Journal of Vocational Studies on Applied Research

Reliability Analysis of Diesel Engine at LNG Plant Using Counting Process

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Abstract- *The purpose of this research is to analyze the reliability of diesel engine as driver for fire water pump. To determine the reliability level of the diesel engine, this research will apply counting process so that the rate of failure of the diesel engine can be known. The data used as basis for calculation is failure data gained from maintenance work order databases from 2012 to 2017. The data obtained will be processed using counting process method to produce mathematical modeling to predict the amount of failure to diesel engines in the future. From 4 diesel engines, only 3 parametric failure rate (λ) that could be generated, $e^{-6,0697+0,0016t}$ for 33-GE-5A, $e^{-5,2203-0,0004t}$ for 33-GE-5B, and $e^{-3,6924-0,0009t}$ for 33-GE-5C, since 33-GE-5D was severely damaged in September 2015. The mathematical modeling will be verified using the Pearson's Chi-squared Test method to ensure the validity of the mathematical model can be guaranteed. The result of the goodness of fit test shows that only parametric failure rate (λ) for 33-GE-5B and 33-GE-5C that could be accepted. The outcome mathematical model will be used to predict future behavior and failure of the unit so effective and efficient maintenance strategy for 33-GE-5B and 33-GE-5C could be applied.*

***Keywords** – counting process, diesel engine, reliability*

Submission : February 16, 2018 Correction : October 21, 2019 Accepted: November 19, 2019

Doi: http://dx.doi.org/10.14710/jvsar.v1i2.4368

[How to cite this article: Darmanto, S., Atmanto, I.S., Permana, B.H.(2019). Reliability Analysis of Diesel Engine at LNG Plant Using Counting Process.*Journal of Vocational Studies on Applied Research,* 1(2), 1-4. doi: http://dx.doi.org/10.14710/jvsar.v1i2.4368]

1. Introduction

In the world of oil and gas industry, the safety of both workers and equipments are the priority since this industry cannot be separated from the hazards of the process in routine operational activities. One of the process hazard which often occurs is fire. On average, almost all fire protection equipments installed in refinery facilities require fire water supply to operate during fire incident.

This fire water is supplied by pumps that are driven using either an electric motor or a diesel engine. Generally, diesel engines are chosen to be the drivers of fire water pumps because they have independent power source. This is one of the many advantages of diesel engine compared to electric motor. However, the numbers of moving component in diesel engine produces its own problems. As the operating hours of diesel engines increases, these components experience degradation from wear to deposit accumulation which decreases engine performance.

Therefore, an effective and efficient maintenance strategy needs to be made to minimize costs from the material and labour side. Also, good maintenance strategy can also be considered as counter-measure step to overcome process hazard[1]. One way to produce maintenance strategy is by employing counting the process. Data of equipment failure collected in maintenance work order database will be processed using counting process. Outcome of this process is creating mathematical model to predict future behavior of the unit so that future failure can be known before it occurs, therefore correct maintenance steps could be taken.

2. Material & Method

The research methodology is basically a scientific way to obtain data with specific purposes and uses. To achieve these goals, a method that is relevant to the goals is needed. This quantitative research takes samples from historical data of the units which is analyzed so that the appropriate parametric failure rate modeling can be obtained to predict the condition of the diesel engine in the future.

Data that will be used as a reference source for this research is obtained from maintenance work order databases with a period of time starting in January 2012 to December 2017. The data obtained will show the distribution of the failure time of each unit and the description of initial failure. Some assumptions related to the data obtained will be applied in the data processing to generate appropriate modeling.

Several assumptions are made for this research. Diesel engine operating time will be measured and written in days. Maintenance time for the diesel engine is considered so short compared to unit operating time, thus will be neglected. Also, maintenance of the unit is assumed put the system back to normal operating state but not in "as good as new" condition. Each components failure will result in whole system downtime. Operating conditions are assumed to be typical for all units. And the last, full replacement of the unit will disqualify data retrieval.

Data that has been collected will be analyzed and then used as basis for mathematical modeling for predicting the condition of the unit in the future time[2]. After such effort, verification process of the mathematical modeling will be carried out. In addition, in 2011 there was database platform migration so that it was not possible to access failure data under 2012. The counting process method that can be used to model diesel engine failure is Homogeneous Poisson Process (HPP) or Non-homogeneous Poisson Process (NHPP), depends on whether the breakdown of the equipment is constant or non-stationary[3].

The approach taken to determine the type of counting process that can be used is Laplace test. This method is based on the Homogeneous Poisson Process character where n events at time intervals (0, F) are denoted by T_1, T_2, ..., T_n is a statistical sequence of uniform independent variables. Statistical method for Laplace Test (U) is as follows:

$$U = {[((\sum_i^n t_i)/n) - (T/2)]}\Big/{T\sqrt{1/12n}}$$

Where,

t_i = start time until failure occur

n = number of events

T = total observation time

Laplace Test result which has value greater than 0 (zero) indicates that the trend of failure rate is increasing with time, while the value of 0 (zero) indicates that the rate of failure is constant[4]. The Laplace test value for 33-GE-5A / B / C / D units is shown in the following table 1:

Table 1. Laplace score for each unit

Unit	Laplace Score
33-GE-5A	2.19
33-GE-5B	-0.40
33-GE-5C	-1.69
33-GE-5D	-0.17

From the Laplace Test result for the entire units, it is known that 33-GE-5A / B / C / D failure rate change over time, so the most suitable counting process to map the rate of failure of 33-GE-5A / B / C / D is NHPP. Parametric Failure Rate (λ) of the NHPP to model the failure rate trend is as follows[5]:

$$\lambda(t) = e^{\alpha+\beta t}$$

This model his very flexible since it is not requires non-linear restriction for each parameter estimator α and β[6]. Parameter values of α and β can be found using each estimator which is for $\hat{\beta}$ are:

$$\sum_{i=1}^{n} s_i + \frac{n}{\beta} - \frac{nt_0}{1-e^{\beta t_0}} = 0$$

Where,

s_i = time when the failure occured

n = number of failures

t_0 = total observation time

After acquiring $\hat{\beta}$, the value of $\hat{\alpha}$ can be known by using equation below:

$$\hat{\alpha} = ln\left(\frac{n\hat{\beta}}{e^{\hat{\beta}t_0} - 1}\right)$$

By using estimators α and β, the value of each parameter can be seen on table 2 below:

Table 2. Parameter value for each unit

Unit	Parameter	
	Alpha	Beta
33-GE-5A	-6,069715739	0,001562202
33-GE-5B	-5,220327274	-3,9436E-04
33-GE-5C	-3,692446719	-0,000920855
33-GE-5D	-	-

The use of mathematical model to predict the condition of the unit in the future certainly must involve suitability evaluation of the model (goodness of fit). Statistical method that often used to evaluate suitability of the model is Pearson's Chi-squared Test[7]. This method compares the amount of actual failure at a predetermined time interval, in this research is 6 months, with the expected amount of failure obtained from mathematical model that has been made. Modeling will be rejected if it has a significant level of less than 5%[8]. The formula for acquiring total Chi-squared value is as follows:

$$\chi^2 = \sum_{i=1}^{k} \frac{(x_i - m_i)^2}{m_i}$$

Where,

χ^2 = total Chi-squared value

x_i = number of actual event

m_i = number of expected event

3. Result & Discussion

Since parameter values for each unit have been known, we can generate parametric failure rate for all diesel engines as follows:

Table 3. Parametric failure rate value for each unit

Unit	λ
33-GE-5A	$e^{-6,0697+0,0016t}$
33-GE-5B	$e^{-5,2203-0,0004t}$
33-GE-5C	$e^{-3,6924-0,0009t}$
33-GE-5D	-

From table 3 we can see that the parameter failure rate for the 33-GE-5D is unknown because in September 2015 it was severely damaged and thus decided to replace with new unit. The new diesel engine which is used as the replacements have been installed in October 2018. The comparison results of the actual failure rate compared to model failure rate are as follows:

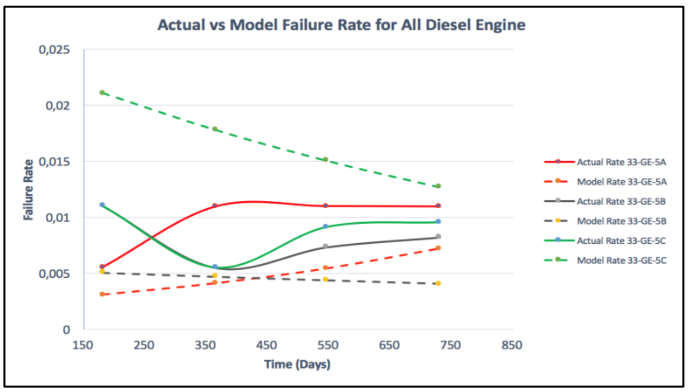

Figure 1. Comparison between actual and model failure rate

The time used as modeling verification period is from January 2016 to December 2017 with interval of 6 months. This verification period has 4 time periods (n), so that each unit which is analyzed have degree of freedom 3. The critical value $\chi^2$for significant level of 5% is 7,81. The results of the Pearson's Chi-squared statistical test for each unit are as follows:

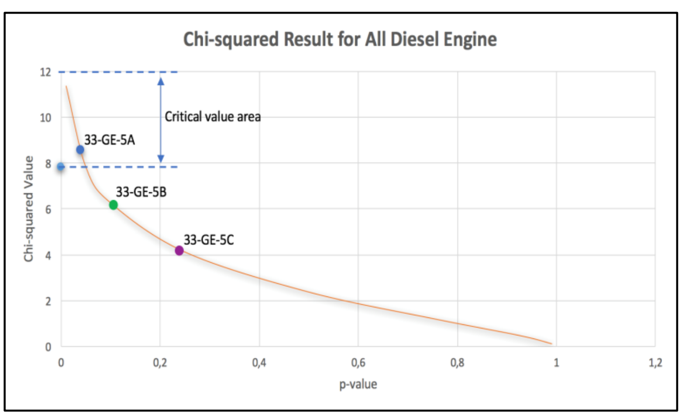

Figure 2. Chi-squared result for all unit

As well as previously discussed, the 33-GE-5D was severely damaged in September 2015 and it was decided to replace with brand new diesel engine, thus make the evaluation for the 33-GE-5D invalid also. Therefore only 33-GE-5B / C which can be discussed further. The mathematical model that has been obtained for the 33-GE-5B / C can be used to determine when to do full unit replacement or minor repair.

Furthermore, in determining the strategic maintenance steps that must be taken, we need to know the cost of purchasing a diesel engine as a basis calculation. It is known from the procurement of diesel engines for replacement 33-GE-5D with document number 177 / TU / SMD-MKT / V / 2017, the total purchase price of the Caterpillar series 3508 diesel engine and unit installation costs is USD 300,000. This new unit has the same type as 33-GE-5B / C so we can use it as a calculation guide.

By dividing the cost of procuring a new diesel engine with an average maintenance cost of each failure per unit as shown in table 9, after 44th failure that will occur in the second semester of 2029, 33-GE-5C is recommended to be replaced with a new diesel engine unit because maintenance cost has equaled the price of the procurement of new units thus make minor repair not profitable from the economic point of view.

For 33-GE-5B with maintenance costs on average per failure of USD 5713, it would be more economical to make a replacement unit after 52nd failure. However, this amount of failures will be achieved in a very long time. According to the mathematical modeling that has been obtained, the 33-GE-5B unit is predicted to have an insignificant number of failure, which is less than 0.1 when it passes 2031. Until 2038, the 33-GE-5B is predicted only experience 18 failures and in order to achieve the 52nd failure, the 33-GE-5B unit will take a very long time. Therefore, for now up to at least next 20 years, the choice of making minor repairs to the 33-GE-5B is seen as a better decision than procuring new diesel engine.

4. Conclusions

The analysis using counting process that has been done for 33-GE-5A / B / C / D produced two valid mathematical models that can be used to predict number of failures for 33-GE-5B and 33-GE-5C in the future. Mathematical model for 33-GE-5B has parametric failure rate $\lambda = e^{-5,22-0,000394t}$, while 33-GE-5C has parametric failure rate $\lambda = e^{-3,692-0,00092t}$. From these two models, we could concur that it would be more economical to make a new unit replacement after 44th failure for 33-GE-5C, which will occur in the second semester of 2029. As for the 33-GE-5B, at least until 2038, doing minor repairs when failure occurs is considered more beneficial.

It is recommended to periodically review the mathematical models for 33-GE-5A /B / C / D in order to maintain the accuracy of the models. Also, It will be very helpful if the previous failure data record, which is the years before 2012, can be added to the maintenance work order database so that it will make mathematical models more accurate.

5. Acknowledgment

This work was supported in part by Vocational School of Diponegoro University.

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