IMPLEMENTATION OF PREVENTIVE MAINTENANCE SCHEDULING ON MAIN ASSEMBLY 1 MACHINE IN SPARE PART MANUFACTURER COMPANY

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THESIS ADVISOR
RECOMMENDATION LETTER

This thesis entitled **"Implementation of Preventive Maintenance Scheduling on Main Assembly 1 Machine in Spare Part Manufacturer Company"** prepared and submitted by **Nabila Aulia Asdin** 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, May 9th, 2017

Anastasia Lidya Maukar, S.T., M.Sc., M.MT.

DECLARATION OF ORIGINALITY

I declare that this thesis, entitled **"Implementation of Preventive Maintenance Scheduling on Main Assembly 1 Machine in Spare Part Manufacturer 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

Production activities often have problems due to malfunctioning of production machinery. To maintain the stability of production needs maintenance activity of machine. PT. NAA is a company of the manufacturing industry in the automotive section which produces two types of vehicle spare parts which are alternator assembly and rotor assembly. During the last six months in 2016, the maintenance activities in PT. NAA have not managed well. Maintenance that not managed well caused the occurrence of unplanned machine downtime. Preventive maintenance scheduling is needed to reduce downtime on the machine. The first step of doing this research is collect the required data which are machine failure data, types of maintenance, interval time of failure for each component, and maintenance cost. Based on the Pareto chart, there are three critical component machines. Analysis used in the treatment of machine by using failure distribution. The minimum cost is obtained by finding the right interval time for each component. The company was given the target of reliability to be achieved which is 70%. By implementing the preventive maintenance scheduling, reliability of machine can be increased by 21.65 % and the maintenance cost can be reduced by 14.56% or IDR 214,694,077.

Keywords: *Maintenance, Machine Downtime, Pareto chart, Failure Distribution, Reliability, Preventive Maintenance Schedule.*

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Downtime machine	:	A period of time when the machine is fails to perform.
Waiting time	:	A period of time for the mechanic to come from the machine stops until the maintenance process starts.
Reliability	:	A probability of machine will perform a bound function under the specified time within a certain limit.
Mean time to repair	:	Average time required from the machine or component to be repaired.
Mean time to failure	:	Average time that a machine will work before it fails, usually used for non-repairable component.
Mean time between failures	:	Average time between two failures for repairable system.
Corrective maintenance	:	A treatment of the machine that the maintenance is done after downtime occurred.
Preventive maintenance	:	A treatment of the machine that the maintenance performed on machine periodically.

CHAPTER I
INTRODUCTION

1.1 Problem Background

Reliability is the probability that a machine will perform a bound function under the specified time within a certain limit (Stapelberg, 2009). Machine reliability has an impact to the production performance. If a machine has a high number of downtime, then can be concluded that the machine has a low reliability. If the machine often experiences downtime, the production line will stop and therefore the quantity of the outcome will decrease. By increasing the machine reliability, the number of occurrences of unplanned downtime or machine failure will decrease. With high machine reliability, production loss and maintenance cost will be lessened.

Maintenance activities have a very important role in supporting the operation of the system to run properly. Maintenance is a function that must be performed under normally significant disadvantage. The importance of planning the maintenance activities for each production machine can maximize existing resources (Dhillon, 2002). The relation between reliability and maintenance cost is if the reliability of machine is decreasing, then the maintenance cost will be decreased. Maintenance activities can also minimize costs or losses incurred due to failure of the machine so the profit to be obtained by the company will be increased.

PT. NAA is a company of the manufacturing industry in the automotive field, which produces two types of vehicle spare parts. PT. NAA supplies spare parts, which are alternator assembly and starter assembly vehicle as a main business in the local scope and exports. This company is a limited liability company with the main business areas in the production of semi-finished goods for automotive devices and supplying to several other automotive companies.

PT. NAA operates nine lines to produce alternators assembly and starter assembly that divided into four lines for producing alternator assembly and five lines for alternator assembly. The alternator assembly consists of rotor assembly, field coil, stator assembly, and alternator bracket, and starter assembly consists of starter bracket, brush holder assembly (BHA), over running clutch (ORC), yoke assembly, and a connector brush holder (CBH). Every process in each line affects the process of the other line.

During the last six months in 2016, the company has been facing some problems that prevent the company to achieve the efficiency target. Based on the data in the last six months from July to December 2016, a problem related with high downtime on rotor assembly that reached around 264.51 hours was found. Downtime that occurred on rotor assembly line is because the average age of the machine is more than 10 years. The policy of the company's management prefers to do maintenance on the machine than to replace the old machines into the new one.

Rotor assembly line runs automatically by the machine. Rotor assembly line has 32 machines, one of them is main assembly 1 machine that affect the highest downtime in rotor assembly line. Main assembly 1 is a machine that used to assembly some parts such as pole front rear field coil, shaft and slip ring. In conclusion, the maintenance activities in PT. NAA have not managed well.

Currently, company uses maintenance breakdown, which is corrective maintenance in the treatment of the machine that the maintenance is done after downtime occurred, where the maintenance of a component is waiting until the component is broken and then repaired or replaced with new component. Corrective maintenance is not a scheduled maintenance activity. If this maintenance is used as a primary strategy, more unplanned maintenance activities will occur. Therefore, would be better if the company perform preventive maintenance rather than corrective maintenance.

Preventive scheduling maintenance will prevent the machine failure before the breakdown occurs (Ebeling, 1997). The importance of preventive maintenance is to improve the performance of the machine to avoid any unplanned maintenance activity and avoid larger, costly fixes down line where maintenance tasks are performed routinely. Having scheduled preventive maintenance can keep the machine up and running, because machine performance is an important aspect that must be considered in production process.

1.2 Problem Statement

Based on the problem faced by company, this research is done to answer the following question:

- Which component in the machine that cause the machine downtime?
- How can the company decrease downtime loss?

1.3 Objectives

The main objectives of this research are as follows:

- To identify which components in the machine that cause the machine downtime.
- To determine the way to reduce downtime loss.

1.4 Scope and Limitation

There are several scope and limitation that will give a clear boundary and the limit of this research:

- The maintenance data were taken from July until December 2016.
- The research is only focused on rotor assembly line.
- The observation was only done on Main Assembly 1 machine.
- Downtime machine began from the machine stops due to the failure.

1.5 Assumptions

There are several assumptions that have to be made in order to support the analysis:

- The maintenance activities such as how to repair, disassembly, replacement, and installation of equipment are not discussed in this research.

- Machine spare parts were assumed to be available when are needed in normal or emergency operating conditions.
- The entire auto machine is identical machine.
- The skills of all mechanics are the same.
- The machine that has been repaired will be good as new.

1.6 Research Outline

Chapter I **Introduction**

This chapter consist of problem background, problem statements as the things to be solved, objectives to be achieved in this research, scope as the limitation, assumption, and research outline of the study.

Chapter II **Literature Study**

This chapter contains the basic theoretical framework that coming from books, journals, thesis, and expertise works use as reference which are maintenance, reliability, failure rate, failure distribution which are normal distribution, exponential distribution, weibull distribution, and lognormal distribution, statistical approach which are probability density function, cumulative density function, and reliability function, and maintenance interval time that support in conducting this research.

Chapter III **Research Methodology**

This chapter describes the flow of this research and explanation of each step to conduct this research start from initial observation until analyze the collected data which come up with an improvement and recommendation.

Chapter IV **Data Collection and Analysis**

This chapter discuss about the way to collect the data including the output of the data. Then, the data that has be collected will be further analyze to achieve the result regarding to problem in the research.

Chapter V **Conclusion and Recommendation**

This chapter will give the conclusion result of this final project, and also recommendation for future research.

CHAPTER II
LITERATURE STUDY

2.1 Maintenance

Maintenance is an activity to maintain and preserve the existing facilities, while also fixing, replacing, adjusting, or changing the components required to obtain a certain state of production that matches the existing planning (O'Connor, 2002). Machine maintenance is affected by several factors, such as: age factor, environment or machinery factor, human resource factor, and supervision factor. If a certain component in a machine is found to be broken, then there will be certain disturbances with particular characteristics.

Generally, there are four types of maintenance activity, such as inspection, repair, component replacement, and zero hour maintenance (overhaul).

- Inspection is a type of periodical maintenance activity conducted to prevent the occurrence of unexpected breakdown and to make sure that the machine can work properly accordingly to the function.
- Repair is an activity of returning the degraded functions of certain tools or components by fixing the broken part of the aforementioned tools or components instead of changing or replacing the problematic part with a new one. That way, the tools or components can operate well according to the functions prior to breaking down.
- Component replacement is an activity of replacement or substitution performed in a certain component of a particular machine or equipment that is found to be breaking down. The replacement activity can be done either without or with planning made my maintenance department.
- Zero hour maintenance (Overhaul) is an arrangement of assignments that have focuses to accomplish, which are to audit the part or machine at planned interims before playing out any mistake (Hunt et al., 2010). This audit depends on leaving the hardware to zero hours of operation when the types of gear or

machines were new. The audit will repair or supplant all things keeping in mind the end goal to guarantee with the high likelihood, a great working time settled ahead of time. According to Dillhon (2002), there are two type of maintenance process:

1. Corrective Maintenance

   Corrective maintenance is an unscheduled maintenance activity, essentially made out of flighty upkeep needs that can't be preplanned or customized on the premise of event at a specific time. The activity requires earnest consideration that must be included, incorporated with, or substituted for already planned work things. This fuses consistence with "incite activity" field changes, rectification of deficiencies found amid hardware/thing operation, and execution of repair activities because of occurrences or mishaps.

2. Preventive Maintenance

   Preventive maintenance is an imperative part of a maintenance activity. Preventive maintenance might be depicted as the care and adjusting by people required with support to keep hardware/offices in agreeable operational state by accommodating orderly examination, location, and amendment of nascent disappointments either before their event or preceding their advancement into significant disappointment.

   A portion of the principle targets of preventive maintenance are to: improve capital gear gainful life, lessen basic hardware breakdowns, permit better arranging and booking of required support work, limit generation misfortunes because of gear disappointments, and advance wellbeing and security of upkeep staff.

2.2 Reliability

Reliability is a characterized as the likelihood that a gadget, machine or framework will play out a predetermined capacity inside given points of confinement, under given ecological conditions, for a predefined time (Stapelberg, 2009). Reliability is one of the trademarks that decides the quality. Reliability is characterized by the different definitions, however when all is said in done that unwavering quality is the capacity of an item apply as per a particular capacity in the plan condition or particular working conditions (Jardine,2013).

The function of the machine is the primary variable that decides the dependability of a machine. A machine can be said dependably if these machines can carry out the occupation as indicated by the capacity of the machine itself. In the event that the machine cannot work appropriately, the machine could be said as untrustworthy. A specific condition called the point of confinement of the machine is the condition when the machine can work ideal. The utmost of the machine is expressed in the determination of the machine. In the event that the machine is compelled to work past the utmost, the machine will prompt breakdown and the dependability will achieve its most minimal point. The unwavering quality of a machine will drop altogether when it utilized out of the utmost of the machine.

2.3 Failure Rate

Pattern of machine or equipment age can be seen from the failure rate of that machine or part. Failure rate of the machine which happened in t is the likelihood for the part failure on the following interim of time that has been set which segment is in the great condition in the start of interim time that will be the contingent likelihood. Documentation of failure rate is λ or R (t). The valuable existence of the machine can be classified into three major gatherings of period which are expanding or diminishing failure rate, and consistent failure rate.

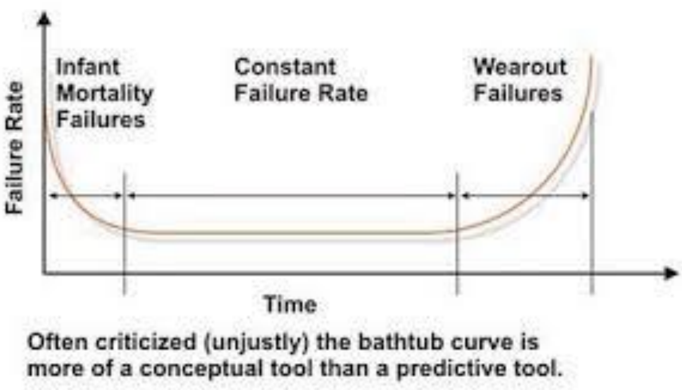


Figure 2.1 The Bathtub Curve

2.4 Failure Distribution

Continuous random variables are utilized as a part of request to decide the reliability of the system. According to Leemis (1995) dedicated a goodly overview of many distributions. The distribution that regularly utilized as a part of deciding the reliability of the system are normal distribution, exponential distribution, weibull distribution, and lognormal distribution. The chosen distribution that is most appropriate to model each particular data set based on goodness-of-fit tests.

2.4.1 The Normal Distribution

The normal distribution or at some point called the Gaussian distribution is the most widely used general purposed distribution, commonly used for reliability and life data analysis. There are some who contend that the typical conveyance is wrong to model lifetime information on the grounds that the left-hand breaking point of the circulation reaches out to negative limitlessness. This could possibly bring about displaying negative circumstances to-disappointment. Nonetheless, gave that the appropriation being referred to have a generally high mean and a moderately little standard deviation, the issue of negative disappointment times ought not to present itself as an issue. Parameters of normal distribution are mean (μ) and standard deviation (σ). The form of normal distribution curve is symmetrical towards the average mean value. The distribution functions that used in normal distribution are:

a. Probability Density Function

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

For $-\infty \leq t \leq \infty$; $\sigma > 0$; $-\infty \leq \mu \leq \infty$

Where:

μ : Mean of the data

σ : Standard deviation from distribution

t : Time

e : Nature Logarithm (e = 2.71828)

b. Cumulative Distribution Function

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

c. Reliability Function

$$R(t) = 1 - F(t) \quad (2\text{-}3)$$

d. Failure Rate Function

$$\lambda(t) = \frac{\phi\left(\frac{t-\mu}{\sigma}\right)}{\sigma R(t)} \quad (2\text{-}4)$$

e. Mean Time to Failure in Normal Distribution

$$MTTF = \mu \quad (2\text{-}5)$$

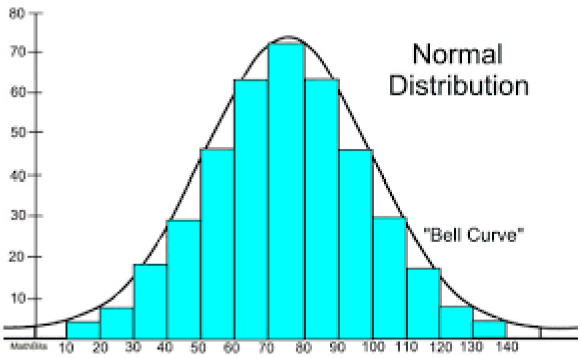


Figure 2.2 The Normal Distribution

2.4.2 The Exponential Distribution

The exponential distribution commonly used in reliability engineering, is a standout amongst the most generally utilized likelihood appropriations in designing, especially in dependability work. It is generally simple to deal with in directing examination. Parameter of exponential distribution is lambda (λ), which implies the normal landing of disappointments that happened. The exponential distribution adequate simple distribution, which causes its use in an inappropriate situation that used to model the units that have a constant failure rate. The distribution functions that used in exponential distribution are:

a. Probability Density Function

$$f(t) = \lambda . e^{-\lambda t} \quad (2\text{-}6)$$

b. Cumulative Distribution Function

$$F(t) = 1 - e^{-\lambda t} \quad (2\text{-}7)$$

c. Reliability Function

$$R(t) = e^{-\lambda t} \quad (2\text{-}8)$$

d. Failure Rate Function

$$\lambda(t) = \frac{f(t)}{R(t)} = \lambda \quad (2\text{-}9)$$

e. Mean Time to Failure in Normal Distribution

$$MTTF = \int_t^{\infty} tf(t)dt \quad (2\text{-}10)$$

$$MTTF = \frac{1}{\lambda}$$

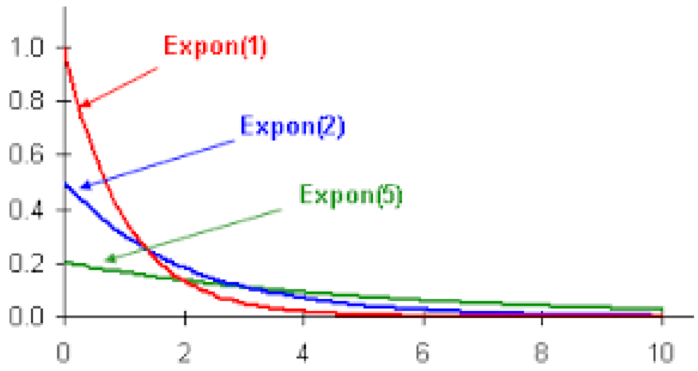


Figure 2.3 The Exponential Distribution

2.4.3 The Weibull Distribution

One of the most widely used in reliability engineering is the Weibull distribution, called versatile distribution that can utilize the characteristics of other types of distribution. Weibull distribution is valuable for speaking to a wide range of physical wonders. Parameters of typical dispersion are shape parameter (β) and scale parameter (θ). The shape parameter decides the disappointment of rate from the information. Its probability density function is defined by:

Table 2.1 Shape of Parameter 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
$\beta > 1$	Increasing Failure Rate (IFR)
	Convex-shaped curve
$3 \leq \beta \leq 4$	Increasing Failure Rate (IFR)
	Symmetric-shaped curve
	Normal Distribution

The distribution functions that used in weibull distribution are:

a. Probability Density Function

$$f(t) = \frac{\beta}{\theta}\left(\frac{t}{\theta}\right)^{\beta-1} e^{\left(\frac{t}{\theta}\right)^{\beta}} \quad (2\text{-}11)$$

Where:

β : Shape parameter

θ : Scale parameter

t : Time

e : Nature Logarithm (e = 2.71828)

b. Cumulative Distribution Function

$$F(t) = 1 - e^{-\left(\frac{t}{\theta}\right)^{\beta}} \quad (2\text{-}12)$$

c. Reliability Function

$$R(t) = e^{-\left(\frac{t}{\theta}\right)^{\beta}} \quad (2\text{-}13)$$

d. Failure Rate Function

$$\lambda(t) = \frac{\beta}{\theta}\left(\frac{t}{\theta}\right)^{\beta-1} \quad (2\text{-}14)$$

e. Mean Time to Failure in Normal Distribution

$$MTTF = (\theta)(\Gamma)\left(1 + \frac{1}{\beta}\right) \quad (2\text{-}15)$$

Which Γ(x) = Gamma Function

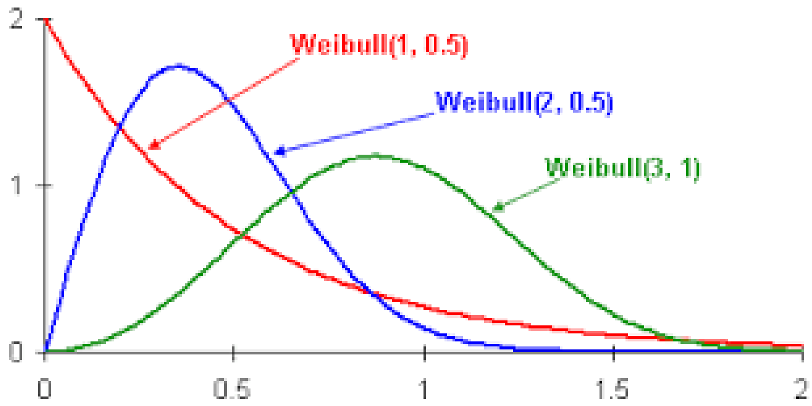


Figure 2.4 The Weibull Distribution

2.4.4 The Lognormal Distribution

The lognormal distribution is regularly used to show the lives of units whose failure modes are of a weariness stretch nature. Since this incorporates most, the lognormal distribution can have boundless application. Therefore, the lognormal distribution is a decent companion to the Weibull distribution when endeavoring to display these sorts of units. As might be deduced by the name, the lognormal distribution has certain likenesses to the typical dispersion. An arbitrary variable is lognormally conveyed if the logarithm of the irregular variable is typically disseminated. Lognormal distribution is utilizing two parameters which are shape parameter and area parameter which is the middle of disappointment appropriation. This circulation is justifiable just for positive t value and more suitable than the normal distribution on account of failure. Lognormal distribution is a distribution that describes the failure distribution for a differing and fluctuated circumstance. The distribution functions that used in lognormal distribution are:

a. Probability Density Function

$$f(t) = \frac{1}{st\sqrt{2\pi}} e^{\left[\frac{1}{2s}\left(ln\frac{t}{tmed}\right)^2\right]} \quad (2\text{-}16)$$

Where:

s : Scale parameter

µ : Mean of the data

t_{med} : Median of the data

t : Time

e : Nature Logarithm (e = 2.71828)

b. Cumulative Distribution Function

$$F(t) = \phi\left[\frac{1}{s} ln \frac{1}{tmed}\right] \quad (2\text{-}17)$$

c. Reliability Function

$$R(t) = 1 - F(t) \quad (2\text{-}18)$$

d. Failure Rate Function

$$\lambda(t) = \frac{\phi\left[\frac{1}{s} ln \frac{1}{tmed}\right]}{stR(t)} \quad (2\text{-}19)$$

e. Mean Time to Failure in Normal Distribution

$$MTTF = tmed \, . \, e^{\left(\frac{s^2}{2}\right)} \quad (2\text{-}20)$$

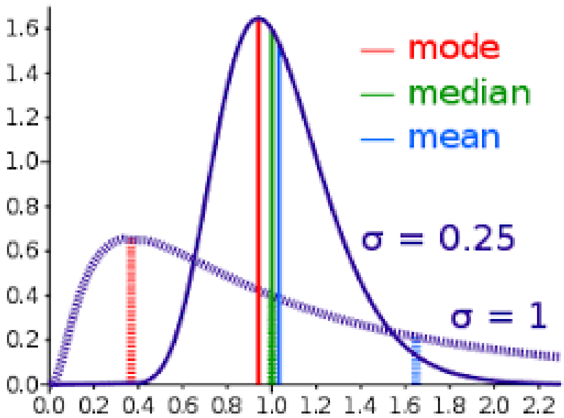


Figure 2.5 The Lognormal Distribution

2.5 Statistical Approach

In order to predict the machine breakdown occurrence, a statistical approach is used. The breakdown occurrence of the performing machine will not be acknowledged.

2.5.1 Probability Density Function

The probability density function of a continuous distribution is characterized as the subsidiary of the combined circulation work (Rusavel, 2015). The probability density function can be utilized to decide the likelihood of constant arbitrary variable between two qualities.

If X is the continuous random variable as failure time from total data of failure time, then it has a consistent distribution function of fx in every point in the real axis, then fx as probability density function the variable x.

The area between tx and ty:

$$\int_{tx}^{ty} f(t)dt \tag{2-21}$$

The probability of failure is occurred between time tx and ty:

$$\int_{tx}^{ty} f(t)dt = 1 \tag{2-22}$$

2.5.2 Cumulative Density Function

Cumulative distribution function is a function that describes the probability or chance of failure in machine or components before time (t). Cumulative distribution function can be formulated in the form of:

$$F(t) = P(x < t) \tag{2-23}$$

Or

$$F(t) = \int_{tx}^{ty} f(t)dt, \text{ which } t \geq 0 \tag{2-24}$$

The value of cumulative distribution function is between $0 \leq F(t) \leq 1$.

$F(t) = 1$, if there is value of t tends to infinity (∞).

2.5.3 Reliability Function

Reliability function is a probability function of a system or machine that will work until a specific time (t). Reliability function is the probability that a system or part will work properly without encountering any sort of failure over a period of time (t) in a predetermined operational capacity. Reliability function can be formulated in the form of:

$$R(t) = \int_t^{\infty} f(t)dt \quad (2\text{-}25)$$

Then,

$$R(t) = 1 - F(t), \text{ for } t \geq 0 \quad (2\text{-}26)$$

2.6 Maintenance Interval Time

In determining maintenance interval time the following failure information must fit with certain distribution. At that point, the majority of the capacity related with fitted distribution is utilized as a part of request to decide the maintenance interval time. Probability density function, cumulative density function, reliability function and hazard or failure rate must be computed. Cost per unit for every unit of time also should be calculated. The equation that is used in calculating the maintenance cost is stated as follows

$$C(t) = \frac{Cp + Cf \cdot H(t)}{t} \quad (2\text{-}27)$$

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 + [maintenance time (hours) x salary of mechanic per hours] + loss of production
Cf	:	Component price + [downtime (hours) x salary of mechanic per hours] + loss of production
Loss of Production	:	Maintenance time (hours) x production capacity (product/hour) x price of product

CHAPTER III
RESEARCH METHODOLOGY

The research methodology of this research is illustrating in the following diagram.

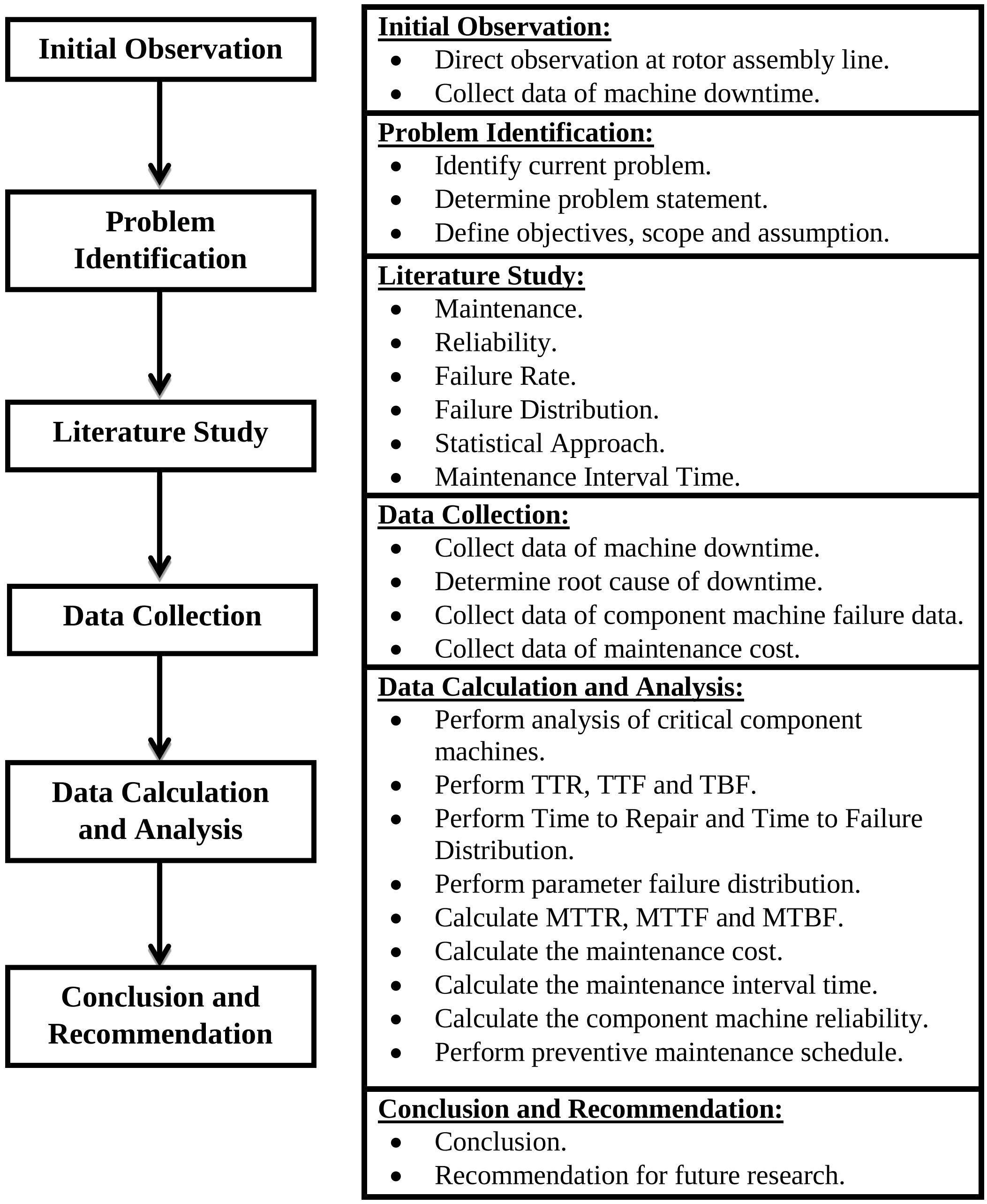


Figure 3.1 General Research Framework

3.1 Initial Observation

The first step of making the research is to do an observation directly into the production floor area. Direct observation is conducted in PT. NAA, specifically the areas that manufacture alternator assembly and starter assembly for vehicle spare parts that operates nine lines, which are rotor assembly, field coil, stator assembly, alternator bracket, starter bracket, brush holder assembly (BHA), over running clutch (ORC), yoke assembly, and a connector brush holder (CBH). The observation is focused on machine performance from nine lines. However, the machine performance does not show a good performance, which means the machine downtime has been occurring frequently. The company should make the scheduling for every machine in order to maintain the performance of every machine.

3.2 Problem Identification

As stated above, problem statement is one of important thing in order to achieve research objectives. The research objectives of this research is conducted in order to identify the critical parts that affect downtime machine so the company can reduce downtime loss by using preventive maintenance scheduling

Based on initial observation during the last six months in 2016, the maintenance activities in PT. NAA have not been managed well. Maintenance activities that are not well managed are the occurrence of unplanned machine downtime. The highest frequency of downtime from nine lines is found in rotor assembly line. The average machine age in rotor assembly line is more than 10 years. The average age of the machine is the factor that causes the downtime machine. There are 32 machines in rotor assembly line. The highest contribution for downtime occurred in main assembly 1 machine from rotor assembly line. Main assembly 1 is a machine used to assembly some parts, which are pole front rear field coil, shaft and slip ring. Main assembly 1 machine consists of several parts. Chuck holder shaft, b-pin and chuck holder slip ring shows the main causes of the downtime.

Company uses maintenance breakdown which is corrective maintenance in the treatment of the machine. Companies must perform maintenance activities on any machine, so the company will not lose a lot of maintenance cost to fix the breakdown machine. Maintenance activities can minimize costs or losses incurred due to failure to the machine. The profit to be obtained by the company will be increased.

Currently, the company uses maintenance breakdown, which is corrective maintenance in the treatment of the machine. This means that the company must perform maintenance activities on any machine, so the company will not lose a lot of maintenance cost to fix the breakdown machine. Maintenance activities can minimize costs or losses incurred due to failure to the machine, thus, the profit to be obtained by the company will be increased.

3.3 Literature Study

The literature study is used to get the essence of theoretical concept and knowledge for conducting this research. After the problem is identified, literature study is provided to support the research conducted. The references are come from textbooks, journal, e-books or website. The main literature studies that used in this research for the analysis are:

1. Maintenance.
2. Reliability.
3. Failure Rate.
4. Failure Distribution.
5. Statistical Approach.
6. Maintenance Interval Time.

3.4 Data Collection

In this section, the data is obtained through direct observation. The purpose of this section is to collect all of data that needed for preventive maintenance scheduling in rotor assembly line. The data were taken from July until December 2016 in PT. NAA. There are several data that collected, which are planned and actual production quantity from July to December 2016, the downtime data for nine lines, actual work time every month during the last six months in 2016, the downtime data for 32 machines of rotor assembly line, Pareto chart that shows the downtime for several component machines of main assembly 1 machine from rotor assembly line, root cause of some component machine which are chuck holder shaft, b-pin, and chuck holder slip ring, and failure data of chuck holder shaft, b-pin, and chuck holder slip ring from July to December 2016.

3.5 Data Calculation and Analysis

After the data that needed for this research is collected, the next phase is to calculate and analyze all the relevant data. There are several steps calculate the data:

1. Perform analysis for critical component machines.

   Pareto analysis is used to acknowledge the critical component of the machines.

2. Perform Time to Repair, Time to Failure and Time between Failures.

   Time to Repair is calculated starting from the mechanics start repairing the machine until finish. Time to failure and time between failures is calculated from the machine start production until stop production or breakdown again

3. Perform Time to Repair and Time to Failure Distribution.

   There are four types of failure distribution for determine the reliability, which are normal distribution, exponential distribution, Weibull distribution and lognormal distribution.

4. Perform parameter of failure distribution.

   - Parameter of normal distribution are mean (μ) and standard deviation (σ).
   - Parameter of exponential distribution is lambda (λ).
   - Parameter of weibull distribution are shape parameter (β) and scale parameter (θ).
   - Parameter of lognormal distribution are shape parameter and location parameter.

5. Calculate MTTR, MTTF and MTBF.

6. Calculate the maintenance cost.
   There are some required data before calculating the maintenance cost which are machine capacity per hour, actual production quantity, product price, component machine price in repairing chuck holder shaft, component machine price in replacing chuck holder shaft, component machine price in repairing chuck holder slip ring, and mechanic fee per hour.

7. Calculate the maintenance interval time.

8. Calculate the component machine reliability.
   The target of machine reliability to be achieved by the company is 70%.

The result will be analyzed to determine the preventive scheduling maintenance and also to compare the maintenance cost.

3.6 Conclusion and Recommendation

This part marks the final step of the research is to give conclusion and recommendation for the company. This chapter will answer the problem statements and to fulfill the objective of this research. Conclusion is the summary of data analysis in previous chapter. The recommendation for further study is also identify in this section that contains several suggestions to improve the current maintenance scheduling system.

3.7 Detailed Research Framework

The purpose of this part is to assist the reader in understanding the steps with more concise way will be included in this chapter. Figure 3.2 on the next page shows the breakdown of every step for the detailed research framework for this research, start from the beginning until finishing. Every step to do this research, data collection, data calculation, data analysis, conclusion and recommendation should be set systematically in order to solve the research problem.

From Figure 3.2, it can be seen this research starts with collect all the failure data of each component machines to know which critical component that affects the highest downtime and need to be investigated further. Machine has low reliability if the machine has the most frequently failure. This research is only focused on the selected machine from nine lines in PT. NAA.

Pareto chart is used to identify which the most critical component machines that affects the highest downtime from July to December 2016. From Pareto chart, there are three component machines that have the highest downtime in the selected machine. The production output for the selected machine is affected by machine downtime.

The failure data for this research were taken from July to December 2016. After all of the data are collected, the next step is determining the time to repair (TTR), time to failure (TTF) and time between failures (TBF). Time to failure is used for calculated the data of replacement activity, and time between failure is used for calculated the data of repairing, setting and cleaning activity. The next step is determining the failure distribution that appropriate with the collected data by using the testing statistical software. After know the appropriate distribution, the parameter of each component machines is needed in order to calculate the MTTR, MTTF and MTBF.

The next step is calculating the maintenance cost and reliability machine based on failure distribution data. In determining maintenance interval time, the certain distribution must be appropriate with the failure data. Maintenance interval is needed to setting the preventive maintenance intervals that needs maintenance activity. The interval time is calculated from maintenance interval time. The target of machine reliability to be achieved by the company is 85%, so each component will have component machine reliability of 85%, then proposed the preventive maintenance schedule.

In order to know the impact of the improvement, the last step is there will be a reliability comparison between current maintenance systems with proposed preventive maintenance system, and comparison between current maintenance cost and proposed preventive maintenance cost. When the proposed system has a positive impact to the company, there will be preventive maintenance schedule from January to June 2017.

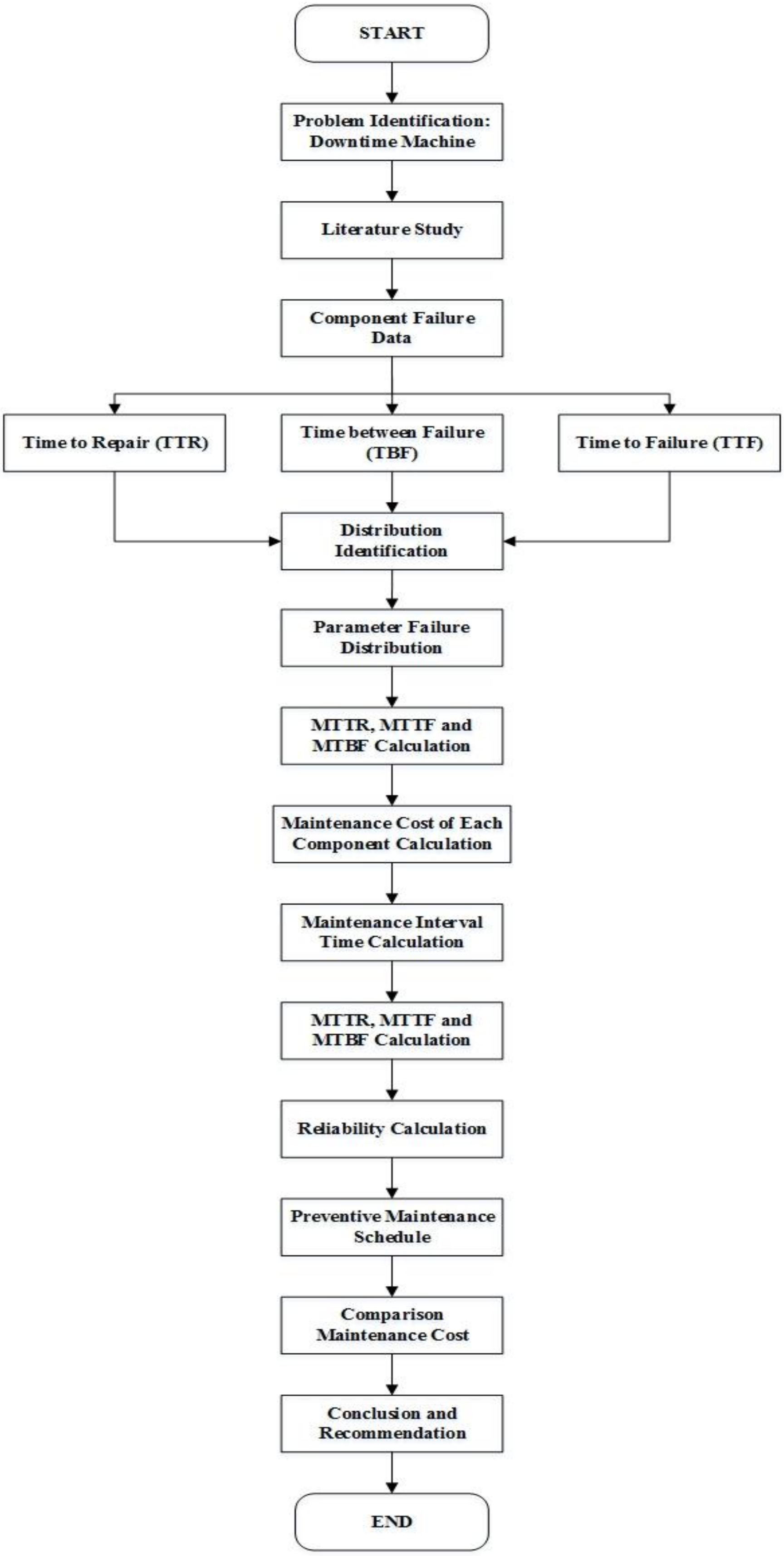


Figure 3.2 Detail Research Framework

CHAPTER IV
DATA COLLECTION AND ANALYSIS

4.1 Data Collection

Data collection in this research consists of the data related to the research, which are gathered from observation. All data required for this research is calculated and analyzed according to the related problems, which has been investigated to achieve the research objective.

4.1.1 Current Condition Analysis

PT. NAA is a manufacturing company that specifically operates in the automotive field and produces two types of vehicle spare parts, which are alternator assembly and starter assembly vehicle that operates nine lines to produce alternator assembly and starter assembly. The production of the aforementioned parts is consists of four lines for producing alternator assembly and five lines for alternator assembly. The alternator assembly consists of rotor assembly, field coil, stator assembly, and alternator bracket, and starter assembly consists of starter bracket, brush holder assembly (BHA), over running clutch (ORC), yoke assembly, and a connector brush holder (CBH). Table 4.1 below shows the comparison between the data of planned production quantity and actual production quantity in rotor assembly line during July to December 2016.

Table 4.1 Monthly 2016 Comparison between Planned and Actual Production

Month (2016)	Production Quantity (units)	
	Planned Production Quantity	Actual Production Quantity
July	36,315	36,314
August	53,325	54,279
September	54,175	52,113
October	50,647	50,464
November	55,049	54,899
December	51,420	50,515
TOTAL	300,931	298,584

Table 4.1 explains about the comparison between monthly planned production quantity and actual production quantity in year 2016. The total of planned production quantity in last six months is 300,931 pcs and the total of actual production quantity in last six months is 298,584 pcs. From Table 4.1 can be seen that the total of planned production quantity and actual production quantity is different. Figure 4.1 below shows the comparison quantity between planned production quantity and actual production quantity.

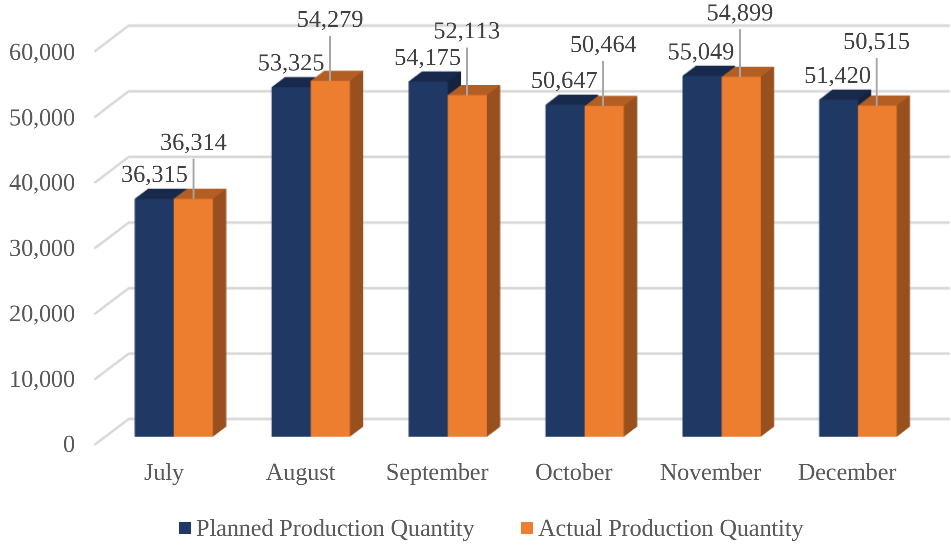


Figure 4.1 Monthly 2016 Comparison between Planned and Actual Production

Based on Figure 4.1, in July, September, October, November, and December 2016, the total of actual production quantity has not reached the total of planned production quantity because of several aspects. One of the aspects is downtime problem. In August 2016, the total of actual production has reached the total of forecasted quantity because of the overtime performed by the operator.

4.1.2 Identify Production Area Downtime

Downtime is the main factor that caused the loss of productivity in most manufacturing processes. Downtime essentially means the amount of time in which machine that cannot operate due to damage or failure. Treatment of downtime can be the fastest way to gain a significant improvement. Figure 4.2 below shows the total downtime of nine lines that becomes basic information to determine which line is critical and need to be checked further. For the detail, Appendix 1 will show the downtime data of assembly line.

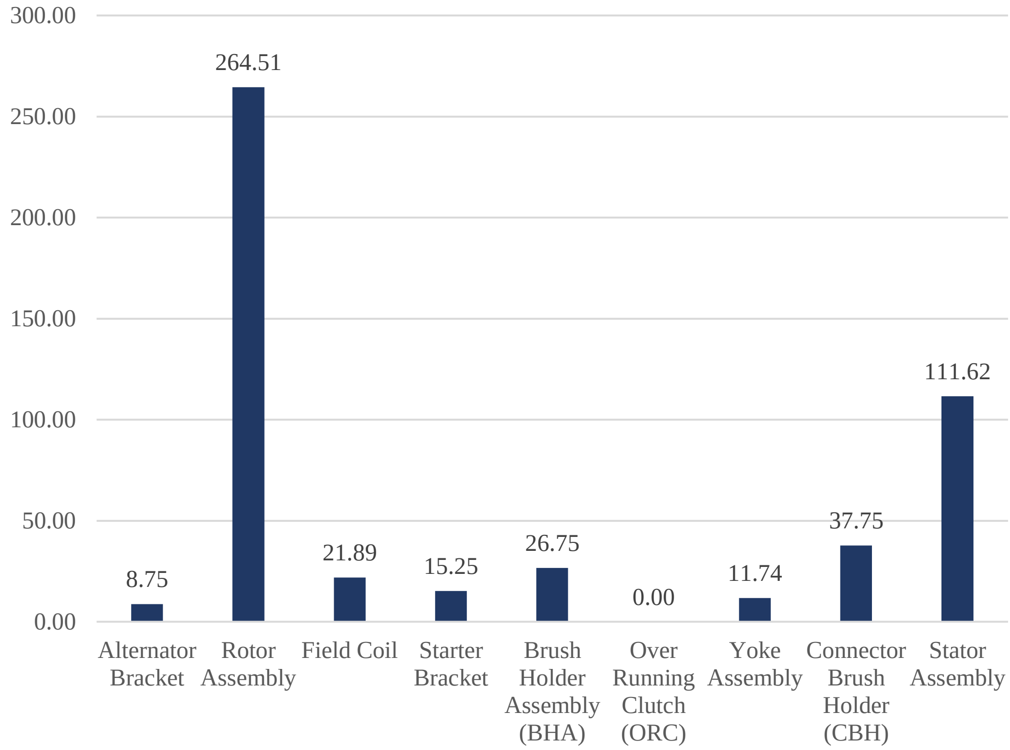


Figure 4.2 Assembly Line Downtime in Hour (July-December 2016)

Based on the graph in Figure 4.2, rotor assembly is the most critical machine that has the highest frequency of downtime, which is 264.51 hours in the production line. The second highest is stator assembly line, which has frequency of downtime about 111.62 hours. During last six months in 2016, over running clutch (ORC) is one of production line that has zero frequency of failure. Thus, rotor assembly line is chosen as the object of observation in this research. Table 4.2 shows the comparison data between downtime and actual work time in rotor assembly line.

Table 4.2 Monthly 2016 Comparison between Downtime and Actual Work Time in Rotor Assembly Line

Period	Year	Downtime /month		Actual Work /month		% Downtime
		Hour	Minute	Hour	Minute	
July	2016	11.07	664.20	361.56	21,693.60	3.06%
August	2016	49.86	2,991.60	520.80	31,248.00	9.57%
September	2016	44.25	2,655.00	581.86	34,911.60	7.60%
October	2016	52.18	3,130.80	560.86	33,651.60	9.30%
November	2016	44.42	2,665.20	337.97	20,278.20	13.14%
December	2016	62.73	3,763.80	254.10	15,246.00	24.69%

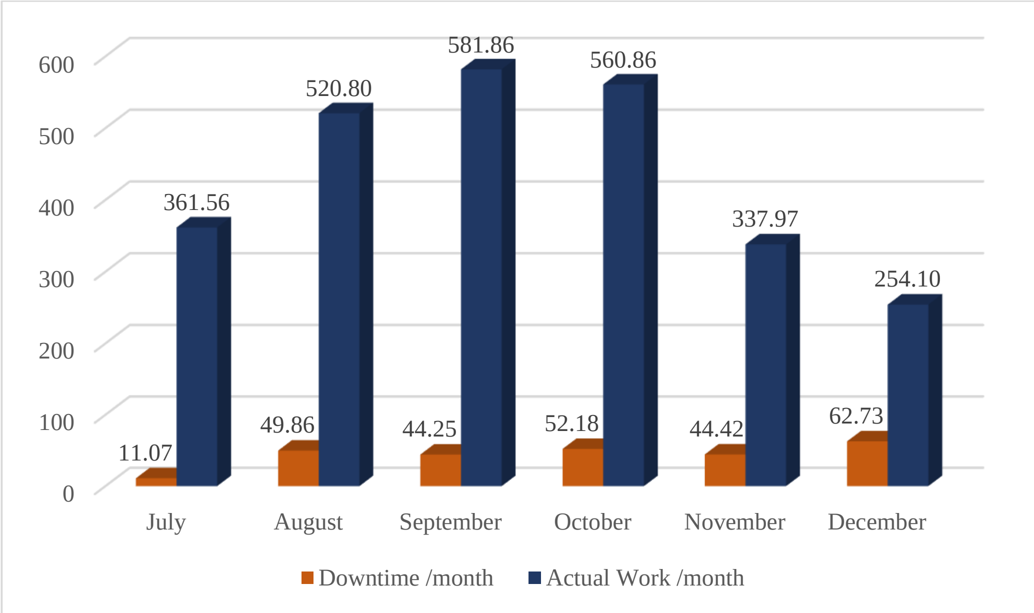


Figure 4.3 Comparison between Downtime and Actual Work Time in Rotor Assembly Line

Table 4.2 and Figure 4.3 explains about the comparison data between the total downtime in rotor assembly line from July to December 2016 and actual work time each month in the same period. Can be seen that the total time of actual work is different each month. The percentage of downtime is obtained from downtime/month divided by actual work/month multiplied by 100%. The percentage of downtime in July 2016 is 11.07 hours or 664.20 minutes while the actual working time is 362.56 hours or 21,693.60 minutes. The condition in August decreased to 9.57%. In September the downtime increased 1.97% become 7.60%. During the last four months in 2016, the percentage of downtime is increasing.

4.1.3 Identify Machine Downtime

Rotor assembly line has 32 machines which are AC box penguin cement, balancing checker, caulking, drilling, epoxy dropping, f-fan spot welding, furnace, heater painting, lathe, laser marking, main assembly, oil machine press, painting, penguin cement, r-fan spot welding, rotor electrical checker new, s/r belt grinding, shaft grinding, solder, sub assembly and utility. Based on the downtime report in rotor assembly line, there are some critical failure machines that have the highest number of downtime that caused downtime machine frequently. Figure 4.4 below shows the frequency of downtime for every machine in rotor assembly line during July to

December 2016. For the detail, Appendix 2 will show the downtime data of each machine in rotor assembly line.

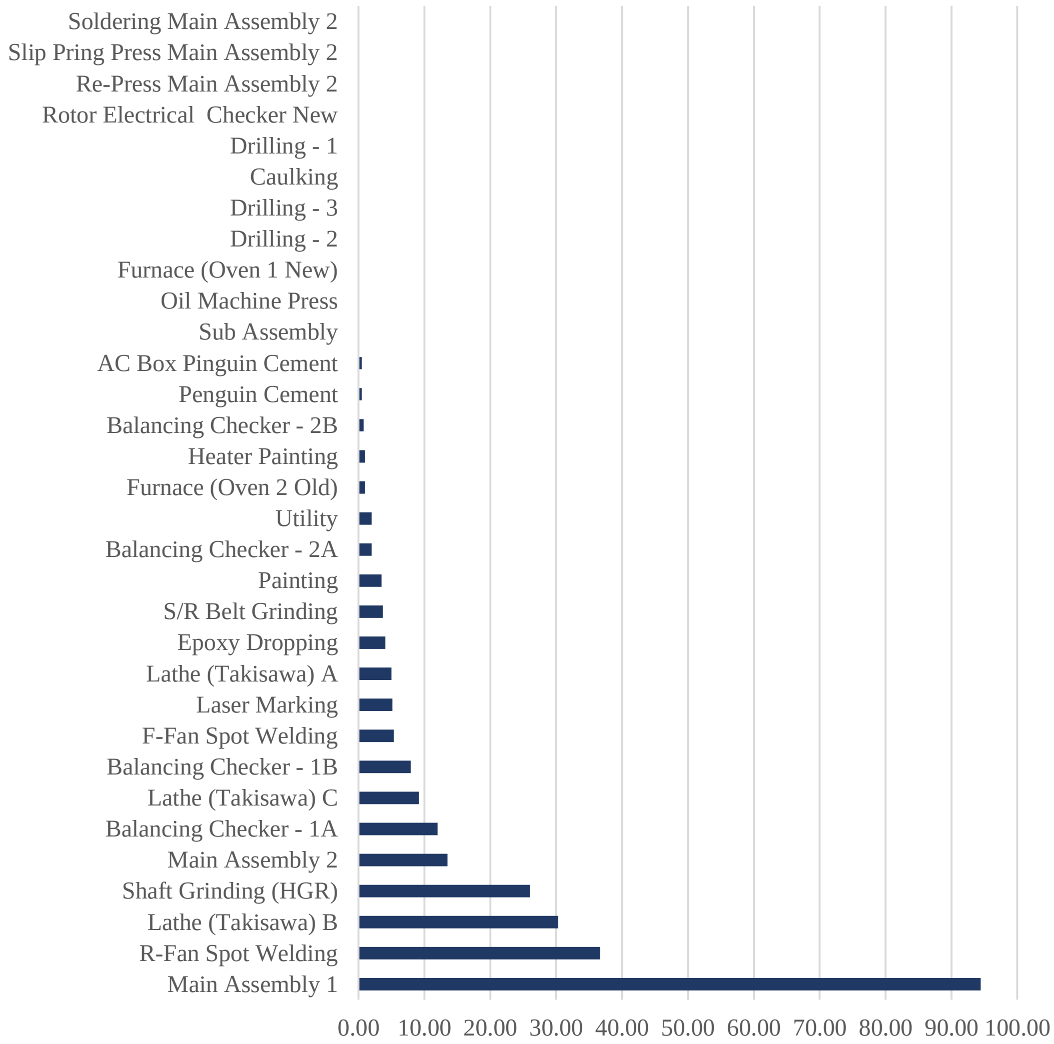


Figure 4.4 Machine Downtime from July-December 2016 (Hour)

Figure 4.4 above shows that Main Assembly 1 machine is the most critical machine in rotor assembly line. From total 264.51 hours downtime in rotor assembly line, 94.42 hours or 35.7% from the downtime data caused by Main Assembly 1 machine. R-fan spot welding breaks down 36.67 hours or 13.86% from the total downtime in Main Assembly 1 while lathe (*takisawa*) B breaks down 30.33 or 11.47%. Furthermore, the calculation and analysis will be focused in Main Assembly 1 machine. During the last six months in 2016, Main Assembly 1 machine had broken down 96 times.

4.1.4 Identify Component Machine Downtime

Table 4.3 below shows the data of occurrence of component machines breakdowns. From the table, it can be seen that the highest frequency of critical part that caused the machine failures were chuck holder shaft, B-Pin and chuck holder slip ring.

Table 4.3 The Occurrences of Component Machines Breakdown

Component Machine	Downtime	Cumulative Downtime	Cumulative (%)
Chuck Holder Shaft	33.00	46.17	48.90%
Chuck Holder Slip Ring	16.00	49.00	51.90%
B-Pin	8.75	57.75	61.16%
Jig Caulking	7.73	65.48	69.35%
Proximity Sensor	7.15	72.63	76.92%
Servo Motor	6.51	79.14	83.82%
Sliding Press	5.37	84.51	89.50%
Regulator Air Pressure	3.64	88.15	93.36%
Nozzle Penguin Cement	3.35	91.50	96.91%
Others	2.92	94.42	100.00%

Figure 4.5 shows the Pareto chart of component machine downtime in Main Assembly 1 machine.

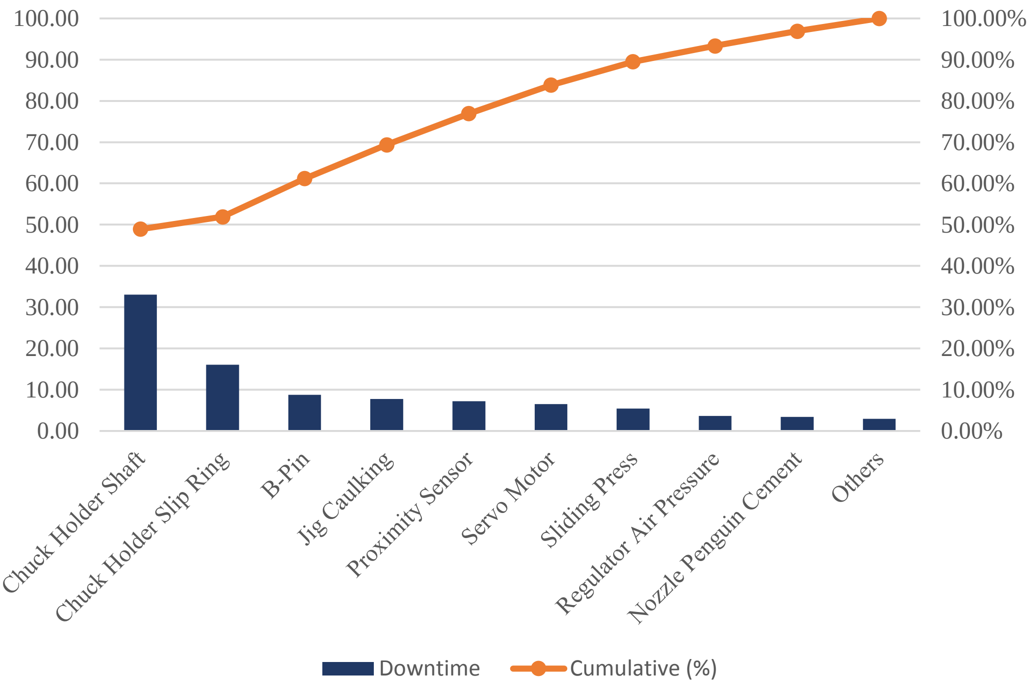


Figure 4.5 Pareto Chart of Component Machine Downtime in Main Assembly 1 Machine

Table 4.3 and Figure 4.5 shows the Pareto chart of the occurrences of component machines breakdown. There are nine component machines and others of Main Assembly 1 machine. Chuck holder shaft, B-Pin and chuck holder slip ring have the highest number that become the main cause of the machine breakdowns. During the last six months in 2016, chuck holder shaft breaks down 24 times with total time 33 hours or 1980 minutes. Chuck holder slip ring breaks down 8 times with total time 960 minutes while B-Pin breaks down 8 times with total time 8.75 hours or 525 minutes. From Table 4.3 shows that 34.95% of the failure is caused by chuck holder shaft, 16.95% caused by chuck holder slip ring and 9.27% caused by B-Pin. Based on the data, the critical component machine will be focused on chuck holder shaft, chuck holder slip ring, and b-pin. Table 4.4 below explains the problem of component machine breakdown.

Table 4.4 Problem of Component Machine Breakdown

Component Machine	Frequency Occurrence	Problem	Action Taken
Chuck Holder Shaft	24	The position of sensor was changed.	Setting.
		The existing sensor cable in the machine was slipped.	Repairing.
		Sensor in the machine was broken.	Replacement.
Chuck Holder Slip Ring	8	Sensor for chuck holder slip ring was not detected.	Repairing.
B-Pin	8	B-Pin was stuck in the pole.	Cleaning.

- Chuck Holder Shaft

  Chuck holder shaft is an installation process of shaft for jig. The function is to transfer the shaft to rotor assembly area. The failure that occurred on chuck holder shaft are:

  1. The position of sensor was change. The position of sensor is exactly in the middle of machine, then skewed because the bolt was slack. The impact of the problem was the sensor will be unable to scan the part, so the process cannot proceed to the next steps. Maintenance that must be done is setting the bolt. It must be tightened.
  2. The existing sensor cable in the machine was slipped. The cable was slipped because pinched. The impact of the issue was the electric system would stop

working. Maintenance that must be done is repairing the sensor cable; reconnect the cable one and another.

3. Sensor in the machine was broken. The movement of the machine exposed the sensor. The impact of the problem was the process cannot proceed to the next steps. Sensor of chuck holder shaft must be replacing the broken sensor with the new sensor.

- Chuck Holder Slip Ring

  Chuck holder slip ring is an installation process of slip ring for jig. The function is as a holder for slip ring when processing of rotor assembly. The position of the sensor is inside the machine. The failure that occurred on chuck holder slip ring was the sensor was not detected because it was contaminated with dust but did not detected. The impact of the problem was the process cannot proceed to the next steps. Maintenance that must be done is repairing the sensor.

- B-Pin

  B-Pin is a process of pressing shaft rotor into the pole for jig. The failure that occurred on B-Pin was B-Pin stuck in the pole because there are many grams stick to the cylinder of B-Pin. Diameter of pole and shaft not allowed to be distantly. It should be fit, so it cannot be avoided that there will be many grams. The impact of the issue was the process cannot proceed to the next steps. Maintenance that must be done is cleaning the grams that stick to the cylinder of B-Pin.

4.1.5 Component Machine Failure Data

Component machine failure data of part during last six months is needed in order to estimate the time to conduct the preventive maintenance. From the previous part, Main Assembly 1 machine has the highest downtime in rotor assembly line. There are three critical failures of component machines which have the highest downtime then the others. Three component machines of Main Assembly 1 that have the highest downtime are chuck holder shaft, chuck holder slip ring and b-pin.

In PT. NAA, the failure data of component machine are differentiated based on several types of the maintenance process which are setting for chuck holder shaft, cleaning for b-pin, repairing for chuck holder shaft and chuck holder slip ring, and replacement for chuck holder shaft from July to December 2016. For the detail, Appendix 4 will shows the detail component failure data.

Table 4.5 Failure Data of Chuck Holder Shaft (Setting)

No.	Component Machine	Machine Stopped		Repair Time	
		Date	Time	Start	Finish
1	Chuck Holder Shaft	7/21/2016	8:36:00	9:12:00	10:02:00
2	Chuck Holder Shaft	8/2/2016	10:05:00	10:42:00	12:12:00
3	Chuck Holder Shaft	8/2/2016	19:50:00	20:15:00	21:00:00
4	Chuck Holder Shaft	8/31/2016	2:54:00	3:20:00	4:00:00
5	Chuck Holder Shaft	9/5/2016	12:14:00	13:05:00	14:05:00
6	Chuck Holder Shaft	9/24/2016	18:50:00	19:05:00	19:50:00
7	Chuck Holder Shaft	9/25/2016	21:10:00	21:30:00	23:10:00
8	Chuck Holder Shaft	10/10/2016	3:17:00	3:36:00	4:51:00
9	Chuck Holder Shaft	10/13/2016	19:35:00	19:56:00	20:36:00
10	Chuck Holder Shaft	10/29/2016	16:40:00	17:05:00	17:55:00
11	Chuck Holder Shaft	12/5/2016	6:24:00	6:39:00	9:39:00
12	Chuck Holder Shaft	12/13/2016	19:45:00	20:05:00	21:35:00
13	Chuck Holder Shaft	12/28/2016	22:29:00	22:45:00	23:45:00

Table 4.5 above explains the failure data of chuck holder shaft for setting activity from July to December 2016. Setting activity is an activity of arranging or putting certain factors into the proper arrangement based on the needs and requirements. The total failure was 13 times.

Table 4.6 Failure Data of Chuck Holder Shaft (Repairing)

No.	Component Machine	Machine Stopped		Repair Time	
		Date	Time	Start	Finish
1	Chuck Holder Shaft	8/15/2016	7:45:00	8:15:00	10:15:00
2	Chuck Holder Shaft	8/18/2016	13:08:00	13:32:00	15:07:00
3	Chuck Holder Shaft	9/18/2016	11:04:00	12:13:00	12:58:00
4	Chuck Holder Shaft	9/24/2016	6:13:00	7:00:00	9:00:00
5	Chuck Holder Shaft	10/14/2016	15:13:00	15:44:00	16:14:00
6	Chuck Holder Shaft	11/10/2016	9:22:00	10:00:00	11:25:00

Table 4.6 above explains the failure data of chuck holder shaft for repairing activity from July to December 2016. Repairing activity is the skill used to repair machines that is damaged, not working correctly or broken. It is an activity of fixing the

machine by the mechanic without changing certain old parts with the new ones. The mechanics make the machine work again back into good condition. Machine that already repaired still can be used. The total failure was 6 times.

Table 4.7 Failure Data of Chuck Holder Shaft (Replacement)

No.	Component Machine	Machine Stopped		Repair Time	
		Date	Time	Start	Finish
1	Chuck Holder Shaft	7/2/2016	1:21:00	1:55:00	4:45:00
2	Chuck Holder Shaft	8/6/2016	11:29:00	11:41:00	14:21:00
3	Chuck Holder Shaft	9/11/2016	9:14:00	9:30:00	11:40:00
4	Chuck Holder Shaft	10/23/2016	6:00:00	7:05:00	7:50:00
5	Chuck Holder Shaft	12/19/2016	15:28:00	15:40:00	16:35:00

Table 4.7 above explains the failure data of chuck holder shaft for replacement activity from July to December 2016. Replacement is an activity of changing certain old parts with the new ones. The total failure was 5 times.

Table 4.8 Failure Data of Chuck Holder Slip Ring (Repairing)

No.	Component Machine	Machine Stopped		Repair Time	
		Date	Time	Start	Finish
1	Chuck Holder Slip Ring	9/24/2016	2:28:00	2:40:00	4:22:00
2	Chuck Holder Slip Ring	10/10/2016	9:21:00	9:30:00	11:48:00
3	Chuck Holder Slip Ring	10/14/2016	19:43:00	19:56:00	22:08:00
4	Chuck Holder Slip Ring	10/24/2016	1:05:00	1:12:00	2:57:00
5	Chuck Holder Slip Ring	12/6/2016	13:54:00	14:00:00	15:54:00
6	Chuck Holder Slip Ring	12/17/2016	10:48:00	11:00:00	12:39:00
7	Chuck Holder Slip Ring	12/22/2016	20:42:00	20:55:00	23:25:00
8	Chuck Holder Slip Ring	12/28/2016	16:00:00	16:05:00	18:05:00

Table 4.8 above explains the failure data of chuck holder slip ring for repairing activity from July to December 2016. The total failure was 8 times.

Table 4.9 Failure Data of B-Pin (Cleaning)

No.	Component Machine	Machine Stopped		Repair Time	
		Date	Time	Start	Finish
1	B-Pin	8/18/2016	9:10:00	9:20:00	10:20:00
2	B-Pin	8/29/2016	19:53:00	20:05:00	20:35:00
3	B-Pin	9/3/2016	0:26:00	0:41:00	2:36:00
4	B-Pin	10/6/2016	6:00:00	6:20:00	6:45:00
5	B-Pin	10/21/2016	14:21:00	14:31:00	15:11:00
6	B-Pin	11/15/2016	19:20:00	19:35:00	20:05:00
7	B-Pin	12/13/2016	20:17:00	20:23:00	23:23:00
8	B-Pin	12/22/2016	10:45:00	11:00:00	11:45:00

Table 4.9 explains the failure data of b-pin for cleaning activity from July to December 2016. Cleaning activity can be defined as activity in cleaning machine from dust and other dirt, especially in certain parts which more sensitive. The total failure was 8 times.

4.2 Data Calculation

Data calculation is the next step after gathered all the data needed for solving the problem statements. The data that used in maintenance data start from July until December 2016. The data calculation is to determine the maintenance scheduling for chuck holder shaft, chuck holder slip ring, and b-pin.

4.2.1 Time to Repair (TTR), Time to Failure (TTF) and Time between Failure (TBF)

Time to repair (TTR) is the time needed by mechanics for repairing the machine from start until finish repaired for the same component machine to restore a machine usefulness from failure. Time to failure (TTF) or time between failures (TBF) is the time required by the system to work without fail within a certain period. Time to failure is used for calculated the data of replacement activity, and time between failure is used for calculated the data of repairing, setting and cleaning activity.

In the calculation of time to repair, time to failure, and time between failures only performed on critical components according to the analysis using Pareto chart. During the last six months in 2016, the data of critical component machine in Main Assembly 1 machine were taken in PT. NAA. Data used in the calculation of time to repair, time to failure and time between failures for three component machines which are chuck holder shaft, chuck holder slip ring, and b-pin were taken from July to December 2016..

4.2.1.1 Chuck Holder Shaft Calculation

Table 4.10 until table 4.15 shows the detail result of time to failure, time between failure and time to repair for chuck holder shaft based on maintenance activities from July to December 2016.

Table 4.10 Waiting Time of Chuck Holder Shaft (Setting)

Component Machine	Type of Maintenance	Date	Machine Stopped	Start Repair	Waiting Time (hours)
Chuck Holder Shaft	Setting	7/21/2016	8:36:00	9:12:00	0.60
Chuck Holder Shaft	Setting	8/2/2016	10:05:00	10:42:00	0.62
Chuck Holder Shaft	Setting	8/2/2016	19:50:00	20:15:00	0.42
Chuck Holder Shaft	Setting	8/31/2016	2:54:00	3:20:00	0.43
Chuck Holder Shaft	Setting	9/5/2016	12:14:00	13:05:00	0.85
Chuck Holder Shaft	Setting	9/24/2016	18:50:00	19:05:00	0.25
Chuck Holder Shaft	Setting	9/25/2016	21:10:00	21:30:00	0.33
Chuck Holder Shaft	Setting	10/10/2016	3:17:00	3:36:00	0.32
Chuck Holder Shaft	Setting	10/13/2016	19:35:00	19:56:00	0.35
Chuck Holder Shaft	Setting	10/29/2016	16:40:00	17:05:00	0.42
Chuck Holder Shaft	Setting	12/5/2016	6:24:00	6:39:00	0.25
Chuck Holder Shaft	Setting	12/13/2016	19:45:00	20:05:00	0.33
Chuck Holder Shaft	Setting	12/28/2016	22:29:00	22:45:00	0.27

Table 4.10 above shows the waiting time of chuck holder shaft for setting activity. Waiting time is time needed from waiting for the mechanic to come and then the mechanic began to repair the machine. On July 21st, 2016, the machine stopped at 08:36:00 and started to repair at 09:12:00. The waiting time was 0.60 hours (09:12:00 - 08:36:00 = 0.60 hours or 36 minutes).

Table 4.11 TTR and TBF of Chuck Holder Shaft (Setting)

Stop Machine		Repair Time		TTR (hours)	TBF (hours)
Date	Time	Start	Finish		
7/21/2016	8:36:00	9:12:00	10:02:00	0.83	0
8/2/2016	10:05:00	10:42:00	12:12:00	1.50	288.05
8/2/2016	19:50:00	20:15:00	21:00:00	0.75	10.12
8/31/2016	2:54:00	3:20:00	4:00:00	0.67	695.68
9/5/2016	12:14:00	13:05:00	14:05:00	1.00	128.23
9/24/2016	18:50:00	19:05:00	19:50:00	0.75	469.00
9/25/2016	21:10:00	21:30:00	23:10:00	1.67	25.33
10/10/2016	3:17:00	3:36:00	4:51:00	1.25	350.97
10/13/2016	19:35:00	19:56:00	20:36:00	0.67	86.73
10/29/2016	16:40:00	17:05:00	17:55:00	0.83	375.33
12/5/2016	6:24:00	6:39:00	9:39:00	3.00	878.92
12/13/2016	19:45:00	20:05:00	21:35:00	1.50	213.70
12/28/2016	22:29:00	22:45:00	23:45:00	1.00	360.90

Below is the example of TTR and TBF of chuck holder shaft for setting activity. The machine stopped on August 2nd, 2016. The previous failure occurred on July 21st, 2016. The interval between the downtime of the machine was 12 days. The machine started to repair at 10:42:00 and finished at 12:12:00. The duration of repairing the component machine was 1.50 hours (12:12:00 – 10:42:00 = 1.50 hours or 92 minutes).

After setting the machine, the machine started the production on August 2nd, 2016 at 12:12:00. Then the machine stopped again on August 2nd, 2016 at 19:50:00. The duration from stop machine until start production called time between failures was 10.12 hours.

Table 4.12 Waiting Time of Chuck Holder Shaft (Repairing)

Component Machine	Type of Maintenance	Date	Stop Machine	Start Repair	Waiting Time (hours)
Chuck Holder Shaft	Repairing	8/15/2016	7:45:00	8:15:00	0.50
Chuck Holder Shaft	Repairing	8/18/2016	13:08:00	13:32:00	0.40
Chuck Holder Shaft	Repairing	9/18/2016	11:04:00	12:13:00	1.15
Chuck Holder Shaft	Repairing	9/24/2016	6:13:00	7:00:00	0.78
Chuck Holder Shaft	Repairing	10/14/2016	15:13:00	15:44:00	0.52
Chuck Holder Shaft	Repairing	11/10/2016	9:22:00	10:00:00	0.63

Table 4.12 above shows the waiting time of chuck holder shaft for repairing activity. On August 15th, 2016, the machine stopped at 07:45:00 and started to repair at 08:15:00. The waiting time was 0.50 hours (08:15:00 - 07:45:00 = 0.50 hours or 30 minutes).

Table 4.13 TTR and TBF of Chuck Holder Shaft (Repairing)

Stop Machine		Repair Time		TTR (hours)	TBF (hours)
Date	Time	Start	Finish		
8/15/2016	7:45:00	8:15:00	10:15:00	2.00	0
8/18/2016	13:08:00	13:32:00	15:07:00	1.58	74.88
9/18/2016	11:04:00	12:13:00	12:58:00	0.75	730.12
9/24/2016	6:13:00	7:00:00	9:00:00	2.00	143.68
10/14/2016	15:13:00	15:44:00	16:14:00	0.50	486.22
11/10/2016	9:22:00	10:00:00	11:25:00	1.42	637.00

Below is the example of TTR and TBF of chuck holder shaft for repairing activity. The machine stopped on August 18th, 2016. The previous failure occurred on August 15th, 2016. The interval between the downtime of the machine was 3 days.

The machine started to repair at 13:32:00 and finished at 15:07:00. The duration of repairing the component machine was 1.58 hours (15:07:00 – 13:32:00 = 1.58 hours or 95 minutes).

After repairing the machine, the machine started the production on August 18th, 2016 at 15:07:00. Then the machine stopped again on September 18th, 2016 at 11:04:00. The duration from stop machine until start production called time between failures was 730.12 hours.

Table 4.14 Waiting Time of Chuck Holder Shaft (Replacement)

Component Machine	Type of Maintenance	Date	Stop Machine	Start Repair	Waiting Time (hours)
Chuck Holder Shaft	Replacement	7/2/2016	1:21:00	1:55:00	0.57
Chuck Holder Shaft	Replacement	8/6/2016	11:29:00	11:41:00	0.20
Chuck Holder Shaft	Replacement	9/11/2016	9:14:00	9:30:00	0.27
Chuck Holder Shaft	Replacement	10/23/2016	6:00:00	7:05:00	1.08
Chuck Holder Shaft	Replacement	12/19/2016	15:28:00	15:40:00	0.20

Table 4.14 above shows the waiting time of chuck holder shaft for replacement activity. On July 2nd, 2016, the machine stopped at 01:21:00 and started to repair at 01:55:00. The waiting time was 0.57 hours (01:55:00 - 01:21:00 = 0.57 hours or 34 minutes).

Table 4.15 TTR and TTF of Chuck Holder Shaft (Replacement)

Stop Machine		Repair Time		TTR (hours)	TTF (hours)
Date	Time	Start	Finish		
7/2/2016	1:21:00	1:55:00	4:45:00	2.83	0
8/6/2016	11:29:00	11:41:00	14:21:00	2.67	846.73
9/11/2016	9:14:00	9:30:00	11:40:00	2.17	850.12
10/23/2016	6:00:00	7:05:00	7:50:00	0.75	1007.68
12/19/2016	15:28:00	15:40:00	16:35:00	0.92	1375.63

Below is the example of TTR and TTF of chuck holder shaft for replacement activity. The machine stopped on July 8th, 2016. The previous failure occurred on July 2nd, 2016. The interval between the downtime of the machine was 35 days. The machine started to repair at 11:41:00 and finished at 14:21:00. The duration of repairing the component machine was 2.67 hours (14:21:00 – 11:41:00 = 2.67 hours or 160 minutes).

After replace the machine, the machine started the production on July 8th, 2016 at 14:21:00. Then the machine stopped again on September 11th, 2016 at 09:14:00. The duration from stop machine until start production called time between failures was 850.12 hours.

4.2.1.1 Chuck Holder Slip Ring Calculation

Table 4.16 shows the detail result of time to failure and time between failures for b-pin based on maintenance activities from July to December 2016.

Table 4.16 Waiting Time of Chuck Holder Slip Ring (Repairing)

Component Machine	Type of Maintenance	Date	Stop Machine	Start Repair	Waiting Time (hours)
Chuck Holder Slip Ring	Repairing	9/24/2016	2:28:00	2:40:00	0.20
Chuck Holder Slip Ring	Repairing	10/10/2016	9:21:00	9:30:00	0.15
Chuck Holder Slip Ring	Repairing	10/14/2016	19:43:00	19:56:00	0.22
Chuck Holder Slip Ring	Repairing	10/24/2016	1:05:00	1:12:00	0.12
Chuck Holder Slip Ring	Repairing	12/6/2016	13:54:00	14:00:00	0.10
Chuck Holder Slip Ring	Repairing	12/17/2016	10:48:00	11:00:00	0.20
Chuck Holder Slip Ring	Repairing	12/22/2016	20:42:00	20:55:00	0.22
Chuck Holder Slip Ring	Repairing	12/28/2016	16:00:00	16:05:00	0.08

Table 4.16 above shows the waiting time of chuck holder slip ring for repairing activity. On September 24th, 2016, the machine stopped at 02:28:00 and started to repair at 02:40:00. The waiting time was 0.20 hours (02:40:00 - 02:28:00 = 0.20 hours or 12 minutes).

Table 4.17 TTR and TBF of Chuck Holder Slip Ring (Repairing)

Stop Machine		Repair Time		TTR (hours)	TBF (hours)
Date	Time	Start	Finish		
9/24/2016	2:28:00	2:40:00	4:22:00	1.70	0
10/10/2016	9:21:00	9:30:00	11:48:00	2.30	388.98
10/14/2016	19:43:00	19:56:00	22:08:00	2.20	106.12
10/24/2016	1:05:00	1:12:00	2:57:00	1.75	239.68
12/6/2016	13:54:00	14:00:00	15:54:00	1.90	1042.95
12/17/2016	10:48:00	11:00:00	12:39:00	1.65	253.00
12/22/2016	20:42:00	20:55:00	23:25:00	2.50	128.05
12/28/2016	16:00:00	16:05:00	18:05:00	2.00	134.97

Below is the example of TTR and TBF of chuck holder slip ring for repairing activity. The machine stopped on October 10th, 2016. The previous failure occurred on September 24th, 2016. The interval between the downtime of the machine was

16 days. The machine started to repair at 09:30:00 and finished at 11:48:00. The duration of repairing the component machine was 2.30 hours (11:48:00 – 09:30:00 = 2.30 hours or 138 minutes).

After repairing the machine, the machine started the production on October 10th, 2016 at 11:48:00. Then the machine stopped again on October 14th, 2016 at 19:43:00. The duration from stop machine until start production called time between failures was 106.12 hours.

4.2.1.2 Chuck Holder Slip Ring Calculation

Table 4.18 shows the detail result of time to failure and time between failures for b-pin based on maintenance activities from July to December 2016.

Table 4.18 Waiting Time of B-Pin (Cleaning)

Component Machine	Type of Maintenance	Date	Machine Stopped	Star Repair	Waiting Time (hours)
B-Pin	Cleaning	8/18/2016	9:10:00	9:20:00	0.17
B-Pin	Cleaning	8/29/2016	19:53:00	20:05:00	0.20
B-Pin	Cleaning	9/3/2016	0:26:00	0:41:00	0.25
B-Pin	Cleaning	10/6/2016	6:00:00	6:20:00	0.33
B-Pin	Cleaning	10/21/2016	14:21:00	14:31:00	0.17
B-Pin	Cleaning	11/15/2016	19:20:00	19:35:00	0.25
B-Pin	Cleaning	12/13/2016	20:17:00	20:23:00	0.10
B-Pin	Cleaning	12/22/2016	10:45:00	11:00:00	0.25

Table 4.18 above shows the waiting time of b-pin for cleaning activity. On August 18th, 2016, the machine stopped at 09:10:00 and started to repair at 09:20:00. The waiting time was 0.17 hours (09:20:00 - 09:10:00 = 0.17 hours or 10 minutes).

Table 4.19 TTR and TBF of B-Pin (Cleaning)

Stop Machine		Repair Time		TTR (hours)	TBF (hours)
Date	Time	Start	Finish		
8/18/2016	9:10:00	9:20:00	10:20:00	1.00	0
8/29/2016	19:53:00	20:05:00	20:35:00	0.50	273.55
9/3/2016	0:26:00	0:41:00	2:36:00	1.92	202.12
10/6/2016	6:00:00	6:20:00	6:45:00	0.42	935.68
10/21/2016	14:21:00	14:31:00	15:11:00	0.67	1159.60
11/15/2016	19:20:00	19:35:00	20:05:00	0.50	1045.00
12/13/2016	20:17:00	20:23:00	23:23:00	3.00	1704.20
12/22/2016	10:45:00	11:00:00	11:45:00	0.75	1886.97

Below is the example of TTR and TBF of b-pin for cleaning activity. The machine stopped on August 29th, 2016. The previous failure occurred on August 18th, 2016. The interval between the downtime of the machine was 11 days. The machine started to repair at 20:05:00 and finished at 20:35:00. The duration of repairing the component machine was 0.50 hours (20:35:00 – 20:05:00 = 0.50 hours or 30 minutes).

After cleaning the machine, the machine started the production on August 29th, 2016 at 20:35:00. Then the machine stopped again on September 3rd, 2016 at 00:26:00. The duration from stop machine until start production called time between failures was 202.12 hours.

4.2.2 Distribution Identification

Statistical software is used to choose the right distribution for every component machines. It is used to show the parameters that are used for each distribution. There are four types of failure distribution for determine the reliability which are normal distribution, exponential distribution, weibull distribution, and lognormal distribution.

The parameters of normal distribution are mean (μ) and standard deviation (σ). Parameter of exponential distribution is lambda (λ). The parameters of weibull distribution are shape parameter (β) and scale parameter (θ). The parameters of lognormal distribution shape parameter and location parameter.

Table 4.20 and Table 4.21 shows the result of appropriate distribution for time to repair (TTR) and time to failure (TTF) or time between failures (TBF) for each component machine. For the detail, Appendix 5 will shows the detail information about failure distribution.

Table 4.20 Time to Repair Distribution

No.	Component Machine	Type of Maintenance	Distribution	AD-Value	P-Value	Result
1	Chuck Holder Shaft	Setting	Normal	1.053	0.006	NOT FIT
			Exponential	2.191	0.005	NOT FIT
			Weibull	0.817	0.028	NOT FIT
			Lognormal	0.499	0.172	FIT
2	Chuck Holder Shaft	Repairing	Normal	0.329	0.381	FIT
			Exponential	0.946	0.107	FIT
			Weibull	0.444	0.244	FIT
			Lognormal	0.433	0.192	FIT
3	Chuck Holder Shaft	Replacement	Normal	0.376	0.352	FIT
			Exponential	0.885	0.144	FIT
			Weibull	0.233	>0.250	FIT
			Lognormal	0.211	0.813	FIT
4	Chuck Holder Slip Ring	Repairing	Normal	0.253	0.625	FIT
			Exponential	2.720	<0.003	NOT FIT
			Weibull	0.306	>0.250	FIT
			Lognormal	0.231	0.709	FIT
5	B-Pin	Cleaning	Normal	2.153	<0.005	NOT FIT
			Exponential	1.869	0.011	FIT
			Weibull	1.447	<0.010	NOT FIT
			Lognormal	1.104	0.005	NOT FIT

Table 4.20 explains about time to repair distribution for each of component machines and followed by type of machine in Main Assembly 1 machine. The table consist of failure distribution, *Anderson-Darling* (AD), P-value and the result of the test which is fit or not fit with the distribution.

Determining the distribution of Time to Repair, Time between Failures and Time to Failure are done by comparing the P-Value with the significant level (α). The significant level (α) is 0.05. If the P-value is more than or equal with significant level (α) then do not reject the null hypothesis (Ho). If the P-value is less than or equal with significant level (α) then reject the null hypothesis (Ho). The null hypothesis (Ho) is the appropriate data to the following distribution. The alternative hypothesis (H_1) is the not appropriate data to the following distribution. For example, in setting of chuck holder shaft, the P-value of normal distribution is

0.006. So, the null hypothesis (Ho) is reject because the P-value is less than the significant level (α).

There are some appropriate distribution in each component machine based on the failure distribution. The selected distribution is based on the easiness in doing the calculation (Fajri, 2017). For example, repairing activity of chuck holder shaft is appropriate with all of the failure distribution. So, the normal distribution has been chosen since the distribution is the easier way to do the calculation.

Table 4.21 Summary of Time to Repair Parameter

No.	Component Machine	Type of Maintenance	Distribution	Parameter	Standard Deviation
1	Chuck Holder Shaft	Setting	Lognormal	s = 0.424484	0.520951
				t-med = 1.07140	
		Repairing	Normal	t-med = 1.375	0.574681
		Replacement	Normal	t-med = 1.87583	1.14508
2	Chuck Holder Slip Ring	Repairing	Normal	t-med = 2	0.288314
3	B-Pin	Cleaning	Lognormal	s = 0.624967	0.629213
				t-med = 0.748756	

Table 4.21 shows the summary of time to repair parameters for each component machine. In setting of chuck holder shaft is appropriate with lognormal distribution. The parameters for lognormal distribution are scale parameter (s) and time median parameter (t-med). The value of scale parameter is 0.424484 and the value of time median parameter is 1.07140. In repairing of chuck holder shaft is appropriate with normal distribution. The parameters for normal distribution is time median parameter (t-med). The value of time median parameter is 1.375.

Table 4.22 Summary of Mean Time to Repair Distribution

No.	Component Machine	Type of Maintenance	Distribution	Mean (hours)	MTTR (hours)
1	Chuck Holder Shaft	Setting	Lognormal	1.17241	1.17241
		Repairing	Normal	1.375	1.375
		Replacement	Normal	1.87583	1.87583
2	Chuck Holder Slip Ring	Repairing	Normal	2	2
3	B-Pin	Cleaning	Lognormal	0.910238	0.910238

Table 4.22 shows the mean time to repair for every component machine. The table consist of maintenance activity for each component machine, the appropriate distribution, and the result of mean time to failure. Based on the calculation, mean time to repair of chuck holder shaft for setting that appropriate with lognormal distribution is 1.17241 hours. The mean time to repair for repairing and replacement activity that appropriate with normal distribution are 1.375 hours and 1.87583 hours. The maintenance activity of repairing chuck holder slip ring is appropriate with normal distribution. The mean time to repair is 2 hours. In cleaning of b-pin that appropriate with lognormal distribution, the mean time to repair is 0.910238 hours. Below are the example of detailed calculation to determine the mean time to repair:

- Chuck Holder Shaft (Repairing): Normal distribution

  $MTTF = \mu$

  $MTTF = 1.375$

- B-Pin (Cleaning): Lognormal distribution

  $MTTF = tmed\ x\ e^{(\frac{s2}{2})}$

  $MTTF = 0.748756\ x\ e^{(\frac{0.624967^2}{2})}$

  $MTTF = 0.910238$

Table 4.23 Time to Failure Distribution

No.	Component Machine	Type of Maintenance	Distribution	AD-Value	P-Value	Result
1	Chuck Holder Shaft	Setting	Normal	0.345	0.422	FIT
			Exponential	0.317	0.771	FIT
			Weibull	0.305	>0.250	FIT
			Lognormal	0.621	0.080	FIT
2	Chuck Holder Shaft	Repairing	Normal	0.309	0.397	FIT
			Exponential	0.403	0.554	FIT
			Weibull	0.459	0.226	FIT
			Lognormal	0.391	0.228	FIT
3	Chuck Holder Shaft	Replacement	Normal	0.434	0.135	FIT
			Exponential	1.252	0.037	FIT
			Weibull	0.488	0.192	FIT
			Lognormal	0.394	0.183	FIT

Table 4.23 Time to Failure Distribution (continued)

No.	Component Machine	Type of Maintenance	Distribution	AD-Value	P-Value	Result
4	Chuck Holder Slip Ring	Repairing	Normal	0.943	0.008	NOT FIT
			Exponential	0.538	0.392	FIT
			Weibull	0.527	0.165	FIT
			Lognormal	0.346	0.364	FIT
5	B-Pin	Cleaning	Normal	0.266	0.566	FIT
			Exponential	0.591	0.331	FIT
			Weibull	0.435	>0.250	FIT
			Lognormal	0.522	0.118	FIT

Table 4.23 explains about time to failure distribution for each of component machines and followed by type of machine in Main Assembly 1 machine. The table consist of failure distribution, *Anderson-Darling* (AD), P-value and the result of the test which is fit or not fit with the distribution.

Determining the distribution of Time to Repair, Time between Failures and Time to Failure are done by comparing the P-Value with the significant level (α). The significant level (α) is 0.05. If the P-value is more than or equal with significant level (α) then do not reject the null hypothesis (Ho). If the P-value is less than or equal with significant level (α) then reject the null hypothesis (Ho). The null hypothesis (Ho) is the appropriate data to the following distribution. The alternative hypothesis (H_1) is the not appropriate data to the following distribution. For example, in setting of chuck holder shaft, the P-value of normal distribution is 0.422. So, the null hypothesis (Ho) is do not reject because the P-value is more than the significant level (α).

There are some appropriate distributions in each component machine based on the failure distribution. The selected distribution is based on the easiness in doing the calculation. For example, setting activity of chuck holder shaft is appropriate with all of the failure distribution. So, the normal distribution has been chosen since the distribution is the easier way to do the calculation.

Table 4.24 Summary of Time to Failure Parameter

No.	Component Machine	Type of Maintenance	Distribution	Parameter	Standard Deviation
1	Chuck Holder Shaft	Setting	Normal	t-med = 323.58	252.922
		Repairing	Normal	t-med = 414.38	261.897
		Replacement	Lognormal	s = 0.197363	203.109
				t-med = 999.453	
2	Chuck Holder Slip Ring	Repairing	Lognormal	s = 0.735460	265.813
				t-med = 239.438	
3	B-Pin	Cleaning	Normal	t-med = 1029.59	594.314

Table 4.24 shows the summary of time to failure parameters for each component machine. For example, in setting of chuck holder shaft is appropriate with normal distribution. The parameters for normal distribution are time median parameter (t-med). The value of time median parameter is 323.58. In replacement of chuck holder shaft is appropriate with lognormal distribution. The parameters for lognormal distribution are scale parameter (s) and time median parameter (t-med). The value of scale parameter is 0.197363 and the value of time median parameter is 999.453.

Table 4.25 Summary of Mean Time to Failure Distribution

No.	Component Machine	Type of Maintenance	Distribution	Mean (hours)	MTTF (hours)
1	Chuck Holder Shaft	Setting	Normal	323.58	323.58
		Repairing	Normal	414.38	414.38
		Replacement	Lognormal	1019.11	1019.11
2	Chuck Holder Slip Ring	Repairing	Lognormal	313.797	313.797
3	B-Pin	Cleaning	Normal	1029.59	1029.59

Table 4.25 shows the mean time to failure for every component machine. The table consist of maintenance activity for each component machine, the appropriate distribution, and the result of mean time to failure. Based on the calculation, mean time between failures of chuck holder shaft for setting and repairing activity that appropriate with normal distribution are 323.58 hours and 414.38 hours. In replacement of chuck holder shaft and repairing of chuck holder slip ring that appropriate with lognormal distribution, the mean times to failure are 1019.11 hours

and 313.797 hours. The maintenance activity of cleaning b-pin is appropriate with normal distribution. The mean time to failure are 1029.59 hours. Below are the examples of detailed calculation to determine the mean time to failure:

- Chuck Holder Shaft (Setting): Normal distribution

  $MTTF = \mu$

  $MTTF = 323.58$

- Chuck Holder Shaft (Replacement): Lognormal distribution

  $MTTF = tmed\ x\ e^{(\frac{s2}{2})}$

  $MTTF = 999.453\ x\ e^{(\frac{0.197363^2}{2})}$

  $MTTF = 1019.11$

4.2.1 Maintenance Cost

Maintenance cost is calculated to know how much the company should spend the money on maintenance. There are two types of maintenance cost which are corrective maintenance and preventive maintenance.

- Corrective maintenance is the treatment of the machine that the maintenance is done after downtime occurred, where the maintenance of a component is waiting until the component is broken and then repaired or replaced with new component.
- Preventive maintenance is the treatment of the machine that the maintenance performed on machine periodically in order to determine the conditions that caused the failure, and keep the machine by repairing or replacing the machine before the failure become worse.

There are some required data in order to calculate the maintenance cost:

- Machine capacity is 103 rotor/hour.
- Actual production quantity is 69 rotor/hour.
- Component selling price is IDR 130,000/unit.

- Component machine price in repairing cable of chuck holder shaft is IDR 100,000.
- Component machine price in replacing sensor of chuck holder shaft is IDR 1,300,000.
- Component machine price in repairing sensor of chuck holder slip ring is IDR 700,000.
- Mechanic fee is IDR 4,100,000 per month. There are 4.33 weeks in a month. The mechanic will work 40 hours in a week or 173 hours per month. So, the mechanic salary per hour becomes IDR 23,699.

4.2.3.1 Corrective Maintenance Cost (Cf)

Corrective maintenance cost is the cost needed for treatment of the machine that the maintenance is done after downtime occurred. Corrective maintenance cost formula is as follows:

Cf = component price + [downtime (hours) x mechanic fee per hour] + cost of production loss

Cost of production loss = downtime (hours) x production capacity per hour x product price

Table 4.26 Total Downtime for Each Component Machine

Component	Type of Maintenance	Waiting Time (hours)	TTR (hours)	Downtime (hours)
Chuck Holder Shaft	Setting	0.418	1.186	1.604
	Repairing	0.664	1.375	2.039
	Replacement	0.463	1.867	2.330
Chuck Holder Slip Ring	Repairing	0.160	2.000	2.160
B-Pin	Cleaning	0.215	1.094	1.309

Table 4.26 above shows the maintenance activity for each component and also the total downtime. The data needed for calculating the corrective maintenance cost is downtime data. The total downtime was obtained the sum of waiting time (hours) of each component machine and time to repair (hours) from Table 4.10 until 4.19 in page 35 to 39. Waiting time is obtained average of whole waiting time for each maintenance activity from the machine stops until repairing time. For example,

downtime for setting of chuck holder shaft is 1.604 hours which obtained from the sum of 0.418 hours and 1.186 hours.

Table 4.27 Corrective Maintenance Cost Calculation

Component	Type of Maintenance	Downtime (hours)	Mechanic Fee (hours)	Component Price (IDR)	Production Loss per hours (IDR)	Cf (IDR)
Chuck Holder Shaft	Setting	1.604	38,013	0	21,477,560	21,515,573
	Repairing	2.039	48,322	100,000	27,302,210	27,450,532
	Replacement	2.330	55,219	1,300,000	31,198,700	32,553,919
Chuck Holder Slip Ring	Repairing	2.160	51,190	700,000	28,922,400	29,673,590
B-Pin	Cleaning	1.309	31,022	0	17,527,510	17,558,532

Table 4.27 explains about the calculation of corrective maintenance cost. Below is the example of detail calculation for corrective maintenance cost of chuck holder shaft in setting activity:

- Downtime = waiting time + time to repair
  = 0.418 + 1.186
  = 1.604 hours

- Mechanic Fee = downtime (hours) x mechanic fee per hour
  = 1.604 x IDR 23,699
  = IDR 38,013

- Production Loss = downtime (hours) x production capacity per hour x product price
  = 1.604 x 103 x IDR 130,000
  = IDR 21,477,560

- Cf = component price + [downtime (hours) x mechanic fee per hour] + cost of production loss
  = IDR 0 + [1.604 x IDR 23,699] + IDR 21,477,560
  = IDR 21,515,573

4.2.3.2 Preventive Maintenance Cost (Cp)

Preventive maintenance cost is the cost of maintenance that the maintenance performed on machine periodically. Preventive maintenance cost formula is as follows:

Cp = component price + [replacement time (hours) x mechanic fee] + cost of production loss

Cost of production loss = replacement time (hours) x production capacity x product price

Table 4.28 Maintenance Time for Each Component Machine

Component	Type of Maintenance	Maintenance Time (hours)
Chuck Holder Shaft	Setting	0.50
	Repairing	0.70
	Replacement	0.95
Chuck Holder Slip Ring	Repairing	0.75
B-Pin	Cleaning	0.40

Table 4.28 above shows the maintenance time for every component followed by the maintenance activity. Maintenance time is needed in order to calculate the preventive maintenance cost. There is no waiting time in preventive maintenance activity since it is already scheduled.

Table 4.29 Preventive Maintenance Cost Calculation

Component	Type of Maintenance	Maintenance Time (hours)	Mechanic Fee (hours)	Component Price (IDR)	Production Loss per hours (IDR)	Cp (IDR)
Chuck Holder Shaft	Setting	0.50	11,850	0	6,695,000	6,706,850
	Repairing	0.70	16,589	100,000	9,373,000	9,489,589
	Replacement	0.95	22,514	1,300,000	12,720,500	14,043,014
Chuck Holder Slip Ring	Repairing	0.75	17,774	700,000	10,042,500	10,760,274
B-Pin	Cleaning	0.40	9,480	0	5,356,000	5,365,480

Table 4.29 explains about the calculation of preventive maintenance cost. The example of detail calculation for preventive maintenance cost of chuck holder shaft in setting activity:

- Replacement Time = waiting time + time to repair
  = 0 + 0.50
  = 0.50

- Mechanic Fee = replacement time (hours) x mechanic fee per hour
  = 0.50 x IDR 23,699
  = IDR 11,850

- Production Loss = replacement time (hours) x production capacity per hour x product price
  = 0.50 x 103 x IDR 130,000
  = IDR 6,695,000

- Cp = component price + [replacement time (hours) x mechanic fee] + cost of production loss
  = IDR 0 + [0.50 x IDR 23,699] + IDR 6,695,000
  = IDR 6,706,850

4.2.2 Component Machine Maintenance Interval

The purpose of maintenance interval is to define the time gap between preventive maintenance in accordance to the breakdown occurrences that require maintenance. When the component machine has reached the useful life of the component machine, the maintenance activity will be done.

4.2.4.1 Maintenance Interval for Chuck Holder Shaft

Table 4.30, table 4.31, and table 4.32 will explain about setting, repairing and replacement interval time for component machine of Main Assembly 1 machine which is chuck holder shaft.

Table 4.30 Setting Interval Time of Chuck Holder Shaft

t(hours)	f(t)	F(t)	R(t)	H(t)	C(t)
330	0.001576825	0.510125392	0.489874608	0.004117233	IDR 20,592
310	0.001575061	0.478590102	0.521409898	0.003629091	IDR 21,887
290	0.001563492	0.44718835	0.55281165	0.003198355	IDR 23,364

Table 4.30 Setting Interval Time of Chuck Holder Shaft (continued)

t(hours)	f(t)	F(t)	R(t)	H(t)	C(t)
270	0.001542334	0.416114383	0.583885617	0.002817723	IDR 25,065
250	0.001511978	0.385556356	0.614443644	0.002480957	IDR 27,041
230	0.00147298	0.355692924	0.644307076	0.002182708	IDR 29,364
210	0.001426042	0.326690128	0.673309872	0.001918379	IDR 32,134
190	0.001371995	0.29869865	0.70130135	0.001684	IDR 35,490
170	0.001311768	0.271851538	0.728148462	0.001476132	IDR 39,639
150	0.001246367	0.246262434	0.753737566	0.001291788	IDR 44,898

Table 4.30 shows the setting interval time for chuck holder shaft component machine. The time to failure of chuck holder shaft accepted the normal distribution. Below is the detail calculation for setting chuck holder shaft that appropriate with normal distribution:

- Probability Density Function (f)

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}} \exp[-\frac{(t-\mu)^2}{2}]$$

$$f(t) = \frac{1}{252.922\sqrt{6.28}} \exp[-\frac{(330-323.58)^2}{2}]$$

$$f(t) = 0.001576825$$

- Cumulative Distribution Function (F)

$$F(t) = \emptyset\left(\frac{t - \mu}{\sigma}\right)$$

$$F(t) = \emptyset\left(\frac{330 - 323.58}{252.922}\right)$$

$$F(t) = 0.510125392$$

- Reliability Function (R)

$$R(t) = 1 - F(t)$$

$$R(t) = 1 - 0.510125392$$

$$R(t) = 0.489874608$$

- Cumulative Hazard Function (H)

$$H\ (t) = \left(\frac{F(t)}{\sigma R(t)}\right)$$

$$H\ (t) = \left(\frac{0.510125392}{252.922\ x\ 0.489874608}\right)$$

$$H\ (t) = 0.004117233$$

- Cost per unit of Time (C)

$$C(t) = \frac{Cp + [Cf\ x\ H(t)]}{t}$$

$$C(t) = \frac{IDR\ 6{,}706{,}850 + [IDR\ 21{,}515{,}573\ x\ 0.004117233]}{330}$$

$$C(t) = \ IDR\ 20{,}592$$

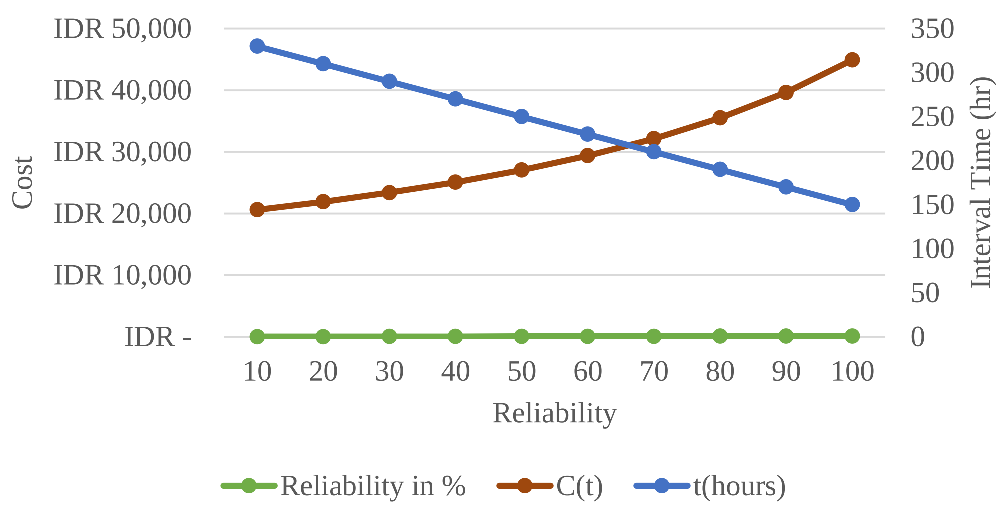


Figure 4.6 Cost per Unit of Time Setting in Chuck Holder Shaft

The optimum point is the point of intersection between the cost line and the interval time line. The optimum point in setting of chuck holder shaft is when the interval time is at 220 hours with IDR 33,000. The maintenance interval time has relationship with the cost. Based on the cost calculation above, when the setting interval time in chuck holder shaft in 330 hours, then the machine will has 49% of reliability with the cost is IDR 20,590. If the setting interval time is getting shorter become 150 hours, then the reliability and cost of the machine will increase. The reliability of machine become 75% with the cost is IDR 44,898.

Table 4.31 Repairing Interval Time of Chuck Holder Shaft

t (hours)	f(t)	F(t)	R(t)	H(t)	C(t)
430	0.001520572	0.523779524	0.476220476	0.004199619	IDR 22,337
400	0.001520985	0.478106245	0.521893755	0.003497935	IDR 23,964
370	0.001501565	0.432719016	0.567280984	0.002912576	IDR 25,864
340	0.001463069	0.388203359	0.611796641	0.002422823	IDR 28,106
310	0.001406976	0.345111067	0.654888933	0.002012152	IDR 30,790
280	0.001335397	0.303939819	0.696060181	0.001667287	IDR 34,055
250	0.001250936	0.265116188	0.734883812	0.001377486	IDR 38,110
230	0.00118892	0.240711022	0.759288978	0.001205878	IDR 41,403

Table 4.31 shows the repairing interval time for chuck holder shaft component machine. The time to failure of chuck holder shaft accepted the normal distribution. Below is the detail calculation for setting chuck holder shaft that appropriate with normal distribution:

- Probability Density Function (f)

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}} \exp[-\frac{(t-\mu)^2}{2}]$$

$$f(t) = \frac{1}{261.897\sqrt{6.28}} \exp[-\frac{(430-414.38)^2}{2}]$$

$$f(t) = 0.001520572$$

- Cumulative Distribution Function (F)

$$F(t) = \emptyset\left(\frac{t-\mu}{\sigma}\right)$$

$$F(t) = \emptyset\left(\frac{430-414.38}{261.897}\right)$$

$$F(t) = 0.523779524$$

- Reliability Function (R)

$$R(t) = 1 - F(t)$$

$$R(t) = 1 - 0.523779524$$

$$R(t) = 0.476220476$$

- Cumulative Hazard Function (H)

$$H\ (t) = \left(\frac{F(t)}{\sigma R(t)}\right)$$

$$H\ (t) = \left(\frac{0.523779524}{261.897\ x\ 0.476220476}\right)$$

$$H\ (t) = 0.004199619$$

- Cost per unit of Time (C)

$$C(t) = \frac{Cp + [Cf\ x\ H(t)]}{t}$$

$$C(t) = \frac{IDR\ 9{,}489{,}589 + [IDR\ 27{,}450{,}532\ x\ 0.004199619]}{430}$$

$$C(t) = IDR\ 22{,}337$$

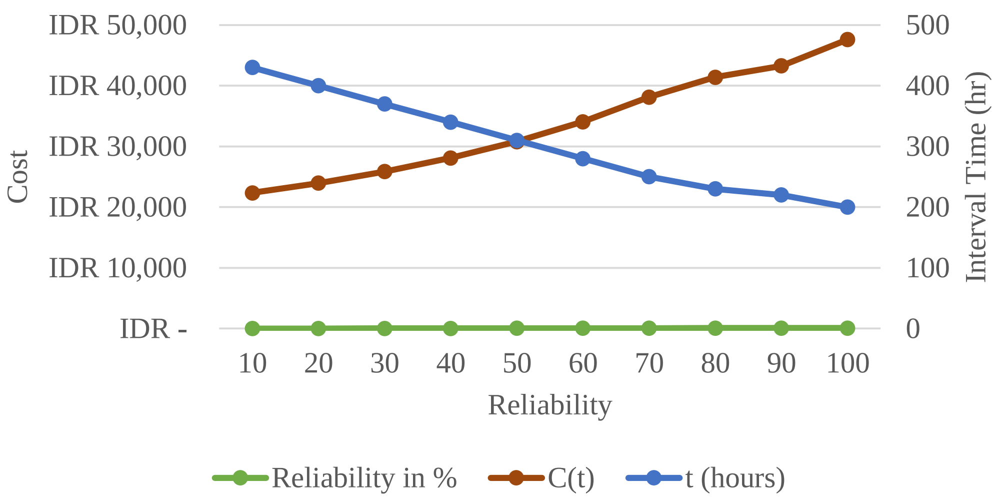


Figure 4.7 Cost per Unit of Time Repairing in Chuck Holder Shaft

The optimum point is the point of intersection between the cost line and the interval time line. The optimum point in repairing of chuck holder shaft is when the interval time is at 310 hours with IDR 31,000. The maintenance interval time has relationship with the cost. Based on the cost calculation above, when the repairing interval time in chuck holder shaft in 430 hours, then the machine will has 48% of reliability with the cost is IDR 22,337. If the repairing interval time is getting shorter become 230 hours, then the reliability and cost of the machine will increase. The reliability of machine become 76% with the cost is IDR 41,403.

Table 4.32 Replacement Interval Time of Chuck Holder Shaft

t (hours)	f(t)	F(t)	R(t)	H(t)	C(t)
1020	0.002090448	0.541061518	0.458938482	0.00585634	IDR 13,955
1000	0.002100997	0.501105987	0.498894013	0.005089271	IDR 14,209
980	0.002073396	0.460334562	0.539665438	0.004410189	IDR 14,476
960	0.002150433	0.419151423	0.580848577	0.00380865	IDR 14,757
940	0.002257326	0.377999768	0.622000232	0.003275725	IDR 15,053
920	0.002400034	0.337350076	0.662649924	0.002803775	IDR 15,363
900	0.002586749	0.297685491	0.702314509	0.00238626	IDR 15,690
880	0.00282873	0.259484793	0.740515207	0.002017574	IDR 16,033
860	0.00314158	0.223203721	0.776796279	0.001692895	IDR 16,393

Table 4.32 shows the replacement interval time for chuck holder shaft component machine. The time to failure of chuck holder shaft accepted the lognormal distribution. Below is the detail calculation for replacement chuck holder shaft that appropriate with lognormal distribution:

- Probability Density Function (f)

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

$$f(t) = \frac{1}{0.197363 \ x \ 1020\sqrt{6.28}} \text{e} \left[\frac{1}{2(0.197363)^2} (ln \frac{1020}{999.453})^2 \right]$$

$$f(t) = 0.002090448$$

- Cumulative Distribution Function (F)

$$F(t) = \emptyset \left[\frac{1}{s} ln \frac{t}{tmed} \right]$$

$$F(t) = \emptyset \left[\frac{1}{0.197363} ln \frac{1020}{999.453} \right]$$

$$F(t) = 0.541061518$$

- Reliability Function (R)

$$R(t) = 1 - F(t)$$

$$R(t) = 1 - 0.541061518$$

$$R(t) = 0.458938482$$

- Cumulative Hazard Function (H)

$$H\ (t) = \left(\frac{F(t)}{s\ x\ t\ x\ R(t)}\right)$$

$$H\ (t) = \left(\frac{0.541061518}{0.197363\ x\ 1020\ x\ 0.458938482}\right)$$

$$H\ (t) = 0.00585634$$

- Cost per unit of Time (C)

$$C(t) = \frac{Cp + [Cf\ x\ H(t)]}{t}$$

$$C(t) = \frac{IDR\ 14{,}043{,}014 + [IDR\ 32{,}553{,}919\ x\ 0.00585634}{1020}$$

$$C(t) = \ IDR\ 13{,}955$$

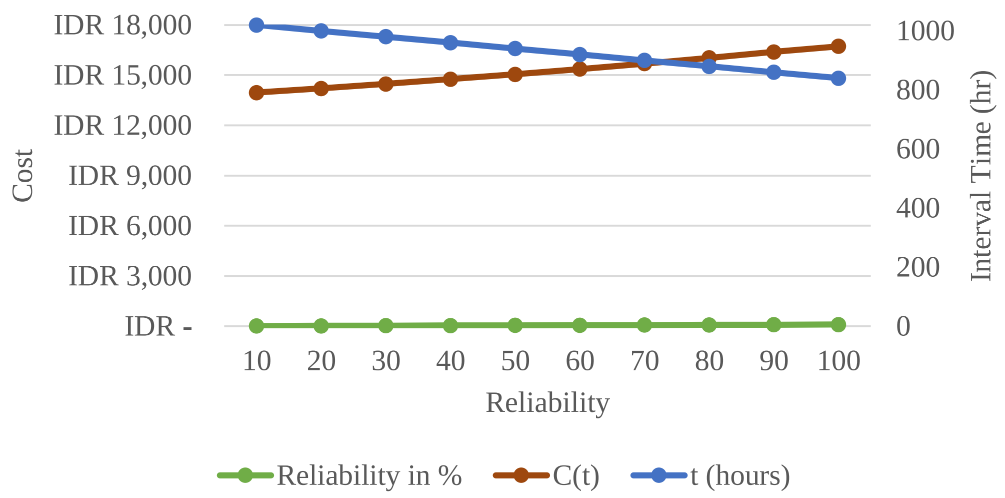


Figure 4.8 Cost per Unit of Time Replacement in Chuck Holder Shaft

The optimum point is the point of intersection between the cost line and the interval time line. The optimum point in replacement of chuck holder shaft is when the interval time is at 890 hours with IDR 16,000. The maintenance interval time has relationship with the cost. Based on the cost calculation above, when the replacement interval time in chuck holder shaft in 1020 hours, then the machine will has 46% of reliability with the cost is IDR 13,955. If the replacement interval time is getting shorter become 860 hours, then the reliability and cost of the machine will increase. The reliability of machine become 78% with the cost is IDR 16,966.

4.2.4.2 Maintenance Interval for Chuck Holder Slip Ring

Table 4.33 will explain about repairing interval time for component machine of Main Assembly 1 machine which is chuck holder slip ring.

Table 4.33 Repairing Interval Time of Chuck Holder Slip Ring

t (hours)	f(t)	F(t)	R(t)	H(t)	C(t)
330	0.001808262	0.56342701	0.43657299	0.005317504	IDR 43,247
300	0.001895622	0.511994831	0.488005169	0.004755113	IDR 47,516
270	0.002036529	0.454941203	0.545058797	0.004203288	IDR 52,735
240	0.002260851	0.3922976	0.6077024	0.003657248	IDR 59,259
210	0.00262513	0.324591526	0.675408474	0.003111661	IDR 67,648
180	0.003249931	0.253186761	0.746813239	0.002560928	IDR 78,832
150	0.004427617	0.180780034	0.819219966	0.002000321	IDR 94,487
120	0.007028406	0.112029947	0.887970053	0.001429537	IDR 117,968
90	0.014607791	0.054031288	0.945968712	0.000862913	IDR 157,103

Table 4.33 shows the repairing interval time for chuck holder slip ring component machine. The time to failure of chuck holder slip ring accepted the lognormal distribution. Below is the detail calculation for repairing chuck holder slip ring that appropriate with lognormal distribution:

- Probability Density Function (f)

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

$$f(t) = \frac{1}{0.735460 \ x \ 330\sqrt{6.28}} \mathrm{e} \left[\frac{1}{2(0.735460)^2} (ln \frac{330}{239.438})^2 \right]$$

$$f(t) = 0.001808262$$

- Cumulative Distribution Function (F)

$$F(t) = \emptyset \left[\frac{1}{s} ln \frac{t}{tmed} \right]$$

$$F(t) = \emptyset \left[\frac{1}{0.735460} ln \frac{330}{239.438} \right]$$

$$F(t) = 0.56342701$$

- Reliability Function (R)

$R(t) = 1 - F(t)$

$R(t) = 1 - 0.56342701$

$R(t) = 0.43657299$

- Cumulative Hazard Function (H)

$$H\ (t) = \left(\frac{F(t)}{s\ x\ t\ x\ R(t)}\right)$$

$$H\ (t) = \left(\frac{0.56342701}{0.735460\ x\ 330\ x\ 0.43657299}\right)$$

$H\ (t) = 0.005317504$

- Cost per unit of Time (C)

$$C(t) = \frac{Cp + [Cf\ x\ H(t)]}{t}$$

$$C(t) = \frac{IDR\ 14{,}113{,}699 + [IDR\ 29{,}673{,}590\ x\ 0.005317504]}{330}$$

$C(t) = \ IDR\ 43{,}247$

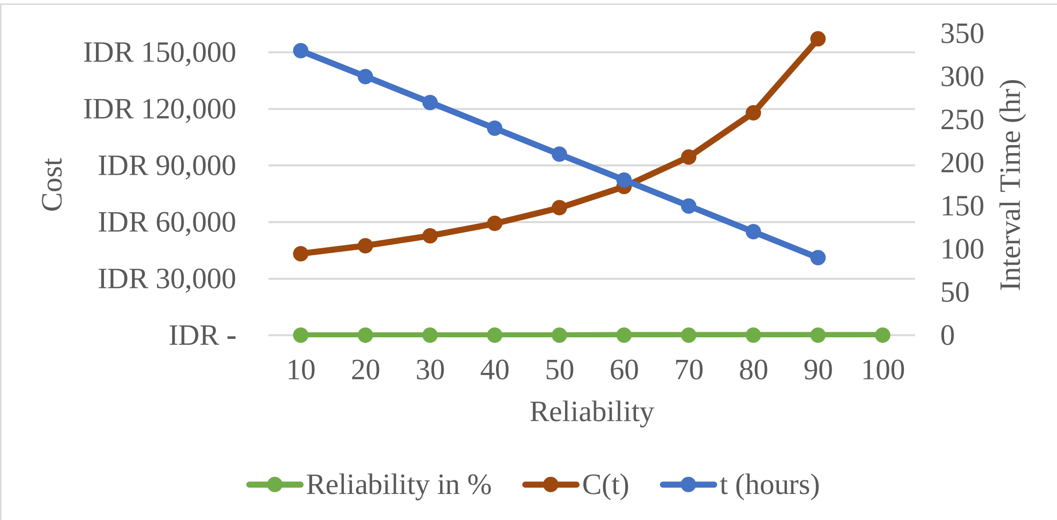


Figure 4.9 Cost per Unit of Time Repairing in Chuck Holder Slip Ring

The optimum point is the point of intersection between the cost line and the interval time line. The optimum point in repairing of chuck holder slip ring is when the interval time is at 179 hours with IDR 79,000. The maintenance interval time has relationship with the cost. Based on the cost calculation above, when the repairing interval time in chuck holder slip ring in 330 hours, then the machine will has 44% of reliability with the cost is IDR 43,247. If the repairing interval time is getting shorter become 170 hours, then the reliability and cost of the machine will increase. The reliability of machine become 77% with the cost is IDR 83,436.

4.2.4.3 Maintenance Interval for B-Pin

Table 4.34 will explain about cleaning interval time for component machine of Main Assembly 1 machine which is b-pin.

Table 4.34 Cleaning Interval Time of B-Pin

t (hours)	f(t)	F(t)	R(t)	H(t)	C(t)
1030	0.000671265	0.500275219	0.499724781	0.001684466	IDR 5,238
980	0.000668932	0.466750548	0.533249452	0.001472782	IDR 5,501
930	0.000661906	0.433460255	0.566539745	0.001287369	IDR 5,794
880	0.000650335	0.40063572	0.59936428	0.001124716	IDR 6,120
830	0.000634459	0.368498563	0.631501437	0.000981851	IDR 6,485
780	0.000614605	0.337256174	0.662743826	0.000856245	IDR 6,898
730	0.000591173	0.307097733	0.692902267	0.000745742	IDR 7,368
680	0.000564624	0.278190839	0.721809161	0.000647402	IDR 7,907
630	0.000535464	0.250678856	0.749321144	0.000561015	IDR 8,532

Table 4.34 shows the cleaning interval time for b-pin component machine. The time to failure of b-pin accepted the normal distribution. Below is the detail calculation for cleaning b-pin that appropriate with normal distribution:

- Probability Density Function (f)

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}}\exp[-\frac{(t-\mu)^2}{2}]$$

$$f(t) = \frac{1}{594.314\sqrt{6.28}}\exp[-\frac{(1030-1029.59)^2}{2}]$$

$$f(t) = 0.000671265$$

- Cumulative Distribution Function (F)

$$F(t) = \emptyset\left(\frac{t - \mu}{\sigma}\right)$$

$$F(t) = \emptyset\left(\frac{1030 - 1029.59}{594.314}\right)$$

$$F(t) = 0.500275219$$

- Reliability Function (R)

$$R(t) = 1 - F(t)$$

$$R(t) = 1 - 0.500275219$$

$$R(t) = 0.499724781$$

- Cumulative Hazard Function (H)

$$H\ (t) = \left(\frac{F(t)}{\sigma R(t)}\right)$$

$$H\ (t) = \left(\frac{0.500275219}{594.314\ x\ 0.499724781}\right)$$

$$H\ (t) = 0.001684466$$

- Cost per unit of Time (C)

$$C(t) = \frac{Cp + [Cf\ x\ H(t)]}{t}$$

$$C(t) = \frac{IDR\ 5{,}365{,}480 + [IDR\ 17{,}558{,}532\ x\ 0.001684466]}{1030}$$

$$C(t) = IDR\ 5{,}238$$

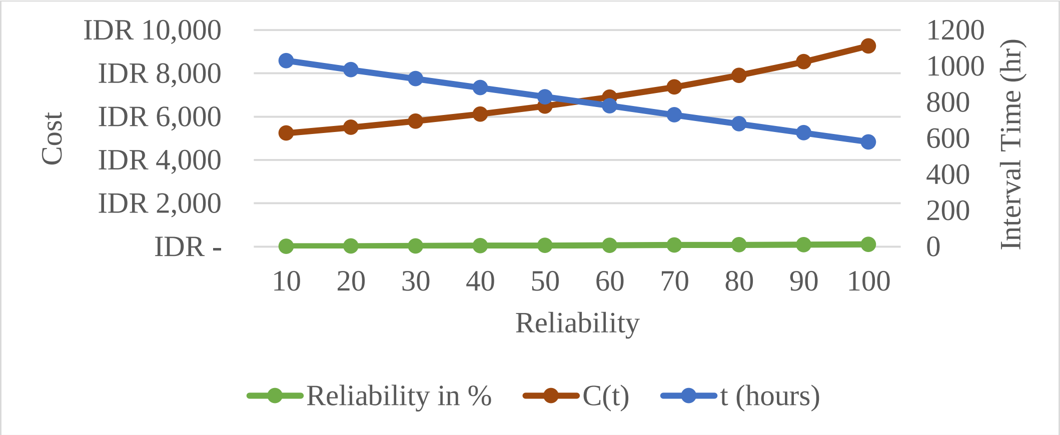


Figure 4.10 Cost per Unit of Time Cleaning in B-Pin

The optimum point is the point of intersection between the cost line and the interval time line. The optimum point in cleaning of b-pin is when the interval time is at 820 hours with IDR 7,000. The maintenance interval time has relationship with the cost. Based on the cost calculation above, when the cleaning interval time in b-pin in 1030 hours, then the machine will have 50% of reliability with the cost is IDR 5,238. If the cleaning interval time is getting shorter become 580 hours, then the reliability and cost of the machine will increase. The reliability of machine become 78% with the cost is IDR 9,266.

4.3 Data Analysis and Improvement

After calculated all required data, there will be an analysis and improvement of the results of the data processing which is the improvement process on maintenance process.

4.3.1 Current Reliability

Before determining the interval time for maintenance activity in component machine of Main Assembly 1 machine, the current reliability of the machine must be calculated. Table 4.35 below shows the current reliability of the machine.

Table 4.35 Current Reliability of Component Machine in Main Assembly 1

No.	Component Machine	Type of Maintenance	Distribution	MTTF (hours)	Reliability
1	Chuck Holder Shaft	Setting	Normal	323.58	50%
		Repairing	Normal	414.38	50%
		Replacement	Lognormal	1019.11	46.07%
2	Chuck Holder Slip Ring	Repairing	Lognormal	313.797	46.37%
3	B-Pin	Cleaning	Normal	1029.59	50%

Table 4.35 above shows the current reliability of component machine in Main Assembly 1 machine based on the maintenance activity and followed by distribution, MTTF and reliability before performing new proposed scheduling maintenance system. Based on the collected data, in the current condition of replacement chuck holder shaft has 46.07% of reliability. The mean time to failure is 1019.11 hours will be replaced after it is used for 1019.11 hours for operation. The details calculation for calculating the current reliability of each component machine are:

- Chuck Holder Shaft (Setting): Normal distribution

  $R(t) = 1 - F(t)$

  $R(t) = 1 - 0.50$

  $R(t) = 0.50$

- Chuck Holder Shaft (Repairing): Normal distribution

  $R(t) = 1 - F(t)$

  $R(t) = 1 - 0.50$

  $R(t) = 0.50$

- Chuck Holder Shaft (Replacement): Lognormal distribution

  $$R\ (t) = 1 - \ \emptyset \left[\frac{\frac{\ln(t)}{tmed}}{s} \right]$$

  $$R\ (t) = 1 - \ \emptyset \left[\frac{\frac{\ln(1019.11)}{999.453}}{0.197363} \right]$$

  $R\ (t) = 0.46069403$

- Chuck Holder Slip Ring (Repairing): Lognormal distribution

  $$R\ (t) = 1 - \ \emptyset \left[\frac{\frac{\ln(t)}{tmed}}{s} \right]$$

  $$R\ (t) = 1 - \ \emptyset \left[\frac{\frac{\ln(313.797)}{239.438}}{0.735460} \right]$$

  $R\ (t) = 0.463663621$

- B-Pin (Cleaning): Normal distribution

  $R(t) = 1 - F(t)$

  $R(t) = 1 - 0.50$

  $R(t) = 0.50$

4.3.2 Interval Time of Maintenance

Based on collected data from July to December 2016, the maintenance activity in PT. NAA is divided into 4 types which are setting, repairing, replacement, and cleaning. Due to the optimum point in each interval time for almost all three components with its maintenance activities is close to the 70%, so the target of component machine reliability to be achieved is 70%. Table 4.36 below shows the maintenance interval time for setting, repairing, and replacement chuck holder shaft, cleaning b-pin, and repairing chuck holder slip ring.

Table 4.36 Maintenance Interval Time

Component Machine	Type of Maintenance	Reliability	Interval Time (hours)
Chuck Holder Shaft	Setting	70%	190
	Repairing	70%	280
	Replacement	70%	900
Chuck Holder Slip Ring	Repairing	70%	200
B-Pin	Cleaning	70%	720

Table 4.36 above explains the maintenance interval time for each component and its maintenance activity. The company should follow the maintenance interval time in table 4.36 if the company wants to achieve 70% of reliability in Main Assembly 1 machine. In order to achieve the 70% reliability of Main Assembly 1 machine, the company should perform the preventive maintenance activity. In setting of chuck holder shaft will be set, repair, and replacement after it is used for 150 hours, 235 hours, and 775 hours. Repairing activity will be held in chuck holder slip ring after the component operates 180 hours. After operating for 620 hours, the b-pin will be clean.

4.3.3 Proposed Preventive Maintenance Schedule

The proposed preventive maintenance schedule is start from January to June 2017. The preventive maintenance schedule for each component machine based on the expected reliability of machine which is 70%. For the detail, Appendix 7 will show the detail preventive maintenance schedule from January to June 2017.

January 2017

Sun	Mon	Tue	Wed	Thu	Fri	Sat
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				

February 2017

Sun	Mon	Tue	Wed	Thu	Fri	Sat
			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				

Figure 4.11 Preventive Maintenance Scheduling in Main Assembly 1 Machine from July to December 2016

Note:

- Chuck Holder Shaft (SETTING)
- Chuck Holder Shaft (REPAIRING)
- Chuck Holder Shaft (REPLACEMENT)
- Chuck Holder Slip Ring (REPAIRING)
- B-Pin (CLEANING)
- Chuck Holder Shaft (SETTING+REPAIRING) and B-Pin
- Chuck Holder Slip Ring (REPAIRING) and B-Pin
- Chuck Holder Shaft (REPAIRING) and Chuck Holder Slip Ring
- Chuck Holder Shaft (SETTING) and Chuck Holder Slip Ring
- Chuck Holder Shaft (REPLACEMENT) and Chuck Holder Slip Ring

Figure 4.11 shows the example of proposed preventive maintenance schedule in Main Assembly 1 machine. To determine the proposed preventive maintenance schedule, maintenance interval time is used as the main indicator. It can be seen in table 4.36. If the maintenance interval time between maintenance activities for each component machine is close or exactly same, then the maintenance schedule can be combined to reduce time lost due to maintenance activities.

For example, the setting activity of chuck holder shaft only done on January 11th, 2017, but in February the setting activity of chuck holder shaft is done on February 1st, 2017 and February 8th, 2017. Actually, the setting activity should be done once a week. The maintenance interval time between setting of chuck holder shaft on January 18th, 2017 and repairing of chuck holder shaft on January 15th, 2017 is close, then the maintenance schedule can be combined since the setting machine is included in repairing machine.

4.3.4 Component Machine Reliability Comparison after Improvement

The comparison of component machine reliability for each component machine in Main Assembly 1 machine is needed to know whether the production process has significant with the proposed preventive maintenance system or not. Table 4.37 will explain about the comparison between current maintenance system and the proposed maintenance system.

Table 4.37 Reliability Comparison between Current Maintenance System and Proposed Preventive Maintenance System

Component Machine	Type of Maintenance	Current		Proposed	
		MTTF (hours)	Reliability	MTTF (hours)	Reliability
Chuck Holder Shaft	Setting	323.58	50%	190	70%
	Repairing	414.38	50%	280	70%
	Replacement	1019.11	46.07%	900	70%
Chuck Holder Slip Ring	Repairing	313.797	46.37%	200	70%
B-Pin	Cleaning	1029.59	50%	720	70%

Table 4.37 above shows the reliability comparison between current maintenance system and proposed preventive maintenance system. In the current maintenance system, setting chuck holder shaft has reliability 50% with interval time 323.58 hours. It means chuck holder shaft was set after it used for 323.58 hours. Then, the proposed preventive maintenance system of setting of chuck holder shaft can reach 70% reliability with interval time of 190 hours. It means that every 190 hours after the operation, the component, which is chuck holder shaft, will be set in order to maintain the reliability of the component machine.

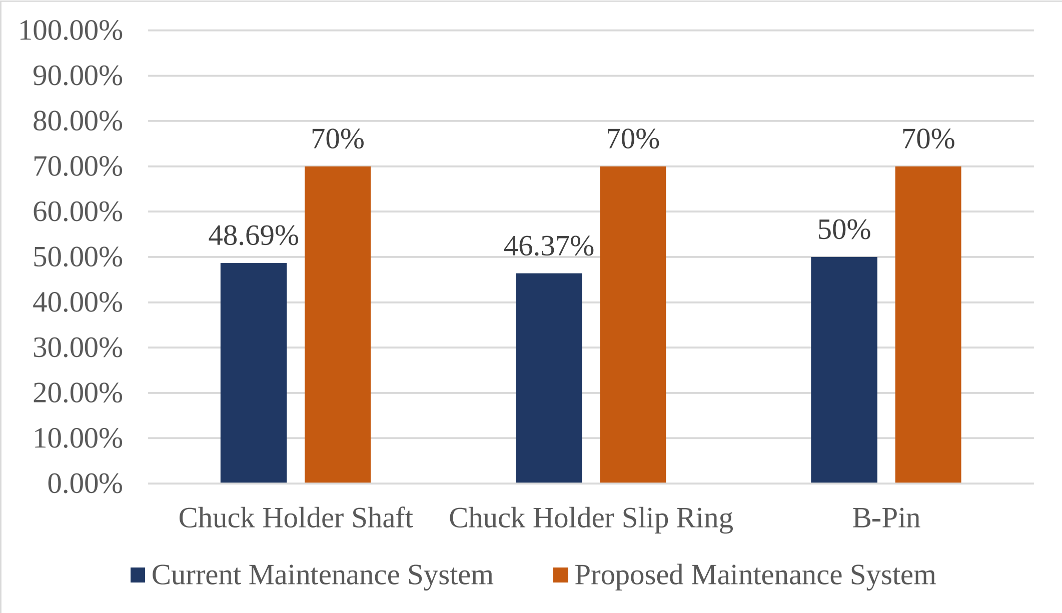


Figure 4.12 Reliability Comparison between Current and Proposed System from July to December 2016

Figure 4.12 shows the component machine reliability between current system and proposed preventive maintenance system. The company wants to achieve 70% of reliability. By implementing the proposed preventive maintenance system, in chuck holder shaft is expected to increase reliability from 48.69% of reliability in current system into 70% of reliability in proposed preventive maintenance system, which is the reliability increased by 21.31%. The reliability of chuck holder slip ring and b-pin also increased by 23.63% and 20%. Total interval time can be increased by 21.65% on average.

4.3.5 Maintenance Cost Comparison

In the proposed preventive maintenance system, maintenance activity will occur more often rather than the current maintenance system, but the downtime when the machine breakdown will be reduced than before. If the company performed preventive maintenance system, there will be no time wasted.

4.3.5.1 Current Maintenance Cost

Table 4.38 below shows the total downtime and frequency of maintenance in the current maintenance system in PT. NAA from July to December 2016.

Table 4.38 Total Downtime and Frequency of Maintenance in the Current Maintenance System from July to December 2016

Component Machine	Type of Maintenance	Downtime (hours)	Frequency of Current Maintenance
Chuck Holder Shaft	Setting	1.604	13
	Repairing	2.039	6
	Replacement	2.330	5
B-Pin	Cleaning	2.160	8
Chuck Holder Slip Ring	Repairing	1.309	8

During the last six months in 2016, chuck holder shaft has been set about 13 times where the average of downtime for every failure was about 1.604 hours. Chuck holder shaft has been repaired about 6 times with total downtime about 2.039 hours while chuck holder shaft has been replaced about 5 times with total downtime about 2.330 hours.

Table 4.39 below shows the total maintenance cost in the current maintenance system from July to December 2016. The component price for each component machine is assumed constant. The price of product is IDR 130,000 while the production capacity is 103 rotor/hour.

Table 4.39 Total Maintenance Cost in the Current Maintenance System from July to December 2016

Component Machine	Type of Maintenance	Component Price	Production Loss	Mechanic Fee	Total Cost
Chuck Holder Shaft	Setting	0	279,208,280	484,172	279,702,452
	Repairing	600,000	163,813,260	289,934	164,703,194
	Replacement	6,500,000	155,993,500	276,093	162,769,593
Chuck Holder Slip Ring	Repairing	5,600,000	231,379,200	409,519	237,388,719
B-Pin	Cleaning	0	140,220,080	248,176	140,468,256
TOTAL					844,563,957

In the current maintenance cost, the total cost spent to set chuck holder shaft about 13 times during the last six months in 2016 was IDR 279,702,452. The total cost spent to repairing and replacement of chuck holder shaft were IDR 164,703,194 and IDR 162,769,593. The example of detail calculation for total current maintenance cost of chuck holder shaft in setting activity:

- Component Price = frequency of maintenance x component price
  = 13 X IDR 0
  = IDR 0

- Production Loss = (downtime x price of product x production capacity) x frequency of maintenance
  = (1.604 x IDR 130,000 x 103) x 13
  = IDR 279,208,280

- Mechanic Fee = (downtime x mechanic fee per hour) x frequency of downtime
  = (1.604 x IDR 23,699) x 13
  = IDR 494,172

- Total Cost = component price + production loss + mechanic fee
  = IDR 0 + IDR 279,208,280+ IDR 494,172
  = IDR 279,702,452

4.3.5.2 Proposed Maintenance Cost

Implementing the proposed maintenance system can reduce the machine downtime due to a long waiting time and increase the reliability of machine in PT. NAA. Waiting time to repair can be eliminated by implementing preventive maintenance system. If the machine is maintained well, the company can reduce the production loss.

Table 4.40 Total Downtime and Frequency of Maintenance in the Proposed Maintenance System from July to December 2016

Component Machine	Type of Maintenance	Downtime (hours)	Frequency of Maintenance
Chuck Holder Shaft	Setting	0.50	26
	Repairing	0.70	16
	Replacement	0.95	4
Chuck Holder Slip Ring	Repairing	0.75	23
B-Pin	Cleaning	0.40	6

By implementing preventive maintenance system, during the last six months in 2016 chuck holder shaft has been set about 26 times. Chuck holder shaft has been repaired about 16 times while chuck holder shaft has been replaced about 4 times.

Table 4.41 below shows the total maintenance cost in the proposed maintenance system from July to December 2016. The component price for each component machine is assumed constant. The price of product is IDR 130,000 while the production capacity is 103 rotor/hour.

Table 4.41 Total Maintenance Cost in the Proposed Maintenance System from July to December 2016

Component Machine	Type of Maintenance	Component Price	Production Loss	Mechanic Fee	Total Cost
Chuck Holder Shaft	Setting	0	174,070,000	308,087	174,378,087
	Repairing	1,600,000	149,968,000	265,429	151,833,429
	Replacement	5,200,000	50,882,000	90,056	56,172,056
Chuck Holder Slip Ring	Repairing	16,100,000	230,977,500	408,808	247,486,308
B-Pin	Cleaning	0	32,136,000	56,878	32,192,878
TOTAL					629,869,880

In the proposed maintenance cost, the total cost spent to set chuck holder shaft about 26 times during the last six months in 2016 was IDR 174,378,087. The total cost spent to repairing and replacements of chuck holder shaft were IDR 151,833,429 and IDR 56,172,056. Below is the example of detail calculation for total proposed maintenance cost of chuck holder shaft in setting activity:

- Component Price = frequency of maintenance x component price
  = 26 x IDR 0
  = IDR 0

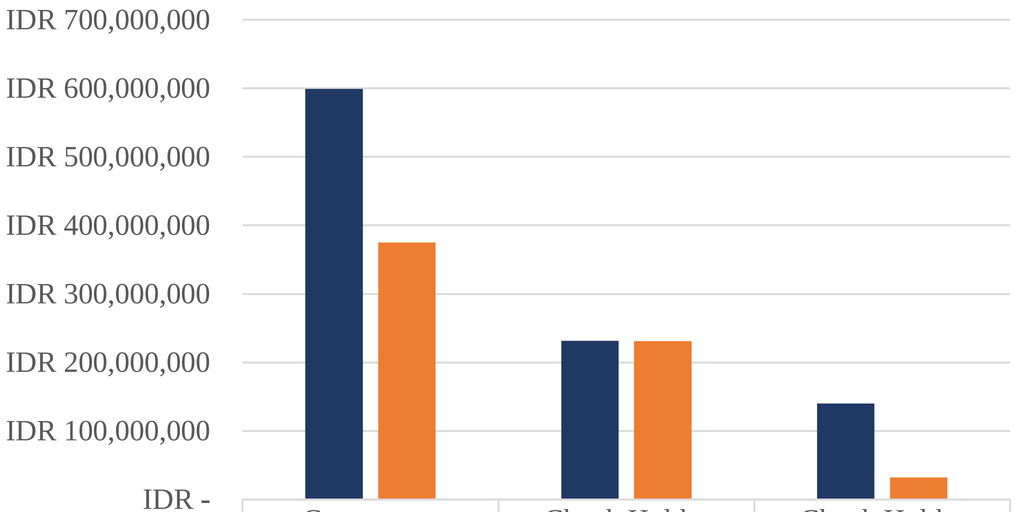
- Production Loss = (downtime x price of product x production capacity) x frequency of maintenance
  = (0.5 x IDR 130,000 x 103) x 26
  = IDR 174,070,000

- Mechanic Fee = (downtime x mechanic fee per hour) x frequency of downtime
  = (0.5 x IDR 23,699) x 26
  = IDR 308,087

- Total Cost = component price + production loss + mechanic fee
  = IDR 0 + IDR 174,070,000 + IDR 308,087
  =IDR 174,378,087

4.3.5.3 Comparison between Current and Proposed Maintenance Cost

Figure 4.13 until Figure 4.16 below shows the production loss, mechanic fee and maintenance cost comparison between current system and proposed preventive maintenance system from July to December 2016.



	Component Machine	Chuck Holder Shaft	Chuck Holder Slip Ring
Current	IDR 599,015,040	IDR 231,379,200	IDR 140,220,080
Proposed	IDR 374,920,000	IDR 230,977,500	IDR 32,136,000

Figure 4.13 Total Production Loss Comparison for Each Component between Current and Proposed Maintenance System from July to December 2016

From Figure 4.13 above, the total production loss of current maintenance system is greater than the total production loss of proposed maintenance system. The total production loss of current maintenance system of chuck holder shaft, chuck holder slip ring, and b-pin are IDR 599,015,040, IDR 231,379,200, and IDR 140,220,080, while the total production loss of proposed maintenance system of chuck holder shaft, chuck holder slip ring, and b-pin are IDR 374,920,000, IDR 230,977,500, and IDR 32,136,000. The total production loss in current maintenance system is IDR 970,614,320, while the total production loss in proposed maintenance system is IDR 638,033,500. It can be seen that the comparison of production loss of chuck holder shaft, chuck holder slip ring, and b-pin can be reduced by IDR 332,580,820.

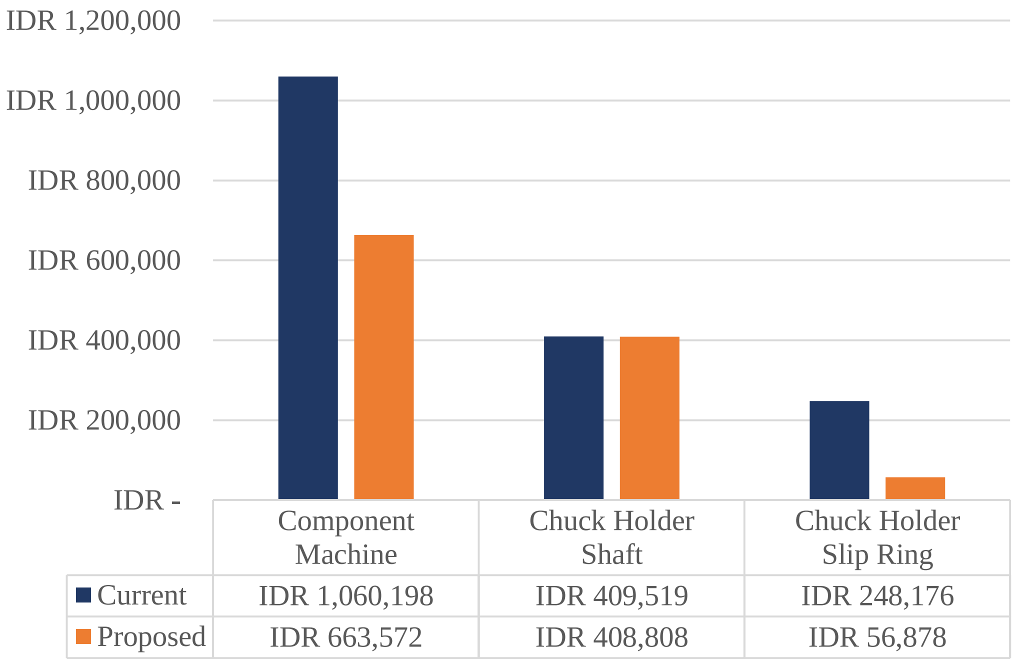
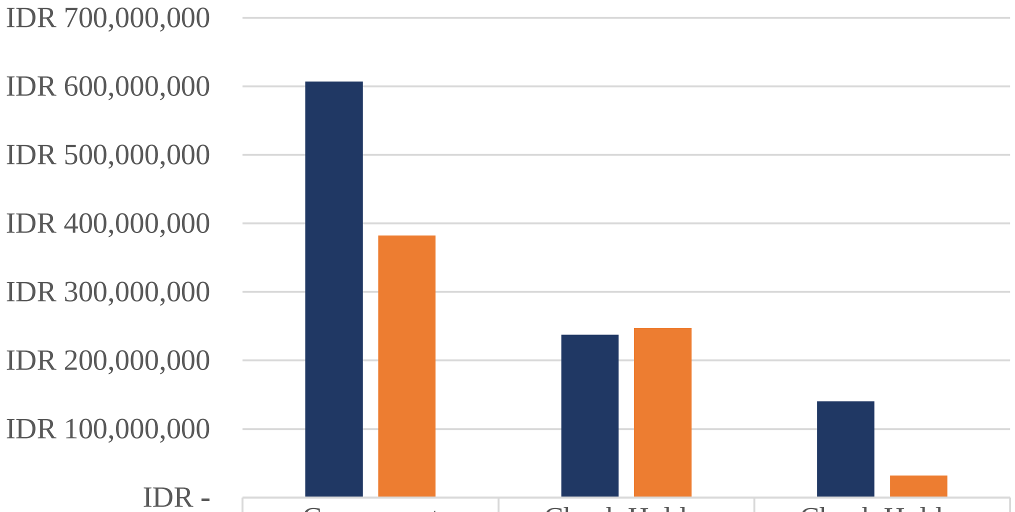


Figure 4.14 Total Mechanic Fee Comparison for Each Component between Current and Proposed Maintenance System from July to December 2016

From Figure 4.14 above, the total mechanic fee of current maintenance system is greater than the total mechanic fee of proposed maintenance system. The total mechanic fee of current maintenance system of chuck holder shaft, chuck holder slip ring, and b-pin are IDR 1,060,198, IDR 409,519, and IDR 248,176, while the total mechanic fee of proposed maintenance system of chuck holder shaft, chuck holder slip ring, and b-pin are IDR 663,572, IDR 408,808, and IDR 56,878. It can be seen that the comparison of production loss of chuck holder shaft, chuck holder slip ring, and b-pin can be reduced by IDR 588,636.



	Component Machine	Chuck Holder Shaft	Chuck Holder Slip Ring
Current	IDR 607,175,238	IDR 237,388,719	IDR 140,468,256
Proposed	IDR 382,383,572	IDR 247,486,308	IDR 32,192,878

Figure 4.15 Total Maintenance Cost Comparison for Each Component between Current and Proposed Maintenance System from July to December 2016

From Figure 4.15 above, the total cost of current maintenance system is greater than the total cost of proposed maintenance system. The total cost of current maintenance system of chuck holder shaft, chuck holder slip ring, and b-pin are IDR 607,175,238, IDR 237,388,719, and IDR 140,468,256, while the total cost of proposed maintenance system of chuck holder shaft, chuck holder slip ring, and b-pin are IDR 382,383,572, IDR 247,486,308, and IDR 32,192,878. It can be seen that the comparison maintenance cost of chuck holder shaft and b-pin is decreased in amount of money. For chuck holder slip ring, the maintenance cost is increased.

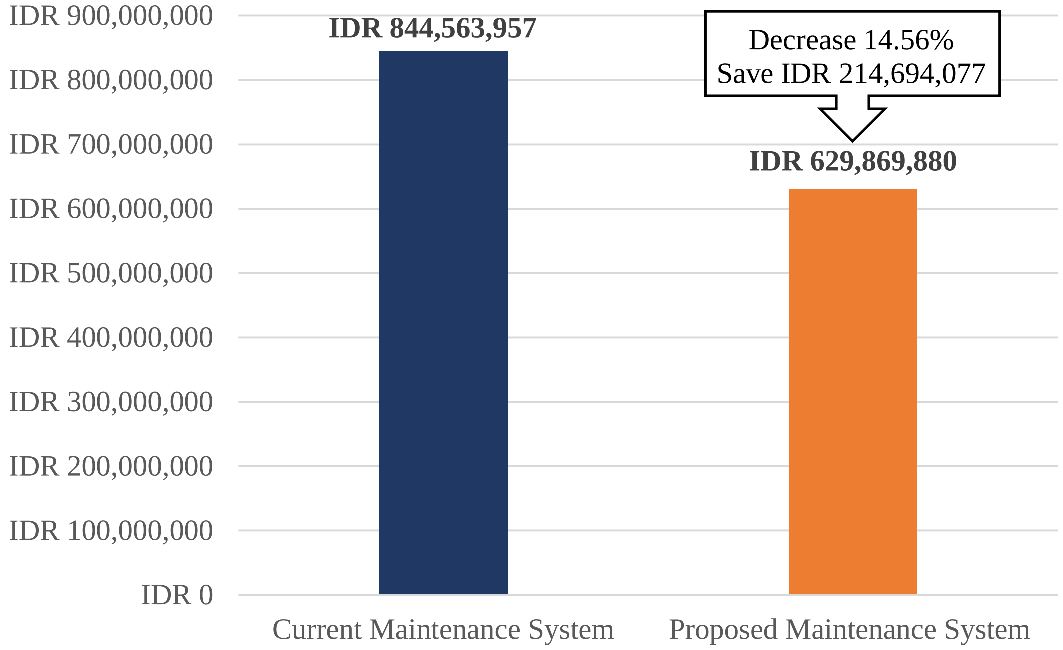


Figure 4.16 Total Maintenance Cost Comparison between Current and Proposed System from July to December 2016

From figure 4.16 shows the total maintenance cost comparison between current maintenance system and proposed maintenance system for three components which are chuck holder shaft, chuck holder slip ring, and b-pin is decreased. The company can reduced the maintenance cost by 14.56% or IDR 214,694,077.

CHAPTER V
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on analysis done during the research, the objectives of this research in PT. NAA are achieved. The conclusions of this research are as follow:

- There are 15 components in Main Assembly 1 machine. Main Assembly 1 is a machine used to assembly some parts such as pole front rear field coil, shaft, and slip ring. During the last six months in 2016, there are some components that cause the highest downtime. The most critical components that activated the highest machine downtime are chuck holder shaft, chuck holder slip ring, and b-pin.

- In order to reduce the downtime loss, the company performed preventive maintenance schedule. In the current condition, MTTF and MTBF of chuck holder shaft, chuck holder slip ring, and b-pin are 585.69 hours, 313.797 hours, and 1029.59 hours. The component machine reliability of chuck holder shaft, chuck holder slip ring, and b-pin are 48.69%, 46.37%, and 50% respectively. Then, the target of machine reliability has is successfully achieved by the company, which is 70% with MTTF and MTBF of each component or 456.67 hours, 200 hours, and 720 hours.

- The current maintenance system cost is IDR 844,563,957. With 70% of reliability, the proposed preventive maintenance system will be IDR 629,869,880. The maintenance cost can be reduced by 14.56%. So, the company will save with the amount of IDR 214,694,077.

5.2 Recommendation

Due to the limitation of time and source, there is a suggestion for further research which is formulate the algorithm in order to integrate the two important factors; schedule of the production and preventive maintenance.

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APPENDICES

APPENDIX 1 - Assembly Line Downtime in Hour (July – December 2016)

No.	LINE	ASSEMBLY LINE DOWN TIME 2016 (HOUR)						TOTAL DOWN TIME (HOUR)
		JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	
1	Alternator Bracket	0.00	5.50	0.00	0.00	2.00	1.25	8.75
2	Rotor Assembly	11.07	49.86	44.25	52.18	44.42	62.73	264.51
3	Field Coil	0.00	1.17	13.02	5.37	0.50	1.83	21.89
4	Starter Bracket	0.00	5.83	0.50	0.50	7.42	1.00	15.25
5	Brush Holder Assembly (BHA)	0.00	5.17	1.33	13.92	5.08	1.25	26.75
6	Over Running Clutch (ORC)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Yoke Assembly	0.00	0.00	0.33	0.00	4.08	7.33	11.74
8	Connector Brush Holder (CBH)	0.00	14.25	0.00	0.00	0.00	23.50	37.75
9	Stator Assembly	18.58	29.20	11.42	26.75	25.67	0.00	111.62
		29.65	110.98	70.85	98.72	89.17	98.89	

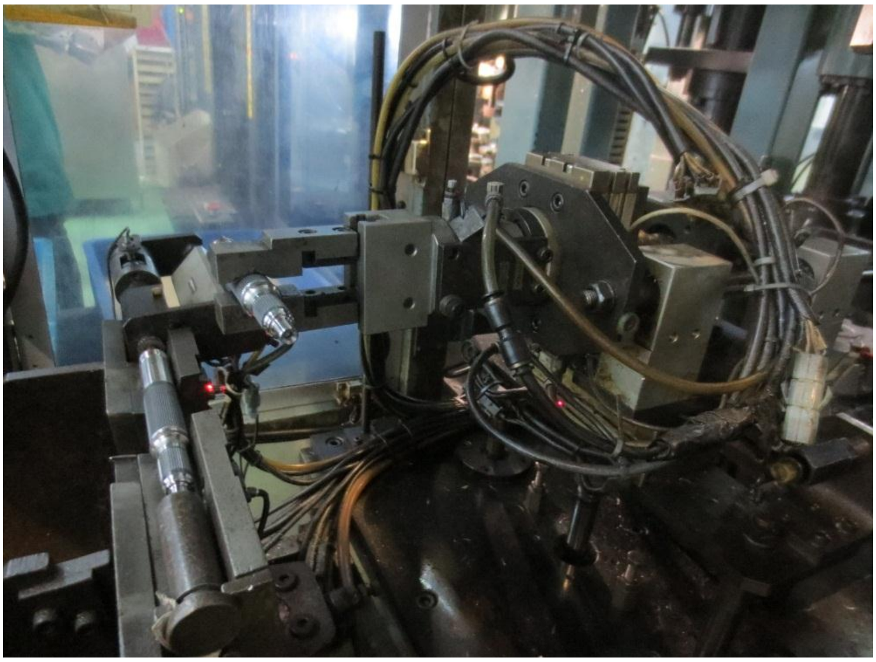
APPENDIX 2 - Machine Downtime from July-December 2016

No.	MACHINE NAME	DOWN TIME (HOUR)						TOTAL DOWN TIME (HOUR)
		JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	
1	Penguin Cement		0.50					0.50
2	AC Box Pinguin Cement				0.50			0.50
3	Sub Assembly							0.00
4	Main Assembly 1	2.08	16.67	17.75	28.92	2.92	26.08	**94.42**
5	Oil Machine Press							0.00
6	Shaft Grinding (HGR)	4.33	4.00	13.75		0.33	3.58	25.99
7	Epoxy Dropping	0.33	1.77	2.00				4.10
8	Furnace (Oven 1 New)							0.00
9	Furnace (Oven 2 Old)		1.00					1.00
10	Lathe (Takisawa) A		0.75		3.00		1.25	5.00
11	Lathe (Takisawa) B		2.33			22.67	5.33	30.33
12	Lathe (Takisawa) C	1.83	3.17	0.83	1.92	1.42		9.17
13	Balancing Checker - 1A				6.00	6.00		12.00
14	Balancing Checker - 1B			2.25	3.58		2.08	7.91
15	Drilling - 2							0.00
16	Drilling - 3							0.00
17	F-Fan Spot Welding		3.50				1.83	5.33
18	R-Fan Spot Welding		4.42	6.17	3.92	10.08	12.08	36.67
19	Caulking							0.00
20	Balancing Checker - 2A		2.00					2.00

No.	MACHINE NAME	DOWN TIME (HOUR)						TOTAL DOWN TIME (HOUR)
		JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	
21	Balancing Checker - 2B		0.75					0.75
22	Drilling - 1							0.00
23	Painting		2.00	1.50				3.50
24	S/R Belt Grinding				3.67			3.67
25	Rotor Electrical Checker New							0.00
26	Heater Painting		1.00					1.00
27	Main Assembly 2	2.50	5.50	0.00	0.67		4.83	13.50
28	Re-Press Main Assembly 2							0.00
29	Slip Ring Press Main Assembly 2							0.00
30	Soldering Main Assembly 2							0.00
31	Lazer Marking					1.00	4.17	5.17
32	Utility		0.50	0.00			1.50	2.00
		11.07	49.86	44.25	52.18	44.42	62.73	264.51

APPENDIX 3 - Picture

Rotor



Chuck Holder Shaft

Chuck Holder Slip Ring

B-Pin

APPENDIX 4 - Component Failure Data

Chuck Holder Shaft

Type of Maintenance	Stop Machine		TTR Start		TTR Finish		Start Production		TBF (hour)	Waiting Time (hour)	TTR (hour)
	Date	Time	Date	Time	Date	Time	Date	Time			
Setting	7/21/2016	8:36:00	7/21/2016	9:12:00	7/21/2016	10:02:00	7/21/2016	10:02:00	0	0.60	0.83
Setting	8/2/2016	10:05:00	8/2/2016	10:42:00	8/2/2016	12:12:00	8/2/2016	12:12:00	288.05	0.62	1.50
Setting	8/2/2016	19:50:00	8/2/2016	20:15:00	8/2/2016	21:00:00	8/2/2016	21:00:00	10.12	0.42	0.75
Setting	8/31/2016	2:54:00	8/31/2016	3:20:00	8/31/2016	4:00:00	8/31/2016	4:00:00	695.68	0.43	0.67
Setting	9/5/2016	12:14:00	9/5/2016	13:05:00	9/5/2016	14:05:00	9/5/2016	14:05:00	128.23	0.85	1.00
Setting	9/24/2016	18:50:00	9/24/2016	19:05:00	9/24/2016	19:50:00	9/24/2016	19:50:00	469.00	0.25	0.75
Setting	9/25/2016	21:10:00	9/25/2016	21:30:00	9/25/2016	23:10:00	9/25/2016	23:10:00	25.33	0.33	1.67
Setting	10/10/2016	3:17:00	10/10/2016	3:36:00	10/10/2016	4:51:00	10/10/2016	4:51:00	350.97	0.32	1.25
Setting	10/13/2016	19:35:00	10/13/2016	19:56:00	10/13/2016	20:36:00	10/13/2016	20:36:00	86.73	0.35	0.67
Setting	10/29/2016	16:40:00	10/29/2016	17:05:00	10/29/2016	17:55:00	10/29/2016	17:55:00	375.33	0.42	0.83
Setting	12/5/2016	6:24:00	12/5/2016	6:39:00	12/5/2016	9:39:00	12/5/2016	9:39:00	878.92	0.25	3.00
Setting	12/13/2016	19:45:00	12/13/2016	20:05:00	12/13/2016	21:35:00	12/13/2016	21:35:00	213.70	0.33	1.50
Setting	12/28/2016	22:29:00	12/28/2016	22:45:00	12/28/2016	23:45:00	12/28/2016	23:45:00	360.90	0.27	1.00

Chuck Holder Shaft

	Stop Machine		TTR Start		TTR Finish		Start Production				
Type of Maintenance	Date	Time	Date	Time	Date	Time	Date	Time	TBF (hour)	Waiting Time (hour)	TTR (hour)
Repairing	8/15/2016	7:45:00	8/15/2016	8:15:00	8/15/2016	10:15:00	8/15/2016	10:15:00	0	0.50	2.00
Repairing	8/18/2016	13:08:00	8/18/2016	13:32:00	8/18/2016	15:07:00	8/18/2016	15:07:00	74.88	0.40	1.58
Repairing	9/18/2016	11:04:00	9/18/2016	12:13:00	9/18/2016	12:58:00	9/18/2016	12:58:00	730.12	1.15	0.75
Repairing	9/24/2016	6:13:00	9/24/2016	7:00:00	9/24/2016	9:00:00	9/24/2016	9:00:00	143.68	0.78	2.00
Repairing	10/14/2016	15:13:00	10/14/2016	15:44:00	10/14/2016	16:14:00	10/14/2016	16:14:00	486.22	0.52	0.50
Repairing	11/10/2016	9:22:00	11/10/2016	10:00:00	11/10/2016	11:25:00	11/10/2016	11:25:00	637.00	0.63	1.42

Chuck Holder Shaft

Type of Maintenance	Stop Machine		TTR Start		TTR Finish		Start Production		TBF (hour)	Waiting Time (hour)	TTR (hour)
	Date	Time	Date	Time	Date	Time	Date	Time			
Replacement	7/2/2016	1:21:00	7/2/2016	1:55:00	7/2/2016	4:45:00	7/2/2016	4:45:00	0	0.57	2.83
Replacement	8/6/2016	11:29:00	8/6/2016	11:41:00	8/6/2016	14:21:00	8/6/2016	14:21:00	846.73	0.20	2.67
Replacement	9/11/2016	9:14:00	9/11/2016	9:30:00	9/11/2016	11:40:00	9/11/2016	11:40:00	850.12	0.27	2.17
Replacement	10/23/2016	6:00:00	10/23/2016	7:05:00	10/23/2016	7:50:00	10/23/2016	7:50:00	1007.68	1.08	0.75
Replacement	12/19/2016	15:28:00	12/19/2016	15:40:00	12/19/2016	16:35:00	12/19/2016	16:35:00	1375.63	0.20	0.92

Chuck Holder Slip Ring

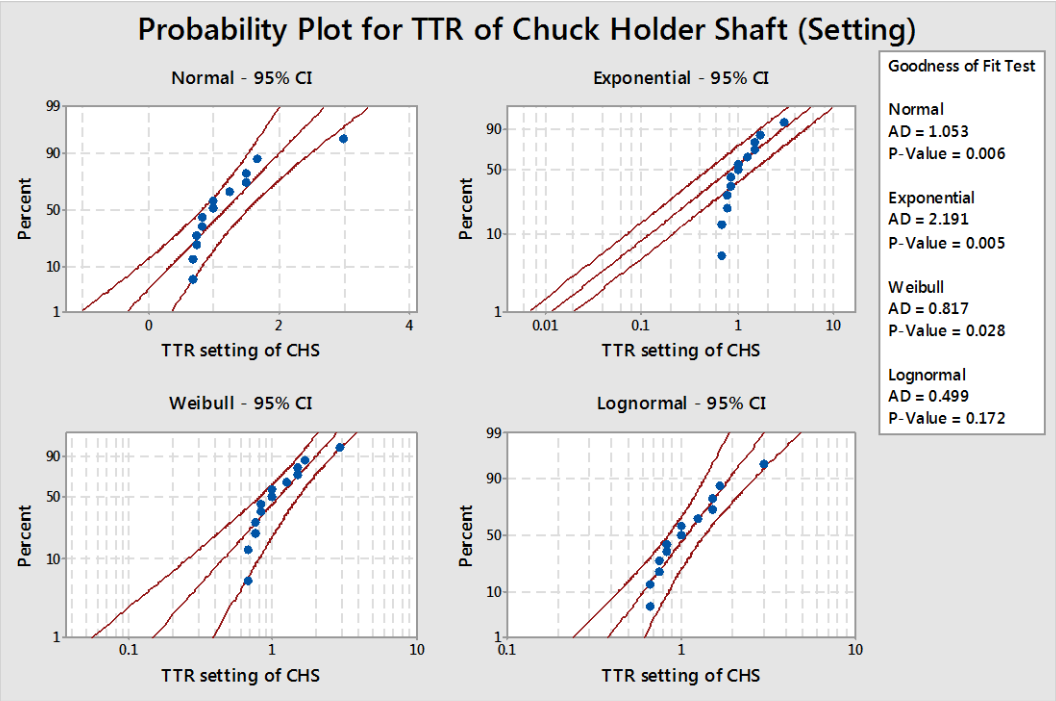
Type Of Corrective	Stop Machine		TTR Start		TTR Finish		Start Production		TBF (hour)	Waiting Time (hour)	TTR (hour)
	Day	Time	Day	Time	Day	Time	Day	Time			
Repairing	24/09/2016	2.28.00	24/09/2016	2.40.00	24/09/2016	4.22.00	24/09/2016	4.22.00	0	0.20	1.70
Repairing	10/10/2016	9.21.00	10/10/2016	9.30.00	10/10/2016	11.48.00	10/10/2016	11.48.00	388.98	0.15	2.30
Repairing	14/10/2016	19.43.00	14/10/2016	19.56.00	14/10/2016	22.08.00	14/10/2016	22.08.00	106.12	0.22	2.20
Repairing	24/10/2016	1.05.00	24/10/2016	1.12.00	24/10/2016	2.57.00	24/10/2016	2.57.00	239.68	0.12	1.75
Repairing	06/12/2016	13.54.00	06/12/2016	14.00.00	06/12/2016	15.54.00	06/12/2016	15.54.00	1042.95	0.10	1.90
Repairing	17/12/2016	10.48.00	17/12/2016	11.00.00	17/12/2016	12.39.00	17/12/2016	12.39.00	253.00	0.20	1.65
Repairing	22/12/2016	20.42.00	22/12/2016	20.55.00	22/12/2016	23.25.00	22/12/2016	23.25.00	128.05	0.22	2.50
Repairing	28/12/2016	16.00.00	28/12/2016	16.05.00	28/12/2016	18.05.00	28/12/2016	18.05.00	134.97	0.08	2.00

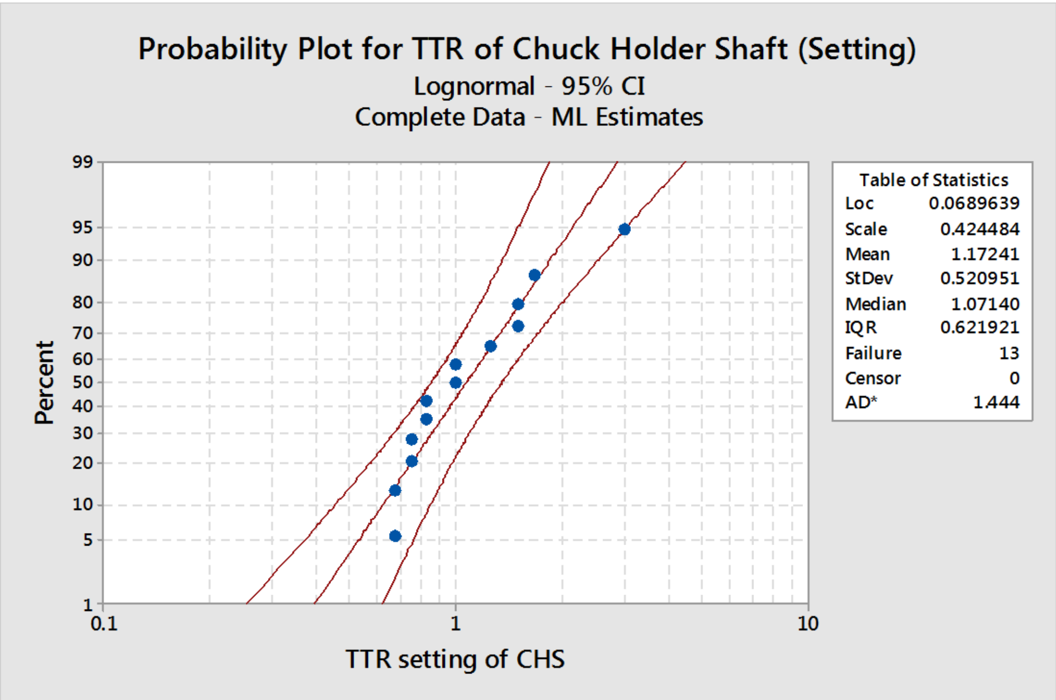
B-Pin

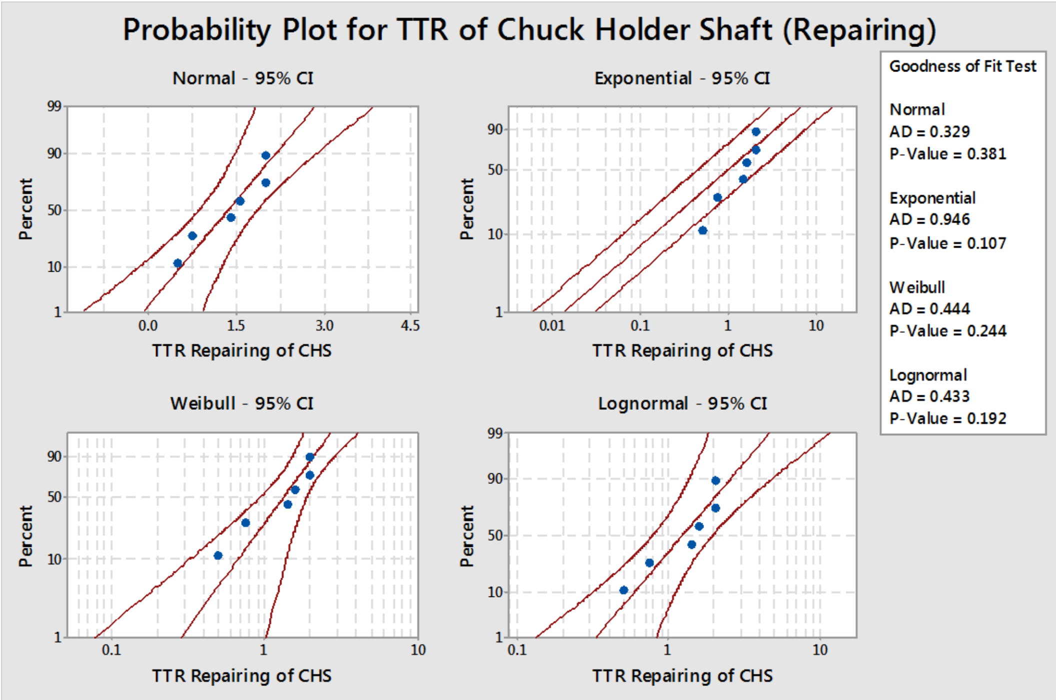
	Stop Machine		TTR Start		TTR Finish		Start Production				
Type of Maintenance	Date	Time	Date	Time	Date	Time	Date	Time	TBF (hour)	Waiting Time (hour)	TTR (hour)
Cleaning	8/18/2016	9:10:00	8/18/2016	9:20:00	8/18/2016	10:20:00	8/18/2016	10:20:00	0	0.17	1.00
Cleaning	8/29/2016	19:53:00	8/25/2016	20:05:00	8/25/2016	20:35:00	8/25/2016	20:35:00	273.55	0.20	0.50
Cleaning	9/3/2016	0:26:00	8/29/2016	0:41:00	8/29/2016	2:36:00	8/29/2016	2:36:00	202.12	0.25	1.92
Cleaning	10/6/2016	6:00:00	9/3/2016	6:20:00	9/3/2016	6:45:00	9/3/2016	6:45:00	935.68	0.33	0.42
Cleaning	10/21/2016	14:21:00	10/3/2016	14:31:00	10/3/2016	15:11:00	10/3/2016	15:11:00	1159.60	0.17	0.67
Cleaning	11/15/2016	19:20:00	10/3/2016	19:35:00	10/3/2016	20:05:00	10/3/2016	20:05:00	1045.00	0.25	0.50
Cleaning	12/13/2016	20:17:00	10/4/2016	20:23:00	10/4/2016	23:23:00	10/4/2016	23:23:00	1704.20	0.10	3.00
Cleaning	12/22/2016	10:45:00	10/5/2016	11:00:00	10/5/2016	11:45:00	10/5/2016	11:45:00	1886.97	0.25	0.75

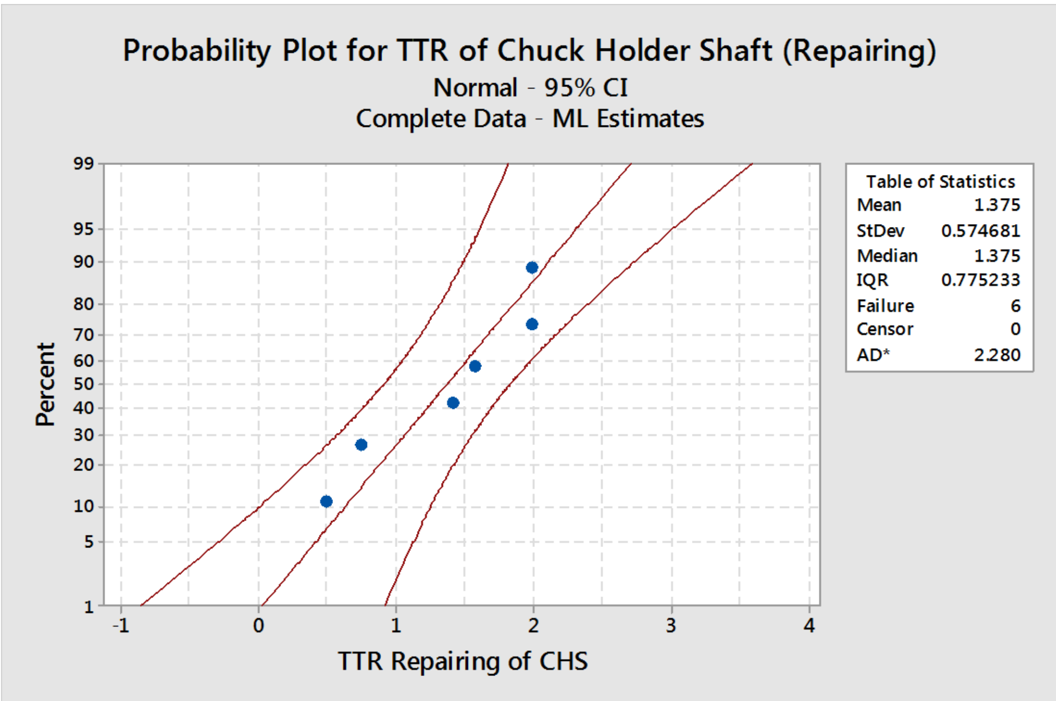
APPENDIX 5 - Goodness of Fit Test Result

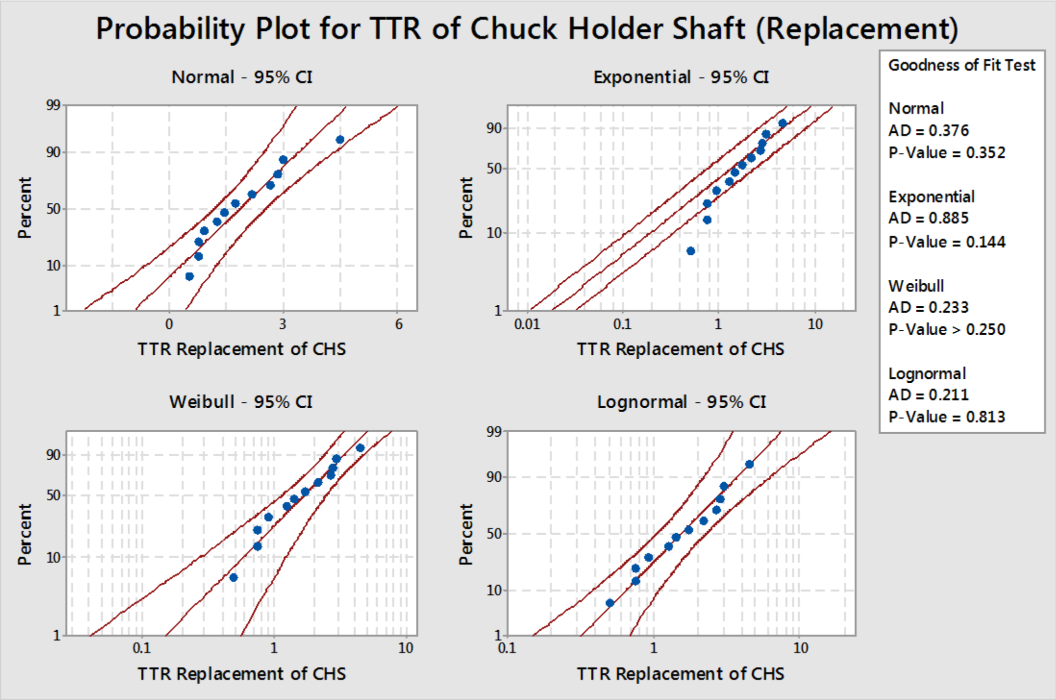
Statistical Analysis Result

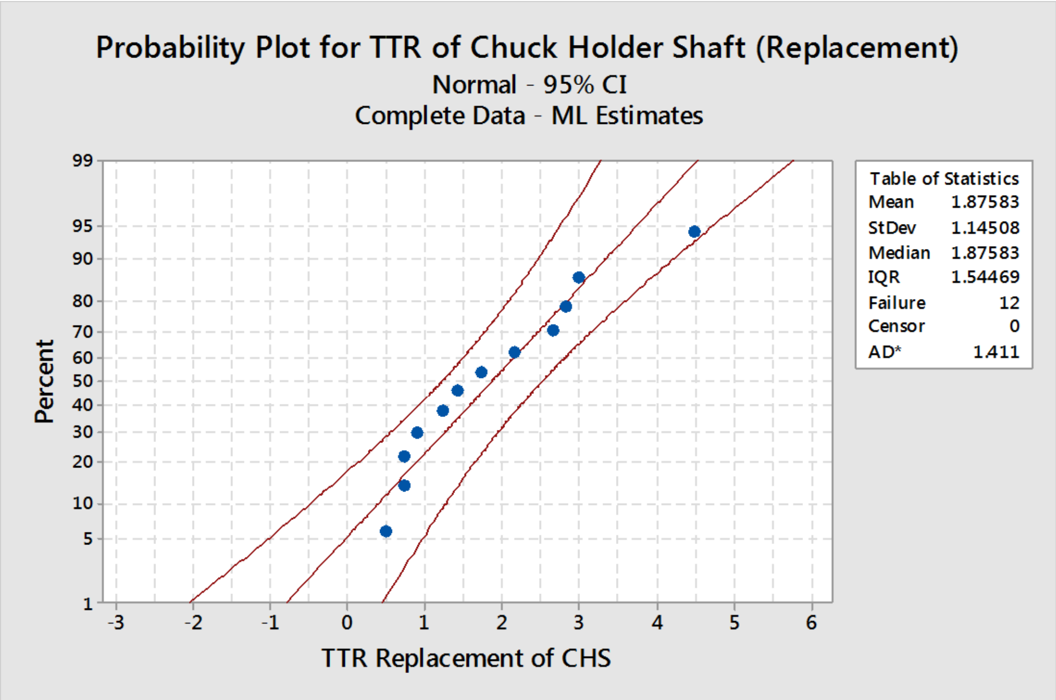


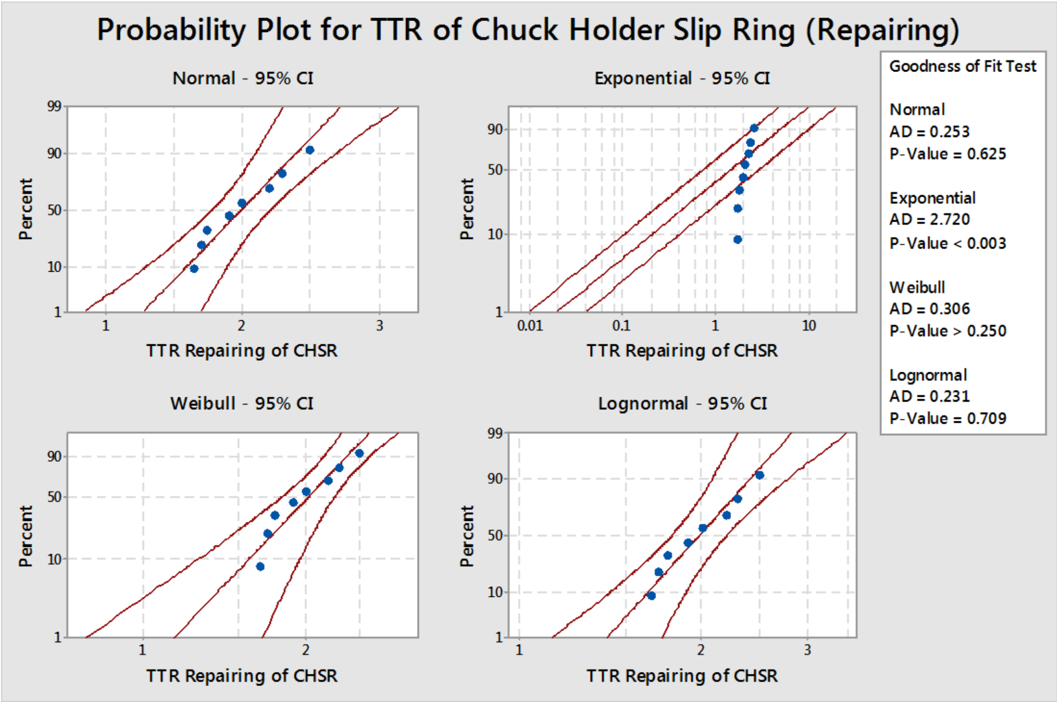


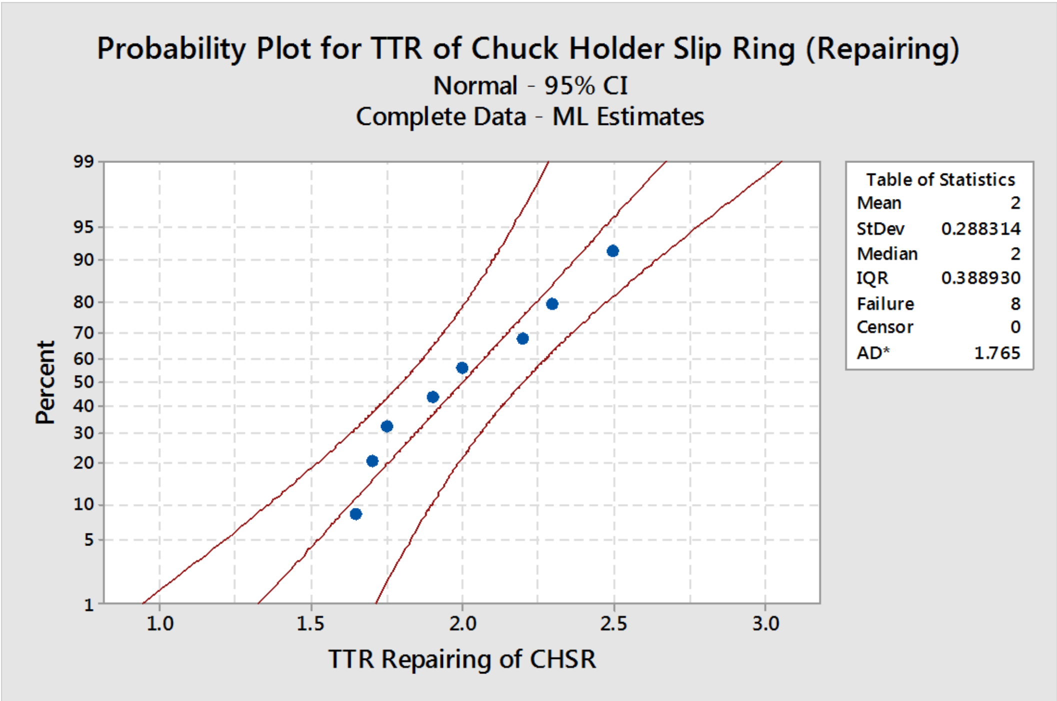

Probability Plot for TTR of Chuck Holder Shaft (Repairing)
Normal - 95% CI
Exponential - 95% CI
Weibull - 95% CI
Lognormal - 95% CI
Percent
TTR Repairing of CHS
Goodness of Fit Test
Normal
AD = 0.329
P-Value = 0.381
Exponential
AD = 0.946
P-Value = 0.107
Weibull
AD = 0.444
P-Value = 0.244
Lognormal
AD = 0.433
P-Value = 0.192

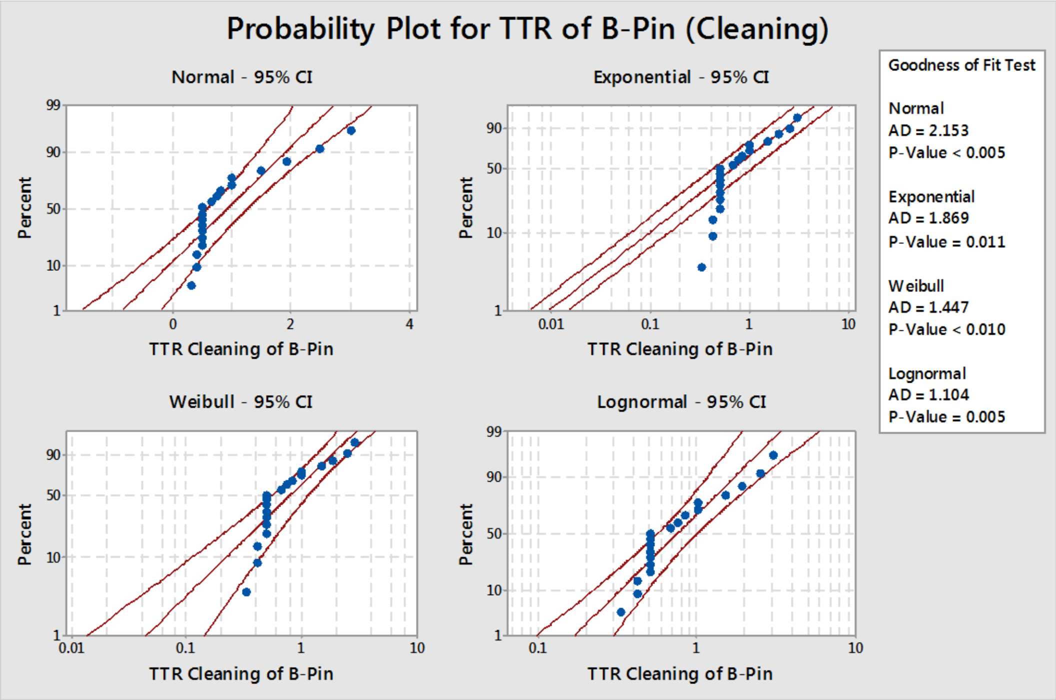

Probability Plot for TTR of Chuck Holder Shaft (Repairing)
Normal - 95% CI
Complete Data - ML Estimates
Percent
TTR Repairing of CHS
Table of Statistics
Mean 1.375
StDev 0.574681
Median 1.375
IQR 0.775233
Failure 6
Censor 0
AD* 2.280

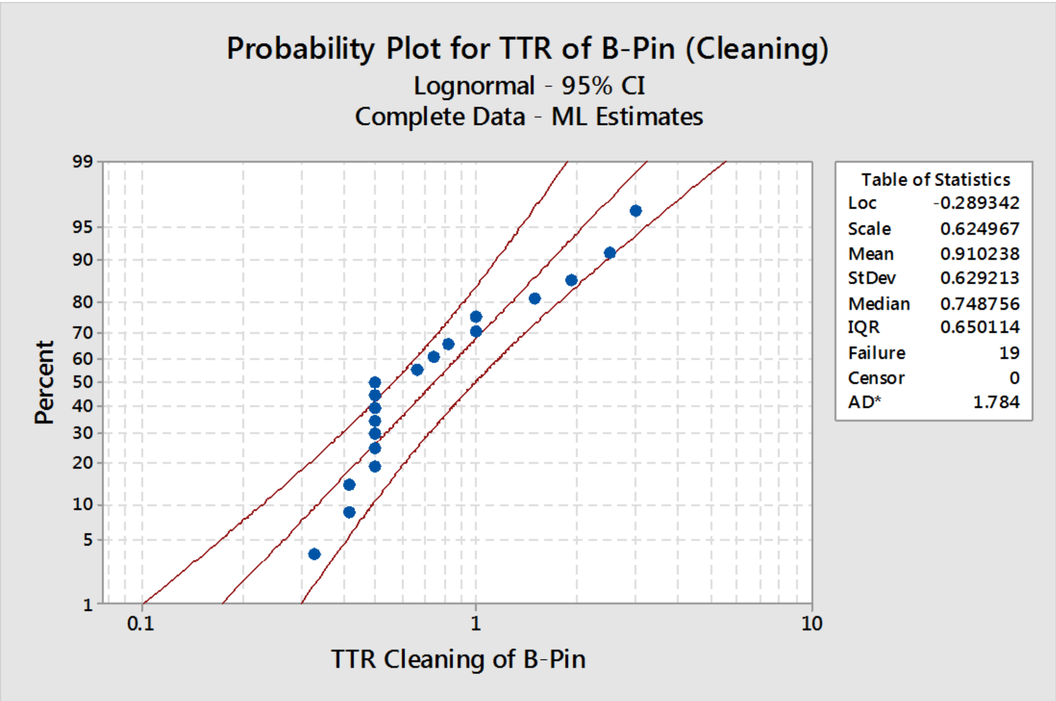

Probability Plot for TTR of Chuck Holder Shaft (Replacement)
Normal - 95% CI
Exponential - 95% CI
Weibull - 95% CI
Lognormal - 95% CI
Percent
TTR Replacement of CHS
Goodness of Fit Test
Normal
AD = 0.376
P-Value = 0.352
Exponential
AD = 0.885
P-Value = 0.144
Weibull
AD = 0.233
P-Value > 0.250
Lognormal
AD = 0.211
P-Value = 0.813

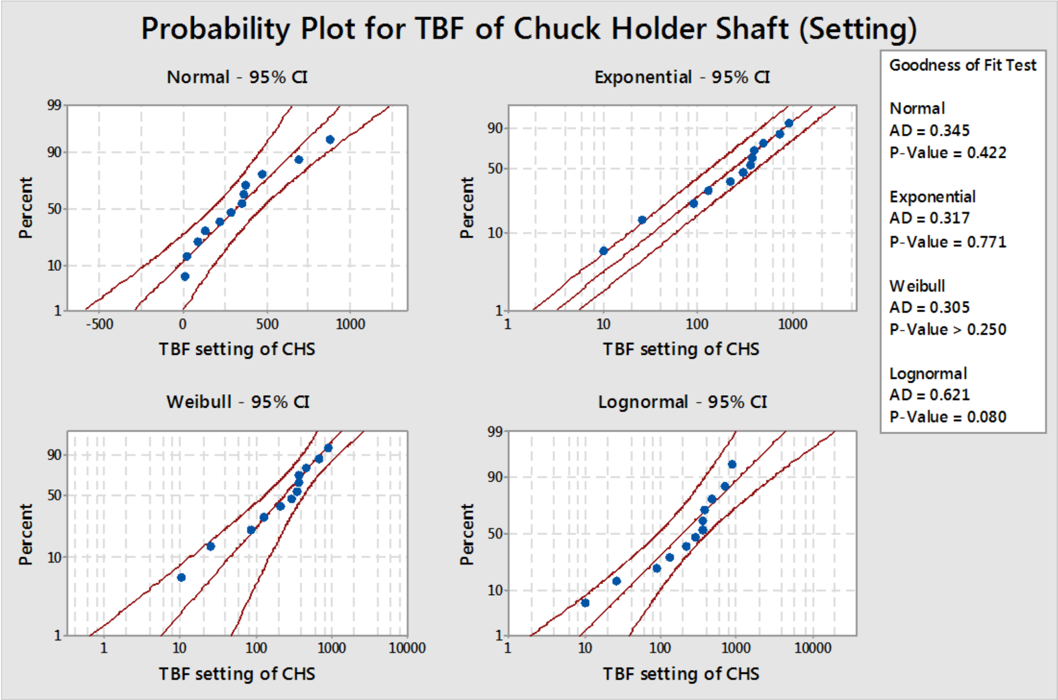

Probability Plot for TTR of Chuck Holder Shaft (Replacement)
Normal - 95% CI
Complete Data - ML Estimates
Percent
TTR Replacement of CHS
Table of Statistics
Mean 1.87583
StDev 1.14508
Median 1.87583
IQR 1.54469
Failure 12
Censor 0
AD* 1.411


Probability Plot for TTR of Chuck Holder Slip Ring (Repairing)
Normal - 95% CI
Exponential - 95% CI
Weibull - 95% CI
Lognormal - 95% CI
Percent
TTR Repairing of CHSR
Goodness of Fit Test
Normal
AD = 0.253
P-Value = 0.625
Exponential
AD = 2.720
P-Value < 0.003
Weibull
AD = 0.306
P-Value > 0.250
Lognormal
AD = 0.231
P-Value = 0.709

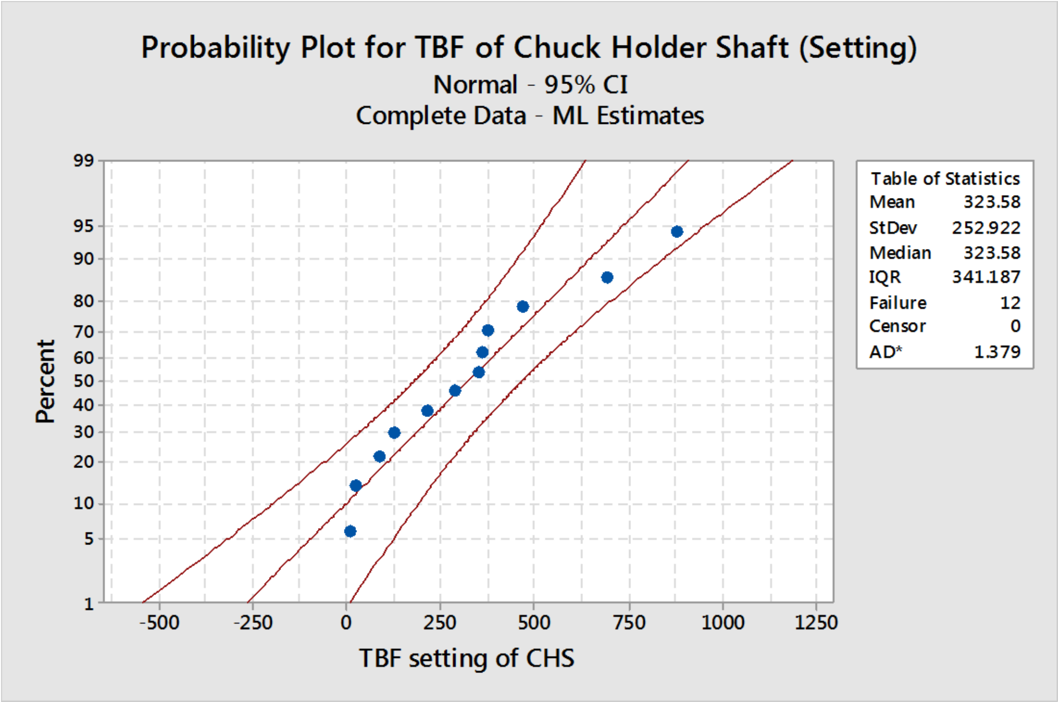

Probability Plot for TTR of Chuck Holder Slip Ring (Repairing)
Normal - 95% CI
Complete Data - ML Estimates
Percent
TTR Repairing of CHSR
Table of Statistics
Mean 2
StDev 0.288314
Median 2
IQR 0.388930
Failure 8
Censor 0
AD* 1.765


Probability Plot for TTR of B-Pin (Cleaning)
Normal - 95% CI
Exponential - 95% CI
Weibull - 95% CI
Lognormal - 95% CI
Percent
TTR Cleaning of B-Pin
Goodness of Fit Test
Normal
AD = 2.153
P-Value < 0.005
Exponential
AD = 1.869
P-Value = 0.011
Weibull
AD = 1.447
P-Value < 0.010
Lognormal
AD = 1.104
P-Value = 0.005

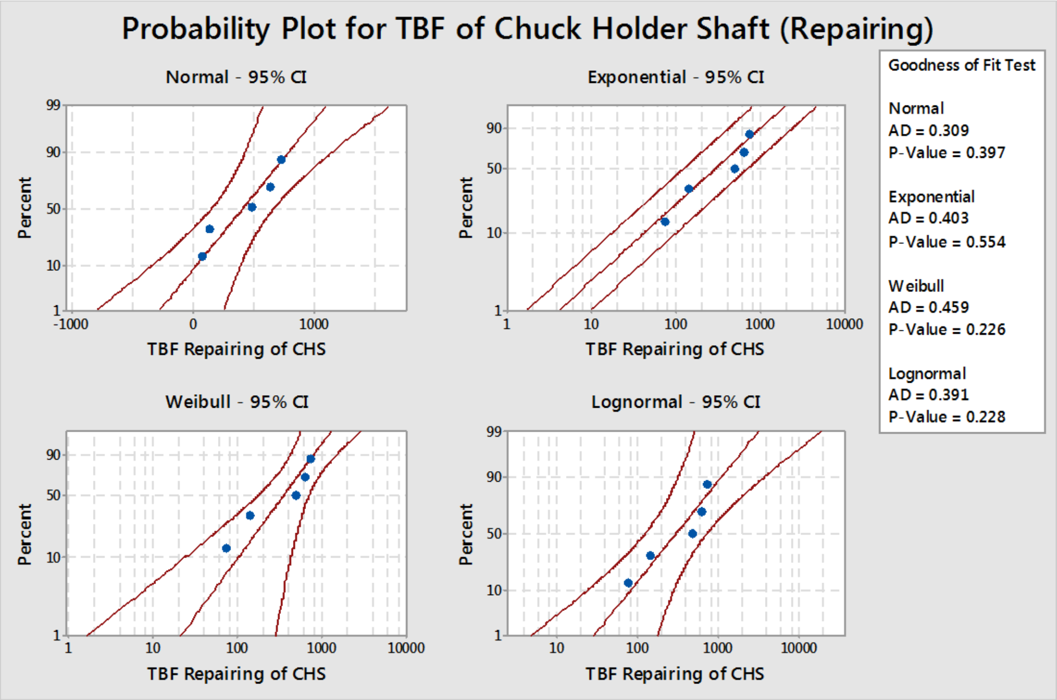

Probability Plot for TTR of B-Pin (Cleaning)
Lognormal - 95% CI
Complete Data - ML Estimates
Percent
TTR Cleaning of B-Pin
Table of Statistics
Loc -0.289342
Scale 0.624967
Mean 0.910238
StDev 0.629213
Median 0.748756
IQR 0.650114
Failure 19
Censor 0
AD* 1.784

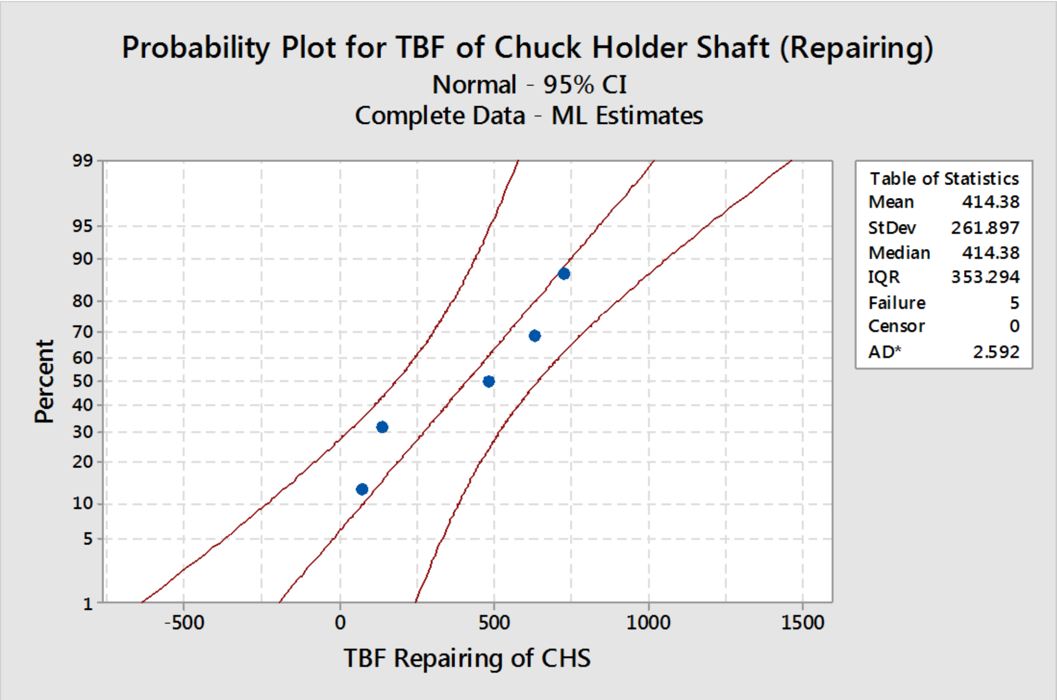


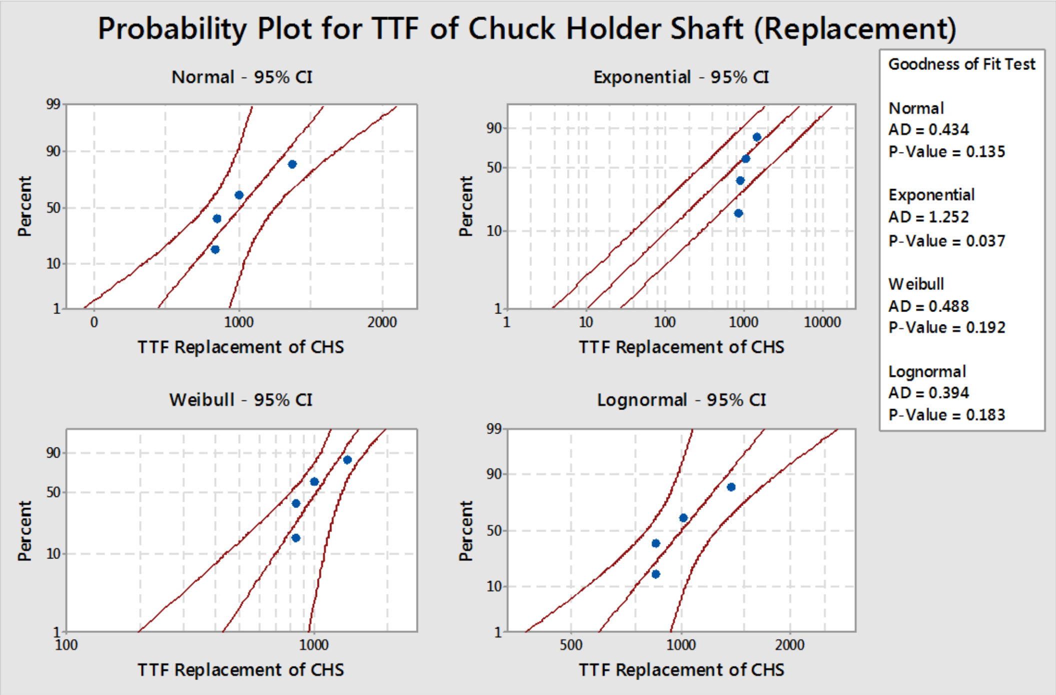
Probability Plot for TBF of Chuck Holder Shaft (Setting)
Normal - 95% CI
Exponential - 95% CI
Weibull - 95% CI
Lognormal - 95% CI
Percent
TBF setting of CHS
Goodness of Fit Test
Normal
AD = 0.345
P-Value = 0.422
Exponential
AD = 0.317
P-Value = 0.771
Weibull
AD = 0.305
P-Value > 0.250
Lognormal
AD = 0.621
P-Value = 0.080

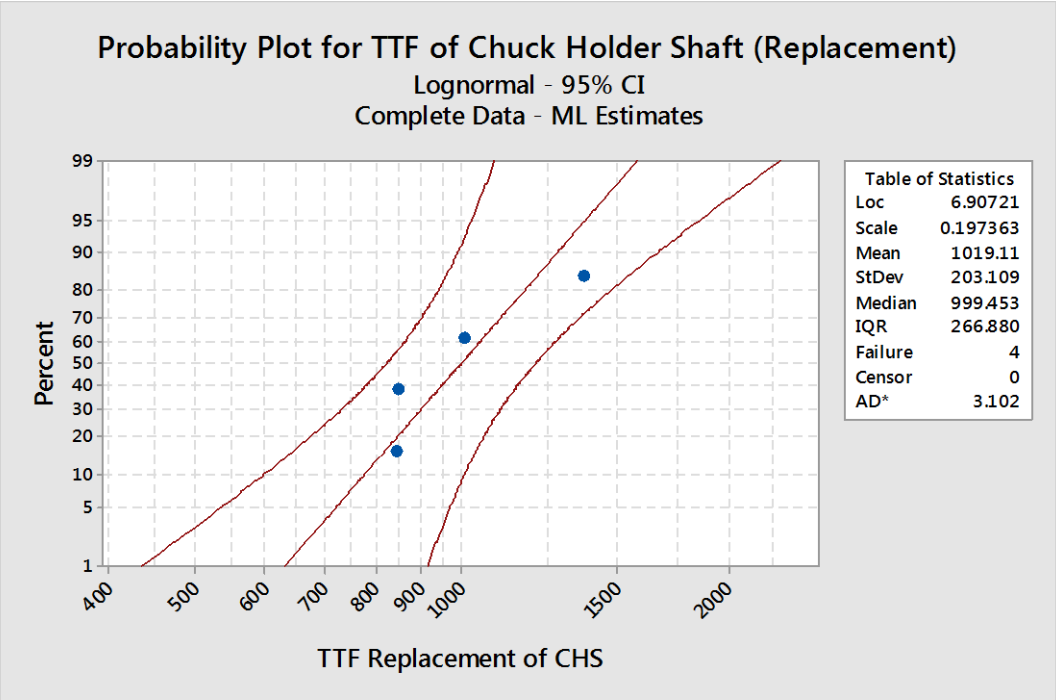


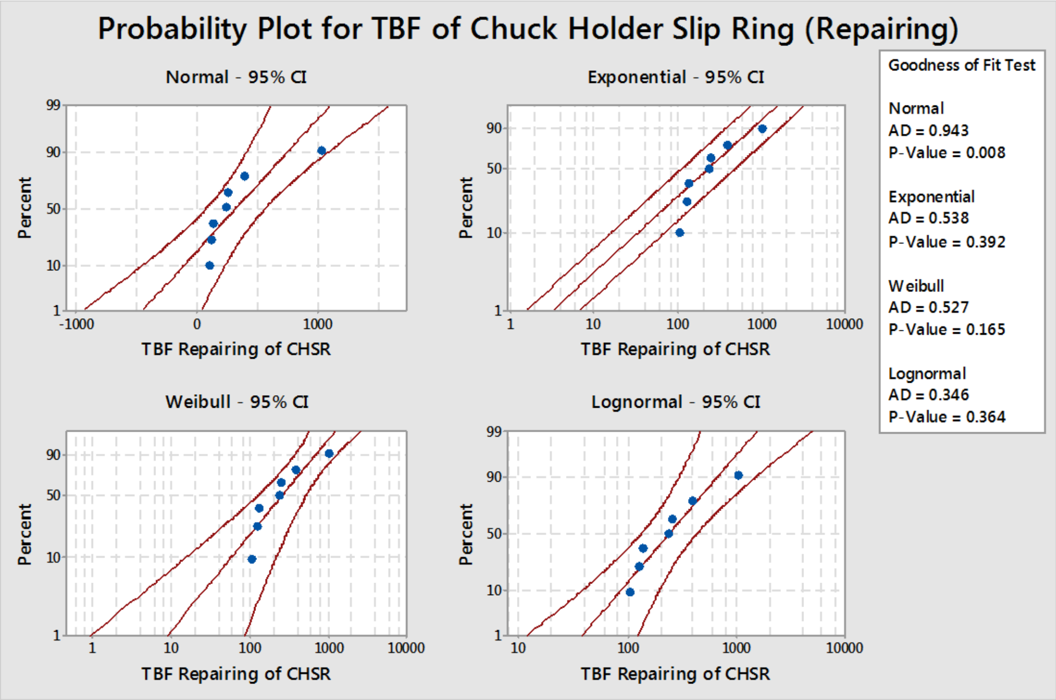
Probability Plot for TBF of Chuck Holder Shaft (Setting)
Normal - 95% CI
Complete Data - ML Estimates
Percent
TBF setting of CHS
Table of Statistics
Mean 323.58
StDev 252.922
Median 323.58
IQR 341.187
Failure 12
Censor 0
AD* 1.379

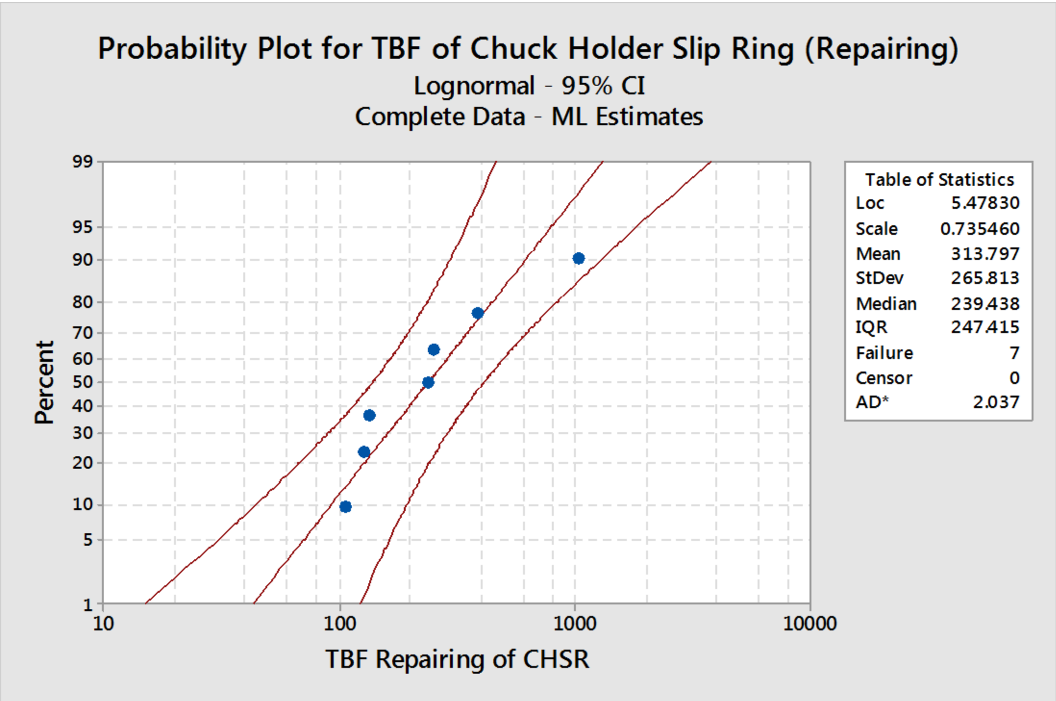

Probability Plot for TBF of Chuck Holder Shaft (Repairing)
Normal - 95% CI
Exponential - 95% CI
Weibull - 95% CI
Lognormal - 95% CI
Percent
TBF Repairing of CHS
Goodness of Fit Test
Normal
AD = 0.309
P-Value = 0.397
Exponential
AD = 0.403
P-Value = 0.554
Weibull
AD = 0.459
P-Value = 0.226
Lognormal
AD = 0.391
P-Value = 0.228

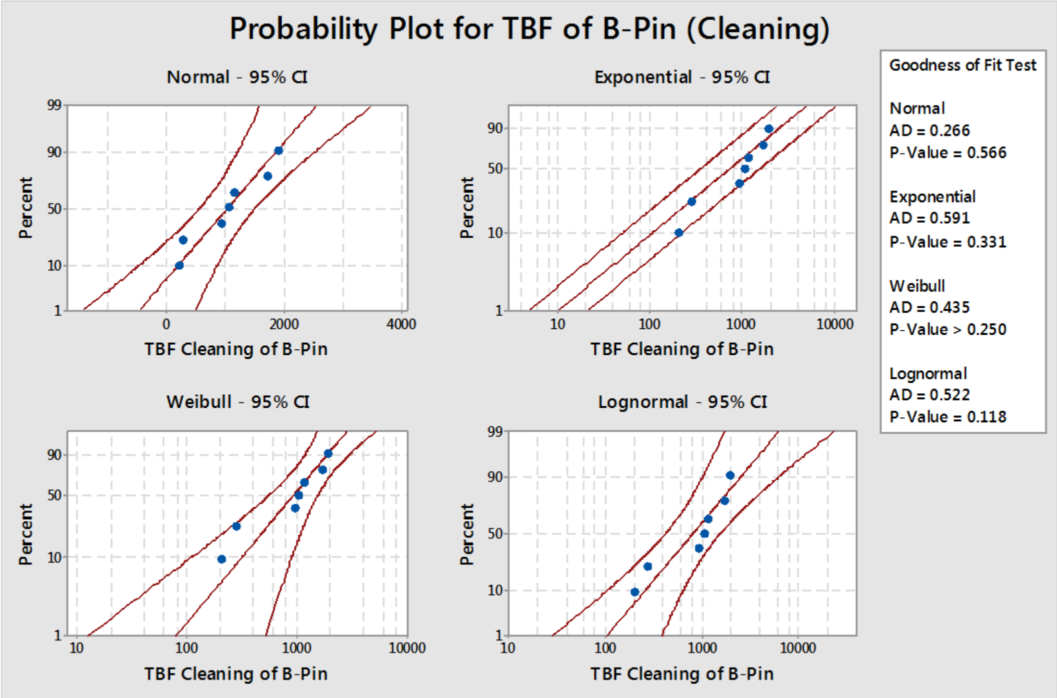

Probability Plot for TBF of Chuck Holder Shaft (Repairing)
Normal - 95% CI
Complete Data - ML Estimates
Percent
TBF Repairing of CHS
Table of Statistics
Mean 414.38
StDev 261.897
Median 414.38
IQR 353.294
Failure 5
Censor 0
AD* 2.592

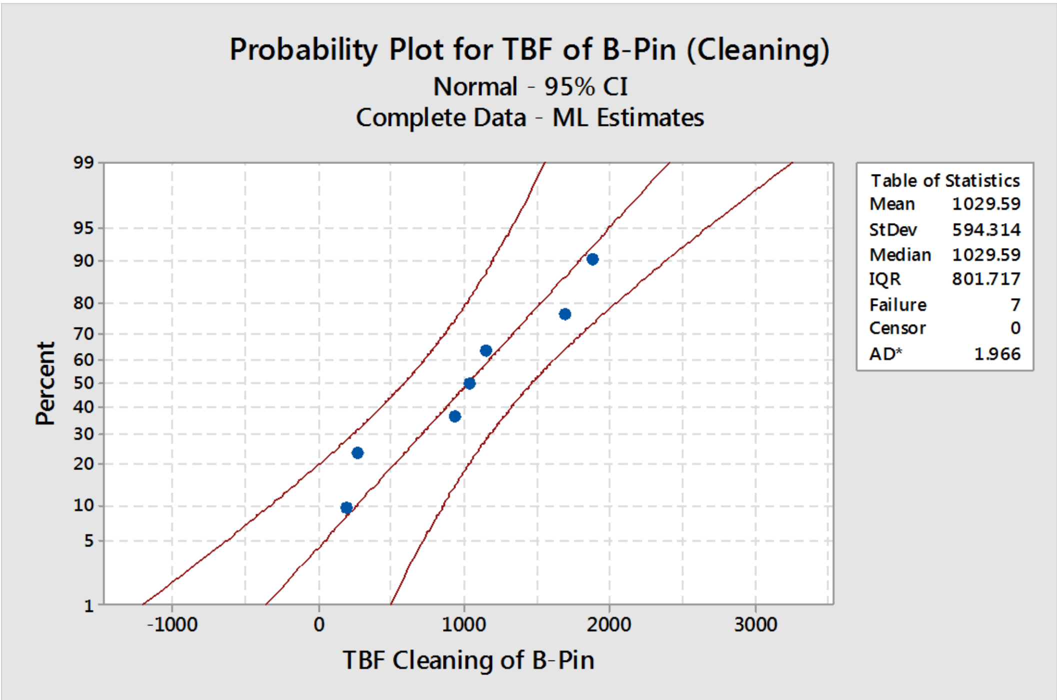

Probability Plot for TTF of Chuck Holder Shaft (Replacement)
Normal - 95% CI
Exponential - 95% CI
Weibull - 95% CI
Lognormal - 95% CI
Percent
TTF Replacement of CHS
Goodness of Fit Test
Normal
AD = 0.434
P-Value = 0.135
Exponential
AD = 1.252
P-Value = 0.037
Weibull
AD = 0.488
P-Value = 0.192
Lognormal
AD = 0.394
P-Value = 0.183


Probability Plot for TTF of Chuck Holder Shaft (Replacement)
Lognormal - 95% CI
Complete Data - ML Estimates
Percent
TTF Replacement of CHS
Table of Statistics
Loc 6.90721
Scale 0.197363
Mean 1019.11
StDev 203.109
Median 999.453
IQR 266.880
Failure 4
Censor 0
AD* 3.102

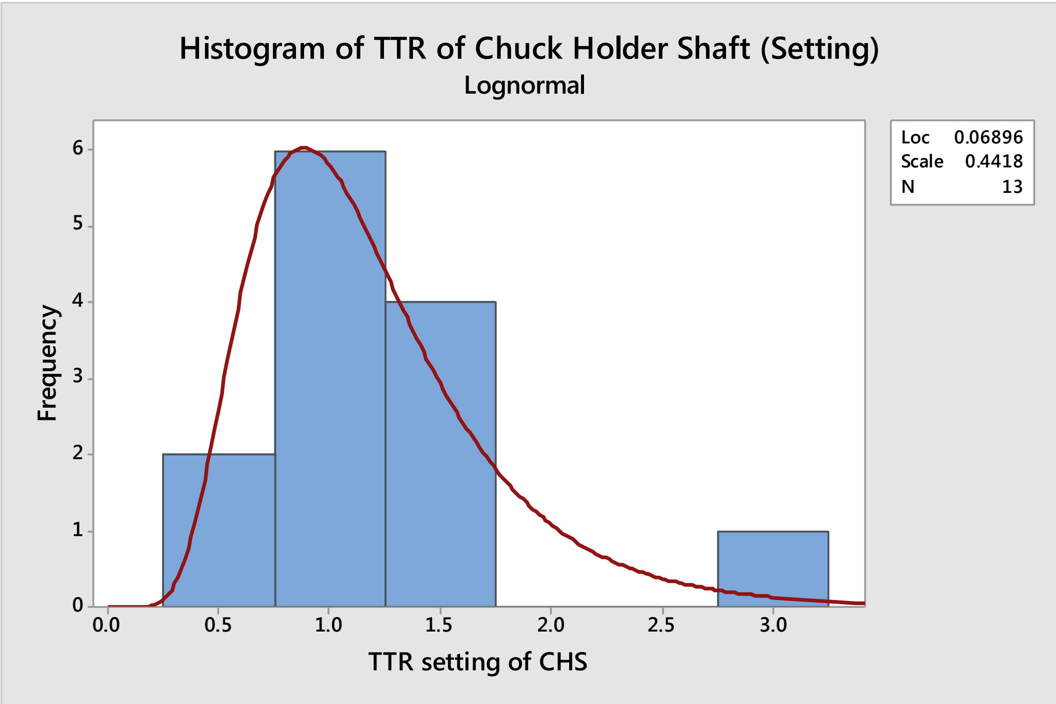

Probability Plot for TBF of Chuck Holder Slip Ring (Repairing)
Normal - 95% CI
Exponential - 95% CI
Weibull - 95% CI
Lognormal - 95% CI
Percent
TBF Repairing of CHSR
Goodness of Fit Test
Normal
AD = 0.943
P-Value = 0.008
Exponential
AD = 0.538
P-Value = 0.392
Weibull
AD = 0.527
P-Value = 0.165
Lognormal
AD = 0.346
P-Value = 0.364

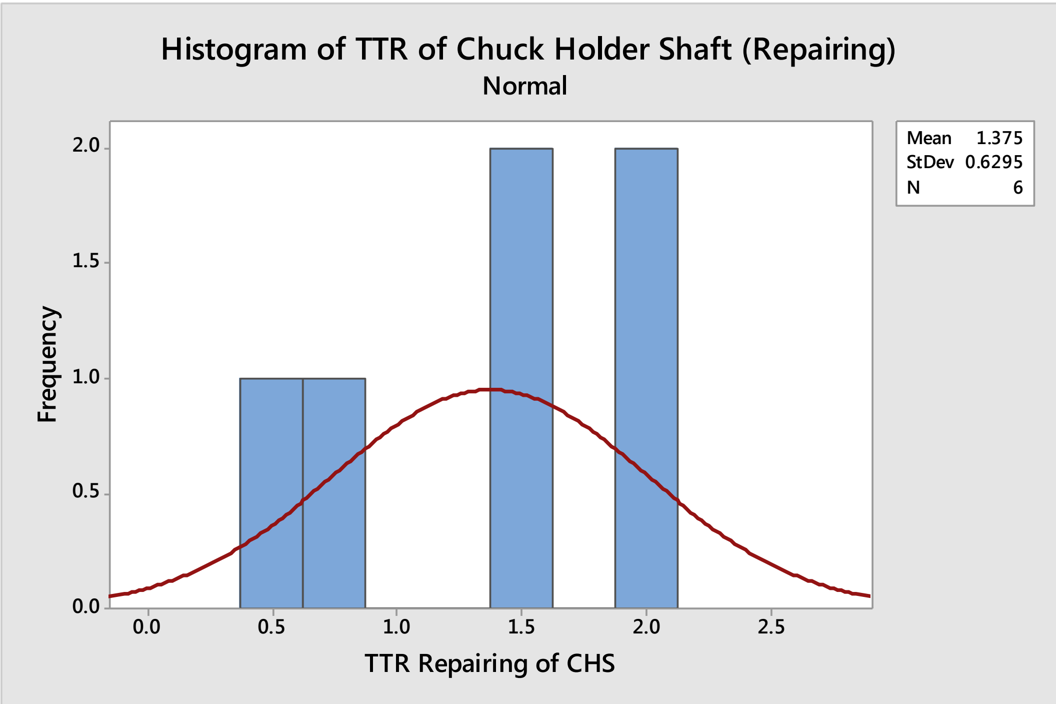

Probability Plot for TBF of Chuck Holder Slip Ring (Repairing)
Lognormal - 95% CI
Complete Data - ML Estimates
Percent
TBF Repairing of CHSR
Table of Statistics
Loc 5.47830
Scale 0.735460
Mean 313.797
StDev 265.813
Median 239.438
IQR 247.415
Failure 7
Censor 0
AD* 2.037

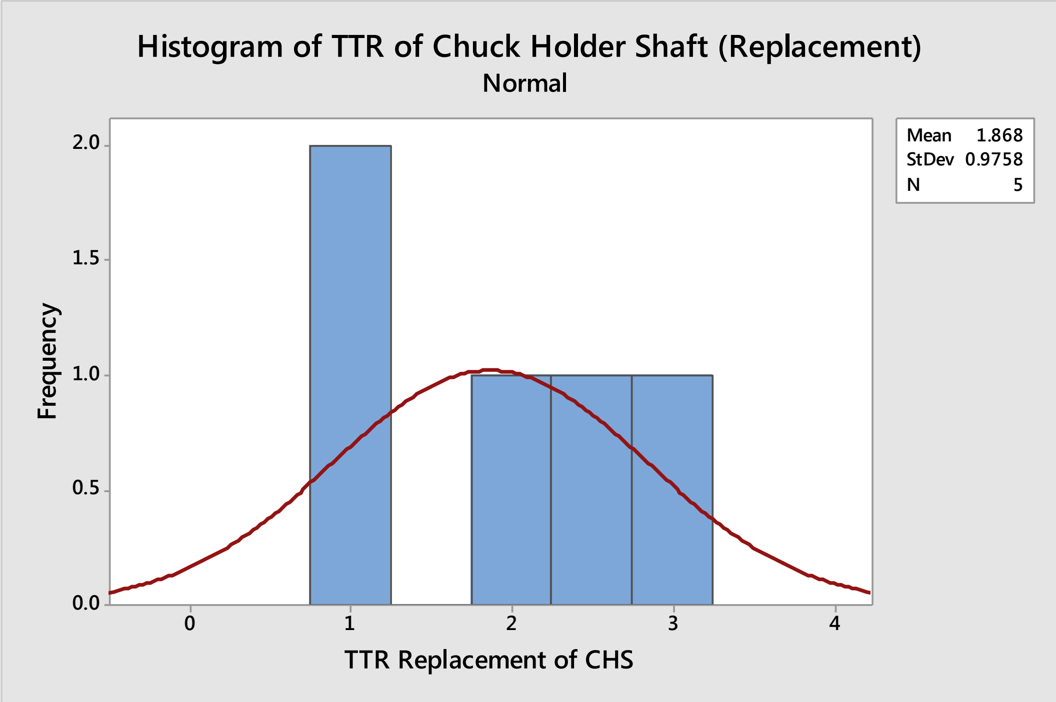

Probability Plot for TBF of B-Pin (Cleaning)
Normal - 95% CI
Exponential - 95% CI
Weibull - 95% CI
Lognormal - 95% CI
Percent
TBF Cleaning of B-Pin
Goodness of Fit Test
Normal
AD = 0.266
P-Value = 0.566
Exponential
AD = 0.591
P-Value = 0.331
Weibull
AD = 0.435
P-Value > 0.250
Lognormal
AD = 0.522
P-Value = 0.118

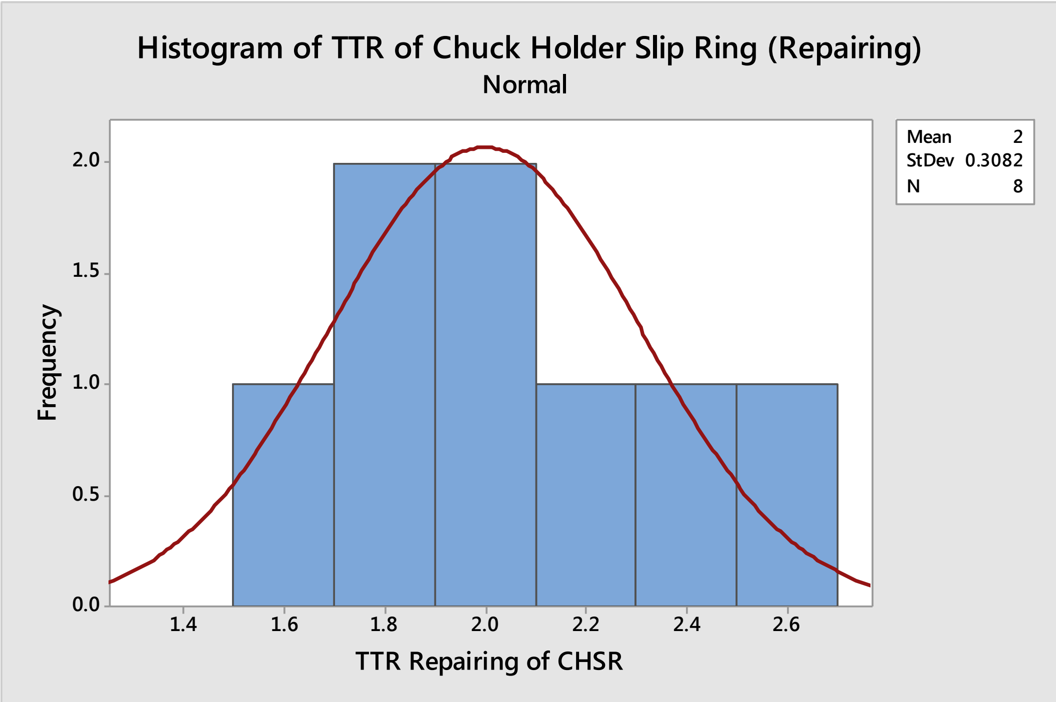

Probability Plot for TBF of B-Pin (Cleaning)
Normal - 95% CI
Complete Data - ML Estimates
Percent
TBF Cleaning of B-Pin
Table of Statistics
Mean 1029.59
StDev 594.314
Median 1029.59
IQR 801.717
Failure 7
Censor 0
AD* 1.966

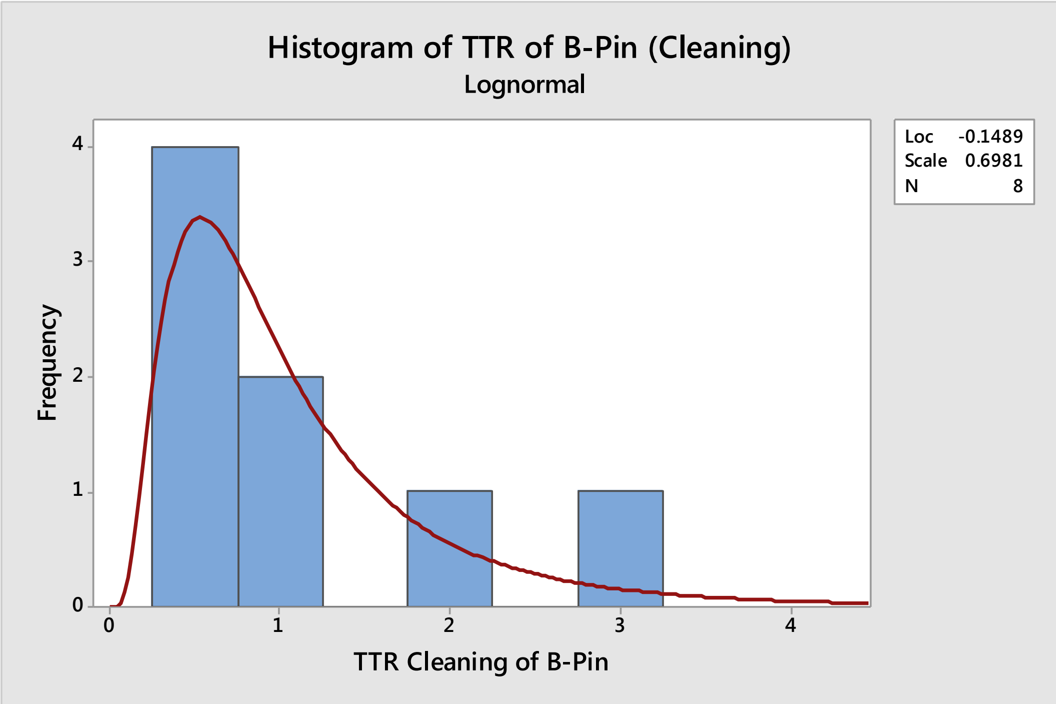
APPENDIX 6 - Histogram

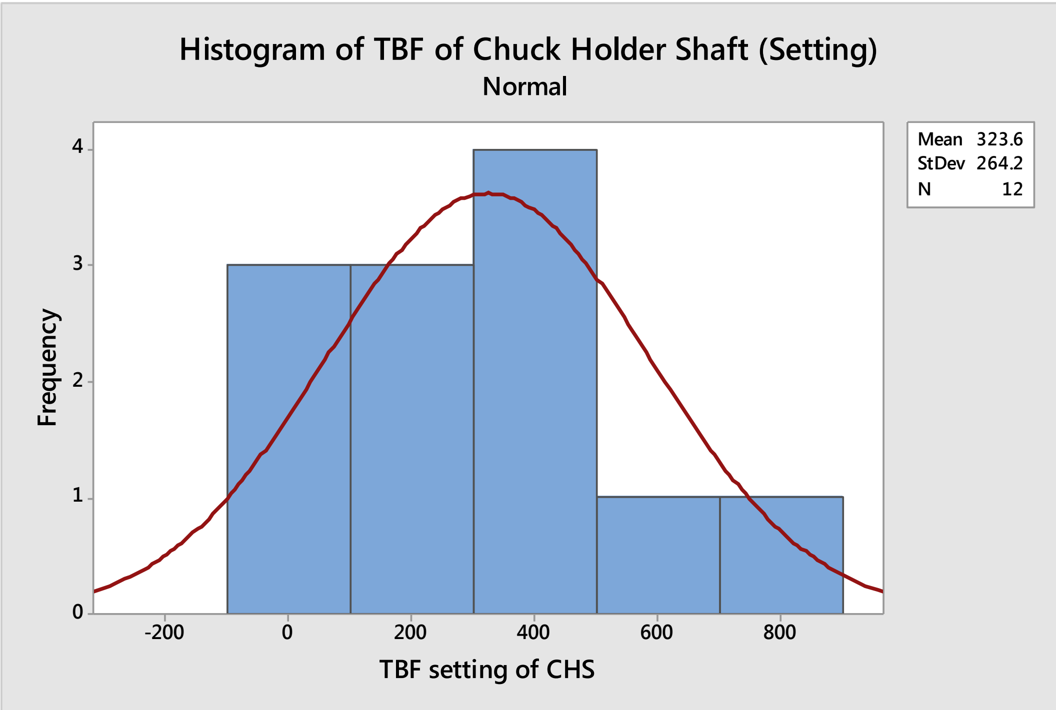


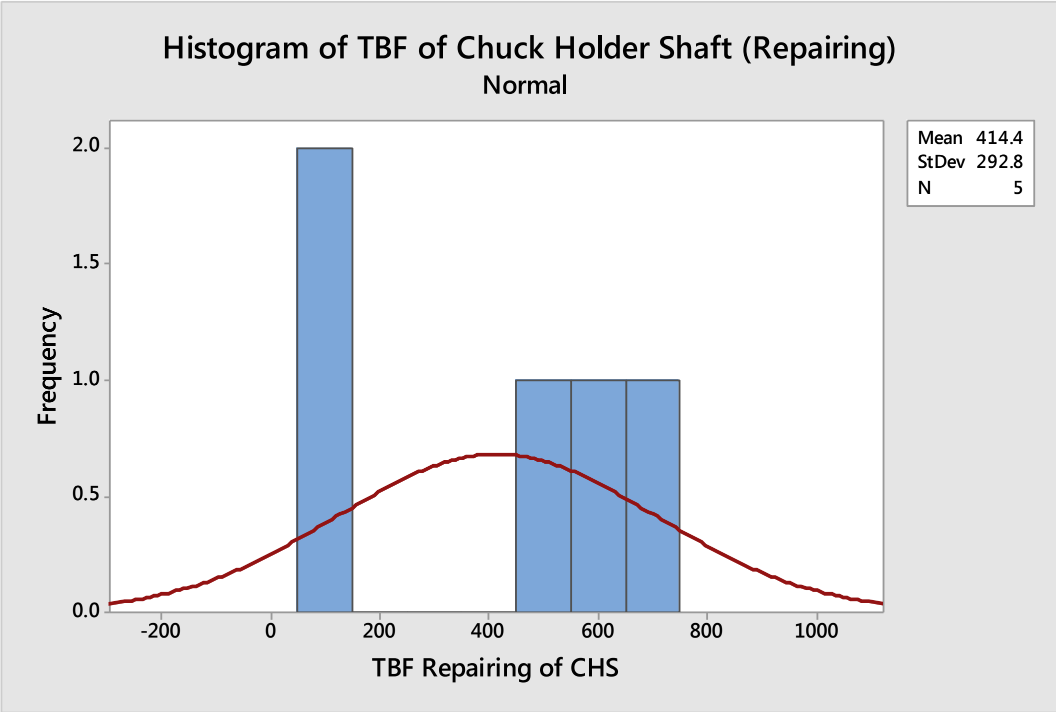


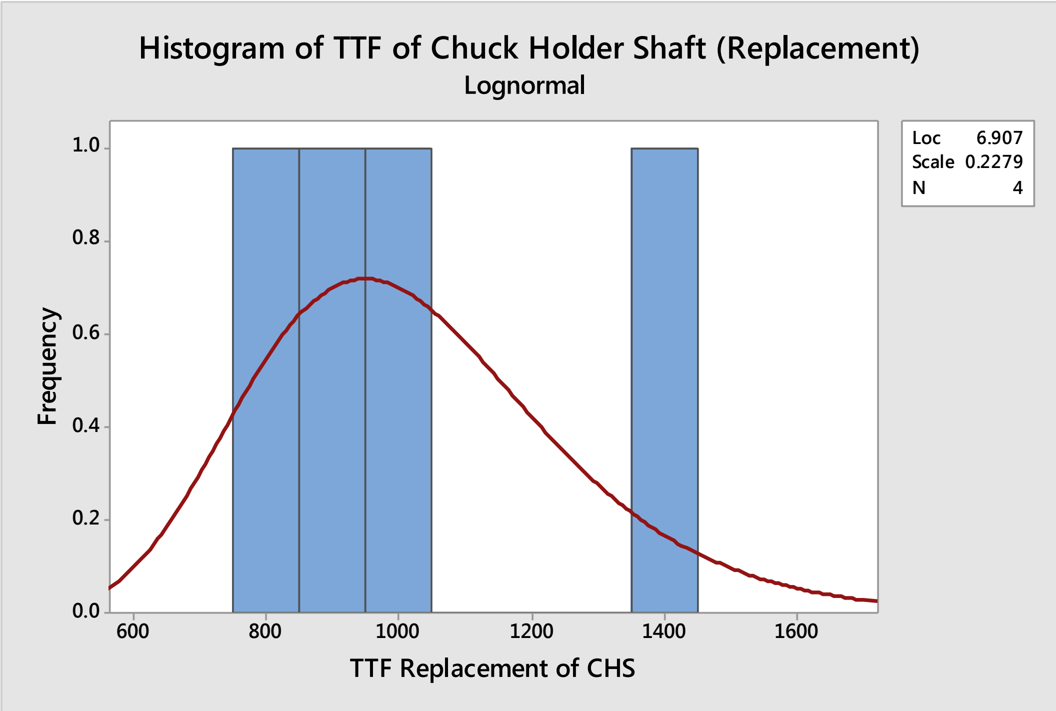

Histogram of TTR of Chuck Holder Shaft (Replacement)
Normal
Mean 1.868
StDev 0.9758
N 5
Frequency
0.0
0.5
1.0
1.5
2.0
0
1
2
3
4
TTR Replacement of CHS

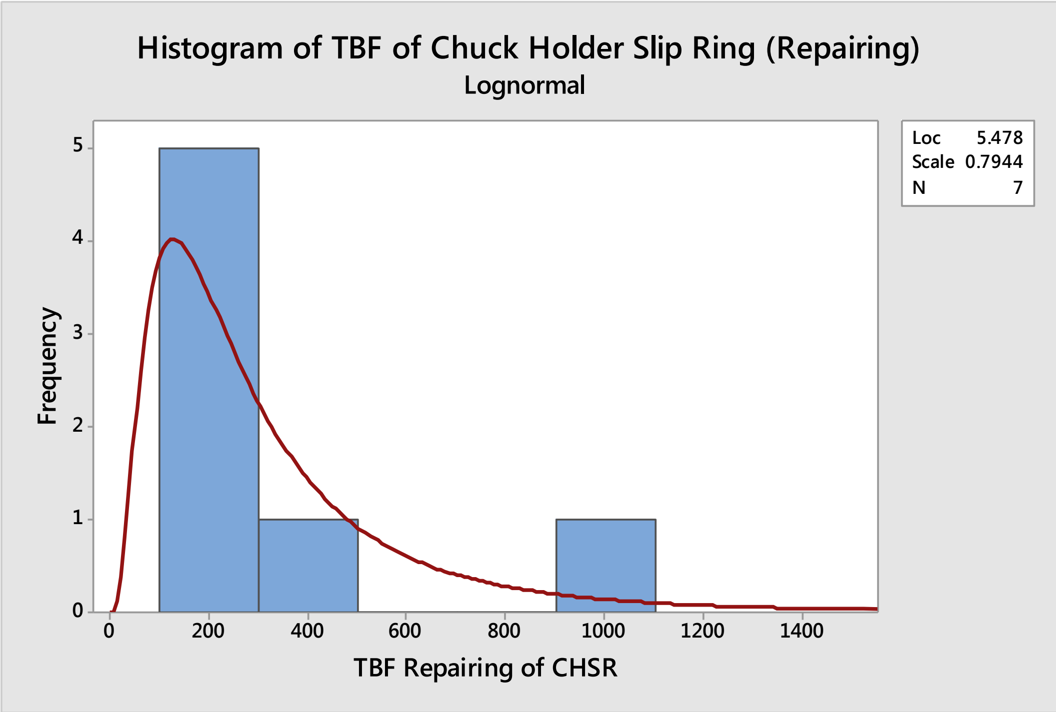

Histogram of TTR of Chuck Holder Slip Ring (Repairing)
Normal
Mean 2
StDev 0.3082
N 8
Frequency
0.0
0.5
1.0
1.5
2.0
1.4
1.6
1.8
2.0
2.2
2.4
2.6
TTR Repairing of CHSR

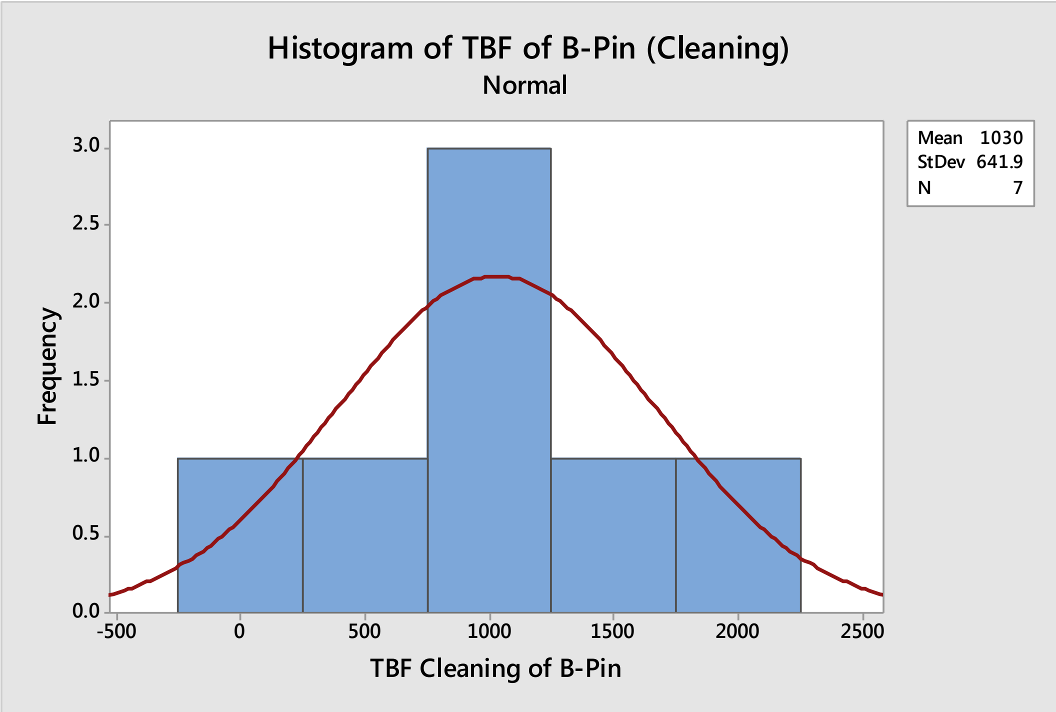

Histogram of TTR of B-Pin (Cleaning)
Lognormal
Loc -0.1489
Scale 0.6981
N 8
Frequency
TTR Cleaning of B-Pin


Histogram of TBF of Chuck Holder Shaft (Setting)
Normal
Mean 323.6
StDev 264.2
N 12
Frequency
TBF setting of CHS


Histogram of TBF of Chuck Holder Shaft (Repairing)
Normal
Mean 414.4
StDev 292.8
N 5
Frequency
2.0
1.5
1.0
0.5
0.0
-200
0
200
400
600
800
1000
TBF Repairing of CHS


Histogram of TTF of Chuck Holder Shaft (Replacement)
Lognormal
Loc 6.907
Scale 0.2279
N 4
Frequency
1.0
0.8
0.6
0.4
0.2
0.0
600
800
1000
1200
1400
1600
TTF Replacement of CHS


Histogram of TBF of Chuck Holder Slip Ring (Repairing)
Lognormal
Loc 5.478
Scale 0.7944
N 7
Frequency
0
1
2
3
4
5
0
200
400
600
800
1000
1200
1400
TBF Repairing of CHSR


Histogram of TBF of B-Pin (Cleaning)
Normal
Mean 1030
StDev 641.9
N 7
Frequency
0.0
0.5
1.0
1.5
2.0
2.5
3.0
-500
0
500
1000
1500
2000
2500
TBF Cleaning of B-Pin

APPENDIX 7 - Proposed Preventive Maintenance Schedule from January to December 2017

January 2017

Sun	Mon	Tue	Wed	Thu	Fri	Sat
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				

February 2017

Sun	Mon	Tue	Wed	Thu	Fri	Sat
			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				

March 2017

Sun	Mon	Tue	Wed	Thu	Fri	Sat
			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	

April 2017

Sun	Mon	Tue	Wed	Thu	Fri	Sat
						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

May 2017

Sun	Mon	Tue	Wed	Thu	Fri	Sat
	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			

June 2017

Sun	Mon	Tue	Wed	Thu	Fri	Sat
				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	

Note:

Green	Chuck Holder Shaft (SETTING)
Blue	Chuck Holder Shaft (REPAIRING)
Amber	Chuck Holder Shaft (REPLACEMENT)
Grey	Chuck Holder Slip Ring (REPAIRING)
Orange	B-Pin (CLEANING)
Light green	Chuck Holder Shaft (SETTING+REPAIRING) and B-Pin
Lavender	Chuck Holder Slip Ring (REPAIRING) and B-Pin
Red	Chuck Holder Shaft (REPAIRING) and Chuck Holder Slip Ring
Cyan	Chuck Holder Shaft (SETTING) and Chuck Holder Slip Ring
Yellow	Chuck Holder Shaft (REPLACEMENT) and Chuck Holder Slip Ring