MAINTENANCE TASK DETERMINATION OF ENGINE DUMP TRUCK COMPONENT USING RELIABILITY CENTERED MAINTENANCE (RCM) AND FUZZY-FMEA METHOD
(AT PA. DARMA TITIPAN)

THESIS

Submitted to International Program
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By

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INTERNATIONAL PROGRAM
DEPARTMENT OF INDUSTRIAL ENGINEERING
UNIVERSITAS ISLAM INDONESIA
YOGYAKARTA
September 2020

AUTHENTICITY STATEMENT

For the sake of Allah SWT, I admit this work is the result of my own work except for the excerpts and summaries from which I have explained the source. If in the future it turns out that my confession is proven to be untrue and violates the legal regulations in the paper and intellectual property rights, then I am willing to get a diploma that I have received to be withdrawn by the Islamic University of Indonesia.

Yogyakarta, September, 2020

METERAI TEMPEL

6000

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MAINTENANCE TASK DETERMINATION FOR ENGINE COMPONENT OF DUMP TRUCK USING RELIABILITY CENTERED MAINTENANCE (RCM) AND FUZZY-FMEA METHOD

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Head of Undergraduate Program-Department of Industrial Engineering Faculty of Industrial Technology
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(Dr. Taufiq Immawan, ST., MM.)

DEDICATION

This thesis is dedicated to my beloved parent who always give me prays and supports that make me able to through all the studying journeys.

This thesis also would not be possible to be completed without the assistance of my supervisor,

Muhammad Ridwan Andi Purnomo, S.T., M.Sc., Ph. D.

MOTIVATIONAL QUOTES

فَبِأَيِّ ءَالَآءِ رَبِّكُمَا تُكَذِّبَانِ

So which of the favors of your Lord would you deny? (Q.S. Ar-Rahman; 13)

PREFACE

Assalamu'alaikum Warahmatullahi Wabarakatuh

Al-hamdu lillahi rabbil 'alamin and Gratitude are presented to Allah the Highest, Glory to Allah Unending, The Exalted, Who granted me the primary inspiration and stamina all along to complete this thesis in acquiring the degree of Sarjana Teknik, entitled "Maintenance Task Determination of Engine Dump Truck Component Using Reliability Centered Maintenance (RCM) and Fuzzy-FMEA Method". Also Blessing of His grace so this thesis project in PA. Darma Titipan can be completed.

The assistance, guidance, support and many helps, either directly or indirectly, from some parties involved. Therefore, thank for those who have been constantly sending supports and motivations in the completing of this thesis report. The author would like to thank:

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3. Dr. Taufiq Immawan, S.T., M.M. as the Head of Undergraduate Program Department of Industrial Engineering Faculty of Industrial Technology Universitas Islam Indonesia.
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The author realizes that there are still shortcomings as well as weaknesses in this report, so the suggestions and critics are fully expected. The author hopes this report would bring advantages for everyone who reads this.

Waasalamu'alaikum Warahmatullahi Wabarakatuh

Yogyakarta, September, 2020

(Dina Farhanah)

ABSTRACT

The intensity growth of coal consumption at industry in Indonesia gives a positive impact for demand of distributor companies especially used dump truck. The condition of the dump truck is important to be maintained to prevent any traffic accidents while distributes. The component of dump truck frequently get failure along with the loss of truck damage is engine component. A proper maintenance task is important to be determined to prevent any failure in the engine component. Therefore, this paper is aimed to find the proposed maintenance task to eliminate or minimize the engine failure. The method of RCM is applied to define the standard function of engine component. The failure analysis is done by using Fuzzy FMEA to minimize the subjectivity at the assessment. The result of Fuzzy FMEA will be classified by using Pareto chart into three classifications; high, medium and low. Afterwards, the LTA is used to classified the failure based on its consequences; safety, outage and minor economic issues. Finally, the maintenance type is defined in accordance to the classification from Pareto and LTA and the maintenance task is defined. The result shows that there are 17 failures on engine component which classified into 9 failures as a high, 4 failures as a medium and 4 failure as a low. While the maintenance task depends on the type of maintenance; preventive maintenance and predictive testing and inspection.

Keywords: RCM, FMEA, Fuzzy, LTA, Maintenance Task

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CHAPTER I

INTRODUCTION

1.1 Background

Indonesia's long history of coal exploration and commercial production began more than 160 years ago, when the colonial era Bureau of Mines began the first coal exploration. The coal industry has subsequently developed mainly in Sumatra and Kalimantan, where the large Cenozoic sedimentary basins include coal deposits with thick seams amenable to low cost mining (Friederich & Leeuwen, 2017). The rapid growth resulted in Indonesia becoming the world's largest steam coal exporter by 2005 (Lucarelli, 2015). Since then, Indonesia has maintained that position. For example, in 2013 it supplied 38% of global steam coal exports, and half of Asia's demand for steam coal imports (Cornot-Gandolphe, 2017), helping to fuel the growing economies of Asia.

In addition to being a major coal exporter, Indonesia's coal mining industry also supplies a rapidly growing domestic market. According to Indonesian Coal Mining Association (APBI) & Ministry of Energy and Mineral, the coal supplies for domestic market has increased since year 2013. The detailed coal domestic supply is represented in Figure 1.1 as follows.

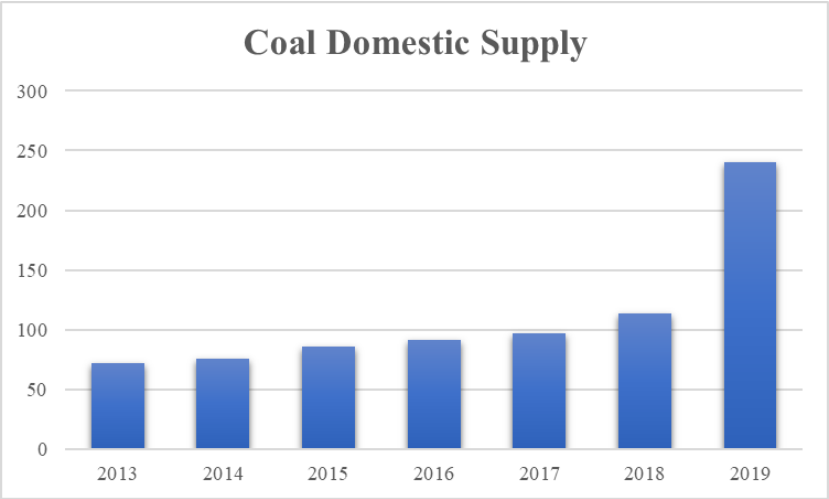


Figure 1.1 Coal Domestic Supply

One of the uses of coal distribution for domestic is used for the needs of industries. According to Directorate of Energy, Mineral and Mining Resources, several industrial sectors of coal users are the cement, metallurgy, pulp, fertilizer and textile industries. The role of coal in these industries is as fuel, except for industry metallurgy, coal is used as one of the raw materials for coke to do iron and steel smelting. Up to the year of 2019, the use of coal for industries in Indonesia has reached a thousand tons of coal. Most of industries used the coal increasingly each year since the advantage of lowering the cost production. For more detail, the recapitulation of the coal used at industrial sector in several years has been done as represented in Table 1.1.

Table 1.1 Domestic Industrial Coal Needs

Domestic Industrial Coal Needs (thousand tons)						
Year	**Cement**	**Fertilizer**	**Metallurgy**	**Pulp**	**Textile**	**Total**
2016	9,727	931	492	1,134	723713	99,722
2017	10,724	973	517	1,190	761257	102,658
2018	10,986	988	542	1,246	798900	121,846
2019	10,986	1,088	567	1,302	836543	180,877

The success of coal supply to industrial sector in Indonesia cannot be separated from the role of coal distributors. The coal producers that located at several islands in Indonesia, such as Kalimantan and Sumatra, are separated from the location of industries. Most of industries in Indonesia located at Java island which is around 369 miles apart by sea from the coal producers. So that to distribute the coal it is needed two kinds of transportation unit which are sea transport and land transport. Sea transport, for instance barge, is used to distribute the coal from the coal producers to the Java island which is anchored in the port. While land transport is used to distribute the coal from the port directly to the industries that separated in many cities in Java island. For this condition, the distributors play an important role to keep coals quality until to the end user of the coal which is the industries.

In the line with the increasing of coal supply for domestic, the distributor companies for coals also facing a growth especially in the land transport. This happened because the distribution of coals to industries scattered in Java island needs a high number of land transportations. Besides, the growth of coal supply for domestic also triggering the transportation growth. The more coal needs to be supplied; the more transportation is need to distribute.

One of port used for anchoring the barge in Java island is Cirebon Port located at Cirebon, West Java. According to Kompas (2019), there are around 100 ships anchored at the Cirebon Port in a month and 80% of them are the coal barge. The coal from Cirebon Port is distributed to industries located at West Java for instance Bandung, Purwokerto, etc. To distribute the coal from Cirebon Port, there are private distributor companies that get contract with the coal provider. These companies provide a kind of dump truck to distribute coals. The distribution mechanism starts from the company getting contract with the coal provider to distribute a certain amount of coal that adjusted to the dump truck capacity. Afterwards, the company will directly distribute the coal to the industries.

PA. Darma Titipan is distributor company involved in the coal distribution from Cirebon Port to industries in West Java. This company has been established since 2007.

Usually, this company distributes the coal from Cirebon Port to industries located at Bandung. The intended industry is textile industry. Based on the interview to the owner of the company, it was found that the company is in a stuck condition where there is no improving since a few years ago. The owner claims that some accidents when distributing the coal are frequently happened in the past few years which causing some big losses. There are two kinds of accidents causes which are external and internal factor.

External factor is all the accident caused from the outside of the company, for instance the road of the truck route. Basically, the route that the truck travelled is quite dangerous. Upward geographical shape coupled with the shape of the road that bent in almost all the route to Bandung are increasing the risk of getting accident in the road. According to the data of traffic accidents location in 2007-2016 from National Transportation Safety Committee, West Java suffer the highest traffic accidents compared to the other province in Indonesia (Saputra, 2017). Figure 1.2 below represents the data of province in Indonesia that the accident was most frequently happened.

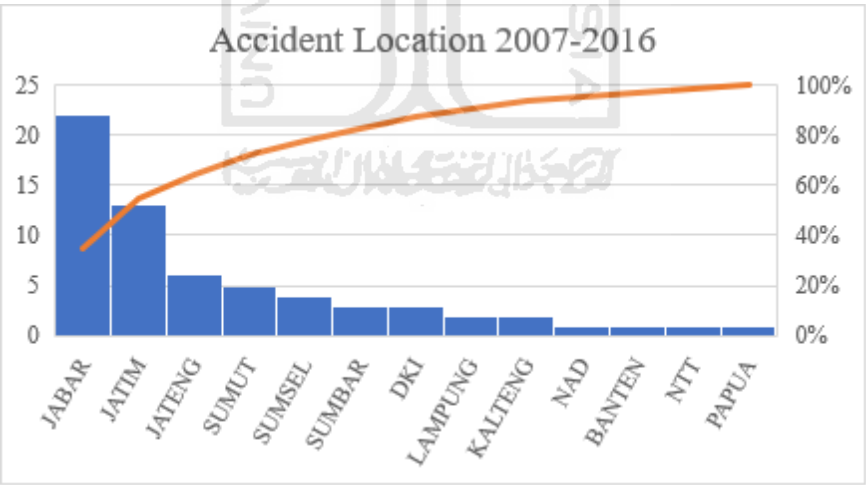


Figure 1.2 Accident Location 2007-2016

The internal factor is all the accident caused by the factor from company. In this case, the internal factor is from the maintenance of the truck in the company. The routine maintenance basically should be done in order to prevent the accident. However, since the

company was built, the type of maintenance used by the company was corrective maintenance which done when there is the part broken. Therefore, usually the company will maintain the dump truck after the accident happen. By this type of maintenance, usually the company cannot prevent the accident because there is some broken part of the truck while distributing the coal to the industries. When the accident happened, it caused a big loss to the company which are the loss of truck damage, the coal compensation to the coal provider, etc.

The data record at PA. Darma Titipan from year 2015 to 2020 shows the broken part causing truck accident along with the loss of truck damage, as depicted in Figure 1.3 below.

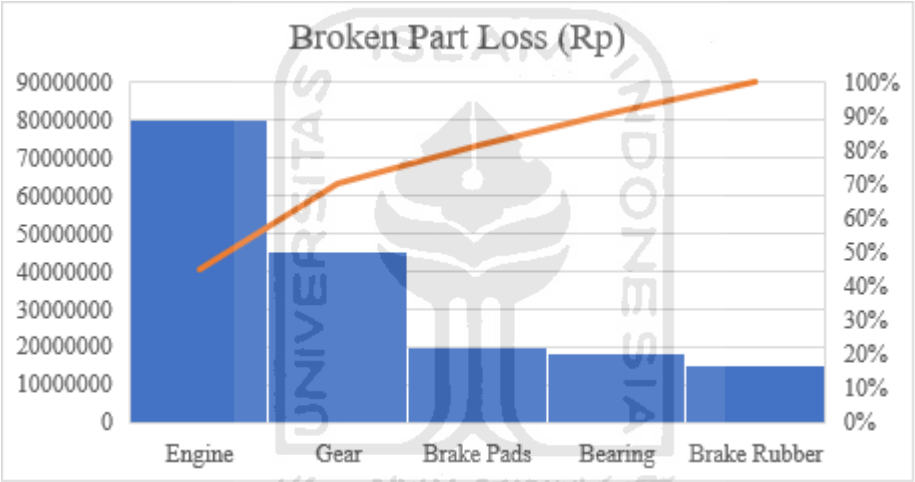


Figure 1.3 Broken Part Loss

According to the data above, the highest loss is in the broken of engine part. Therefore, in order to make a better maintenance, the company need to determine the potential risk might happen of the engine component of the dump truck. Therefore, the analysing of engine failure component should be done to determine the risk that can occur and determine the maintenance strategy to prevent the risk happen. Identifying the potential risk that might happen in the company need to be develop therefore the company can take the control of the risk and prevent the big loss of the company. However, the subjectivity of the data might lead to the inaccurate result of failure analysis. Therefore, the Fuzzy FMEA

is adopted to minimize the subjectivity of experts' assessment in the risk factors evaluation stage.

The method of Reliability Centered Maintenance (RCM) and Fuzzy Failure Mode Effect Analysis (Fuzzy-FMEA) will be used to deal with the problem of the company. RCM is used to determine the standard functions of each part in engine and determine the best maintenance task for each part in engine. This method is chosen because it provides a structured and practical approach for arriving at an acceptable maintenance strategy for each component of a given system. Fuzzy Failure Mode Effect Analysis (Fuzzy-FMEA) is used to identified the effect of failure on the engine and give a rank of each failure to determine the highest risk of failure. This method is chosen since Fuzzy-FMEA method will overcome the subjectivity of given severity, occurrence and the detection in the analysis that make it more accurate. With the help of Pareto chart, the rank of failure comes from the Fuzzy-FMEA will be classified to make a better decision of maintenance strategy. By having these methods, the company can determine the appropriate maintenance task to eliminate or minimize the effects of the failures and prevent the big loss in the company.

1.2 Problem Formulation

According to the research background, the problem can be formulated, what are the proposed maintenance task to eliminate or minimize the engine failure at PA. Darma Titipan.

1.3 Research Objectives

According to the problem formulation, therefore this research has an objective to find the proposed maintenance task to eliminate or minimize the engine failure at PA. Darma Titipan.

1.4 Research Limitation

The limitation of this research are as follows:

1. This research does not analyse the dump truck below year 2005.
2. This research does not analyse the dump truck above year 2015.
3. This research does not analyse the other component of dump truck rather than the engine.
4. The maintenance strategy does not consider the other aspects rather than the performance aspect.

1.5 Research Benefits

By doing this research, it is expected to provide benefits to some parties involved in this research. Expected benefits include as follows:

1. Adding the knowledge of the researchers and companies about the risk of failure that exists in the engine of dump truck at PA. Darma Titipan.
2. Knowing the handling that needs to be done to manage the risk of failure that exists in the engine of dump truck at PA. Darma Titipan.
3. Giving suggestion for the improvement at PA. Darma Titipan in managing the causes of risks.

1.6 Systematical Writing

In order to make this writing and compiling thesis is easy to understand, writing thesis uses the following writing system:

CHAPTER I INTRODUCTION

This chapter contains a preliminary description of the research which consists of the background of the problem, formulation of the problem, the objective to be achieved in the research, the benefits of the research and systematic writing. According to the background, the objective of this research is to propose maintenance task to eliminate or minimize the engine failure at PA. Darma Titipan.

CHAPTER II LITERATURE REVIEW

This chapter consists the previous study that discussed the topic that related to this research (inductive study) which stated that by using the RCM and Fuzzy FMEA method, it can identify the maintenance task. Moreover, this chapter also discussed the theories that support this research (deductive study).

CHAPTER III RESEARCH METHODOLOGY

This chapter consists of explanation of the research framework in detail as well as the research subject which is PA. Darma Titipan, research object which is the engine component of dump truck, data types which are primary and secondary data, and the research flow.

CHAPTER IV DATA COLLECTING AND PROCESSING

This chapter consists of the data obtained during the research in the form of description, table and the analysis. Data collection consists of FMEA data and Fuzzy logic. In FMEA, the data are engine

component and its function, failure mode, effect of failure and its severity, causes and occurrence, current control and detectability value. In Fuzzy logic, the data are input and output membership function and the fuzzy rule base. While data processing is processed the collected data using MATLAB software and LTA to determine the failure classification. The selected failure will be simulated its reliability to determine the maintenance task.

CHAPTER V DISCUSSION

This chapter consists of further explanation of the result from the data processing that was held in chapter IV.

CHAPTER VI CONCLUSION AND RECOMMENDATION

This chapter consists of the conclusion of the analysis and any recommendation based on the result that have been analyzed during the research.

REFERENCES

APPENDIX

CHAPTER II

LITERATURE REVIEW

This chapter explains the basic theory used in doing research. This chapter will discuss the inductive and deductive study. Inductive study will explain the previous research relates to this research. While deductive study will explain the theory in this study that covers the concept of Reliability Centered Maintenance (RCM), Fuzzy Failure Mode and Effect Analysis (Fuzzy-FMEA) and Pareto Chart.

2.1 Inductive Study

Gupta et al., (2016) conducted research on conventional lathe machine. A study on reliability centered maintenance (RCM) has been conducted to reduce the total number of failures and its effects on the conventional lathe machine. The risk priority number (RPN) is one of the key factors in determining the critical ranking of a failure mode of the mechanical equipment. The result presents that 43% of the component are highly critical, 29% of the components are low critical and 28% of the components are medium critical. RCM logic is used to suggest the strategy for maintenance which in general shows that the CM strategy is used for low critical components and periodical predictive maintenance strategy for the high critical components, is mostly used.

Abdel-Aziz & Helal (2012) conducted research on large-sized axial plunger pump in an Egyptian fertilizers production plant. The failure mode and effects analysis (FMEA) has been used in identifying and reducing risks of failures in systems, equipment, and components following a bottom-up approach. The technique has been criticized for being unintuitive and cumbersome. The fault tree analysis (FTA) follows a top-down approach to identifying the root causes of failures. The FMEA results indicate that the critical components of the system are the gear box pumps command and oil cycle. This result comes from the relatively high severity of the failures in these components.

Suryoputro, et al (2019), conducted research at a manufacturing company, PT. XYZ, to carry out risk management on machines that had low performance (forklift machine). The method used in this research was Fuzzy FMEA (Failure Mode and Effect Analysis), in order to obtain priority in repair and maintenance of forklifts. The result of this study was that the failure mode of the hydraulic hose rupture got the highest FRPN (Fuzzy RPN) value of 631 so that the hydraulic part with the failure mode of the broken hydraulic hose was recommended to be the main focus in the repair and maintenance of the forklift. The result of using Fuzzy FMEA was more proposed as a reference focus to get more objective risk management compared to conventional FMEA results in machine repair and maintenance.

Balaraju, et al. (2019), conducted research to evaluate Load-Haul-Dumper LHD machine. In conventional FMEA, the estimation of RPN is made by multiplying the Severity (S), Occurrence (O) and Detection (D) alone and irrespective of the degree of importance of each input. Hence, a new risk management approach known as the Fuzzy rule base interface system was proposed in this research in order to mitigate the failures. There are 16 potential risks of various sub-system breakdowns were identified in Fuzzy FMEA. The highest value of RPN 168 (for potential failure mode-F9) was obtained for the electrical subsystem (SSE), as was the highest FRPN 117 (F9). The FRPN value is obtained from Fuzzy field generation with consideration of the degree of importance of the given input data.

Duminica, et al. (2011) conducted research on the functioning of a water meter used in domestic application. The FMEA analysis was based on the causes and effects diagram. In order to obtain a risk prioritization that would reflect better the customer perception in terms of dissatisfaction, a fuzzy computation of the RPN was proposed. The results obtained by fuzzy inference provide a hierarchy of potential risks that differs from the ranking established by typical computation of the RPN, but reflect more accurately the dissatisfaction felt by the customer that faces the effects of a certain failure mode. Also, the fuzzy inference does not allow identical values of RPNs to appear for different sets of risk factors. The method can be extended considering even more risk factors.

Shirouyehzad, et al. (2010), conducted research on ERP implementation. One of the most significant methods for defect prevention is FMEA. Fuzzy logic as complementation of FMEA measures the degree of membership in a class instead of arguing over inclusion or exclusion. Fuzzy-FMEA is used as a preventive technique to decrease the failure rate in ERP implementation. The proposed Fuzzy-FMEA also identifies the major failure causes and effect of potential defects in ERP implementation by using fuzzy number. Then failure preferences can be characterized by the severity, occurrence and detection fuzzy values and overall fuzzy risk priority number.

Haq, et al. (2015), conducted research on case study within powertrain sector of the automotive assembly line. A fuzzy based approach is proposed for FMEA in this study. The proposed fuzzy algorithm allows the experts to utilize linguistic variables for determining Severity, Occurrence and Detection factors. The Fuzzy-FMEA is presented in order to highlight the most critical risk type among six common risk types.

Widianti & Firdaus (2018), conducted research focusing on the analysis of risk in refrigerator temperature. Fuzzy-FMEA implementation in this test is conducted as precaution toward risk failure in testing as require on SNI ISO/IEC 17025:2008. The case study of temperature testing of refrigerator has been selected since is it a one of the products that are required to obtain SNI Marking Product Certificate (SPPT-SNI) refers to SNI IEC 60335-2-

7:2009 standard. The Fuzzy-FMEA result show that the highest failure risk in the process of temperature testing of refrigerator occurs in failure mode: power source unexpectedly shutdown with RPN value is 5.8887.

Hidayat, et al. (2010), conducted research to discusses maintenance activity planning using the RCM II method to evaluate failure function risk on compressor screw. The calculation of maintenance time is performed by considering maintenance and repair costs. The risk evaluation result with RPN shows that the critical component that needs to get the main priority in applying maintenance on compressor screw is function disorder on timeworn piston and on the broken outgoing air sponge's filter that receives RPN 45. The optimum maintenance time calculation is applied on components that undergo scheduled restoration and scheduled discard task so that this action becomes technically feasible in decreasing the consequence of damage. The optimum maintenance time value that is acquired to prevent damage on compressor screw is lower than the value of its MTTF, which demonstrates that optimum maintenance time will be significant in avoiding component function damage before the damage happens.

Mansur & Ratnasari (2015), conducted research to analyse the bagging scale machine by comparing the method of FMEA and Fuzzy-FMEA. When compared with actual conditions in the packaging unit in the company, the method Fuzzy FMEA is more suitable to be applied in terms of risk management assessment. This is caused if only using FMEA method only, not all experts have the same ability in handle cases.

Shamayleh, et al. (2019), conducted research to analyse maintenance management-related activities for medical equipment. The method used is Reliability-Centered Maintenance (RCM) and Failure Mode and Effect Analysis (FMEA). The analysis highlights the inability of traditional time-driven preventive maintenance alone in preventing failures. Thus, a systematic RCM approach focused on criticality is more beneficial and more time and cost effective than traditional time-driven preventive maintenance practices.

Okwuobi, et al. (2018), conducted research on individual section-forming machine (ISM); a glassblowing machine for making glass bottles. In this work, information is provided on the steps and procedures to identify critical components of the ISM using failure modes and effect analysis (FMEA). A relationship between the failure rate of the machine components and the maintenance costs was established such that using the recommended PM program demonstrates evidence of an improvement in the machine's availability, safety, and cost-effectiveness and will result in an increase in the company's profit margin.

Afefy (2010), conducted research on steam-process plant to identify the cost-effective maintenance. Applying of the reliability-centered maintenance methodology showed that the main time between failures for the plant equipment and the probability of sudden equipment failures are decreased. The proposed PM planning results indicate a saving of about 80% of the total downtime cost as compared with that of current maintenance. In addition, the proposed spare parts programs for the plant components are generated. The results show that about 22.17% of the annual spare parts cost are saved when proposed preventive maintenance planning other current maintenance once. Based on these results, the application of the predictive maintenance should be applied.

Table 2.2 Literature Review

No.	Author	Year	Object	Review			
				RCM	FMEA	Fuzzy-FMEA	Pareto Chart
1.	Gupta, et al.	2016	Conventional Lathe Machine	√	√		
2.	Abdel-Aziz & Helal	2012	Large-sized axial plunger pump	√	√		
3.	Suryoputro, et al.	2019	Forklift machine		√	√	
4.	Balaraju, et al.	2019	LHD machine		√	√	
5.	Duminica, et al.	2011	Functioning of a water meter		√	√	
6.	Shirouyehzad, et al.	2010	ERP implementation			√	
7.	Haq, et al.	2015	Automotive powertrain			√	

No.	Author	Year	Object	Review			
				RCM	FMEA	Fuzzy-FMEA	Pareto Chart
			assembly systems				
8.	Widianti & Firdaus	2018	Refrigerator temperature		√	√	
9.	Hidayat, et al.	2010	Compressor screw	√	√		
10.	Mansur & Ratnasari	2015	Bagging scale machine		√	√	
11.	Shamayleh, et al.	2019	Medical equipment	√	√		
12.	Okwuobi, et al.	2018	Individual section-forming machine	√	√		
13.	Afefy	2010	Steam-process plant	√	√		
14.	Author	2020	Engine component of dump truck	√		√	√

Based on the above previous researches about maintenance strategy especially using the method of reliability centered maintenance (RCM), this research can be differentiated based on the methods are being used. The method of RCM is commonly used to identified maintenance strategy since it provides way to select appropriate maintenance strategy. However, this method has weakness on its limited assessment of risk and uncertainty. Therefore, the method of failure mode and effect analysis (FMEA) is commonly used to identify the risk of failure. FMEA is mostly used because of its failure assessment that used three parameters; severity, occurrence and detection. However, FMEA has weakness related to the subjective verdict of the risks that lead to improper priorities setting based on RPN significance. To handle its subjectivity, the use of fuzzy logic is the better option to prevent the improper RPN result. Some researchers have analysed the failure of some different products using different approach of FMEA and Fuzzy-FMEA. Most of the researchers conclude that the use of Fuzzy-FMEA is more suitable to be applied in risk assessment. Therefore, this research will focus on the method of RCM with Fuzzy-FMEA. In order to prevent the plagiarism, this research will use pareto diagram to analyse the classification of

the failure. The classification will be divided into three which are high, medium and low. Therefore, the maintenance strategy will consider the degree of failure.

2.2 Deductive Study

2.2.1 Reliability Centered Maintenance (RCM)

Reliability centered maintenance is a process used to determine the maintenance requirement of any physical assets in its operating context (Islam, 2010). According to Maintenance Steering Group (MSG-1), RCM is defined as a logical discipline for the development of scheduled maintenance programs (Al haiany, 2016). Therefore, RCM focused towards preserving equipment functionality and used to selection of appropriate maintenance strategy for each equipment (Huang, et al, 2012). The RCM has several steps (Kullawong & Butdee, 2015):

Step 1: System selection and data collection

The first step for RCM analysis process is to select a critical asset (equipment, system or a component). The critical asset is the asset that gives most pain to the company. It could be critical due to its effect on safety, environment, operations, its previous costs of repair and previous costs of preventive maintenance.

Step 2: System boundary definition

After the previous step, the system (or part, component or the facility) boundaries should be determined. This step is important in the RCM analysis process. According to (Hinchcliffe, et al, 2004), the precise system boundary definition is essentially important for a reason; there must be precise knowledge of what has or has not been included in the system, so an accurate list of components can be identified or, conversely, so the identified components will not overlap with components in an adjacent system.

Step 3: System description and function block

After selecting the system and collecting the information regarding the first system, the essential details of the selected system should be identified and documented.

Step 4: System function failures

In this step, for the intended system (or subsystem), functional failure will be written.

Step 5: Failure mode effect analysis

In this step, the Failure Mode that potentially could produce unwanted functional failure will be identified. By other words, FMEA will be used to identify the potential failure mode or failure cause and illustrates their effects.

Step 6: Logic tree diagram

In this step, the failure modes are further classified in a qualitative process, called logic tree or decision tree analysis (LTA). The purpose of this step is to prioritise the resources that could be devoted to each failure mode.

Step 7: Task selection

After completing the previous six steps, the most appropriate maintenance task for each failure mode is determined. The maintenance task which is selected must be technically appropriate (applicable) and worth done (cost effective).

The reliability analysis is obtained by using Equation 2.1 as follows.

$$R(t) = e^{-\lambda t} \qquad \text{... (2.1)}$$

Where,

R(t)	:	Reliability
λ	:	Failure rate parameter
t	:	Time

In general, reliability can be defined as the probability that a system or product can operate properly without experiencing damage to a certain condition and a predetermined time. While maintenance is the main supporting activity aimed at ensuring the functional continuity of a production system (equipment) therefore when it is needed it can be used according to the expected conditions. Basically, the RCM is divided into 3 components;

1. Reactive Maintenance

Reactive maintenance which is also commonly called breakdown maintenance, fix-fail maintenance, run-to-failure maintenance, or repair maintenance. This approach performs component / engine replacement only when the component or machine does not work in accordance with its function.

2. Preventive Maintenance

Preventive maintenance (PM), also called time-driven maintenance or interval-based maintenance, is carried out regardless of the condition of the components. Preventive maintenance activities consist of periodic inspection schedules, component replacement, component repairs, engine adjustment adjustments, calibration, lubrication, and cleaning. preventive maintenance is scheduled regularly with a few checks and maintenance at intervals in order to reduce the failure of components that are prone to malfunction. In determining the time interval for PM implementation, the parameters used are Mean Time Between Failure (MTBF).

3. Predictive Testing and Inspection

predictive testing and inspection is also often referred to as predictive maintenance. To determine the condition of a machine, PTI uses performance data, non-intrusive test techniques, and visual observation.

2.2.2 Failure Mode and Effect Analysis (FMEA)

One of the failure analysis techniques that has been applied in various fields is Failure Mode and Effect Analysis (FMEA). A hardware-oriented or bottom-up approach is emphasized in FMEA analysis which is characterized by an analysis process carried out starting from the equipment or process and forwarding it to a system that is a higher level (Liu, et al, 2015). According to Shaker, Shahin & Jahanyan (2019), FMEA defines as "a systematic method of identifying and preventing product and process problems before they occur". Based on the definition given, it can be understood that FMEA has the purpose of examining the process and the product to determine the possibility of failure by identifying potential failures, the consequences and the possibility of emergence.

FMEA can be used both to analyze failure modes in processes and products. In this study, the FMEA used was the FMEA product which is the dump truck. According to Gugaliya, Boral & Naikan (2019), FMEA is done by using three indicators, namely severity (S), occurrence (O) and detection (D). To determine the priority value of failure mode, the three indicators are multiplied and generate Risk Priority Number (RPN). This RPN shows the priority level of a failure mode obtained from the results of the analysis of the analysed process. The higher the RPN value, the higher the order of improvement. The RPN value is calculated using Equation 2.1 below:

$$RPN = S \times O \times D \qquad \text{... (2.2)}$$

Where:

S = Severity, O = Occurrence, D = Detection

S value or severity is an assessment of the seriousness of an effect or result of potential failures in the analyzed process. A scale of 1 to 10 is used to determine the severity value. The value of O in the analysis reflects the probability or chance of failure occurring while the value of D is the chance of failure that can be detected before it occurs. The grading scale of O, D is the same as the value scale S, from 1 to 10, the difference is the description at each scale.

When applying FMEA to a process, the elements of analysis in the process need to be considered. So, the first step that must be done is to identify the process and its elements. Then a table of ranges of values for S, O, and D values can be made which can be seen in the Table 2.2 until Table 2.4 respectively.

Table 2.3 Severity Description

Ranking	**Severity**	**Description**
10	Hazardous - no warning	System failures that produce very affect dangerous
9	Hazardous - with warning	System failures that produce harmful effects
8	Very high	The system is not operating
7	High	The system operates but cannot be run in a manner
6	Moderate	The system is operating and safe but has decreased performance so that it affects output
5	Low	A gradual decline in performance
4	Very low	Minor effect on system performance
3	Minor	Small effect on system performance
2	Very minor	Negligible effect on system performance
1	None	No effect

Table 2.4 Occurrence Description

Ranking	Occurrence	Description
10	Very high	Often fails
9		
8	High	Repeated failures
7		
6	Medium	Failure rarely happens
5		
4	Low	Very small failure occurs
3		
2	No effect	Almost no failure
1		

Table 2.5 Detection Description

Ranking	Detection	Description
10	Uncertain	Check will always be unable to detect potential causes or mechanisms of failure and modes failure.
9	Very small	Check have a very remote possibility able to detect potential causes or mechanism failures and failure mode.
8	Small	Checks have a possibility of remote to be able to detect potential causes or mechanism of failure and failure mode.
7	Very Low	Checks have a very low probability of being able to detect potential causes of failure and failure mode.
6	Low	Checking has a low likelihood of being able to detect potential causes or mechanism of failure and failure mode.
5	Moderate	Checking has a moderate possibility to detect potential causes or mechanism of failure and failure mode.
4	Middle and above	Checks have a moderately high possibility to detect potential causes or mechanism of failure and failure mode.
3	High	Check has a high likelihood of detecting potential causes or mechanism of failure and failure mode.
2	Very high	Check has a very high probability of detecting potential causes or mechanism of failure and failure mode.
1	Almost certain	Check will always of detecting potential causes or mechanism of failure and failure mode.

2.2.3 Fuzzy Logic

Fuzzy logic is developed for solving problems where parameters are description are subjective, vague and imprecise, was considered a promising tool for directly manipulating

the linguistic term used for the description of severity, occurrence and detection (Duminica et al, 2011). Fuzzy logic is the tool for transforming the vagueness of human feeling and recognition and its decision-making ability into a mathematical formula. It also provides meaningful representation of measurement for uncertainties and vague concepts expressed in natural language (Kutlu & Ekmekcioglu, 2012).

In Fuzzy-FMEA, the risk indexed parameter such as severity (S), occurrence (O) and detection (D) are fuzzified with suitable membership function. The concept of Fuzzy-FMEA is described as follows:

a. Fuzzification

Fuzzification is a process used to transform input parameters into membership degree quantities, which express the input parameters in the form of qualitative linguistic terms (Sharma et al., 2005).

b. Fuzzy Rule Based

The fuzzy rule base explains the level of criticality of a system for each combination of input variables. In general, the combination of input variables can be created in linguistic form, for example, by using rule-based logic like “if – then”, “or – else” etc. This can be created in two different ways namely, (i) Familiarity and proficiency of a specialist (ii) Process of the Fuzzy based model (Yang, 2007).

c. De-fuzzification

De-fuzzification is a process of looking at standard results after they have been normally included and that they will be the final output responses of the fuzzy controller. During de-fuzzification, the controller exchanges the fluffy yield into response information (Sharma et al., 2005).

2.2.4 Logic Tree Analysis (LTA)

Logic Tree Analysis (LTA) is a qualitative process that is used to find out the consequences caused by each failure mode (Azis, et al, 2010). The purpose of this method is to prioritize further the resources that are to be committed to each failure mode. This is done since each failure mode and its impact on the whole plant is not the same. Any logical scheme can be adopted to do this ranking. RCM processes a simple and intuitive three question logic of decision structure that enables a user, with minimal effort, to place each failure mode into one of the four categories (Ibrahim & Rosmiati, 2019). Each question is answered yes or no only. Each category which is also known as bin forms natural segregation of items of respective importance. The categories of LTA are A, B, C, D/A, D/B or D/C. For the priority scheme, A and B have higher priority over C when it comes to allocation of scarce resources and A is given higher priority than B. In summary, the priority for PM task goes in the following order: A or D/A; B or D/B; and C or D/C.

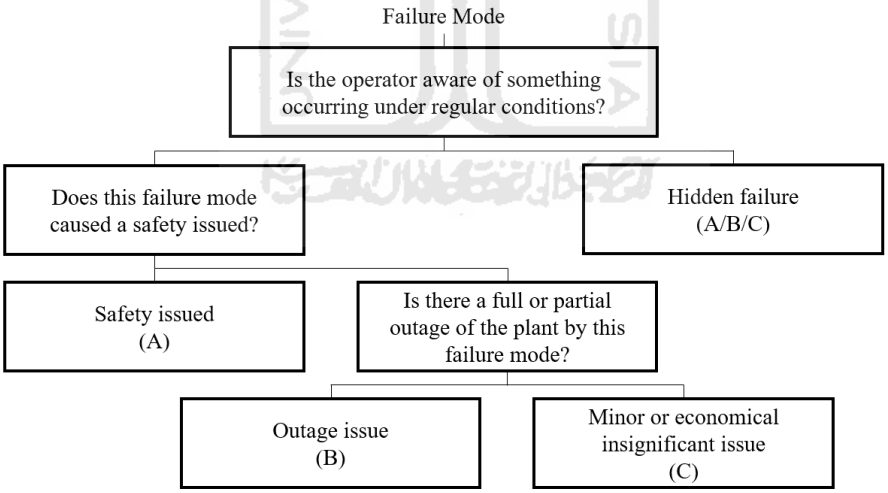


Figure 2.4 Logic Tree Analysis Concept

2.2.5 Pareto Chart

The Pareto chart is useful for non-numeric data, such as ‘cause’, ‘type’ or ‘classification’ and is useful to prioritize where action and process changes should be focused and are commonly used for identifying the downtime and other wastages (Hossen et al, 2017). The Pareto chart is a graphical display of the Pareto principle. When observing events, it is often a phenomenon that approximately 80% of events are due to 20% of the possible causes (Franch et al, 2015). It uses bar diagrams to sort problems based on frequency, severity, nature, or source and displays them size which problems are vital ones (Benjamin, Marathamuthu, & Murugaiah, 2015).

CHAPTER III

RESEARCH METHODOLOGY

3.1 Research Subject

The subject of this research is PA. Darma Titipan, the coal distributor company, located at Randu Alas Street, Kedawung, Cirebon, West Java. This research focus on the engine component of dump truck.

3.2 Research Object

The object of this research is the list of engine component of dump truck, the failure mode of the component and its severity, the causes of the failure and its probability of occurrence, the existence control to the failure and its detectability value, the Fuzzy Risk Priority Number (F-RPN) and the maintenance strategy of the engine failure of dump truck at PA. Darma Titipan.

3.3 Data Types

In this research, there are two types of data would be used. Those data will be explained as follows:

1. Primary Data

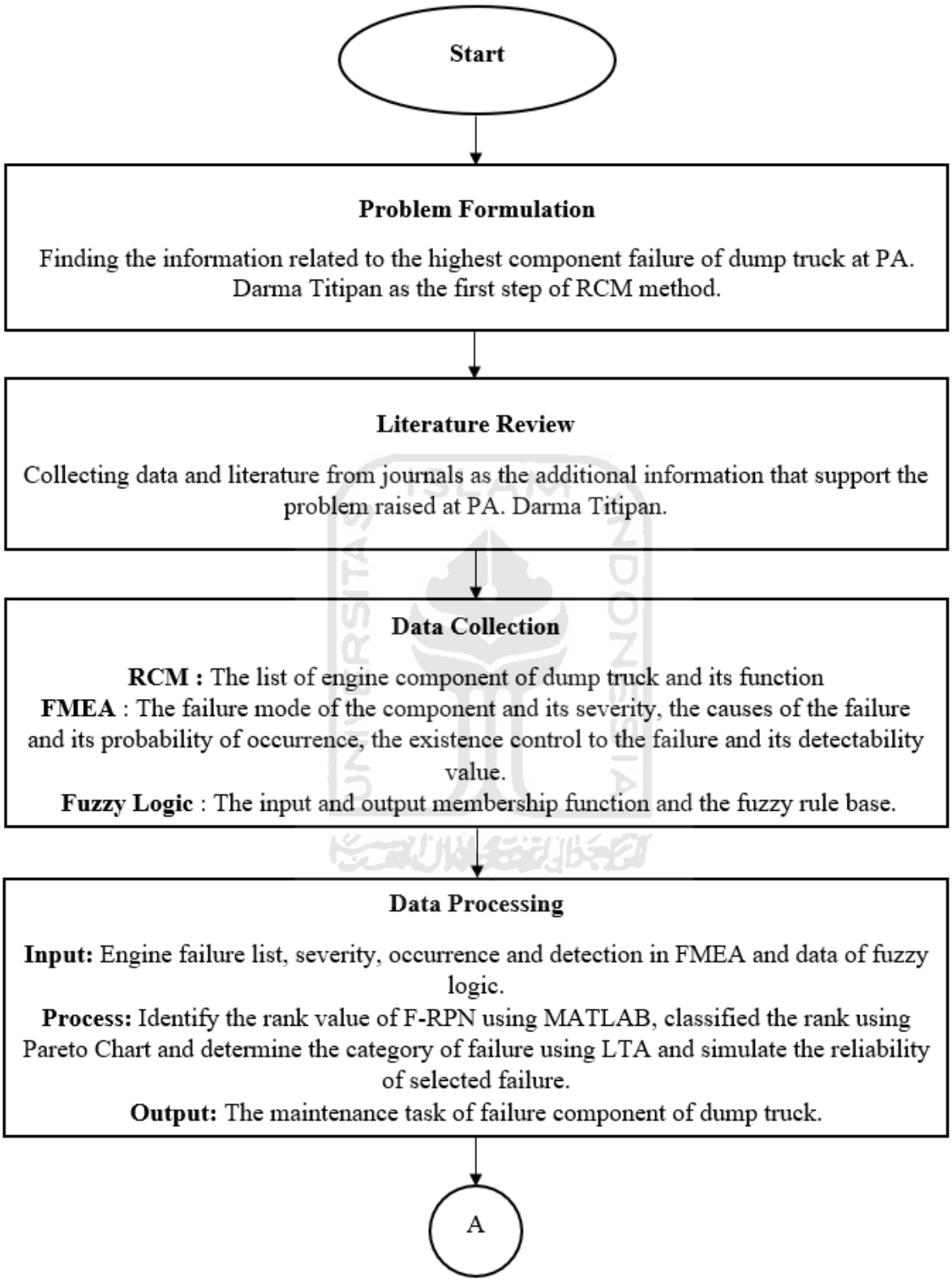
Primary data is the data that collected with the objective of identifying some specific factors needed in this research. In this research, primary data is obtained by using interview to the expert at PA. Darma Titipan which are the list of engine component, the failure mode and its severity, the causes and its probability of occurrence, the existence control to the failure and its detectability value. Moreover, the category of failure based on the LTA also included in this data.

2. Secondary Data

The secondary data is obtained from some online journals or articles. In this research, the secondary data is the data of engine component function and the support study of methodology that used in this research.

3.4 Research Flow

The research is done by finished several steps. The steps are represented in Figure 3.1 as follows:


Start
Problem Formulation
Finding the information related to the highest component failure of dump truck at PA. Darma Titipan as the first step of RCM method.
Literature Review
Collecting data and literature from journals as the additional information that support the problem raised at PA. Darma Titipan.
Data Collection
RCM : The list of engine component of dump truck and its function
FMEA : The failure mode of the component and its severity, the causes of the failure and its probability of occurrence, the existence control to the failure and its detectability value.
Fuzzy Logic : The input and output membership function and the fuzzy rule base.
Data Processing
Input: Engine failure list, severity, occurrence and detection in FMEA and data of fuzzy logic.
Process: Identify the rank value of F-RPN using MATLAB, classified the rank using Pareto Chart and determine the category of failure using LTA and simulate the reliability of selected failure.
Output: The maintenance task of failure component of dump truck.
A

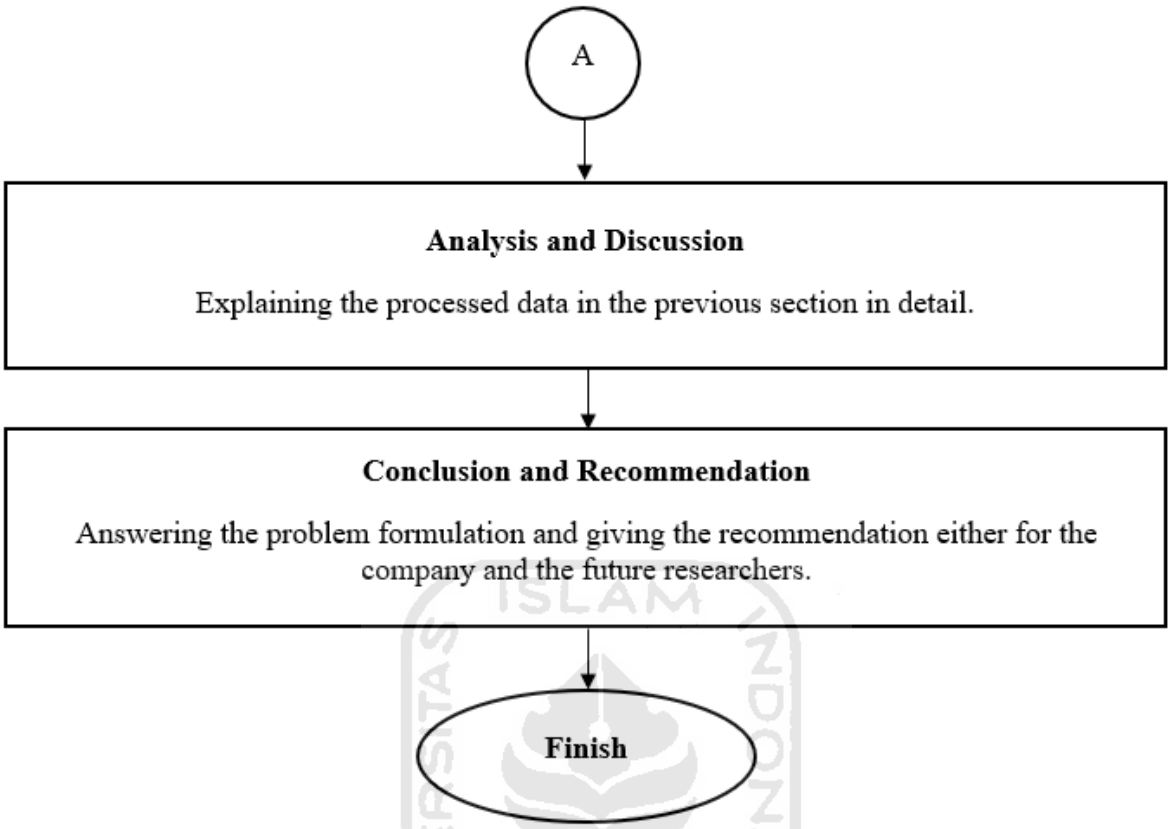


Figure 3.1 Research Flow

The explanation of the research flow is as followed,

1. Problem Formulation

Problem formulation is the initial process to look for problem outlines that will be the topic of this research. The method used is interviews to find the information related to the highest component failure of dump truck at PA. Darma Titipan as the first step of RCM method.

2. Literature Review

Literature review is the secondary data that relates to the observation. The literature review is divided into two, which are:

a. Inductive study, studies that explain the previous research in which the sources used are journals.
b. Deductive study, studies where the sources used can be in the form of journals, books, official websites, and final project reports that discuss the same research object to serve as a theoretical basis.

3. Data collection

In this step, the researcher will find the data to be used in this research. The data collected are based on the needs of Failure Mode and Effect Analysis (FMEA) and Fuzzy Logic.

a. Reliability Centered Maintenance (RCM)

As the third step of RCM, the list of engine component is collected along with the function of each component. The list of components is obtained by interviewing the expert at PA. Darma Titipan while the function of component is obtained from the journal from Akhmad & Taufik (2010).

b. Failure Mode and Effect Analysis (FMEA)

To evaluate the engine component of dump truck using FMEA, there are several data needed as the source of evaluation, which explained as follows.

a1. Determination of Failure Mode

The potential of failure modes for each engine part of dump truck are identified. The failure can include the complete failure, partial failure, incorrect operation, etc. This data is obtained from the interview with expert of PA. Darma Titipan.

a2. Determine the Effect and Severity

For each failure mode, the consequence or effects of the failure is identified. The effect can be to the product, property or people. While the severity (S) is given in the form of numeric in range of 1-10 which 1 is the lowest severity level. This data is obtained from the interview with expert of PA. Darma Titipan.

a3. Determination of Causes and Occurrence

The causes of the failure are identified coupled with the probability of occurrence (O). The probability of occurrence is performed in the form of numeric in range 1-10 which 1 is the lowest probability of occurrence. This data is obtained from the interview with expert of PA. Darma Titipan.

a4. Determination of Current Control and the Detection

The current control of the failure is identified. The effectiveness of the control (O) also identified in the form numeric in range of 1-10 which 1 is the most effective control for the failure. This data is obtained from the interview with expert of PA. Darma Titipan.

c. Fuzzy Logic

Fuzzy logic is used to calculate the RPN which is carried out by using MATLAB software. The data needed operate the software are input membership function, output membership function and fuzzy rule based.

4. Data Processing

Processing data is the step of processing the output data collected in the previous step into more meaningful information. Data processing is done into several steps which explained as follows.

a. Fuzzy Failure Mode and Effect Analysis (F-FMEA)

F-FMEA is the process of evaluating the FMEA using MATLAB software. The output of this stage is the F-RPN that showing the level of failure on each engine component.

b. Pareto Chart

Pareto chart is used to classified the level failure of each engine component into three classification which are high, medium and low. This result will be used as consideration to determine the objective of this research which is determining the maintenance strategy.

c. Logic Tree Analysis (LTA)

LTA is used to analyse the category of the failure. It is causing safety problem, system problem or small economic loses. This data will be used as the consideration to determine the mitigation strategy.

d. Reliability Simulation

Reliability simulation used to simulate the reliability value of selected failure after its maintenance. The result will be used to consider either the preventive maintenance is needed to be used or not.

5. Analysis and Discussion

In this step, it is done the analysis of the result of Fuzzy-Failure Mode and Effect Analysis (F-FMEA) to the engine component of dump truck and the maintenance strategy that properly effective to prevent the risk failure at PA. Darma Titipan.

6. Conclusion and Recommendation

Finally, to conclude all the research, the answering of the problem formulation is done. Moreover, the recommendation for the company and for the future research is given in this step.

CHAPTER IV

DATA COLLECTING AND PROCESSING

4.1 Data Collecting

Data collecting is divided into two, which are reviewing journal and interviewing the expert of PA. Darma Titipan. The data that be obtained from the interview are the profile of the company and the Fuzzy-FMEA data. Meanwhile, the data obtained from the reviewing journal is to determine the standard functions of each part in engine of dump truck.

4.2.1 Company Profile

PA. Darma Titipan, established since 2007, is one of distribution companies located at Cirebon, West Java that provide dump trucks to distribute the coal from Cirebon port to some textile industries located at Bandung, West Java. This company is located at Randu Alas Street, Kedawung, Cirebon. In a month, PA. Darma Titipan has distributed coal as much as 3.375 tons in average to the intended textile industries at Bandung.

PA. Darma Titipan is led by one owner and managed by several departments which are finance, secretary, warehouse and engineering and provider relation. In this research, the intended department is department of warehouse and engineering which related to maintenance activity of the truck at the company.

4.2.2 Business Process

PA. Darma Titipan is a distributor company which focus on distributing coal from Cirebon Port to some textile industries located at Bandung, West Java. The flow of distribution process will be explained clearly in Figure 4.2 as follows.

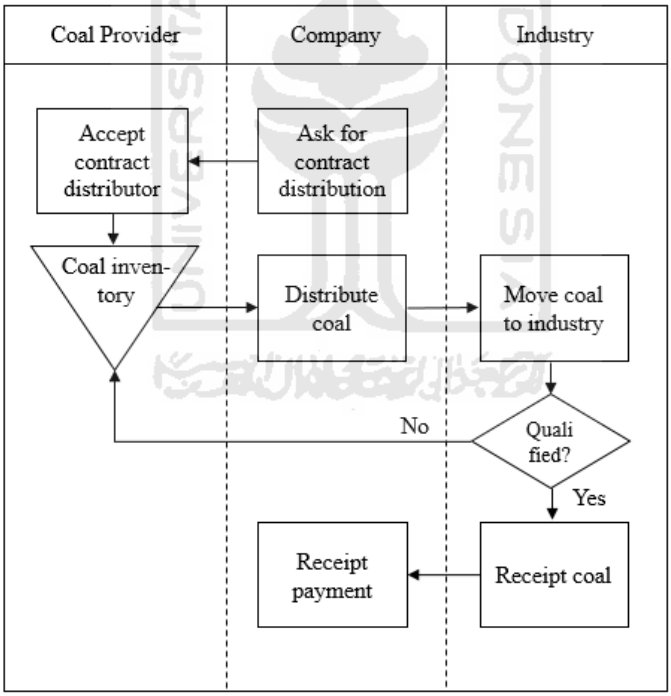


Figure 4.1 Business Process PA. Darma Titipan

The distribution process is started from the asking contract by the company to the coal provider. After the coal provider was accepting the request, the coal provider will inform to

the coal inventory to give a few tons of coal to be distributed by the company. Then, the process of distribution is done by the company. In the intended industry, the coal will be moved to the industry. In this process, there is a quality control process to check either the coal is qualified or not. If the coal is not qualified, the industry will reject the coal back to the coal provider. The company will deliver the rejected coal to the coal provider and the coal distribution process will be repeated. However, if the coal is qualified, the industry will receipt the coal and the company will receive the payment of distribution coal.

4.2.3 Maintenance Process

This research will focus on the maintenance of the dump truck especially on the engine of the truck. Therefore, to give a better understanding of the engine maintenance process at PA. Darma Titipan, the flow of maintenance will be presented in Figure 4.3 as follows.

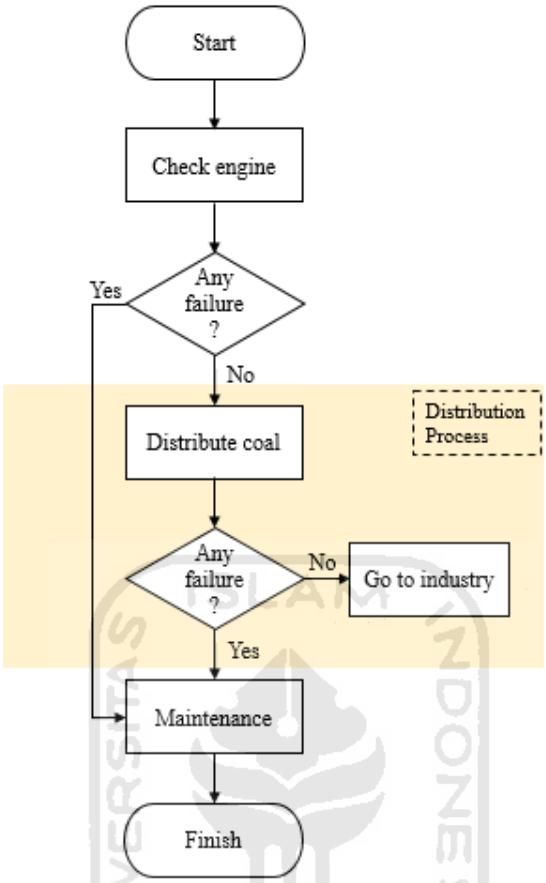


Figure 4.2 Engine Maintenance Process PA. Darma Titipan

The process of engine maintenance at PA. Darma Titipan is started by checking the engine condition before the dump truck distributed coal to industry. If there is a failure on the engine, then the dump truck should be maintenance. If the engine condition is good, the dump truck can distribute coal to industry. In the trip of distributing coal, if there is a failure on the engine, the dump truck should stop the trip and wait for the engineer from the company to fix the engine. While if the engine condition is good, the dump truck will finish the trip to the intended industry. From the explanation, the kind of maintenance is corrective maintenance because the maintenance process is done after there is a failure on the engine.

4.2.4 FMEA

In processing the method of FMEA, there are several data needed to be collected; engine component and its function, engine failure, failure effect and its severity, potential cause and its occurrence and current control with its detectability. Those data will be explained as follows.

a. Engine Component

Engine is the important part to turn on the truck. Engine consists of some components which work together build a system. Every component of engine has its function that support each other. According to Akhmad & Taufik (2010), the function of each engine component is explained in Table 4.1 below.

Table 4.1 Engine Component

No	Component	Function
1.	Cylinder head	Cover the top of the engine block and as a housing for the valve mechanism
2.	Valve	Opening the intake channel so that the air intake process can take place
3.	Camshaft	Open and close the valve according to the specified timing
4.	Cylinder block	As a block to support various engine components as well as a place to move up and down the piston
5.	Gasket	Connect between the cylinder block and cylinder head
6.	Piston	Intake air pressure and pressure receiver results in combustion chamber combustion.
7.	Ring piston	Close the piston with the cylinder block so that no leakage occurs during the compression step
8.	Crankshaft	Change the up and down energy of the piston into a rotary motion
9.	Main bearing	Be a cushion when the crankshaft rotates
10.	Round bearing	Coat or become a bearing for the piston handlebar
11.	Oil pan	Holds engine oil in the engine used to lubricate all engine components
12.	Oil pump	Pump engine oil to all engine components in the lubrication path
13.	Cylinder liner	Form a sliding surface for the piston to obtain a smoothly reciprocating motion, resist the wear form the piston and piston rings and sustain high pressure and high temperature.

No	Component	Function
14.	Bosch pump	Pressing diesel fuel from the tank to the nozzle to be atomized in the combustion chamber

b. Engine Failure

Engine components have the standard function. If there are any failure in the components, the engine will not work properly. There will be imbalance function among engine components. Table 4.2 listed the failure of engine components as well as the effect of the failure. The code stated in the Table 4.2 is represented the sequence to ease the written in the next step.

Table 4.2 Engine Failure

No	Component	Failure Mode	Code
1.	Cylinder head	Cracked cylinder head	F1
2.	Valve	The valve is leaking	F2
3.	Camshaft	Worn out camshaft	F3
4.	Cylinder block	a. Scratched cylinder	F4
		b. Enlarged cylinder hole	F5
5.	Gasket	Leaked gasket	F6
6.	Piston	Piston scratched	F7
7.	Ring piston	a. Worn out ring piston	F8
		b. Broken ring piston	F9
8.	Crankshaft	Cracked crankshaft	F10
9.	Main bearing	Worn out main bearing	F11
10.	Round bearing	Worn out round bearing	F12
11.	Oil pan	Oil pan leaking	F13
12.	Oil pump	Decreased oil pressure	F14
13.	Cylinder liner	a. Worn out cylinder liner	F15
		b. Scratched cylinder liner	F16
14.	Bosch pump	The bosch pump is stuck or cannot pump diesel to the nozzle	F17

c. Failure Effect

Every failure in the component is affecting the performance of the engine. Each effect has their own severity which represents their rate of dangerous to the engine system. The failure effect and its severity are represented in Table 4.3 below.

Table 4.3 Failure Effect and Severity

Failure Code	Effect	Severity
F1	Engine becomes hot and radiator water becomes oily	2
F2	Engine power goes down and engine is difficult to start	4
F3	Weak engine	5
F4	Leak compression	3
F5	Loose piston in cylinder	6
F6	Gasket cannot work optimally and radiator water becomes oily	4
F7	The compression result becomes weak and the oil is transported to the combustion chamber	8
F8	Reduce the ring piston diameter which facilitates oil to get into the combustion chamber	7
F9	Cylinder scratched	6
F10	Problem in piston	7
F11	Problem in crankshaft	6
F12	Problem in piston	7
F13	Oil engine is not enough for lubrication system	4
F14	The lubrication system will not circulate properly, there will be engine parts that are not lubricated	8
F15	Gas leakage	9
F16	Compression pressure is reduced and the power produced is also reduced	8
F17	Engine is difficult to start	6

d. Potential Cause

Engine consist of component that work together formed into the system. Each component is affecting each other. Therefore, the failure in one component can affect to other components in the engine. In this part, the potential cause of the failure will be identified to know the occurrence of the causes which will be represented in Table 4.4 as follows.

Table 4.4 Cause and Occurrence

Failure Code	Cause	Occurrence
F1	Overheat engine or damaged cooling system due to leakage	1
F2	The valve seat is not tight on the cylinder head	2
F3	Poor lubrication	4
F4	The presence of engine impurities carried by engine oil	4
F5	Overheat engine	3
F6	Overheat engine	6
F7	Incorrect use of engine oil	5
F8	Overheat engine	5
F9	Poor-quality engine oil	7
F10	Poor lubrication and problem in main bearing	4
F11	Lack of engine oil or poor oil condition	7
F12	Lack of engine oil or poor oil condition	8
F13	Glue density at the oil pan connection to the engine block is not good	2
F14	There is fuel mixed with engine oil	5
F15	Overheat engine	5
F16	Lack of engine oil or poor oil condition which oil is needed as a lubrication and minimize friction with the piston	6
F17	There is a dirt fuel tank that will be carried by diesel fuel and cause the bosch pump plunger to jam	2

e. Current Control

The company has the control to fix the engine failure in the dump truck. In this case, the control done by the company is to measure either the engine component still can work or not. The current control to the engine is represented in Table 4.5 as follows.

Table 4.5 Current Control and Detectability

Failure Code	Current Control	Detectability
F1	Pending repair component	5
F2	Repair component	4
F3	Repair component	7
F4	Pending repair component	3
F5	Replace component	5

Failure Code	Current Control	Detectability
F6	Repair component	6
F7	Pending repair component	7
F8	Repair component	4
F9	Repair component	4
F10	Repair component	6
F11	Repair component	7
F12	Repair component	8
F13	Repair component	6
F14	Repair component	6
F15	Repair component	5
F16	Pending repair component	5
F17	Repair component	4

4.2.5 Fuzzy Logic

Fuzzy logic is done using MATLAB software. To operate the software, it is needed the data of membership function completely with the fuzzy set and the rule base data. The detail data will be explained as follows.

a. Input Membership Function

There are three kinds of input needs for calculating Fuzzy-RPN; severity, occurrence, detection. Severity and occurrence have 10 ranks; 1 is the lowest and 10 is the highest. While the detection is opposite of both; 1 is the highest and 10 is the lowest. These inputs will be divided into five fuzzy sets which represented in Table 4.6 below. The selection of fuzzy set is based on the reference from journal from Filo, et al (2018) which divided the crisp value into five fuzzy sets.

Table 4.6 Input Fuzzy Set

Crisp Value	Factors					
	Occurrence (O)		Severity (S)		Detection (D)	
	Verbal	Fuzzy Set	Verbal	Fuzzy Set	Verbal	Fuzzy Set
1	Absent	LT	Unnoticeable	LT	Very high	LT
2,3	Rare	L	Small meaning	L	High	L
4,5,6	Sometimes	M	Moderate	M	Medium	M
7,8	Often	H	Serious	H	Low	H
9,10	Very often	HT	Critical	HT	Very low	HT

LT : Lowest
L : Low
M : Medium
H : High
HT : Highest

After the fuzzy set is determined, the membership function then is defined. Inputs has two kinds of membership function which are triangular and trapezoidal. The selection of fuzzy set is based on the reference from journal from Filo, et al (2018) which be explained in the Table 4.7.

Table 4.7 Input Membership Function

Membership Function Type	**Fuzzy Set**	**Parameter**
Triangular	LT	[0 0 2]
Trapezoidal	L	[1 2 3 4]
Triangular	M	[3 5 7]
Trapezoidal	H	[6 7 8 9]
Triangular	HT	[8 10 10]

In input membership function, the parameter is adjusted for the rank value of each input which is [1 10] corresponds to the minimum and maximum rank value of inputs; severity, occurrence and detection. The membership function is represented in Figure 4.4 below.

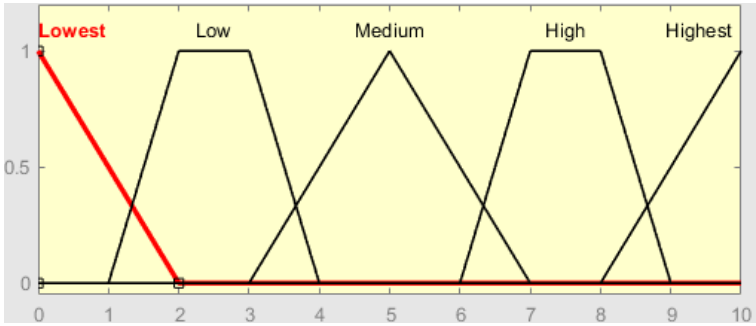


Figure 4.3 Input Membership Function

b. Output Membership Function

The output of fuzzy logic is Fuzzy-RPN which will be divided into 12 fuzzy sets. The range of output fuzzy set is [1 1000]. The output fuzzy set is represented in Table 4.8 as follows. The selection of fuzzy set in output membership function also based on the reference Haq, et al (2015) that divides the output fuzzy set into 12 to get the a more accurate result.

Table 4.8 Output Fuzzy Set

Fuzzy Set	
Almost None	AN
Lowest	LT
Lower	LR
Low	L
Medium Lowest	MLT
Medium Lower	MLR
Medium	M
Medium Higher	MHR
Medium Highest	MHT
High	H
Higher	HR
Highest	HT

After the output fuzzy set is determined, the membership function then is defined. There is a kind of membership function which is triangular. The parameter of each fuzzy set is based

on the reference Haq, et al (2015) and determined in accordance the trial and error. The description of output membership function will be explained in the Table 4.9 below.

Table 4.9 Output Membership Function

Membership Function Type	Fuzzy Set	Parameter
Triangular	AN	[0 75 150]
Triangular	LT	[75 150 225]
Triangular	LR	[150 225 300]
Triangular	L	[225 300 375]
Triangular	MLT	[300 375 450]
Triangular	MLR	[375 450 525]
Triangular	M	[450 525 600]
Triangular	MHR	[525 600 675]
Triangular	MHT	[600 675 750]
Triangular	H	[675 750 825]
Triangular	HR	[750 825 900]
Triangular	HT	[825 900 1000]

In output membership function, the parameter is adjusted based on the value of RPN which is 1 to 1000. As well as the range of the output [1 1000] also corresponds to the minimum and maximum value of multiplication S, D and O. The membership function is represented in Figure 4.5 as follows.

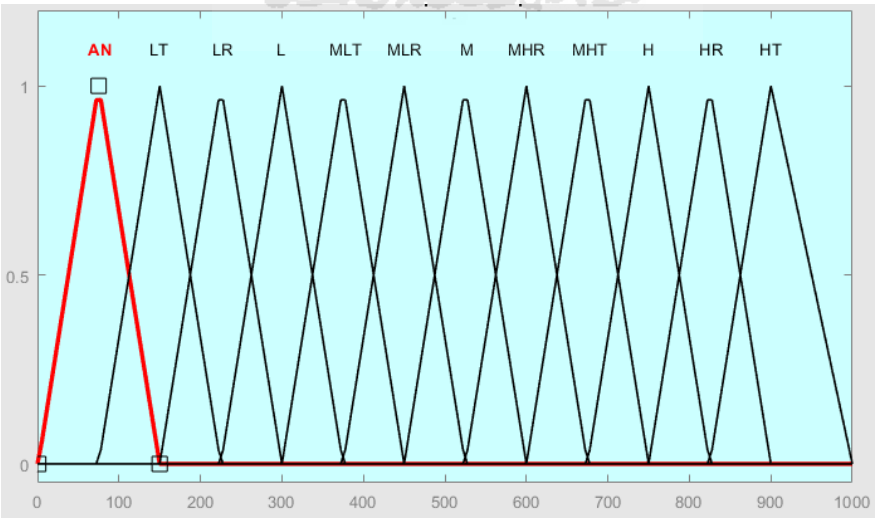


Figure 4.4 Output Membership Function

c. Fuzzy Rule Base

Fuzzy rule base is defined as the proposed algorithm for calculating RPN. The fuzzy rule has defined as much as 125 rules. The determination of fuzzy rule base is based on the reference from journal from Haq, et al (2015) that has a similarity in topics that raised. Moreover, the rules are also been discussed with the expert from the company to conform with the condition in the company. More detail fuzzy rules are described in Table 4.10 – Table 4.14 as follows.

Table 4.10 Fuzzy Rule for Lowest Severity

Severity is LT						
RPN		**Detection**				
		LT	**L**	**M**	**H**	**HT**
Occurrence	**LT**	AN	AN	LT	L	MLT
	L	LT	LR	L	MLT	MLR
	M	LR	L	MLT	MLR	M
	H	L	MLT	MLR	M	MHR
	HT	MLT	MLR	M	MHR	MHR

Table 4.11 Fuzzy Rule for Low Severity

Severity is L						
RPN		**Detection**				
		LT	**L**	**M**	**H**	**HT**
Occurrence	**LT**	LT	LR	L	MLT	MLR
	L	LR	L	MLT	MLR	M
	M	L	MLT	MLR	M	MHR
	H	MLT	MLR	M	MHR	MHT
	HT	MLR	M	MHR	MHT	MHT

Table 4.12 Fuzzy Rule for Medium Severity

Severity is M						
RPN		**Detection**				
		LT	**L**	**M**	**H**	**HT**
Occurrence	**LT**	LR	L	MLT	MLR	M
	L	L	MLT	MLR	M	MHR
	M	MLT	MLR	M	MHR	MHT
	H	MLR	M	MHR	MHT	H
	HT	M	MHR	MHT	H	H

Table 4.13 Fuzzy Rule for High Severity

Severity is H						
RPN		**Detection**				
		LT	**L**	**M**	**H**	**HT**
Occurrence	**LT**	L	MLT	MLR	M	MHR
	L	MLT	MLR	M	MHR	MHT
	M	MLR	M	MHR	MHT	H
	H	M	MHR	MHT	H	HR
	HT	MHR	MHT	H	HR	HR

Table 4.14 Fuzzy Rule for Highest Severity

Severity is HT						
RPN		**Detection**				
		LT	**L**	**M**	**H**	**HT**
Occurrence	**LT**	MLT	MLR	M	MHR	MHT
	L	MLR	M	MHR	MHT	H
	M	M	MHR	MHT	H	HR
	H	MHR	MHT	H	HR	HT
	HT	MHT	H	HR	HT	HT

4.2 Data Processing

The data collected in previous section, will be processed by using Fuzzy-FMEA. Moreover, the maintenance strategy can be defined with the help of logic tree analysis (LTA) diagram. The detailed processes will be explained as follows.

4.2.1 Fuzzy-FMEA

Fuzzy-FMEA is done using MATLAB software. The data is processed by using AND connection. Table 4.15 represented the result of Fuzzy-FMEA.

Table 4.15 Fuzzy FMEA Result

Failure Code	Severity	Occurrence	Detection	F-RPN	Rank
F1	2	1	5	300	17
F2	4	2	4	450	12
F3	5	4	7	600	5
F4	3	4	3	375	16
F5	6	3	5	450	12
F6	4	6	6	525	11
F7	8	5	7	675	2
F8	7	5	4	600	5
F9	6	7	4	600	5
F10	7	4	6	600	5
F11	6	7	7	675	2
F12	7	8	8	750	1
F13	4	2	6	450	12
F14	8	5	6	600	5
F15	9	5	5	675	2
F16	8	6	5	600	5
F17	6	2	4	450	12

Fuzzy-FMEA ranked the data into 17 ranks. The higher F-RPN value, the higher rank will be given. The 1st rank of F-RPN is represented that the failure have more probability to give the loss to the company. Then, the pareto chart is used to clarify the classification of rank

priority. The classification of rank priority is divided into three; high, medium and low. The pareto chart is represented in Figure 4.6 as follows.

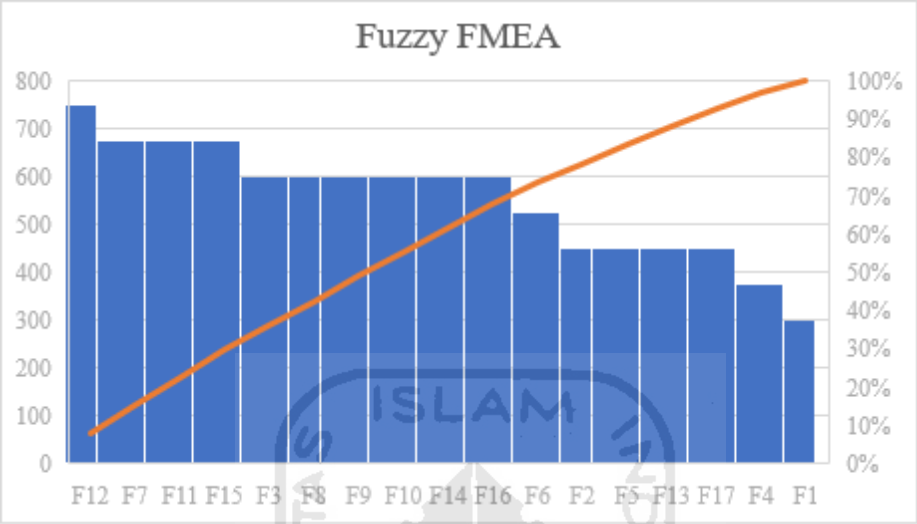


Figure 4.5 F-FMEA Pareto Chart

From pareto chart, the result of Fuzzy-FMEA is divided into three classifications which are high, medium and low. The classifications are represented by the percentage based on pareto chart. For high, the percentage is 60%, for medium is 30% and for low is 10%. The high classification is represented that the failures have more probability to give the loss for the company. The description is shown in Table 4.16 as follows.

Table 4.16 F-FMEA Classification

Classification	Failure Code	Failure Mode
60%	F12	Worn out round bearing
	F7	Piston scratched
	F11	Worn out main bearing
	F15	Worn out cylinder liner
	F3	Worn out camshaft
	F8	Worn out ring piston
	F9	Broken ring piston
	F10	Cracked crankshaft
	F14	Decreased oil pressure
30%	F16	Scratched cylinder liner
	F6	Leaked gasket
	F2	The valve is leaking

Classification	Failure Code	Failure Mode
10%	F5	Enlarged cylinder hole
	F13	Oil pan leaking
	F17	The bosch pump is stuck or cannot pump diesel to the nozzle
	F4	Scratched cylinder
	F1	Cracked cylinder head

4.2.2 Logic Tree Analysis

Logic Tree Analysis (LTA) was used to determine the consequences and give priority to each failure mode. The category of each failure will be gotten by answering yes/no question of the evident, safety and outage which has been standardized as stated in Chapter II. The result of LTA is described in Table 4.17 as follows.

Table 4.17 Logic Tree Analysis

Code	Failure Mode	Evident	Safety	Outage	Category
F1	Cracked cylinder head	Yes	Yes	No	A
F2	The valve is leaking	Yes	Yes	Yes	B
F3	Worn out camshaft	Yes	Yes	Yes	B
F4	Scratched cylinder	Yes	Yes	No	A
F5	Enlarged cylinder hole	No	No	No	D/C
F6	Leaked gasket	Yes	No	No	C
F7	Piston scratched	No	Yes	Yes	D/B
F8	Worn out ring piston	No	Yes	No	D/A
F9	Broken ring piston	Yes	No	No	C
F10	Cracked crankshaft	Yes	No	Yes	B
F11	Worn out main bearing	Yes	No	No	C
F12	Worn out round bearing	Yes	No	Yes	B
F13	Oil pan leaking	Yes	Yes	No	A
F14	Decreased oil pressure	No	No	No	D/C
F15	Worn out	Yes	No	No	C
F16	Scratched cylinder liner	No	Yes	Yes	D/B
F17	The bosch pump is stuck or cannot pump diesel to the nozzle	Yes	Yes	Yes	B

4.2.3 Maintenance Type

Maintenance type is determined by considering the failure classification and logic tree analysis (LTA). The failure classification is divided into three; high, medium and low. Moreover, LTA is also divided into three; A or D/A, B or D/B, C or D/C. The logic determination of maintenance strategy is described in Figure 4.6 as follows.

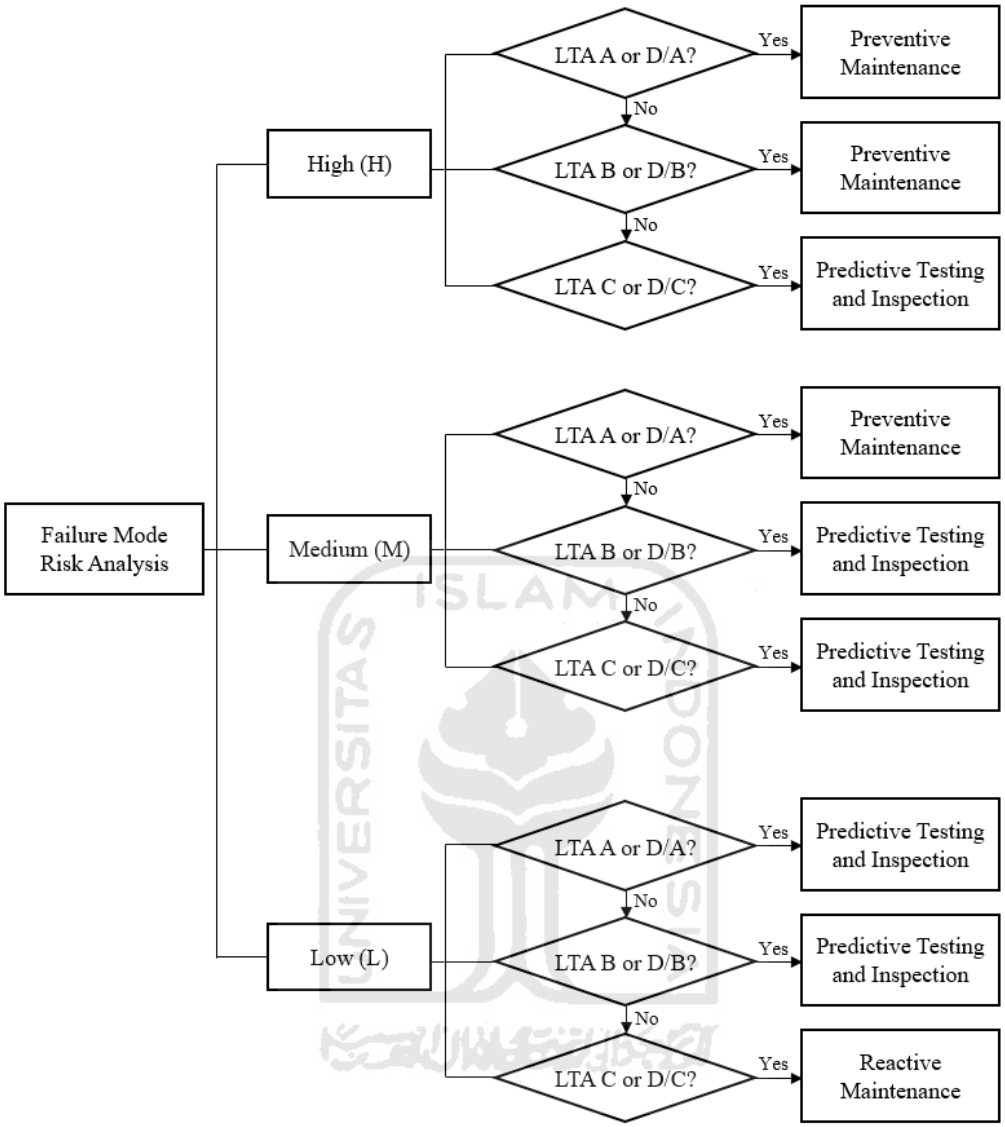


Figure 4.6 Maintenance Decision Tree

Based on the maintenance decision tree, the maintenance strategy is divided into three categories which are preventive maintenance, predictive testing and inspection maintenance and reactive maintenance. The detail of maintenance strategy for each failure is describe in Table 4.18 as follows.

Table 4.18 Maintenance Strategy

Classification	Failure Code	LTA	Maintenance Strategy
High	F12	B	Preventive maintenance
	F7	D/B	Preventive maintenance
	F11	C	Predictive testing and inspection
	F15	C	Predictive testing and inspection
	F3	B	Preventive maintenance
	F8	D/A	Preventive maintenance
	F9	C	Predictive testing and inspection
	F10	B	Preventive maintenance
	F14	D/C	Predictive testing and inspection
Medium	F16	D/B	Predictive testing and inspection
	F6	C	Reactive maintenance
	F2	B	Predictive testing and inspection
	F5	D/C	Reactive maintenance
Low	F13	A	Predictive testing and inspection
	F17	B	Predictive testing and inspection
	F4	A	Predictive testing and inspection
	F1	A	Predictive testing and inspection

4.2.4 Maintenance Task

Maintenance task is the output of reliability centered maintenance (RCM). The maintenance task for preventive maintenance is done by determining the maintenance interval of the component. While for predictive testing maintenance, the maintenance task is determined by checking the symptoms of the component failure.

1. Preventive Maintenance

In this category, the maintenance task is done by determining the maintenance interval of the component. The highest category of failure mode is the failure of round bearing. Therefore, the identification of maintenance task will be focused on the round bearing. There are several steps to determine the maintenance interval which will be describe as follows.

a. Time to Failure Data (TTF)

Time to failure data of round bearing is obtained from year 2007. According to the data, the failures are happened in yearly intervals. The data of TTF is explained in Table 4.19 as follows.

Table 4.19 Round Bearing Time to Failure Data

Failure Number n	TTF (days)	Cumulative TTF (days)
1	440	440
2	548	988
3	212	1200
4	1125	2325
5	244	2569
6	592	3161
7	896	4057
8	426	4483

b. Goodness of Fit

Goodness of fit probability distribution is used using Minitab 17 software. According to the software, the TTF data of round bearing has an exponential distribution with the goodness of fit value of 2.376.

c. Reliability Analysis

The reliability analysis is done by determining the mean time to failure (MTTF) which used exponential distribution formula from TTF data. The MTTF is 560,375 days therefore the failure rate parameter (λ) is 0.002. From the MTTF value, the reliability could be calculated by applying Equation 2.1 using a multiple of 540 days within 660 days, the reliability value before and after preventive maintenance every 18 months is obtained in the Table 4.20 below.

Table 4.20 Reliability Simulation of Round Bearing Component

t	R(t)	n	T	t-nT	R(T)^n	R(t-nT)	Rm(t)
15	0,970	0	0	15	1	0,970	0,970
30	0,942	0	0	30	1	0,942	0,942
45	0,914	0	0	45	1	0,914	0,914
60	0,887	0	0	60	1	0,887	0,887
75	0,861	0	0	75	1	0,861	0,861
90	0,835	0	0	90	1	0,835	0,835
105	0,811	0	0	105	1	0,811	0,811
120	0,787	0	0	120	1	0,787	0,787
135	0,763	0	0	135	1	0,763	0,763
150	0,741	0	0	150	1	0,741	0,741
165	0,719	0	0	165	1	0,719	0,719
180	0,698	0	0	180	1	0,698	0,698
195	0,677	0	0	195	1	0,677	0,677
210	0,657	0	0	210	1	0,657	0,657
225	0,638	0	0	225	1	0,638	0,638
240	0,619	0	0	240	1	0,619	0,619
255	0,600	0	0	255	1	0,600	0,600
270	0,583	0	0	270	1	0,583	0,583
285	0,566	0	0	285	1	0,566	0,566
300	0,549	0	0	300	1	0,549	0,549
315	0,533	0	0	315	1	0,533	0,533
330	0,517	0	0	330	1	0,517	0,517
345	0,502	0	0	345	1	0,502	0,502
360	0,487	0	0	360	1	0,487	0,487
375	0,472	0	0	375	1	0,472	0,472
390	0,458	0	0	390	1	0,458	0,458
405	0,445	0	0	405	1	0,445	0,445
420	0,432	0	0	420	1	0,432	0,432
435	0,419	0	0	435	1	0,419	0,419
450	0,407	0	0	450	1	0,407	0,407
465	0,395	0	0	465	1	0,395	0,395
480	0,383	0	0	480	1	0,383	0,383
495	0,372	0	0	495	1	0,372	0,372
510	0,361	0	0	510	1	0,361	0,361
525	0,350	0	0	525	1	0,350	0,350
540	0,340	1	540	0	0,340	1,000	0,340
555	0,330	1	540	15	0,340	0,970	0,330

t	R(t)	n	T	t-nT	R(T)^n	R(t-nT)	Rm(t)
570	0,320	1	540	30	0,340	0,942	0,310
585	0,310	1	540	45	0,340	0,914	0,292
600	0,301	1	540	60	0,340	0,887	0,275
615	0,292	1	540	75	0,340	0,861	0,259
630	0,284	1	540	90	0,340	0,835	0,244
645	0,275	1	540	105	0,340	0,811	0,230
660	0,267	1	540	120	0,340	0,787	0,217

The example of reliability calculation of round bearing in a day of 570 without preventive maintenance is described as follows.

$$R(570) = e^{-(0.002*570)}$$

$$= 0.320$$

From the calculation, the reliability of round bearing in 570 days is 32%. However, by doing the preventive maintenance in day 540, the round bearing has a reliability probability of t-nT time from preventive maintenance, R(t-nT) as much as:

$$R(t - nT) = e^{-\lambda(t-nT)}$$

$$R(570 - 540) = e^{-0.002*(570-540)}$$

$$R(570 - 540) = 0.942$$

Therefore, the reliability probability of component which got preventive maintenance, Rm(t), is described as follows.

$$Rm(570) = R(540)^1 * R(570)$$

$$Rm(570) = 0.340 * 0.942$$

$$Rm(570) = 0.310$$

From the simulation as shown in Table 4.20, the value of R(t) and Rm(t) will be used to analyze the reliability of round bearing. R(t) is represented the reliability value of round bearing without preventive maintenance and Rm(t) is represented the value of round bearing with the preventive maintenance. Therefore, the reliability simulation result is represented in Figure 4.7 below.

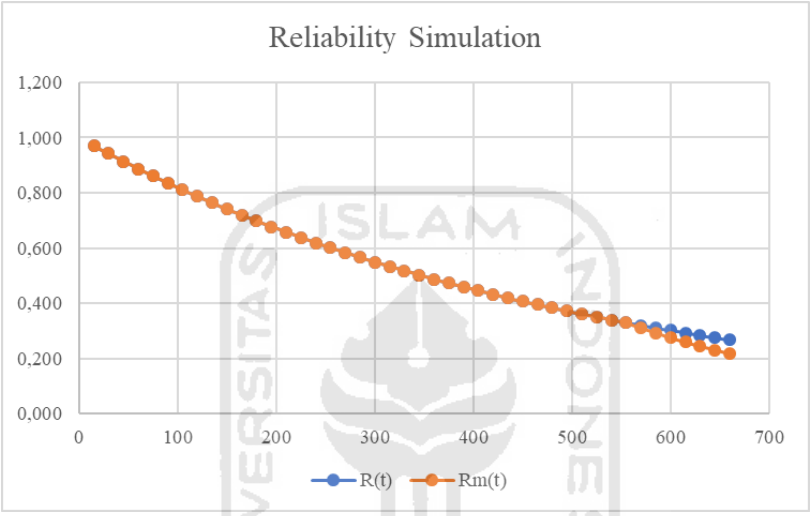


Figure 4.7 Reliability Simulation of Round Bearing Component

According to the Figure 4.7, the value of round bearing reliability after it maintained is decreasing which represented in Rm(t) line. Therefore, the routine maintenance will not be effective to prevent the failure of the round bearing.

2. Predictive Testing and Inspection

Predictive testing and inspection are done by checking the symptoms of the failure. In this research, the maintenance task will focus on the high classification failure. The symptoms will be explained as follows.

Table 4.21 Condition-Based Maintenance Task

Failure	Failure Code	Maintenance Task
Worn out main bearing	F11	Checking the sound of the engine when the truck in the constant state. The knocking sound or *"tuk tuk"* from the engine indicate the failure on the main bearing.
Scratched cylinder liner	F15	Checking the vehicle emission. The white vehicle emission along with the smelled of burnt oil indicates failure at the cylinder liner.
Broken ring piston	F9	Checking the vehicle emission. The white vehicle emission along with the smelled of burnt oil indicate failure at the ring piston. Checking the engine oil. The wasteful engine oil indicates the failure at ring piston.
Decrease oil pressure	F14	Checking the volume of engine oil. The engine oil should fill the minimum limit. Checking the oil filter. The oil filter should be clean.

CHAPTER V

DISCUSSION

5.1 Failure Classification

This research focused on defining maintenance task of engine component of dump truck. To achieve this aim, the research is started by classified the failure of engine component. There are several steps to classified the failure.

a. Fuzzy-FMEA

Fuzzy-FMEA is started by listing the engine component of dump truck. In this research, the listed component is the main component in the engine. The sub-component of engine is not listed. There are 14 main engine components of dump truck along with its functions have been considered which resulted 17 failure modes. Each failure has its own impact to the performance of the engine which will give domino effect to the stoppage of the engine. Each failure mostly caused by overheat engine and improper oil engine maintenance. The overheat engine happened because of some factors. The long usage time of truck which not supported by the good condition of cooling system is mostly happened that causing the overheat engine.

However, this research does not consider the other parts than the engine component. Therefore, the effect will be focused on component of engine. Currently, the company has maintained the failure by repairing and replacing after there is a component failure. Repairing component is done when the failure can be handled and it is not causing a big effect to the engine performance. Repairing also divided into direct repair and pending repair. Direct repair is done when the failure cannot be longer tolerated while pending repair is done when the failure can be tolerated. While for replace component is done when the failure is potentially causing a big impact to the performance of the engine and the failure cannot be handled by repair anymore.

Fuzzy-FMEA is done to rank the failure from the highest to the lowest by considering the value of severity from the impact of failure, occurrence from the cause of failure and detection from the current control. In this research, the severity, occurrence and detection are not considered its priority, therefore those value of each aspect are assumed the same. FMEA value is obtained by interviewing the expert of PA. Darma Titipan. To minimize the subjectivity of FMEA, then the fuzzy logic approach is added. The fuzzy logic is carried out by using MATLAB software.

b. Pareto Chart

The result of failure rank from Fuzzy-FMEA is processed using Pareto chart to classified the failure into three classifications; high (60%), medium (30%) and low (10%). There are 9 failure modes classified as high, 4 failure modes as medium and 4 failure modes as low. This classification is used as first consideration to determine the maintenance strategy.

c. Logic Tree Analysis (LTA)

Another consideration to determine maintenance strategy is from the LTA classification. There are three issues considered in LTA; safety, outage and minor issues. The safety issue is categorized for every failure that impacted to the safety of people related to the distribution

activity. It can be the drives or people through the journey of the distribution. Moreover, the safety issue also can be categorized to every failure that impacted the environmental condition. The outage issue is categorized for every failure that impacted the stoppage of engine. While minor issue is categorized for every failure that impacts to a small economic value.

The Fresult of LTA classification shows that there are 4 failure modes classified as safety issue, 7 failures as outage issue and 6 failure modes as minor issue. The safety issue happened to the drivers when there is an accident caused by the failure in engine component. Another safety issue happened to the environment when there is a leaking oil or white vehicle emission. The oil will spill to road or the place where the sump truck is stopped. While the white vehicle emission is polluted the air. The outage issues happened when the failure of engine component causing the stoppage of the engine therefore the truck cannot start before it maintained. Finally, the minor issue happened when the failure is causing minor cost in maintenance. However, this research is not considering the cost aspect therefore the cost of maintenance is based on the history of maintenance cost.

5.2 Maintenance Type

Maintenance type is done to determine the type of maintenance suitable for the failures; preventive maintenance, predictive testing and inspection maintenance and reactive maintenance. The maintenance type is considered by the failure classification from Pareto chart and LTA. The maintenance decision tree was created to ease the determination of maintenance type. Preventive maintenance is arranged for failure that assessed as priority failure based on the Pareto and LTA consideration. Predictive testing and inspection is arranged for priority failure that can still be tolerated. While corrective maintenance is arranged for failures that assessed as a not priority failure. From the maintenance decision tree, it was found that there are 5 failure modes use time-based maintenance, 10 failure modes use condition-based maintenance and 2 failure modes use corrective maintenance.

5.3 Maintenance Task

The maintenance task focuses on preventive maintenance and predictive testing and inspection. For preventive maintenance, the maintenance task depends on the maintenance interval time which determined by the calculation of reliability value. While predictive testing and inspection depends on the failure symptoms of the component.

a. Preventive Maintenance

In this research, the calculation of reliability value is done only to the highest failure classification which is round bearing. From the data of time to failure (TTF), the mean time to failure (MTTF) is 560,375 days and resulted the rate of failure as much as 0.002. From the MTTF, the reliability analysis is done by 540 days interval time. The reliability simulation also done to predict the appropriate maintenance task for the round bearing. The type of distribution is analyzed by using Minitab 17 software. According to the Minitab, the distribution type is exponential distribution. The result of reliability simulation shows that the reliability value is not increase even after the preventive maintenance is done. Therefore, the maintenance task appropriate for a round bearing is a replacement component before the interval time of maintenance and prepared the replaced component.

Currently, the replacement of bearing is done after the bearing is broken. The broken bearing will affect other components; therefore, the maintenance time will be longer. The maintenance time of broken bearing consuming 5 days in average. In this condition, the company will suffer the opportunity loss as much as Rp.10.000.000,- in average. However, if the company change the bearing in the specified replacement time, the maintenance time will spend a day for replacement. Therefore, the opportunity loss suffered by the company is as much as Rp.2.000.000,-. By the opportunity loss consideration, therefore the replacement of bearing in day 540 is more beneficial for the company.

b. Predictive testing and inspection

In this research, the maintenance task for predictive testing and inspection focused on the high classification. There are four components in high classification needs the condition-based maintenance type which are main bearing, cylinder liner, ring piston and oil pump. For main bearing, the maintenance is by checking the sound of the engine when the truck in the constant state. The knocking sound or “tuk tuk” from the engine indicate the failure on the main bearing. For cylinder liner, the maintenance is by checking the vehicle emission. The white vehicle emission along with the smelled of burnt oil indicates failure at the cylinder liner. For ring piston, the maintenance is by checking the vehicle emission. The white vehicle emission along with the smelled of burnt oil indicate failure at the ring piston. Another one is checking the engine oil. The wasteful engine oil indicates the failure at ring piston. Last, the oil pump is checked by the volume of engine oil condition. The engine oil should fill the minimum limit. Checking the oil filter. The oil filter should be clean.

CHAPTER VI

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Based on the discussion, it can be concluded that the maintenance tasks depend on the type maintenance type used for component; preventive maintenance and predictive testing and inspection. For preventive maintenance, the maintenance task for round bearing as the highest F-RPN value, is preparing the component and change the component in month 18 after the previous replacement. For predictive testing and inspection, the maintenance is done by checking the symptoms of failure in every component. For main bearing is checking the knocking sound. For cylinder liner is checking the color of vehicle emission and its smell of burnt. For ring piston is the same with cylinder liner but adding with the checking of volume of oil engine. Finally, for fuel pump is by checking the checking the volume of engine oil and the oil filter.

6.2 Recommendation

The recommendations for the future research are:

1. Doing more in-depth research about the sub-component of each engine component.
2. Applying the pairwise comparison among severity, occurrence and detection to know which aspect is more meaningful for the company.

REFERENCES

Abdel-Aziz. I. H.. & Helal. M. (2012. May). Application of FMEA-FTA in Reliability-Centered Maintenance Planning. In The International Conference on Applied Mechanics and Mechanical Engineering (Vol. 15. No. 15th International Conference on Applied Mechanics and Mechanical Engineering.. pp. 1-11). Military Technical College. Retrieved from https://www.researchgate.net/publication/334300288_APPLICATION_OF_FMEA-FTA_IN_RELIABILITY-CENTERED_MAINTENANCE_PLANNING.

Akhmad, E. P. A., & Taufik, M. Pengembangan Sistem Pakar untuk diagnosis kerusakan mesin diesel. *Jurnal Ilmiah Universitas Hang Tuah*, *1*, 16.

Al Haiany. H. (2016). Reliability Centered Maintenance: Different Implementation Approaches. Retrieved from https://www.diva-portal.org/smash/get/diva2:974288/FULLTEXT01.pdf.

Azis. M. T.. Suprawhardana. M. S.. & Purwanto. T. P. (2010). Penerapan Metode Reliability Centered Maintenance (RCM) Berbasis Web Pada Sistem Pendingin Primer Di Reaktor Serba Guna Ga. Siwabessy. In Jurnal Forum Nuklir (Vol. 4. No. 1. pp. 81-98).

Balaraju. J. & Murthy. C. (November. 2019). Fuzzy-FMEA risk evaluation approach for LHD machine – a case study. *Journal of Sustainable Mining*. 18(4). pp257-268. Retrieved from https://www.sciencedirect.com/science/article/pii/S2300396019301077.

Cornot-Gandolphe. S.. 2017. Indonesia's electricity demand and the coal sector: export or meet domestic demand? Oxford Institute for Energy Studies Paper CL5. Retrieved from https://www.oxfordenergy.org/wpcms/wpcontent/uploads/2017/03/Indonesias-Electricity-Demand-and-the-Coal-Sector-Export-or-meet-domestic-demand-CL-5.pdf.

Directorate of Energy. Mineral and Mining Resources. (2019). *Laporan Akhir Kajian Ketercapaian Target DMO Batubara Sebesar 60% Produksi Nasional Pada Tahun*

2019. Retrieved from https://www.bappenas.go.id/files/5415/0898/5954/Laporan_Akhir_Kajian_DMO_Batubara_Final.pdf.

Duminică. D.. Avram. M.. & Apostolescu. T. C. (2011). Fuzzy logic used in FMEA analysis. The Romanian Review Precision Mechanics. Optics & Mechatronics. 1. 37-40. Retrieved from https://www.incdmtm.ro/editura/documente/pag.%2037-40%20Comefim%2010%20-%20Duminica.pdf.

Filo, G., Fabiś-Domagała, J., Domagała, M., Lisowski, E., & Momeni, H. (2018). The idea of fuzzy logic usage in a sheet-based FMEA analysis of mechanical systems. In *MATEC Web of Conferences* (Vol. 183, p. 03009). EDP Sciences.

Franch. X.. Kenett. R. S.. Susi. A.. Galanis. N.. Glott. R.. & Mancinelli. F. (2015). Community data for OSS adoption risk management. In The Art and Science of Analyzing Software Data (pp. 377-409). Morgan Kaufmann.

Friederich. M. C.& Leeuwen. T. (April. 2017). A review of the history of coal exploration. discovery and production in Indonesia: The interplay of legal framework. coal geology and exploration strategy. *Coal Geology*. 178. pp56-73. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0166516216308229.

Gugaliya. A.. Boral. S. & Naikan. V. (2019). A hybrid decision making framework for modified failure mode effects and criticality analysis: A case study on process plant induction motors. *International Journal of Quality & Reliability Management*. 36(8). pp.1266-1283. Retrieved from https://www.emerald.com/insight/content/doi/10.1108/IJQRM-08-2018-0213/full/html.

Gupta. G.. Mishra. R. P.. & Singhvi. P. (2016). An application of reliability centered maintenance using RPN mean and range on conventional lathe machine. International *Journal of Reliability. Quality and Safety Engineering*. 23(06). 1640010. Retrieved from https://www.researchgate.net/publication/309614803_An_Application_of_Reliability

_Centered_Maintenance_Using_RPN_Mean_and_Range_on_Conventional_Lathe_Machine.

Hamilton. A. & Finley. E. (2019). Qualitative methods in implementation research: An introduction. *Psychiatry Research*. 280. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0165178119307917.

Haq. I. U.. Izhar. K.. Anwar. S.. Khan. M. T.. Ahmed. B.. & Maqsood. S. (2015). Fuzzy logic based failure mode and effect analysis of automotive powertrain assembly systems. *Technical Journal*. University of Engineering and Technology (UET) Taxila. 20 (SI). 57-64. Retrieved from https://www.researchgate.net/publication/302895887_Fuzzy_Logic_Based_Failure_Mode_and_Effect_Analysis_of_Automotive_Powertrain_Assembly_Systems.

Hinchcliff, Anthony M. & Smith, Glenn R. (2004). RCM: gateway to world-class maintenance. Boston, MA: Butterworth-Heinemann.

Hossen. J.. Ahmad. N.. & Ali. S. M. (2017). An application of Pareto analysis and cause-and-effect diagram (CED) to examine stoppage losses: a textile case from Bangladesh. *The journal of the textile institute*. 108(11). 2013-2020. Retrieved from https://www.researchgate.net/publication/315765784_An_application_of_Pareto_analysis_and_cause-and-effect_diagram_CED_to_examine_stoppage_losses_a_textile_case_from_Bangladesh

Huang. L.. Chen. Y.. Chen. S.. & Jiang. H. (2012. June). Application of RCM analysis based predictive maintenance in nuclear power plants. In 2012 International Conference on Quality. Reliability. Risk. Maintenance. and Safety Engineering (pp. 1015-1021). IEEE.

Ibrahim. T.. & Rosmiati. R. (2019). Maintenance of Decision Engineering Programs In The Distribution Of Sea Water Pump In PT. KMI With The RCM-II Approach. International Journal of Engineering. Information Science and Applied Sciences (IJEIS-AS). 2(1). 1-10.

Ishikawa. K (1986). Guide to Quality Control. Tokyo. Japan: Asian Productivity Organization.

Islam. H. (2010). Reliability-centered maintenance methodology and application: a case study. Engineering. 2010. Retrieved from https://pdfs.semanticscholar.org/8561/c1a681e755a760c689e6b674989ef4b6aac7.pdf.

Kolick. M. (2018). Using Failure Mode and Effects Analysis to design a comfortable. automotive driver seat. *Applied Ergonomics*. 45. pp1087-1096.

Kompas. (December. 2019). *Bongkar Muat Batubara di Pelabuhan Cirebon*. Retrieved from https://kompas.id/baca/foto/2019/12/10/bongkar-muat-batubara-di-pelabuhan-cirebon/.

Kullawong. T.. & Butdee. S. (2015). Integrating Reliability-Centered Maintenance with Cost Optimization & Application in Plant of Hard Chrome Plating. *International Journal of Industrial Engineering and Management*. 6(2).

Kutlu. A. & Ekmekcioglu. M. (2012). Fuzzy failure and effects analysis by using fuzzy TOPSIS-based fuzzy AHP. *Expert Systems with Application*. 39. pp61-67. Retrieved from

Liu. H.. You. J.. Ding. X. & Su. Q. (August. 2015). Improving risk evaluation in FMEA with a hybrid multiple criteria decision making method. *International Journal of Quality & Reliability Management*. 32(7). pp.763-782. Retrieved from https://www.emerald.com/insight/content/doi/10.1108/IJQRM-10-2013-0169/full/html.

Lucarelli. B.. 2015. Government as creator and destroyer. Indonesia's rapid rise and possible decline as steam coal supplier in Asia. in: Thurber. M.C.. Morse. R.K. (Eds.). The Global Coal Market: supplying the major fuel for emerging economies. Cambridge University Press. Cambridge. pp. 294-374.

Mansur. A.. & Ratnasari. R. (2015). Analisis Risiko Mesin Bagging Scale Dengan Metode Fuzzy Failure Mode and Affact Analysis (Fuzzy-fmea) Di Area Pengantongan Pupuk Urea PT. Pupuk Sriwijaja. Teknoin. 21(4).

Okwuobi. S.. Ishola. F.. Ajayi. O.. Salawu. E.. Aworinde. A.. Olatunji. O.. & Akinlabi. S. A. (2018). A Reliability-Centered Maintenance Study for an Individual Section-Forming Machine. Machines. 6(4). 50. Retrieved from https://www.researchgate.net/publication/328549342_A_Reliability-Centered_Maintenance_Study_for_an_Individual_Section-Forming_Machine.

Saputra. A. D. (September. 2017). Studi tingkat kecelakaan lalu lintas jalan di Indonesia berdasarkan data KNKT (Komite Nasional Keselamatan Transportasi) dari tahun 2007-2016. *Warta Penelitian Perhubungan*. 29(2). pp179-190. Retrieved from https://www.researchgate.net/publication/323665573_Studi_Tingkat_Kecelakaan_Lalu_Lintas_Jalan_Di_Indonesia_Berdasarkan_Data_KNKT_Komite_Nasional_Keselamatan_Transportasi_Dari_Tahun_2007-2016.

Shaker. F.. Shahin. A. & Jahanyan. S. (September. 2019). Developing a two-phase QFD for improving FMEA: an integrative approach. *International Journal of Quality & Reliability Management*. 36(8). pp.1454-1474. Retrieved from https://www.emerald.com/insight/content/doi/10.1108/IJQRM-07-2018-0195/full/html.

Sharma. R. K.. Kumar. D.. & Kumar. P. (2005). Systematic failure mode effect analysis (FMEA) using fuzzy Linguistic modelling. *International Journal of Quality & Reliability Management*. 22(9). 986–1004. Retrieved from https://doi.org/10.1108/0265671051062524.

Shamayleh. A.. Awad. M.. & Abdulla. A. O. (2019). Criticality-based reliability-centered maintenance for healthcare. *Journal of Quality in Maintenance Engineering*. Retrieved from https://www.emerald.com/insight/content/doi/10.1108/JQME-10-2018-0084/full/html.

Shirouyehzad. H.. Badakhshian. M.. Dabestani. R.. & Panjehfouladgaran. H. (2010). Fuzzy FMEA analysis for identification and control of failure preferences in ERP implementation. *The Journal of Mathematics and Computer Science*. 1(4). 366-376. Retrieved from https://www.researchgate.net/publication/256455282_Fuzzy_FMEA_Analysis_for_Identification_and_Control_of_Failure_Preferences_in_ERP_Implementation.

Singh. J.. Singh. H.. & Singh. G. (2018). Productivity improvement using lean manufacturing in manufacturing industry of Northern India: a case study. *International Journal of Productivity and Performance Management*. 67(8). pp.1394-1415. Retrieved from https://www.emerald.com/insight/content/doi/10.1108/IJPPM-02-2017-0037/full/html.

Suryoputro. M. R.. Sari. A. D.. & Widiatmaka. N. W. (2019. May). Failure Mode and Effect Analysis (Fuzzy FMEA) Implementation for Forklift Risk Management in Manufacturing Company PT. XYZ. In *IOP Conference Series: Materials Science and Engineering* (Vol. 528. No. 1. p. 012027). IOP Publishing. Retrieved from https://www.researchgate.net/publication/333730343_Failure_Mode_and_Effect_Analysis_Fuzzy_FMEA_Implementation_for_Forklift_Risk_Management_in_Manufacturing_Company_PTXYZ.

Widianti. T.. & Firdaus. H. (2018). PENGUJIAN SUHU LEMARI ES DENGAN METODE TERINTEGRASI FUZZYFAILURE MODE AND EFFECT ANALYSIS (FUZZY-FMEA). *Jurnal Standardisasi*. 18(1). 9-24.

Yang. G. (2007). Life cycle reliability engineering. New Jersey: John Wiley &Sons. Inc978-0-471-71529-0.

Zhou. W.. Yang. X.. Li. Y.. & Zhang. Y. (2019). Pattern versus level: a new look at the personality-entrepreneurship relationship. *International Journal of Entrepreneurial Behavior & Research*. Vol. 25 No. 1. pp. 150-168. Retrieved from https://www.emerald.com/insight/content/doi/10.1108/IJEBR-03-2018-0176/full/html