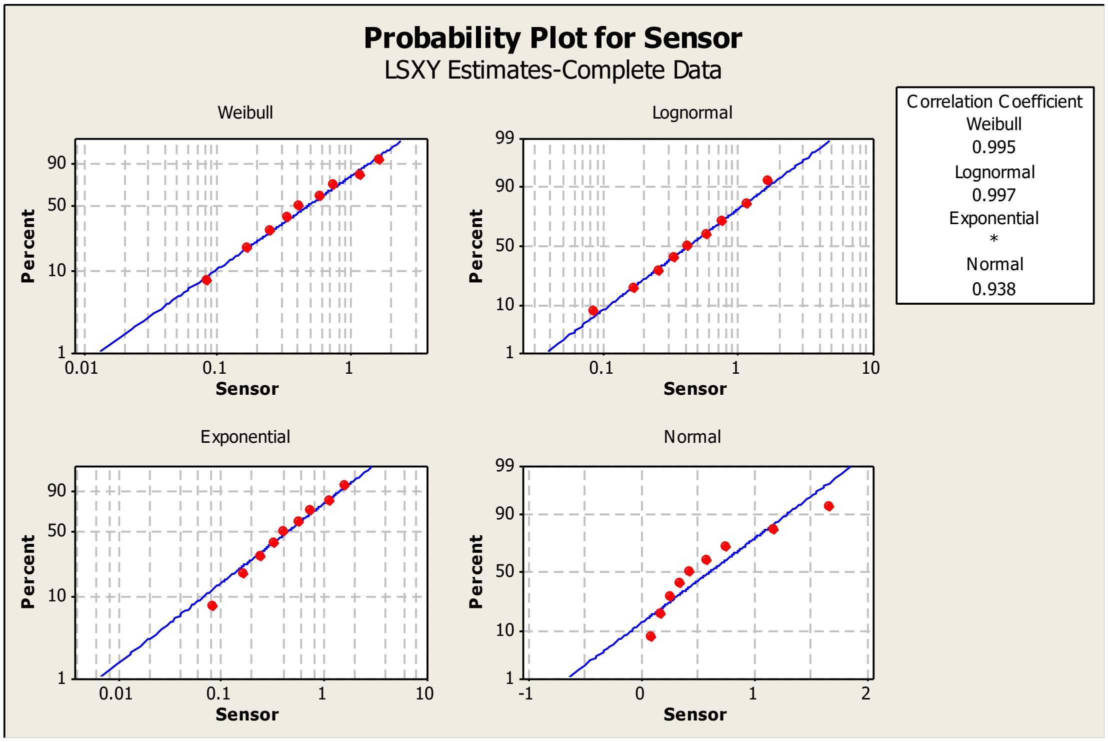
Appendix 1 Statistical Analysis Result for MTTR Calculation

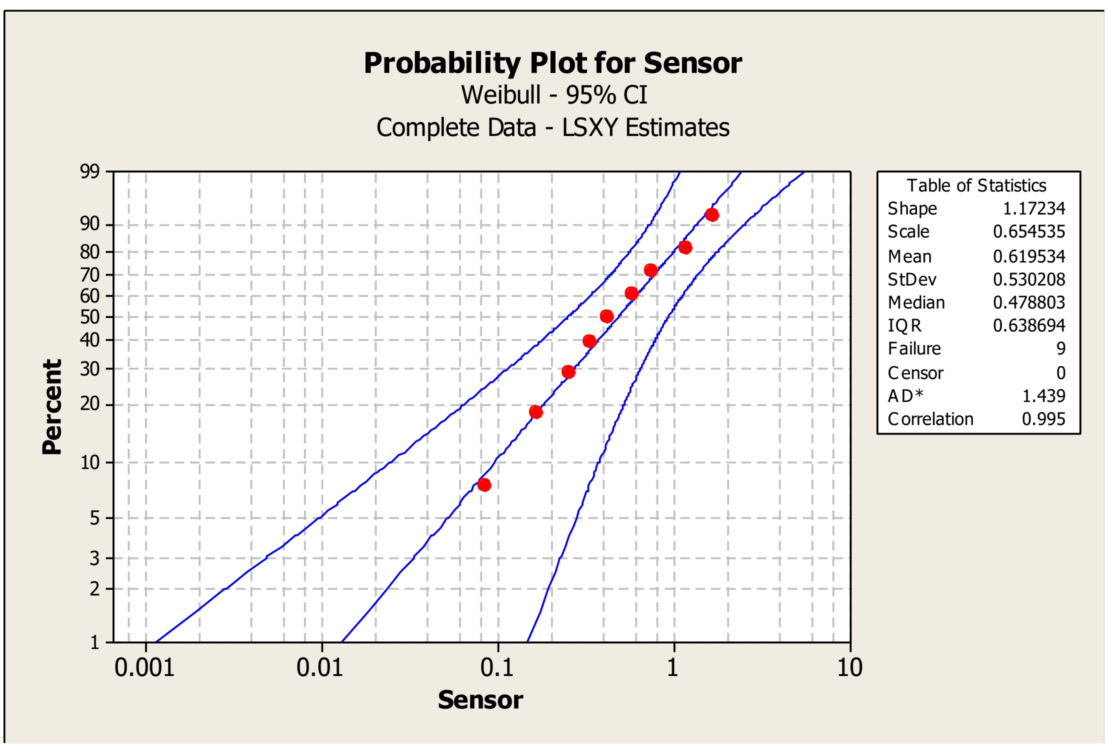


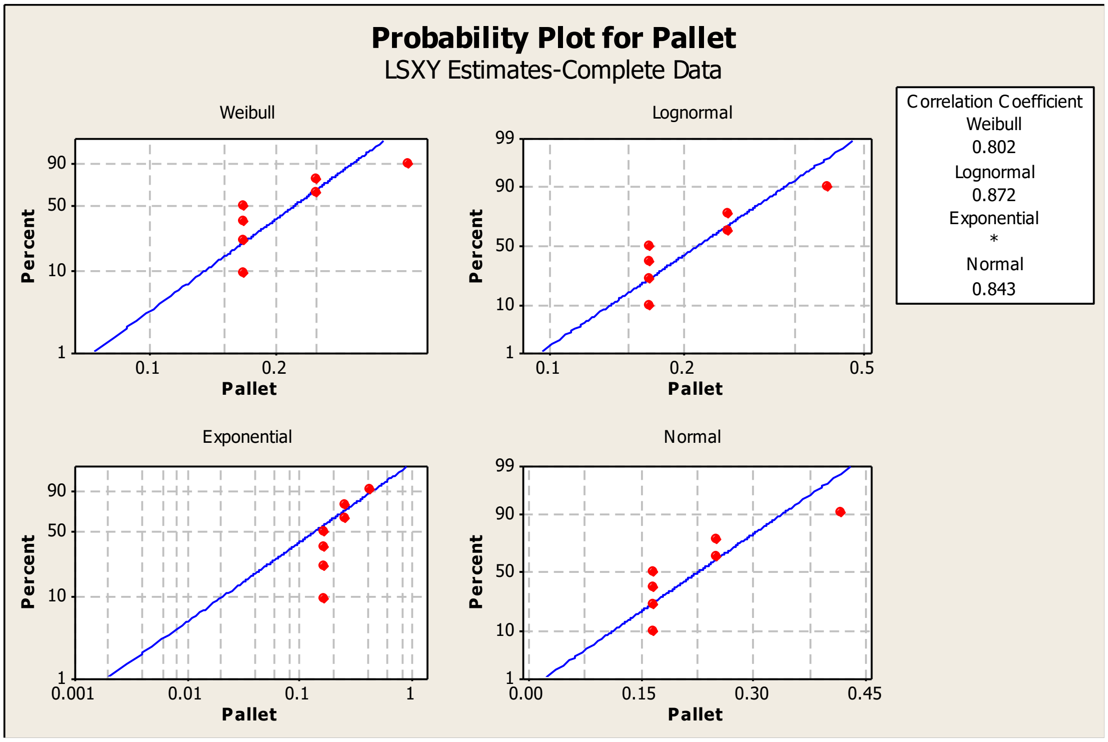


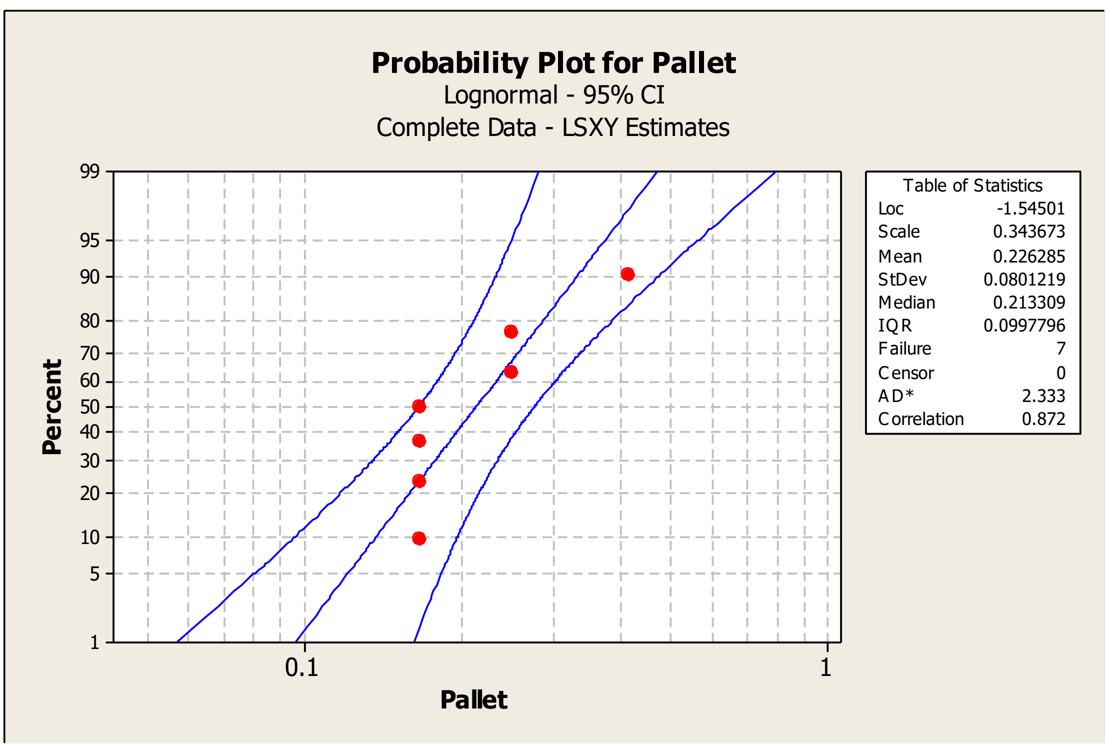

Probability Plot for Vacuum
LSXY Estimates-Complete Data
Weibull
Lognormal
Exponential
Normal
Percent
Vacuum
Correlation Coefficient
Weibull
0.951
Lognormal
0.949
Exponential
*
Normal
0.946

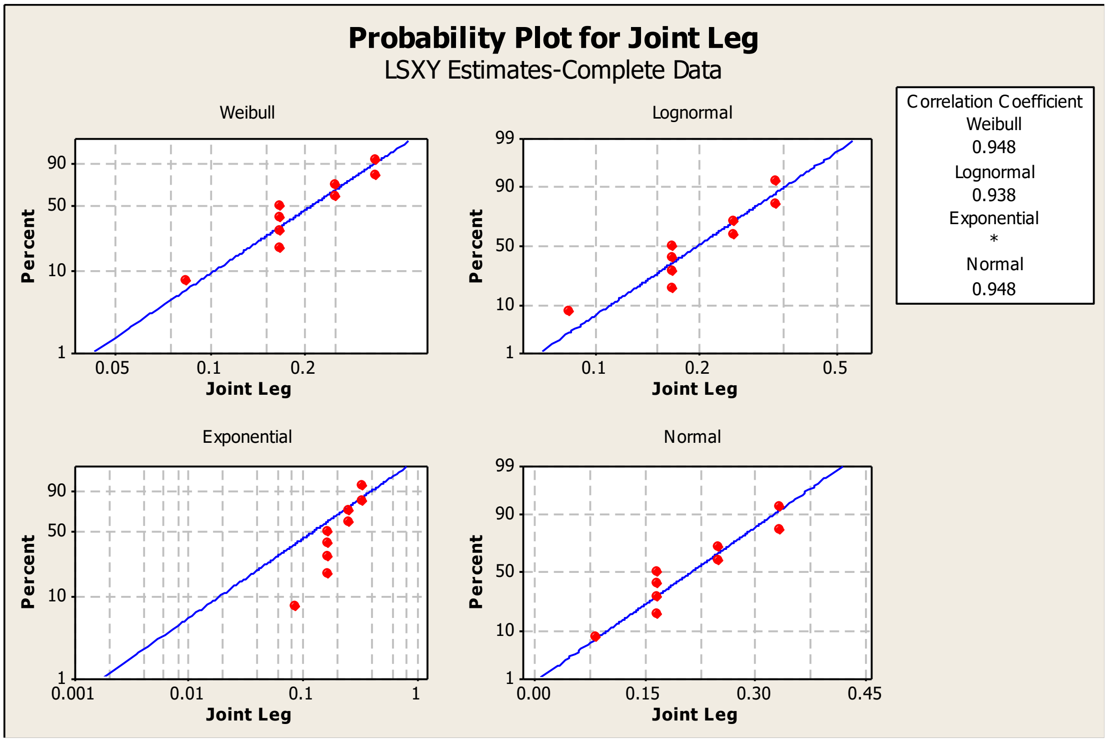

Probability Plot for Vacuum
Weibull - 95% CI
Complete Data - LSXY Estimates
Percent
Vacuum
Table of Statistics
Shape 2.65614
Scale 0.415283
Mean 0.369103
StDev 0.149604
Median 0.361757
IQR 0.209829
Failure 9
Censor 0
AD* 1.833
Correlation 0.951

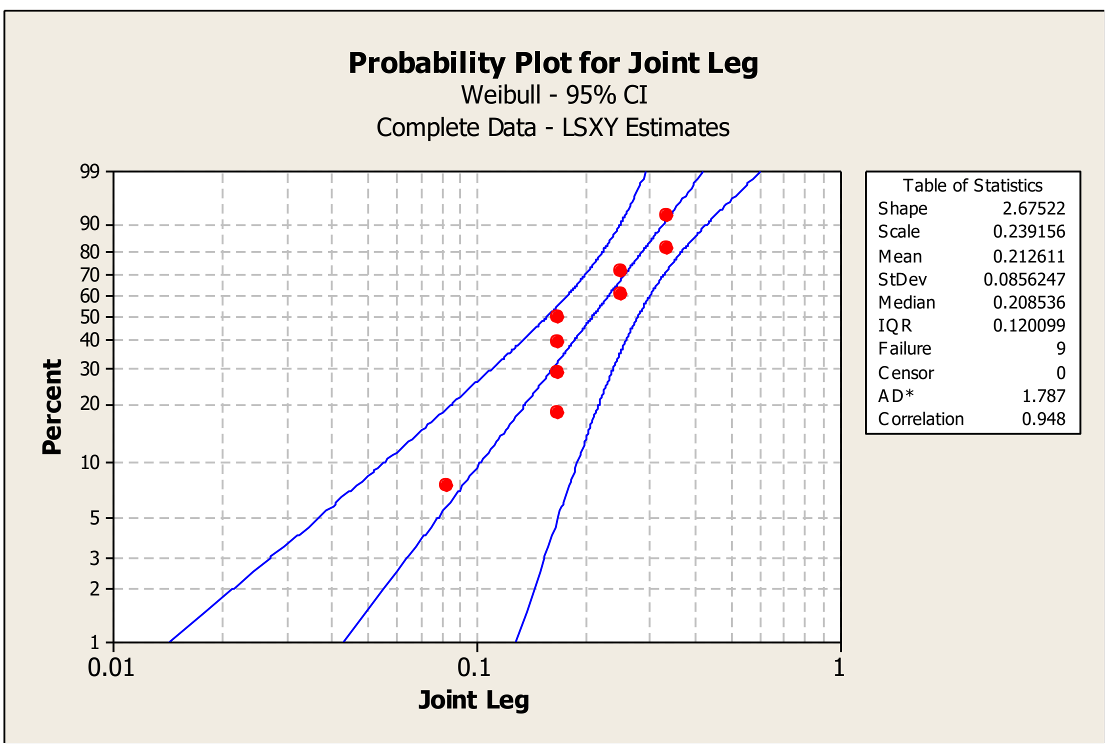

Probability Plot for Sensor
LSXY Estimates-Complete Data
Weibull
Lognormal
Exponential
Normal
Percent
Sensor
Correlation Coefficient
Weibull
0.995
Lognormal
0.997
Exponential
*
Normal
0.938

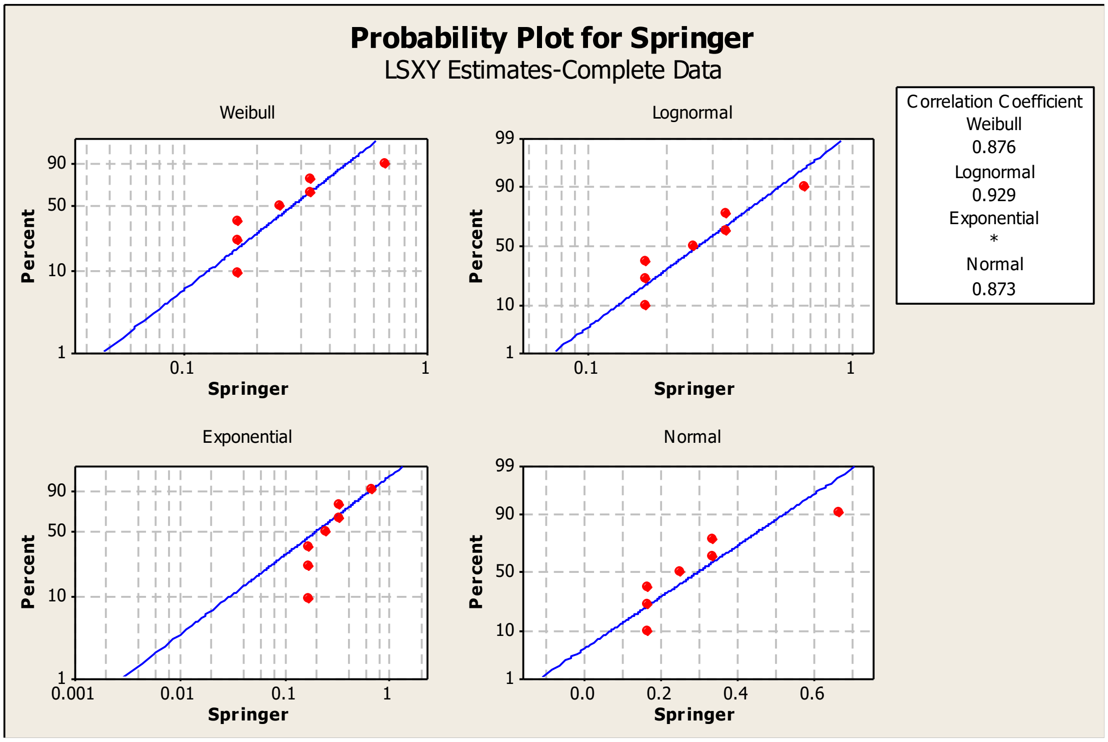

Probability Plot for Sensor
Weibull - 95% CI
Complete Data - LSXY Estimates
Percent
Sensor
Table of Statistics
Shape 1.17234
Scale 0.654535
Mean 0.619534
StDev 0.530208
Median 0.478803
IQR 0.638694
Failure 9
Censor 0
AD* 1.439
Correlation 0.995

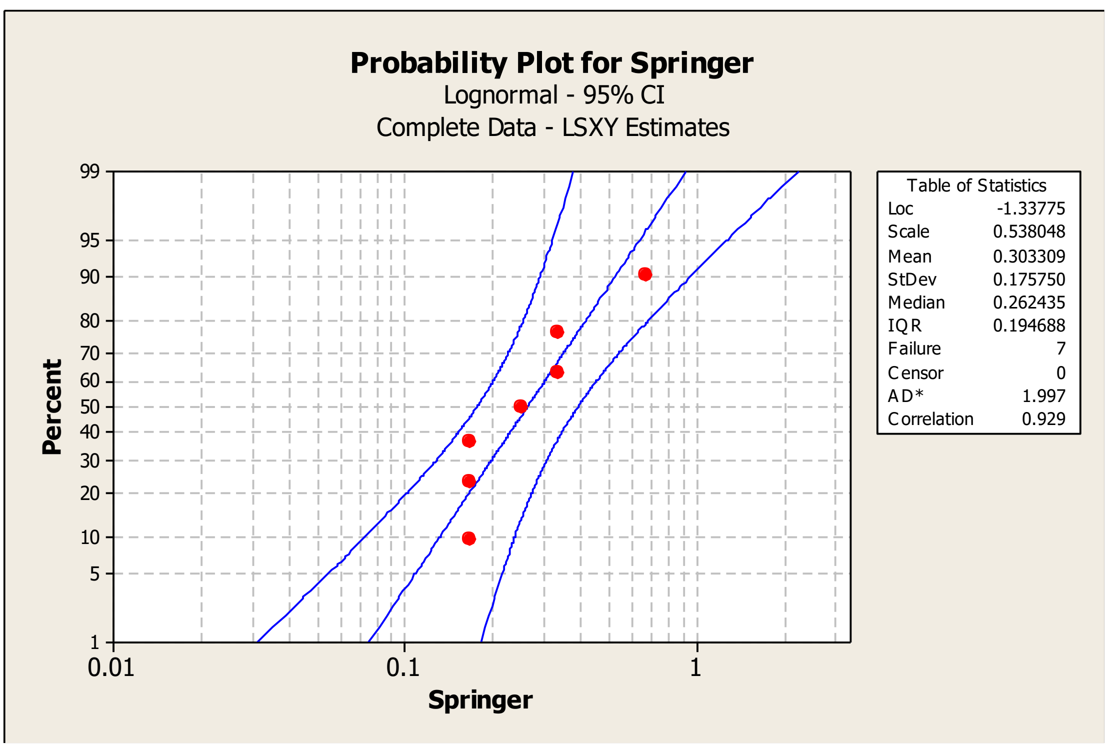

Probability Plot for Pallet
LSXY Estimates-Complete Data
Weibull
Lognormal
Exponential
Normal
Percent
Pallet
Correlation Coefficient
Weibull
0.802
Lognormal
0.872
Exponential
*
Normal
0.843


Probability Plot for Pallet
Lognormal - 95% CI
Complete Data - LSXY Estimates
Percent
Pallet
Table of Statistics
Loc -1.54501
Scale 0.343673
Mean 0.226285
StDev 0.0801219
Median 0.213309
IQR 0.0997796
Failure 7
Censor 0
AD* 2.333
Correlation 0.872


Probability Plot for Joint Leg
LSXY Estimates-Complete Data
Weibull
Lognormal
Exponential
Normal
Percent
Joint Leg
Correlation Coefficient
Weibull
0.948
Lognormal
0.938
Exponential
*
Normal
0.948


Probability Plot for Joint Leg
Weibull - 95% CI
Complete Data - LSXY Estimates
Percent
Joint Leg
Table of Statistics
Shape 2.67522
Scale 0.239156
Mean 0.212611
StDev 0.0856247
Median 0.208536
IQR 0.120099
Failure 9
Censor 0
AD* 1.787
Correlation 0.948


Probability Plot for Springer
LSXY Estimates-Complete Data
Weibull
Lognormal
Exponential
Normal
Percent
Springer
Correlation Coefficient
Weibull
0.876
Lognormal
0.929
Exponential
*
Normal
0.873
99
90
50
10
1
0.001
0.01
0.1
1
0.0
0.2
0.4
0.6


Probability Plot for Springer
Lognormal - 95% CI
Complete Data - LSXY Estimates
Percent
Springer
99
95
90
80
70
60
50
40
30
20
10
5
1
0.01
0.1
1
Table of Statistics
Loc -1.33775
Scale 0.538048
Mean 0.303309
StDev 0.175750
Median 0.262435
IQR 0.194688
Failure 7
Censor 0
AD* 1.997
Correlation 0.929

Appendix 2 Component's Picture

Sensor

Cylinder

Vacuum

Springer

Pallet