Reliability, Availability and Maintainability Analysis for Main Oil Line Pump by Dominant Failure Modes

By

Muhammad Mokri Bin Misren

13723

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

MAY 2014

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Reliability, Availability and Maintainability Analysis for Main Oil Line Pump by Dominant Failure Modes

By
Muhammad Mokri Bin Misren
13723

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

____
(DR AINUL AKMAR BINTI MOKHTAR)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

____

MUHAMMAD MOKRI BIN MISREN

ABSTRACT

A good maintenance strategy requires a good reliability, availability and maintainability (RAM) analysis in order to cater the real problem to specific equipment or a system. Resolving the real problem will improve the equipment reliability to ensure higher availability of the system to operate. In this project, 2 units of main oil line (MOL) pumps of a crude oil transfer system were selected for RAM analysis. The analysis was carried out based on individual dominant failure modes that contributed to failures of the pumps which involve data of time-to-failure and time-to-repair. Reliability and maintainability analysis was carried out with the aid of Reliasoft Weibull++ software to obtain the required parameters. ReliaSoft BlockSim software was used for reliability block diagram (RBD) construction and simulation to obtain the availability of the whole system by assessing individual failure modes. External leakage – process medium was found to be the most critical failure mode which was a failure contributed by mechanical seal malfunction.

ACKNOWLEDGEMENT

In the name of Allah, SWT The Most Gracious and The Most Merciful all praise to Him the Almighty that in His will I managed to complete this final year project within allocated time.

Deepest gratitude to my family, who is always giving moral support and encouragement that, has been a great inspiration to survive all difficulties in completing this project.

Special appreciation is dedicated to project supervisor, Dr. Ainul Akmar binti Mokhtar for precious advices and guidance not only limited to the project completion but also for future undertakings. Thank you for the countless hours in knowledge and valuable experiences sharing throughout the supervision.

Many thanks to project team members especially to Mr Azmi bin Muda, who is continuously and devotedly giving support to ensure this project will be beneficial for both party. Also special recognition to Mr Mohd Farid bin Mohd Ismail who is consistently giving the support, ideas and recommendations as well as understanding especially in deeper parts of the project.

Last but not the least, special thanks to Dr. Masdi bin Muhammad and Mr Eddy Damsuri bin Mat Daud for advices and concern that has helped me in improving the final year project from time to time.

May Allah bless and repay all the kindness and good deeds.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATION AND NOMENCLATURE

CM	Corrective Maintenance
COTP	Crude Oil Transfer Pump
DOR	Daily Operation Report
LDA	Life Data Analysis
MOL	Main Oil Line
MTBF	Mean Time Between Failures
MTTF	Mean Time To Failure
MTTR	Mean Time To Repair
OREDA	Offshore Reliability Data
PM	Preventive Maintenance
RAM	Reliability, Availability and Maintainability
RBD	Reliability Block Diagram
RDA	Repairable Data Analysis
TTF	Time To Failure
TTR	Time To Repair

CHAPTER 1

INTRODUCTION

1.1 Background of Study

This study is focusing on 2 units of main oil line (MOL) pumps or known as crude oil transfer pumps (COTP). MOL pump is subsurface equipment used to transfer crude oil from one of the offshore facilities. Figure 1.1 shows the type of MOL pump being used.

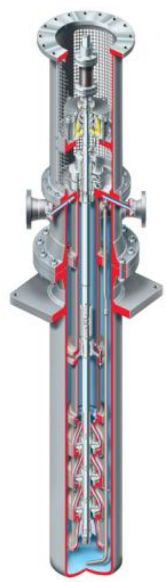


Figure 1.1: MOL pump [1]

This study is carried out to analyze and predict equipment failure and future performance of the whole system by emphasizing the essence of reliability engineering and RAM methodology.

Time-to-failure (TTF) and time-to-repair (TTR) data of these 2 pumps are taken from daily operation report (DOR) which states the uptime and downtime status of both pumps in a daily basis from January 2008 – August 2013.

Failure modes involved in every failure event are identified with reference to Offshore Reliability Data (OREDA) handbook. Failure mode is referring to the effect by which a failure is observed on the failed item [2]. It can either be associated with components of the pump or the failure events.

Analysis of individual failure modes allows the quantification of the impact of each failure mode by assessing the product reliability as if that failure mode is the sole reason of failure. Besides, evaluation of the impact on product reliability by removing each failure mode can be analyzed [3]**.**

1.2 Problem Statement

In this competitive world, failure and its effect are increasingly intolerable especially in oil and gas industry. Regardless if at the onshore plants or the offshore platforms, equipment failure will lead to reduction in output, loss of production and also creates unsafe working environment.

MOL pump is rotating equipment that falls under cluster of critical equipment which means failures occur to this equipment has an impact towards the safety, repair cost as well as the production loss. Based on the historical data, these 2 MOL pumps had experienced frequent failures which contributed to the mean time between failures (MTBF) to be less than 2 months. This study is done to identify the critical failure modes that contributed to this problem.

1.3 Objectives & Scope of Study

The main objective of this research is to assess the reliability, maintainability and system performance of the 2 MOL pumps in term of operational availability by failure modes.

This research covers the following sub-objectives in order to achieve the main objective:

1. To identify dominant failure modes based on Offshore Reliability Data (OREDA) as a guideline and analyze the failure characteristics of each failure mode using Weibull++ software.

2. To perform Reliability, Availability and Maintainability (RAM) study using BlockSim software and project future system performance in term of operational availability.
3. To identify critical failure modes that caused the system unavailability and come out with recommended actions.

CHAPTER 2

LITERATURE REVIEW

2.1 Equipment Boundary

MOL pump is the primary equipment in the crude oil transfer system from a central processing platform to the central pumping platform before being pumped to the onshore terminal via pipeline as shown in the Figure 2.1.

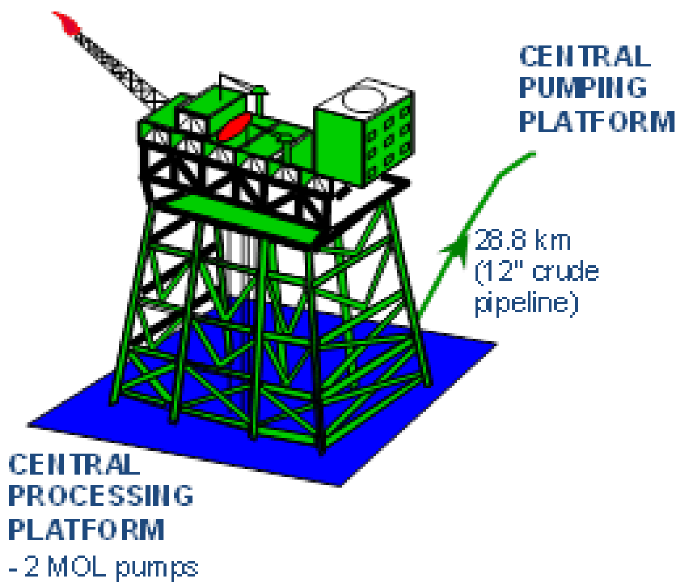


Figure 2.1: Crude oil transfer system layout

There are 2 skids to accommodate 2 units of pumps and the current operating philosophy of the pumping system is 1 unit in running mode and the other 1 unit in standby mode.

The pump is a vertical centrifugal pump and electric motor driven. Based on the OREDA handbook, the Figure 2.2 below shows the equipment boundary of the pump.

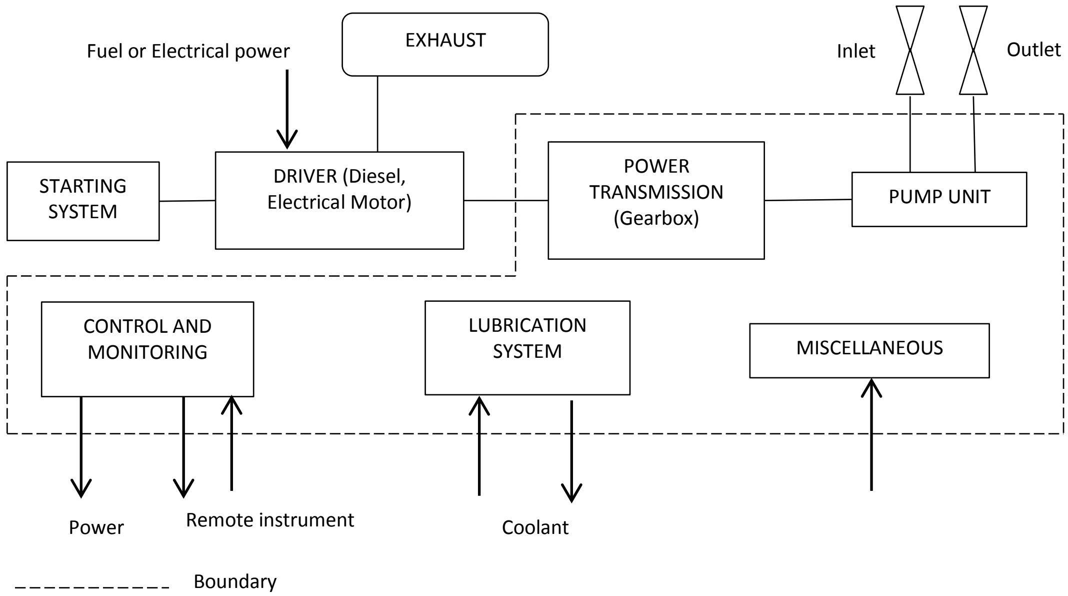


Figure 2.2: Pump boundary [2]

In this study of reliability and system performance assessment, the study of the pump is focusing on its failure modes. Therefore, it is important to identify the component and maintainable item of the pump since the failure modes are more correlated to the components. In addition, failure modes occurrence is showing the failure of certain components that result to unavailability of the system. According to the OREDA handbook, the components or the maintainable items of a pump are tabulated in Table 2.1.

Table 2.1: Pump subunit and maintainable items [2]

Subunit	**Maintainable Items**
Power Transmission	Gearbox/var. Drive, Bearing, Seals, Lubrication, Coupling to Driver, Coupling to Driven Unit, Instruments
Pump	Support, Casing, Impeller, Shaft, Radial Bearing, Thrust Bearing, Seals, Valves & Piping, Cylinder Liner, Piston, Diaphragm, Instruments
Control and Monitoring	Instruments, Cabling & Junction Boxes, Control Unit, Actuating Device, Monitoring, Internal Power Supply, Valves
Lubrication System	Instruments, Reservoir w/heating System, Pump w/motor, Filter, Cooler, Valves & Piping, Oil, Seals
Miscellaneous	Purge Air, Cooling/heating System, Filter, Cyclone, Pulsation Damper

In this study, only critical failure type is counted. This type of failure is a failure that resulted in 100% system unavailability. On the other hand, degraded and incipient failure types are not taken into account. Degraded failure type causes in degradation of the system performance while the incipient failure type does not cause immediate effect to the system performance and the failure can be found during repair or scheduled maintenance.

A reliability study of a gas turbine generator by M Ismail, M Farid [4] was carried out to analyze individual dominant failure modes of the equipment by identifying failure characteristic of each failure mode. The failure modes were analyzed to determine the criticality by the percentage of contribution to the overall system unavailability. Besides, this method is also able to forecast the future system performance by applying reliability, availability and maintainability (RAM) method.

OREDA handbook stated that there are 19 dominant failure modes for a pump. This includes abnormal instrument reading; breakdown; erratic output; external leakage-process medium; external leakage-utility medium; fail to start on demand; fail to stop on demand; high output; internal leakage; low output; minor in-service problem; noise; overheating; parameter deviation; spurious stop; structural deficiency; vibration; unknown; and other. Failure modes involved in this study will be identify, grouped and analyzed based on ISO 14224 [5] and OREDA 2009 handbook [2].

2.2 Failure Rate and Failure Characteristics

Generally, there are 3 types of failure rates so called failure characteristics pattern that can be described in the 3 regions of a bathtub curve as shown in the Figure 2.3. This figure is also known as a Bathtub Curve.

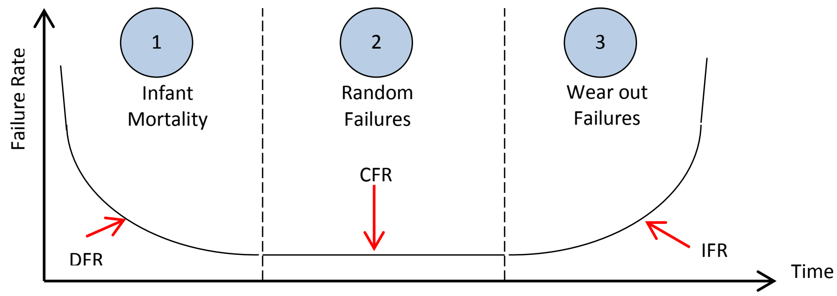


Figure 2.3: Failure characteristics in a bathtub curve

The bathtub curve is divided into 3 regions of different failure characteristics pattern i.e. decreasing failure rate (DFR), constant failure rate (CFR) and increasing failure rate (IFR). The causes of each failure characteristic and the remedial actions are shown in the Table 2.2. This information will be used as a guideline for discussion to interpret each failure mode based on each failure characteristic and recommendation for improvement.

Table 2.2: Failure characteristics causes and remedial action [4]

Failure Characteristic	Causes	Remedial Actions
Decreasing Failure Rate (DFR)	Manufacturing defects: welding flaws, cracks, defective parts, poor quality control, poor workmanship (after overhaul), contamination	Burn-in operation, screening, quality control, acceptance testing
Constant Failure Rate (CFR)	Environment: random loads, human error (operation & maintenance), chance events	Redundancy, excess strength, operation within design envelope, strict adherence to operation & maintenance procedures
Increasing Failure Rate (IFR)	Normal / abnormal fatigue, corrosion, aging, cyclical loads	Part replacement (prior to failure)

2.3 Common Reliability Distributions

Reliability can be defined as the probability that a system will perform its intended function under specified working condition for a specified period of time [6]. Nelson [7] stated that most definition of reliability has 5 common elements which are probability, failure, function, condition and time. The basic unit to measure reliability is the failure rate function or hazard function which specifies the rate of the system aging as shown in Equation 2.1.

$$\lambda(t) = \frac{Number\ of\ failures}{Total\ operating\ time} \tag{2.1}$$

There are 2 significant tactics in improving the reliability and maintenance of products and equipment as well as the system as listed below [8]:

1. Improving individual components
2. Providing redundancy

Since the study is focusing on reliability analysis by failure modes which are correlated to the reliability of the components, the best tactic to improve the reliability is by improving individual components in order to reduce the frequency of the failure modes to happen.

When performing reliability analysis, a correct distribution must be chosen to represent the data. There are several kinds of distribution used to represent the reliability statistics. The most commonly used in a reliability analysis are Weibull distribution and exponential distribution.

2.3.1 Weibull Distribution

The Weibull distribution is a very widely used probability distribution in reliability [9]. Abernethy [10] mentioned that the primary advantage of Weibull analysis is the ability of this distribution to provide reasonably accurate failure analysis with even a small sample.

Weibull model with 2 parameters of scale parameter, η (known as Eta) and the shape parameter, β (known as Beta) are generated from the Weibull reliability function as shown in Equation 2.2.

$$R(t) = e^{-(\frac{t}{\eta})^{\beta}} \tag{2.2}$$

Weibull analysis can model a failure rate or the hazard function that is decreasing, increasing or constant, allowing it to describe any phase of an item's lifetime. This analysis will be used to identify the failure characteristics of each failure mode in this study. Weibull distribution is easy to interpret and extremely versatile in which the characteristic of other life distributions can be modeled only by adjusting the value of its shape parameter, β as shown in the Table 2.3.

Table 2.3: Weibull distribution with different value of β [11]

Shape Parameter	Hazard Function (Failure Rate)	Type of Product Failure
$\boldsymbol{0 < \beta < 1}$	 Initially high failure rate decreases over time (first part of bathtub – shaped hazard function)	Early failure, also known as infant mortality, because they occur in initial period of product life. These failures may necessitate a product "burn-in" period to reduce risk of initial failure.
$\boldsymbol{\beta = 1}$	Constant failure rate over life of product	Random failures, multiple cause failures. Models "useful life" of product.
$\boldsymbol{\beta > 1}$	 Increasing failure rate, with most rapid increase initially	Wear-out failure. Models final period of product life, when most failures occur.

2.3.2 Exponential Distribution

The exponential distribution can be used to model the time to failure of components and systems with constant failure rate and this situation is often realistic [12]. It is the simplest life distribution with only one parameter of λ. The reliability function of an exponential distribution can be written as in Equation 2.3.

$$R(t) = e^{-\lambda t} \tag{2.3}$$

If the failure of a component is exponentially distributed, the probability of failure in a specified time interval does not depend on the age of the component since the failure rate of this distribution is as in Equation 2.4.

$$h(t) = \lambda \tag{2.4}$$

This shows that the failure rate of this exponential distribution is a constant. Consequently, the probability that the component will fail within the specified time interval is the same regardless whether the component has been used for some time or just been placed in use.

This characteristic of the exponential model is called the memory-less property which means this probability does not depend on t [9]. Consequently, this model is suitable for components which do not degrade or wear out with time whose conditional probability of failure within a specified time interval practically does not depend on age.

2.4 Maintainability Lognormal Distribution

Maintainability is the probability of a failed system will be restored or repaired to a specified condition within a specified period of time when maintenance is performed in accordance with prescribed procedures [13]. In general, system maintainability is the measure of how long it takes to restore functions to a failed. The important term in measuring the maintainability is the mean time-to-repair (MTTR) or the mean downtime which defines as the expected value of the repair time.

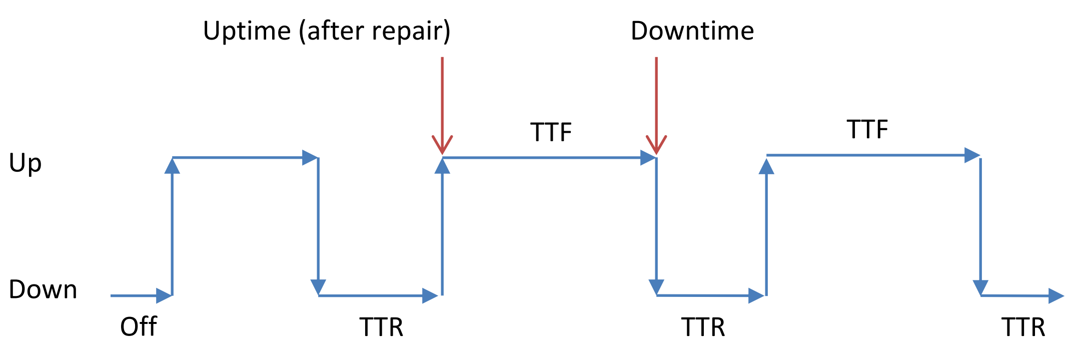


Figure 2.4: Typical uptime/downtime graph

The Figure 2.4 shows the typical uptime/downtime graph for easier description of time-to-repair (TTR) and time-to-failure (TTF) where the former is more related to maintainability and the latter is related to reliability.

According to Heizer and Render [8] the 2 important tactics to improve maintainability of a system are by:

1. Implementing or improving preventive maintenance
2. Increasing repair capabilities and speed

These 2 general tactics will be used as a basis in maintainability improvement in later parts of this study.

In order to represent repair data, the lognormal distribution is the most familiar model for repair time or downtime distribution. Downtime is treated as a random variable since every failure event will always has different downtime duration due to different failure modes, component failure, spare parts availability and skill level of maintenance people.

Weibull++ software is being used in this study to assess the lognormal distribution parameters for maintainability function as per formula in Equation 2.5.

$$M(t) = \Phi \, \frac{\ln t - \mu}{\sigma} \tag{2.5}$$

Where: Φ = standard normal distribution cumulative function

μ = lognormal distribution mean value

σ = lognormal distribution standard deviation

2.5 RAM Modeling

RAM refers to 3 related elements of a system and its operational support; reliability, availability and maintainability. RAM modeling emphasized the use of both reliability and maintainability data of a system in order to analyze the availability of the system. System availability is a measure of how well a system performs or meets its design objectives [14].

Ebeling [15] stated the meaning of availability as the probability that a system is performing its required function at a given point in time or over a stated period of time when operated and maintained in a prescribed manner. He added that availability measures include inherent availability (Ai), achieved availability (Aa), operational availability (Ao), generalized operational availability and total system availability. In this study, the availability analysis is in term of operational availability.

Operational availability considers logistics, supply and administrative downtime, and both preventive maintenance (PM) downtime and corrective maintenance (CM) downtime. The operational availability can be computed by the following formula of Equation 2.6.

$$Ao = \frac{MTBF}{MTBF + MDT} \tag{2.6}$$

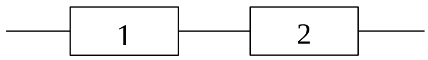
Where: $MTBF =$ Mean Time Between Failures

$MDT =$ Mean Down Time

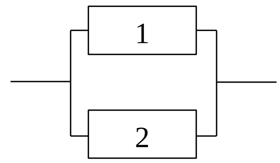
There are many methods of doing the RAM modeling. The most widely used techniques are reliability block diagrams (RBD), fault tree analysis, Monte Carlo simulation and Markov model [6]. In this study, RBD method will be used to assess the system performance of the 2 MOL pumps based on the availability of the whole system.

2.5.1 Reliability Block Diagram

RBD is also known as reliability network [16] showing the relationship of the components in a system by graphical representation. The advantage of using this approach is the ease of expressing and evaluating reliability [6]. RBD is made up of individual blocks connected either in series, parallel or the combination of these 2. Figure 2.5 shows how the individual block is combined in series and parallel of the RBD method.



a) Series blocks



b) Parallel blocks

Figure 2.5: Basic relationship between 2 blocks

A system is composed of a number of component is called as a series system if one failure occur to any component and causes failure to the entire system. For a parallel system, it operates if any one of or more of its components operates. The reliability of the entire series system is the product of the reliability of each individual component as shown in the following formula of Equation 2.7.

$$R_s = R_1 \times R_2 \times \dots \times R_n \tag{2.7}$$

In a parallel system, the redundant component acts as a standby component where it operates if the other component fails. This is a common method used in a plant management to ensure the highest availability of the system and continuous production. The total reliability of the entire system can be computed using Equation 2.8.

$$R_s = 1 - [\,(1 - R_1) \times (1 - R_2) \times \dots \times (1 - R_n)\,] \tag{2.8}$$

BlockSim Software is used in this study to build and evaluated the system performance of the pumps by failure modes. Therefore, the connection of the RBD in this study is actually the connection of the failure mode event. Certain parameters of reliability and maintainability are needed for each failure mode before simulation of the entire RBD can be carried out. This method is used to analyze the criticality of the failure modes to the effect of the availability of the whole system.

CHAPTER 3

METHODOLOGY

Reliability, Availability and Maintainability (RAM) modeling actually involves a lot of calculations and mathematical model. It is important to have adequate and reliable data and information to ensure the result of a RAM study is precisely represent the real situation. In order to ease the analysis, some software is needed in the study i.e. Microsoft Excel, Weibull++ and BlockSim.

3.1 Preliminary Research

At the beginning of the study, preliminary research is done on the MOL pump to identify equipment boundary, functions, components and dominant failure modes. In addition, it is important to study the elements of a RAM modeling such as reliability analysis, reliability distribution, maintainability distribution and reliability block diagram (RBD). Focus is given into the knowledge in analyzing the reliability distribution and also RBD.

3.2 Data Gathering

Data are collected from daily operation report (DOR) which states the daily status of the equipment. This type of data received from PCSB is the historical failure data of the equipment. From this data, the TTF and the TTR are arranged chronologically and dominant failure modes are identified and grouped together to specific failure event by referring to OREDA handbook.

Dominant failure modes are associated to significant components of the pump in order to relate the failure event with the failed components. This step can be done based on the description of the failure events in DOR. It is vital to associate correct components to respective failure mode in order to cater the real culprit of certain failure events.

3.3 Data Analysis

There are few steps need to be done to analyze the data before getting the ultimate result of the study. The overall procedure of the study can be referred to the flow chart in Figure 3.1.

3.3.1 Trend Test

Trend test consist of 2 different test which are Mann test and graphical test. The Mann-Whitney test is a nonparametric test that compares 2 uncorrelated samples. This test can be used to determine the differences such as performance and result between the 2 samples taken before and after an improvement has been done.

Graphical test is the simplest method for obtaining results in both life data and accelerated life testing analysis according to ReliaSoft Corporation [17]. Both type of trend test are carried out to the TTF data of every failure mode to detect present of trend for renewal process assumption.

This method is used to test the assumption of the distribution for each failure mode. The distribution of each failure mode is dependent on the repair assumption i.e. “as good as new”, “as bad as old” or “in between”. This kind of trend test is a simple way to confirm this assumption with certain confidence level.

3.3.2 Laplace Test

Laplace test is important in determining the reliability of the equipment. This test is used to validate the use of exponential distribution model (constant failure rate). Assumption of constant failure rate is important because the variable of the system is no longer the lifetime of the system, but the times of successive failures of the system. Exponential distribution model can be used if there is no trend detected in the Mann test and also no trend identified in Laplace test.

3.3.3 Life Data Analysis

Life data analysis (LDA) can only be used if there is no trend detected in trend test and Laplace test. LDA requires the fitting of the TTF data into suitable life distribution. Originally, LDA method is only suitable to be used for non-repairable item [18]. On the other hand, if a trend is identified from the trend test and Laplace test, a repairable data analysis (RDA) will be carried out.

3.4 Parameters Evaluation in Weibull++

Both TTF and TTR data will be analyzed in Weibull++ software to fit into specific probability distribution and to find the required parameters. This information from Weibull++ will help in further analysis of the reliability status of the equipment. Besides, the parameters from Weibull ++ analysis are also important for RBD construction in BlockSim.

3.5 RBD Simulation in BlockSim

RBD is constructed based on the relation of failure modes with each other. Since only critical failure modes type is considered in this study, all of the RBD will be in series configuration. It means that if any one of the failure modes occurs, the whole system will fail.

The RBD construction and simulation assist in determining the percentage of criticality of each failure mode to the operational availability of the whole system. This in a way will help in identifying the severe failure modes. Good recommendations can be implemented in order to improve the system availability in the future by tackling the most severe failure modes.

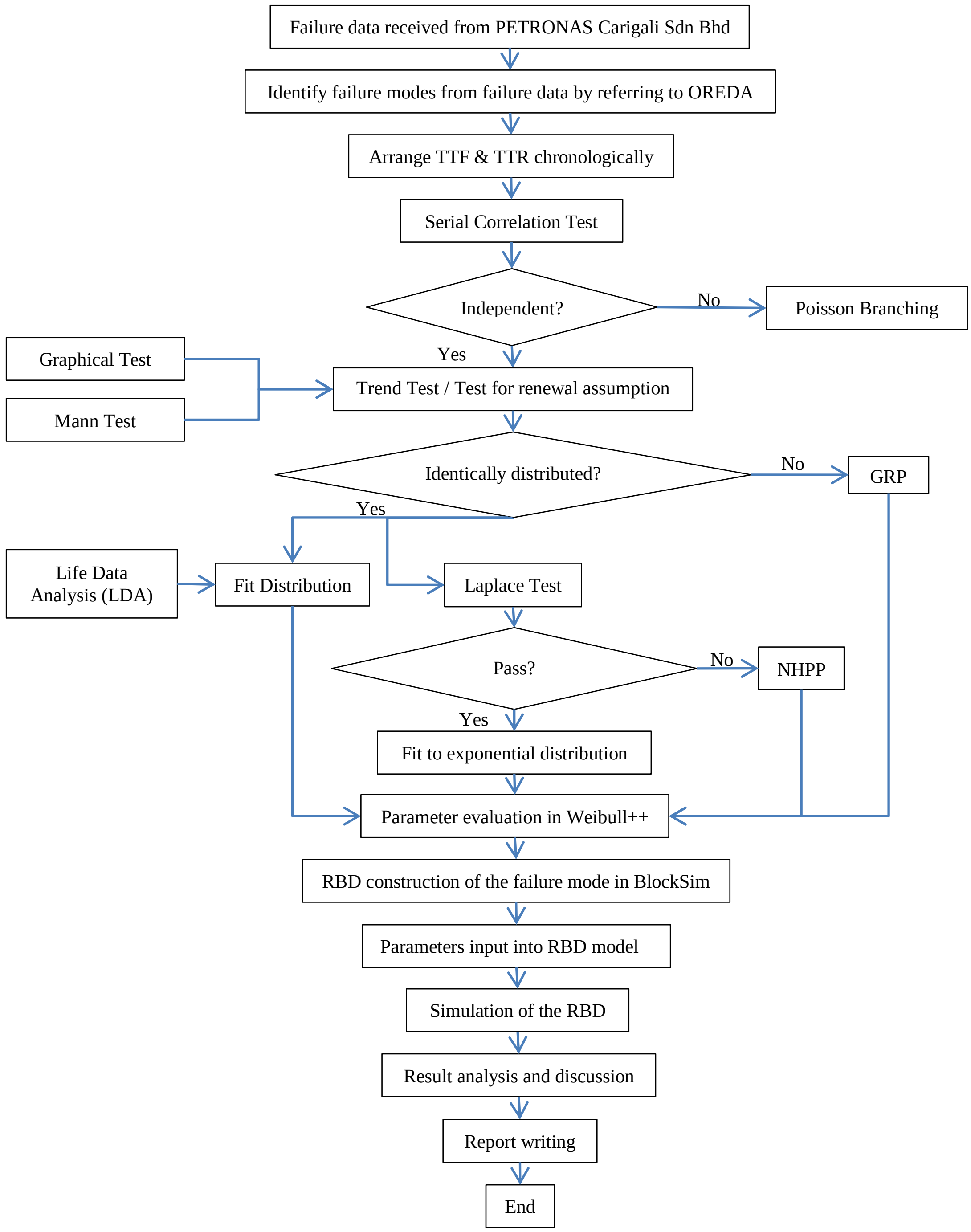


Figure 3.1: Research methodology flowchart

3.6 Assumptions

1. The result of the analysis is highly dependent of description and equipment status in the DOR. Engineering judgment is applied for some info on equipment status which was found to be ambiguous / unrealistic.
2. A total of 68 months period is taken as the duration for the study starting from January 1, 2008 to August 31, 2013. The actual running time or operational time (excluding standby time, downtime during out of service and planned maintenance) for each MOL pump are 22,754 hours for Pump A and 22,462 hours for Pump B. Thus, the total operation hours for both pump is 45,216 hours (approximately 5 years).
3. Only critical failure types which immediately cease the COTP function is considered in the study. Degraded and incipient failure types are not considered.

3.7 Tools

3.7.1 Microsoft Office Excel

The Microsoft Excel is used to prepare TTF and TTR data received from PCSB. From this data, failure modes that affect the downtime of the pump are identified. Besides that, result analysis for data testing i.e test for independence, trend test, test for renewal assumption and Laplace test are all done in Microsoft Excel.

3.7.2 Weibull++ Software

The Weibull++ software is used to analyze the data input from the Microsoft Excel. This software is capable to generate the failure characteristic of each failure mode by graphical output. A single data input can produce different graphs for instance probability density function (PDF), probability, reliability versus time, failure rate versus time and other graphical representation in a single run of the analysis.

3.7.3 BlockSim Software

The BlockSim software is used to draw the RBD of the dominant failure modes of pumps. Reliability data from the analysis in Weibull++ together with maintainability data are the input data to analyze the criticality of each failure mode. Operational availability of the whole system can also be identified from the simulation of the RBD in this software.

3.8 Key Project Milestones

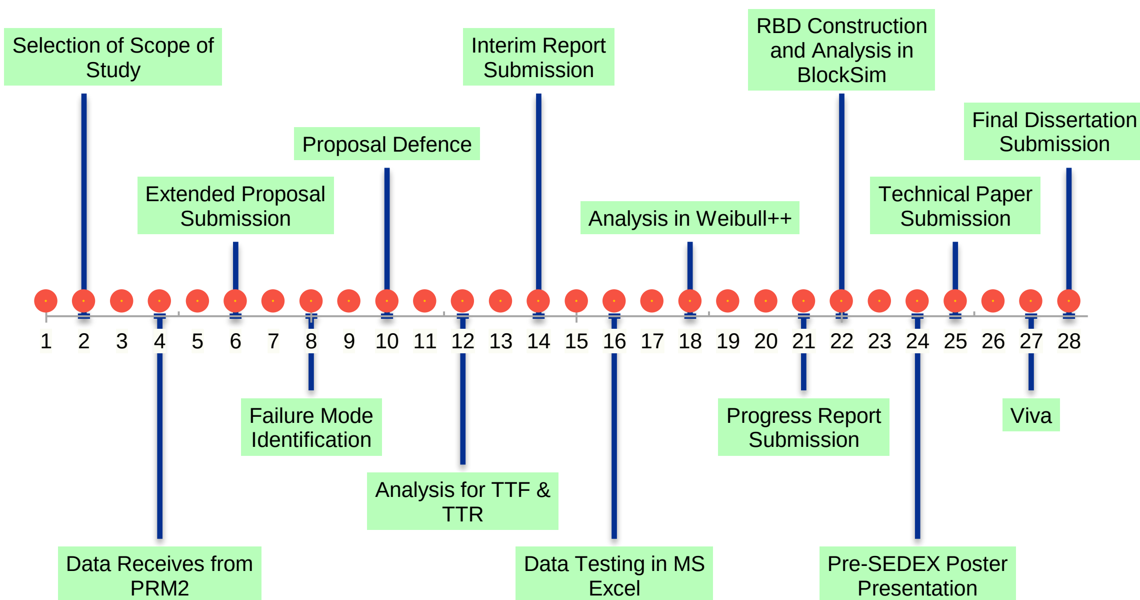


Figure 3.2: Key milestones of the project

3.9 Project Timeline

Table 3.1: Research Gantt chart

PLANNING	PERIOD OF PLANNING (WEEK)																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
FINAL YEAR PROJECT 1																												
Selection of Project Title																												
Waiting for Concurrence from PRM2																												
Research on Pump Boundary																												
Research on Reliability Analysis																												
Research on RAM Study																												
Research on the Methodology of the Project																												
Preparation of Extended Proposal																												
Data Gathering from PRM2																												
Proposal Defense Preparation																												
Preparation of Interim Report																												
Data Analysis by Failure Mode occurrence																												
FINAL YEAR PRJECT 2																												
Data Analysis by Weibull++																												
Design & Evaluate RBD by BlockSim																												
Result Evaluation & Discussion																												
Progress Report Preparation																												
Pre-SEDEX Preparation																												
Technical Report Preparation																												
Viva Preparation																												
Dissertation Preparation																												

	Planned Activities
	Actual Timeline

CHAPTER 4

RESULT AND DISCUSSION

4.1 Failure Mode Statistics

Throughout the 68 months duration, a total of 18 failures occur to Pump A whereas there are 15 failures occur to Pump B at the same period of time making the total number of failures occur to the whole system to be 33 failures in 68 months. The failure modes distribution of the individual pump is illustrated in Figure 4.1.

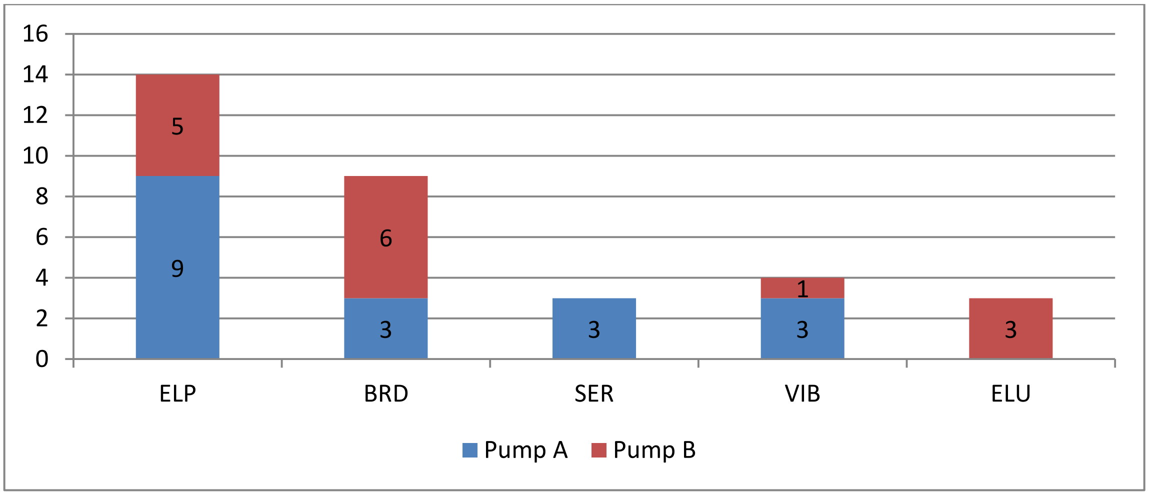


Figure 4.1: Failure modes distribution

There are mainly 5 failure modes identified affecting the pump system from January 2008 to August 2013. The failure modes are grouped together based on ISO 14224 [5] and OREDA [2] as shown in the Table 4.1.

Table 4.1: MOL pump failure modes distribution

No	Failure Mode	Failure Mode Code	Pump A	Pump B	Total
1	External Leakage – Process Medium	ELP	9	5	**14**
2	Breakdown	BRD	3	6	**9**
3	Minor In Service Problem	SER	3	0	**3**
4	Vibration	VIB	3	1	**4**
5	External Leakage – Utility Medium	ELU	0	3	**3**
Sub – Total			**18**	**15**	**33**

By referring to OREDA as a main reference in grouping the failure mode, these failure modes are associated to components of the pump and also failure event based on the description of failure from the DOR and is derived as in Table 4.2.

Table 4.2: Failure mode grouping based on failed components/issues

No	Failure Mode	Failure Mode Code	Failure Issue
1	External Leakage – Process Medium	ELP	Mechanical seal leakage
2	Breakdown	BRD	Spider bearing, shaft
3	Minor In Service Problem	SER	Failure upon service, contaminant
4	Vibration	VIB	Impeller, shaft, contaminant
5	External Leakage – Utility Medium	ELU	Lube oil leakage

4.2 Weibull++ Analysis

Before analysis in Weibull++ is carried out, trend test has shown no trend present for all of the failure modes. The Laplace test also showed no trend for all of the 5 failure modes. This in a way allows the use of either exponential distribution model or fitting the model into distribution in Weibull++ by using LDA method. LDA method is selected for parameters evaluation in Weibull++.

In order to perform failure mode life data analysis, each similar failure mode must be grouped together, ranked and plotted. This process is done in Weibull++ Software using Maximum Likelihood (MLE) method since the data consists of heavy suspension and huge data set. The 5 failure modes are treated individually during analysis in Weibull++ software. The outcomes from the analysis are tabulated as in Table 4.3.

Table 4.3: Failure and repair characteristics from Weibull++

		Reliability Data				**Maintainability Data**		
No	**Failure Mode**	**Failure Distribution**	**Parameters**		**Failure Characteristic**	**Repair Distribution**	**Parameters**	
			β	η (year)			μ (hour)	σ
1	ELP	Weibull (2P)	0.57	0.47	DFR	Lognormal	7.43	1.02
2	BRD	Weibull (2P)	0.63	0.88	DFR	Lognormal	7.88	1.28
3	SER	Weibull (2P)	0.33	115.1	DFR	Lognormal	11.06	3.16
4	VIB	Weibull (2P)	0.44	10.72	DFR	Lognormal	9.19	1.90
5	ELU	Weibull (2P)	0.99	1.75	CFR	Lognormal	11.04	3.12

Based on the result, all of the failure data of the failure modes fit into Weibull 2 parameters (Beta, Eta) distribution while the repair data fits into lognormal distribution. The result generated by Weibull++ software is also graphically generated into graphs of Failure Rate vs Time and Probability Distribution for each failure mode as shown in the following figures:

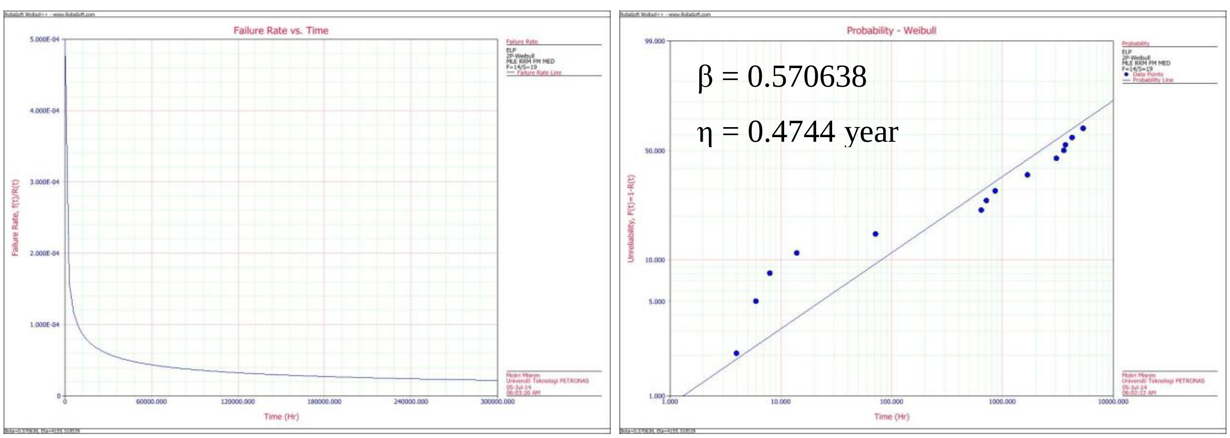


Figure 4.2: Plot for external leakage – process medium (ELP)

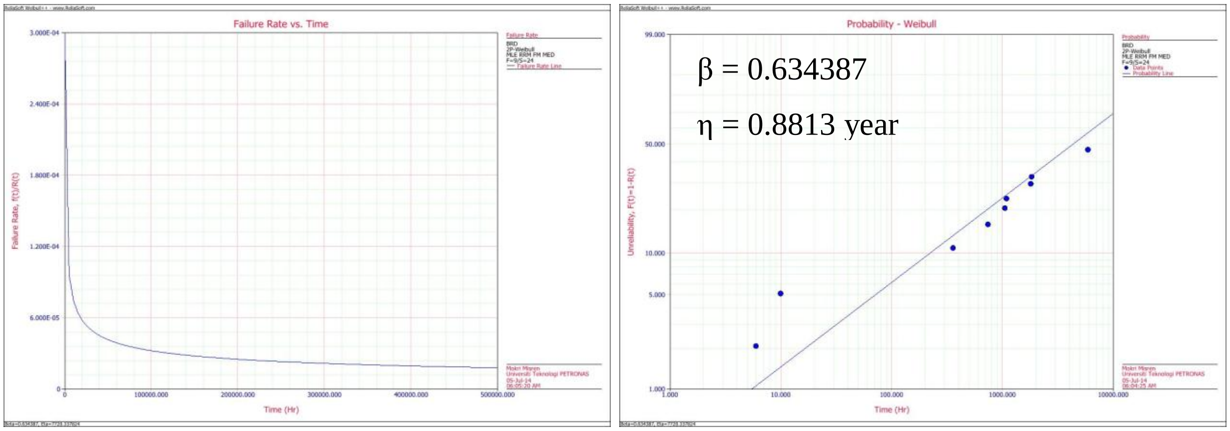


Figure 4.3: Plot for breakdown (BRD)

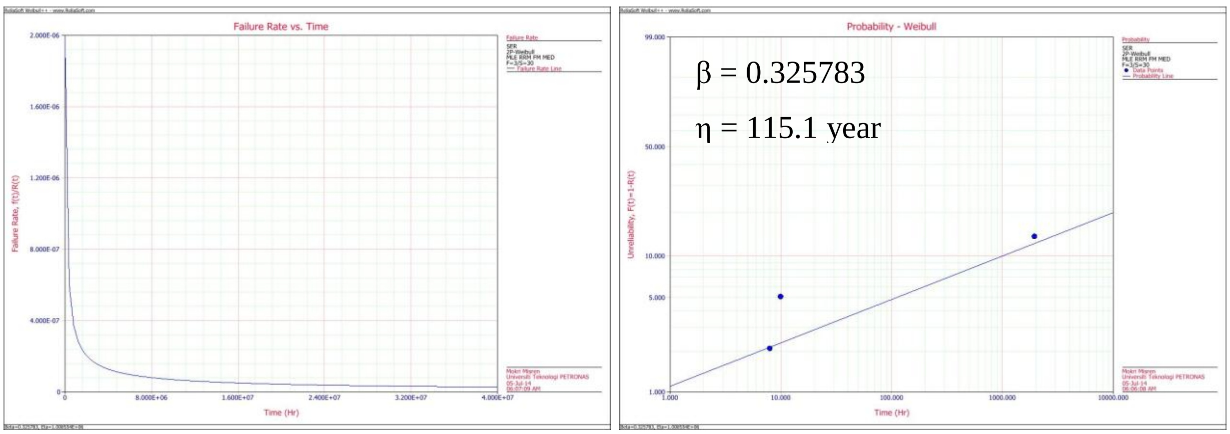


Figure 4.4: Plot for minor in-service (SER)

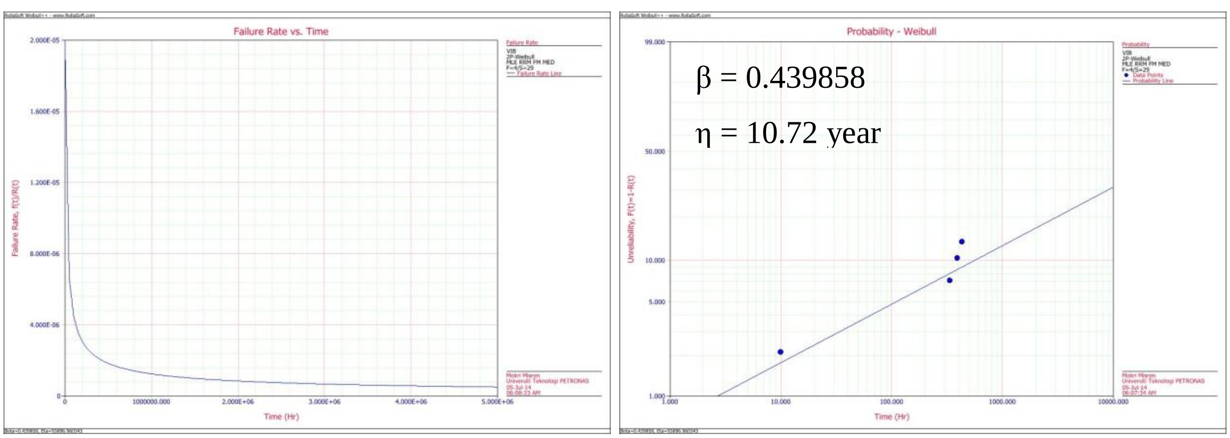


Figure 4.5: Plot for vibration (VIB)

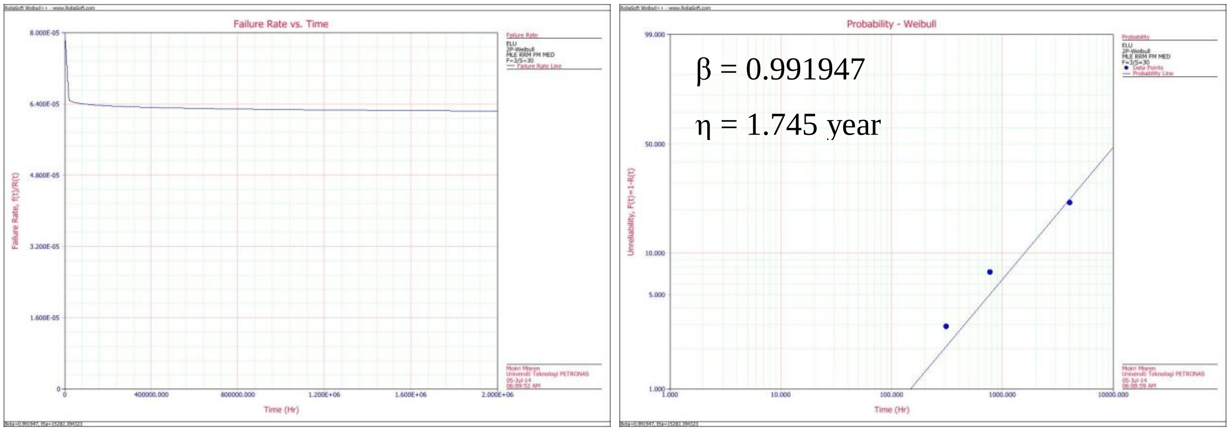


Figure 4.6: Plot for external leakage – utility medium (ELU)

Based on the analysis made in Weibull++ software, it is shown that 4 of the failure modes are in decreasing failure rate (DFR) and 1 failure mode is in constant failure rate (CFR). There is no failure mode with increasing failure rate which represents aging and wear out. The following observation can be made from this result:

External leakage - process medium failure mode has a Beta, $\beta = 0.5706$ and Eta, $\eta = 0.4744\ year$. This suggests that failure event mechanical seal leak is now in decreasing failure rate (DFR) which is in the infant mortality stage. It might be due to defective part of the seal and maintenance error during mechanical seal installation during maintenance work.

Breakdown failure mode has a Beta, $\beta = 0.6344$ and Eta, $\eta = 0.8813\ year$. The low beta value indicates in decreasing failure rate (DFR) might be due to defective parts especially bearings and shafts, crack and welding flaws.

Minor in-service problems failure mode has a Beta, $\beta = 0.3258$ and Eta, $\eta = 115.1\ year$. It suggests there might be poor in quality control especially during final acceptance test (FAT). It causes the equipment fail during testing after installation. Poor workmanship can also be a contributor.

Vibration failure mode has a Beta, $\beta = 0.4399$ and Eta, $\eta = 10.72\ year$. The low Beta value suggests there might be contamination like present of sands during oil transfer, defective parts of impeller and poor workmanship especially post – overhaul period.

External leakage - utility medium failure mode has a Beta, $\beta = 0.9920$ and Eta, $\eta = 1.745\ year$. This suggests that the failure event lube oil leak is now approaching constant failure rate (CFR) which is in the random failure stage. This might be due to environment or temperature variance and human error (operating and maintenance error).

4.3 BlockSim Analysis of RBD

BlockSim software is used to illustrate the connection of the individual failure mode with each other. In this case of study, RBD of the failure modes is constructed in a series configuration. This series configuration means that each failure event occurs due to any failure mode will contribute to the failure and unavailability of the whole pump system. Since only critical failure type is considered in this analysis, any failure occurrence will contribute to the downtime of the whole system. The Figure 4.7 below shows how the RBD is constructed in the software.

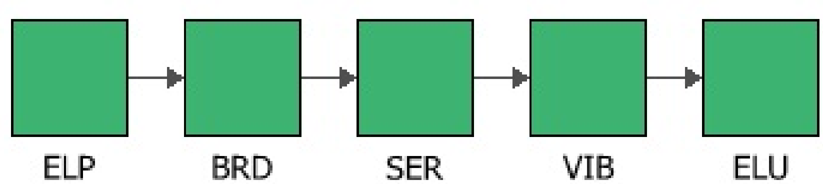


Figure 4.7: RBD configuration in BlockSim

From the simulation of the RBD, the mean availability of the system after 1 year is shown graphically in Figure 4.8. Based on the simulation of the RBD, the mean availability of the whole system is equal to 33.6%.

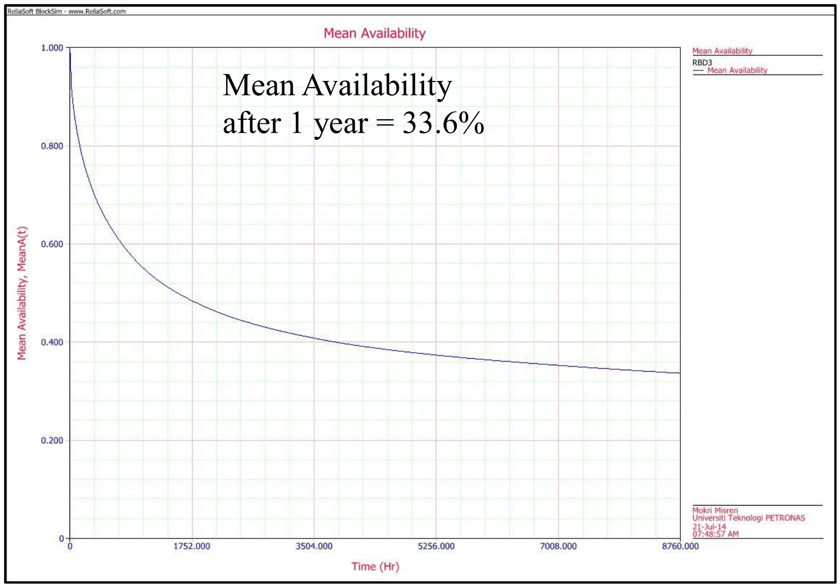


Figure 4.8: Plot of system availability against time

The system operational availability after 1 year is lower when compared to OREDA. OREDA is the compilation of reliability data among the best oil and gas operator worldwide. Based on OREDA, the mean availability of a centrifugal pump is 99.89% after 1 year duration. This suggests that the 2 MOL pumps are not properly maintained and operated during its service life.

In order to check for validity of the result of the simulation, manual calculation of the operational availability is calculated as in Equation 4.1.

$$Ao = \frac{Total\ Uptime}{Total\ Uptime + Total\ Downtime} = 54.5\% \qquad (4.1)$$

The operational availability from above calculation is slightly higher than the obtained operational availability from the RBD simulation in BlockSim. However, the value shows the low availability of the system compared to availability value from OREDA handbook. This shows that the result from the RBD simulation is validated.

The RBD of failure mode is also able to give the result of individual block availability ranking and is shown in Figure 4.9. From the figure, external leakage-process medium is having the least availability while minor in-service failure mode is having the most availability to the whole system.

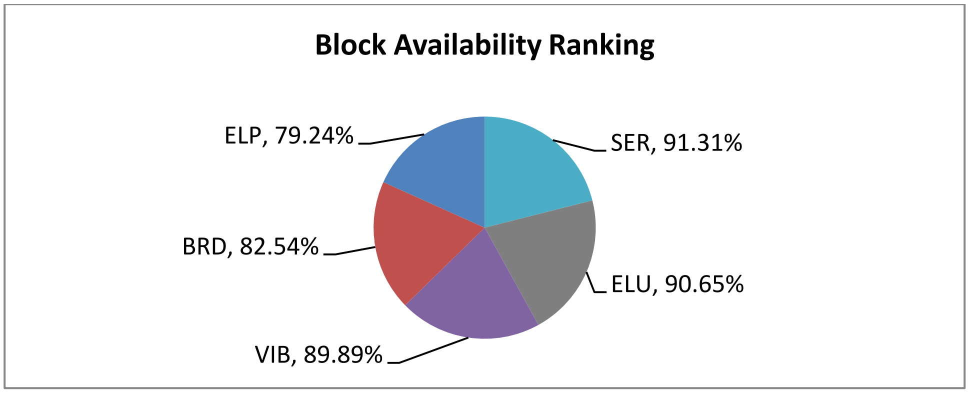


Figure 4.9: Failure mode availability ranking

The criticality of each failure mode is measured by 2 categories. The first category is measured by the individual failure criticality ranking. It measured the expected number of failures contributed by each failure mode in 1 year. The failure mode criticality based on this category is shown in the pie chart in Figure 4.10.

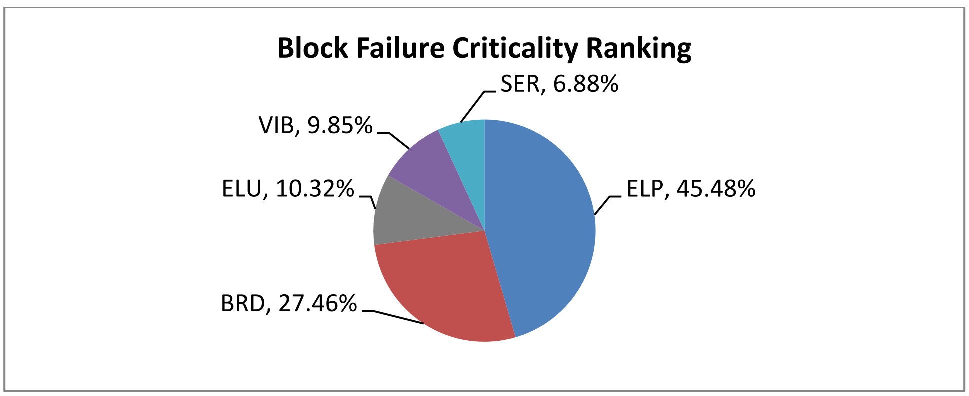


Figure 4.10: Failure mode failure criticality ranking

From this result, external leakage-process medium failure mode is the highest contributor to the number of failure of the whole system followed by breakdown, external leakage-utility medium, vibration and lastly minor in-service problem.

The second category to measure the criticality ranking of each failure mode is by the downtime criticality. This category measured the downtime duration of each failure mode. Failure mode that has the longest downtime will contribute to the highest unavailability to the system. The downtime criticality ranking is shown in Figure 4.11.

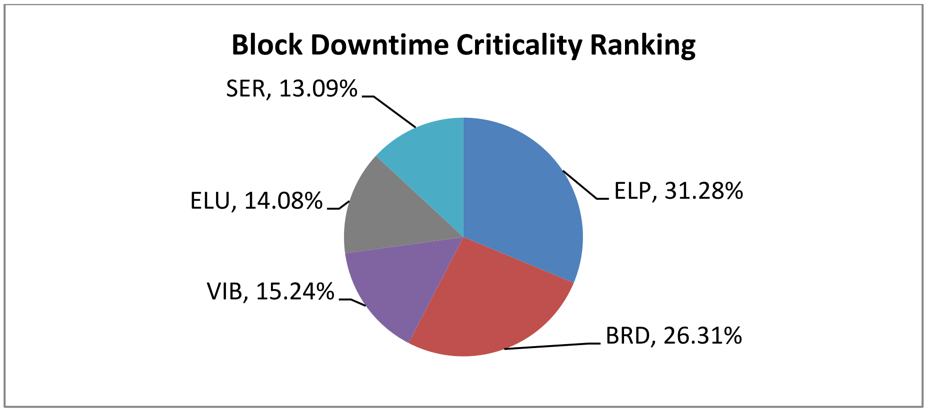


Figure 4.11: Failure mode downtime criticality ranking

From the Figure 4.11, the most critical failure mode due to its downtime ranking is external leakage-process medium failure mode followed by breakdown, vibration, external-leakage utility medium and minor in-service problem. Based on simulation of the RBD in BlockSim, external leakage-process medium failure mode and breakdown contributed to 1818 hours and 1529 hours of downtime respectively. Meanwhile, vibration failure mode contributed to 886 hours, external leakage-utility medium, 819 hours and minor in-service contributed to downtime of 761 hours.

Based on both category of failure mode criticality ranking, external leakage-process medium and breakdown failure modes are the 2 most critical in term of both expected number of failure and also downtime contribution to the whole pump system. It means that, failure event mechanical seal leakage and failure to bearings and shaft of the pumps are the 2 highest frequency of failure based on the historical records and having the longest downtime duration on failure occurrence. On the other hand, minor in-service problem failure mode is the least critical failure mode in both categories.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Reliability analysis and system performance assessment by dominant failure modes is a successful method in understanding the characteristic of individual failure modes involved in a particular equipment or system. This method helps in catering the root cause that affecting the reliability and availability of the system. The main objective; to assess the reliability, maintainability and operational availability of the pump system by the dominant failure modes is well achieved.

From the analysis, there are 5 dominant failure modes involved in the failures occurrence from January 2008 to August 2013. 4 out of 5 failure modes are in decreasing failure rate which is in infant mortality stage. It is not normal for an old system to have failures in decreasing failure rate unless there is flaw in manufacturing or poor workmanship either during operation or during maintenance of the system. Proper training for every technician is required to ensure they are capable of operating and maintaining the system and improving the workmanship integrity.

A decreasing failure rate also indicates that the equipment is either having design flaw during its manufacturing. This may be due to different undesirable environment of operation of the MOL pump. Therefore, the design of the pump need to be reviewed based on the operating condition. The objectives to identify the dominant failure modes and to determine the characteristics of individual failure modes are succeeded.

RAM study by RBD analysis in BlockSim is successfully carried out. From the analysis, it is found that the future system operational availability to be as low as 33.6% after 1 year of operation compared to OREDA which is much higher (99.89%) availability.

This analysis is capable to achieve the objective to determine the future performance of the system. A strategic preventive maintenance must be carried out from time to time to avoid long duration during a particular downtime. Proper maintenance strategy for critical failure modes or critical components of the system is important in order to cater the ultimate root cause of a failure.

The failure event of mechanical seal leakage is found to be the most critical failure mode which is indicated by external leakage – process medium. Removing the most critical failure mode in this analysis can make a huge improvement on both reliability of the equipment as well as the availability of the MOL pump system. In order to remove or to reduce failures due to mechanical seal leakage, maintenance strategy should focus on sparing mechanical seal parts. However, without competent manpower, sparing strategy alone cannot tackle the problem in a long run. Therefore, it is important to have skillful technicians to install the mechanical seal properly. In a nutshell, all of the objectives of this study are well achieved.

5.2 Recommendations

1. The result of this analysis should be used as a reference to conduct maintenance strategy of the MOL pumps.
2. A proper maintenance tasks are needed to mitigate or reduce the consequences of all identified failure modes to reduce the frequency of repetitive occurrence of the failures.
3. Proper ownership scheme can be managed to nurture self-awareness and responsibility amongst the workforces since there are issues in workmanship.
4. Further RAM study must be carried out after some time to keep track the performance of the MOL pumps from time to time.
5. RAM study should be replicated to other equipment that involved directly or indirectly in the crude oil transport system.

REFERENCES

[1] (2014, January) Flowserve Corporation. [Online]. http://www.flowserve.com/

[2] SINTEF Technology and Society, *Offshore Reliability Data Handbook*, 5th ed. Norway: Det Norske Veritas, 2009, vol. 1 - Topside Equipment.

[3] Necip Doganaksoy, Gerald J. Hahn, and William Q. Meeker, "Reliability Analysis by Failure Mode: A Useful Tool for Product Reliability Evaluation and Improvement," *Quality Progress*, pp. 47-52, June 2002.

[4] M Farid M Ismail, "Angsi Gas Turbine-Generator Reliability Analysis and System Performance Assessment," PETRONAS Carigali Sdn. Bhd., Terengganu, 2013.

[5] International Organization for Standardization, *ISO 14224:2006*, 2nd ed. Switzerland: ISO, 2006.

[6] Min Xie, Leng Kim Poh, and Yuan Shun Dai, *Computing System Reliability: Models and Analysis*. US: Springer, 2004.

[7] Wayne B. Nelson, *Applied Life Data Analysis*. New York: Wiley Interscience, 2003.

[8] J. Heizer and B. Render, *Operations Management*, 10th ed. New Jersey, USA: Pearson Education Inc., 2011.

[9] F. P. A. Coolean, "Parametric Probability Distributions in Reliability," *Encyclopedia of Quantitative Risk Analysis and Asessment*, 2008.

[10] R.B. Abernethy, "Chapter 1: An Overview of Weibull Analysis," in *The New Weibull Handbook*. 536 Oyster Road, North Palm Beach, 2002, pp. 1 - 11.

[11] Minitab. (2014) Minitab Inc. Web site. [Online]. http://www.minitab.com/support/answers

[12] N. A. Messaoudene, "Fundamental of Reliability and Maintenance," 2012.

[13] Andrew P. Sage and William B. Rouse, *Handbook of Systems Engineering and Management*, 2nd ed.: Wiley-Interscience, 2009.

[14] P. C. Sorabh Gupta and A. K. Sharma Tewari, "Development of Simulation Model for Performance Evaluation of Feed Water System in a Typical Thermal Power Plant," *Journal of Industrial Engineering International*, vol. 7, no. 12, pp. 1-9, Jan 2011.

[15] Charles E. Ebeling, *An Introduction to Reliability and Maintainability Engineering*, 2nd ed.: Waveland Pr Inc, 2009.

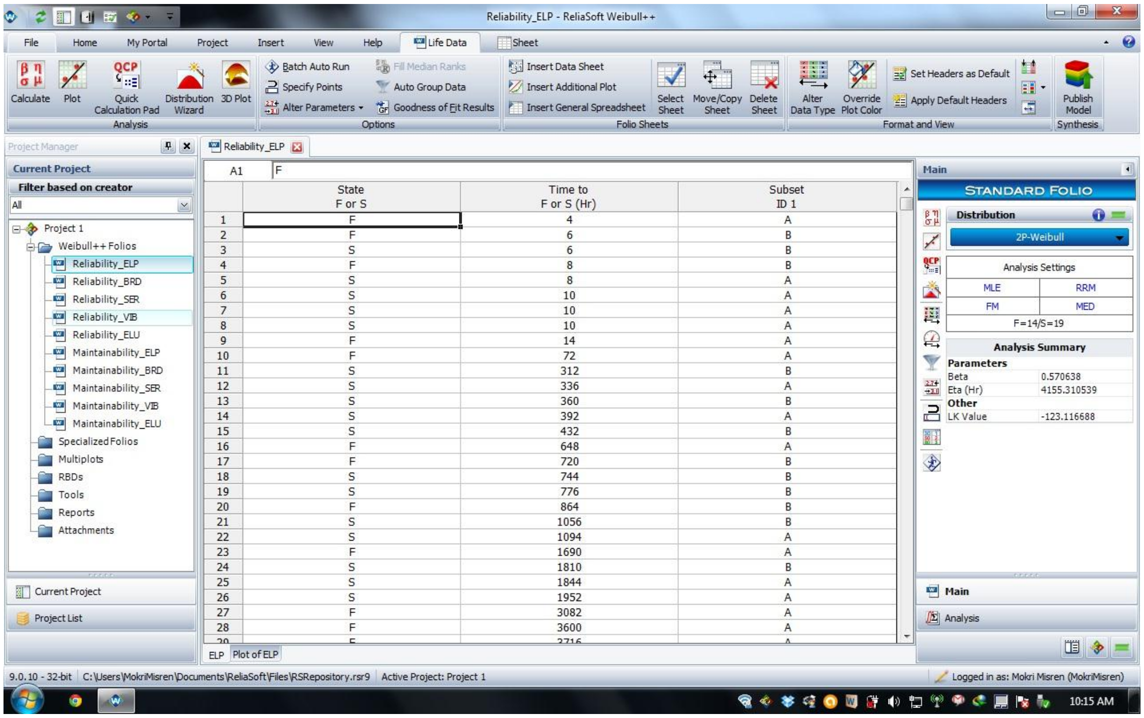
[16] Roy Billinton and N. Ronald Allan, *Reliability Evaluation of Engineering Systems: Concepts and Techniques*, 2nd ed. New York & London: Springer, 1992.

[17] ReliaSoft Corporation. Reliability Engineering Resource Website. [Online]. http://www.weibull.com/AccelTestWeb/graphical_method.htm

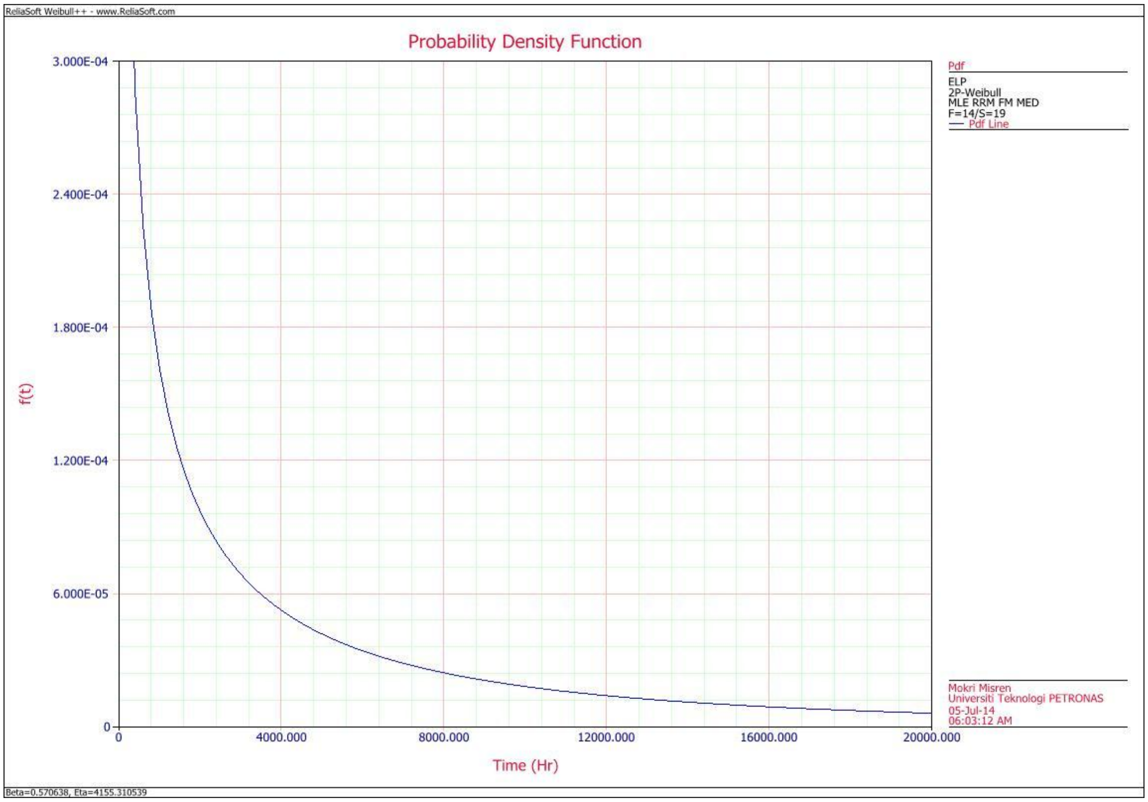
[18] ReliaSoft Corporation, "Life Data Analysis," in *Weibull++ Version 8*. Singapore: ReliaSoft Publishing, 2014, p. 11.

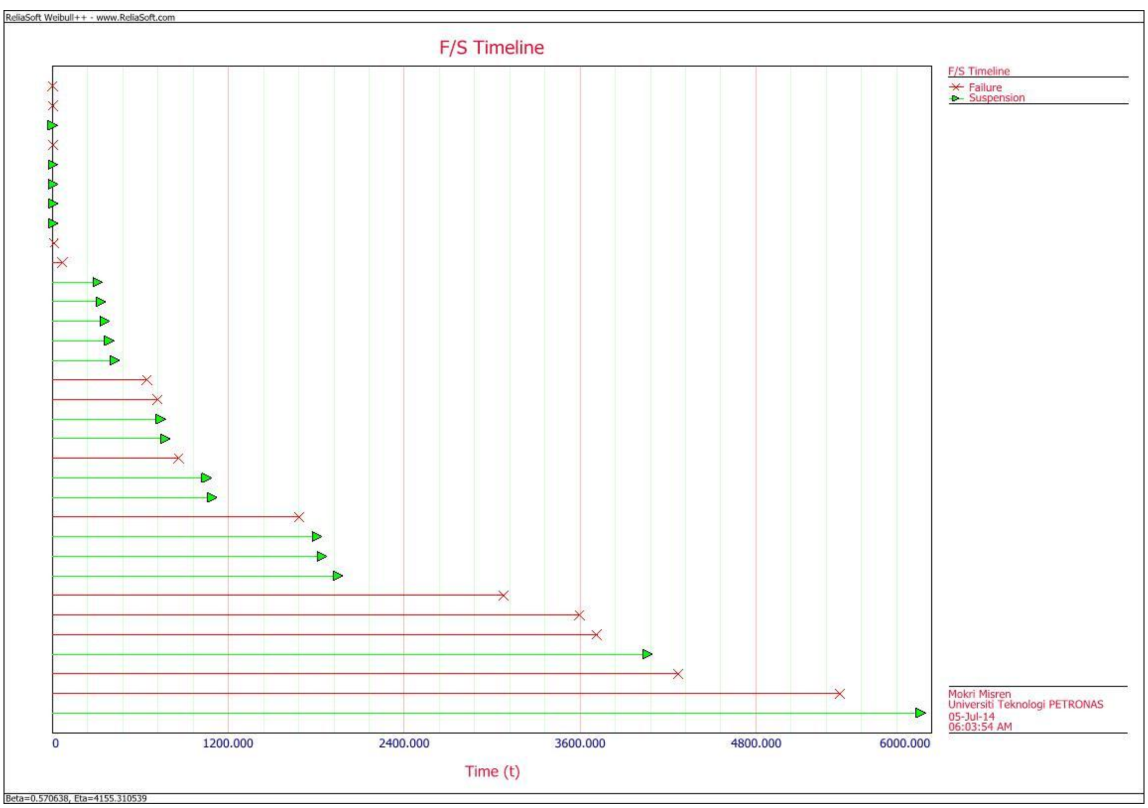
APPENDICES

Appendix 1: Weibull++ Software Data Input

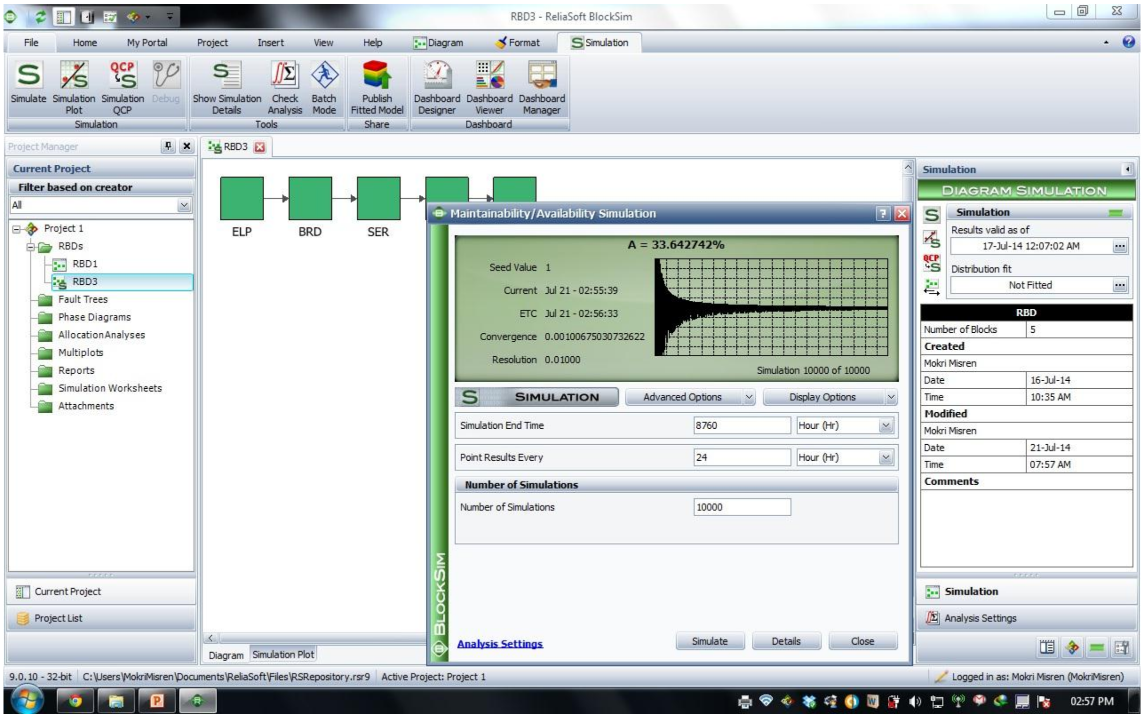


Appendix 2: ELP – Probability Density Function & F/S Timeline

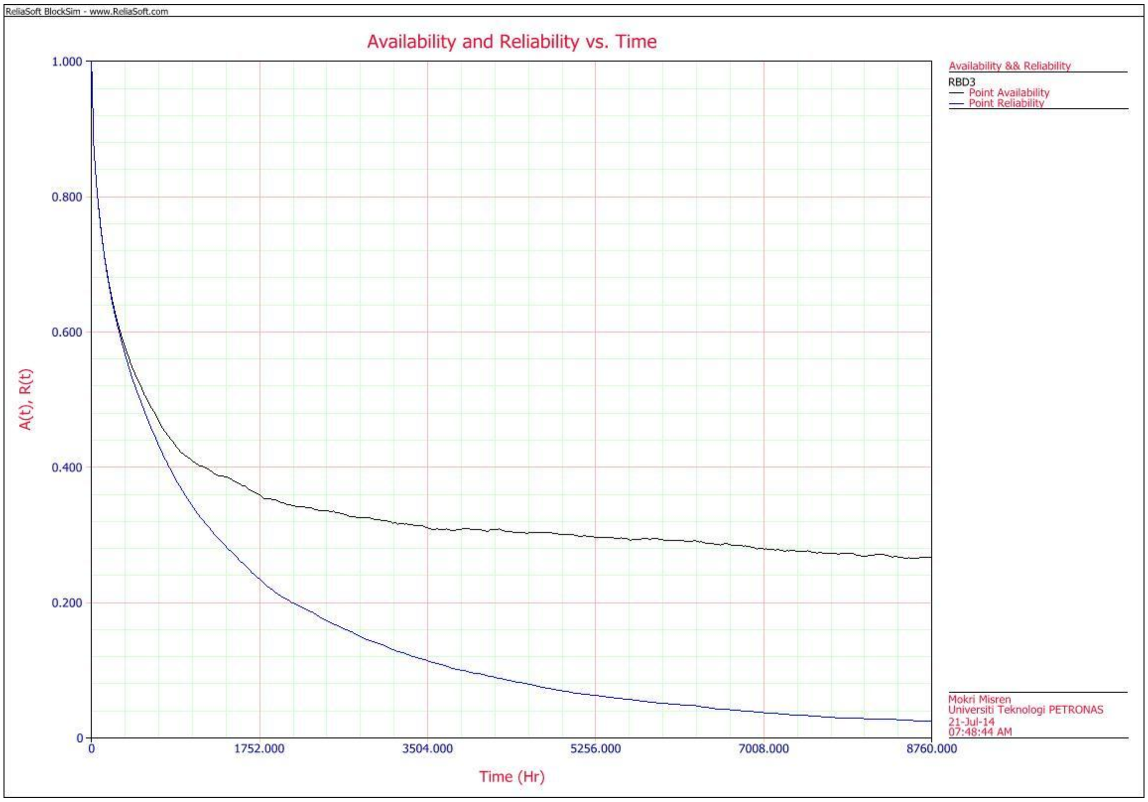




Appendix 3: Simulation of RBD in BlockSim



Appendix 4: Availability and Reliability vs Time



Appendix 5: System Overview Result

System Overview	
General	
Mean Availability (All Events):	0.336427
Std Deviation (Mean Availability):	0.280561
Mean Availability (w/o PM, OC & Inspection):	0.336427
Point Availability (All Events) at 8760:	0.2665
Reliability(8760):	0.0239
Expected Number of Failures:	1.9246
Std Deviation (Number of Failures):	1.028018
MTTFF (Hr):	1360.966286
MTBF (Total Time) (Hr):	4551.595137
MTBF (Uptime) (Hr):	1531.281393
MTBE (Total Time) (Hr):	4551.595137
MTBE (Uptime) (Hr):	1531.281393
System Uptime/Downtime	
Uptime (Hr):	2947.10417
CM Downtime (Hr):	5812.89583
Inspection Downtime (Hr):	0
PM Downtime (Hr):	0
OC Downtime (Hr):	0
Waiting Downtime (Hr):	0
Total Downtime (Hr):	5812.89583
System Downing Events	
Number of Failures:	1.9246
Number of CMs:	1.9246
Number of Inspections:	0
Number of PMs:	0
Number of OCs:	0
Number of OFF Events by Trigger:	0
Total Events:	1.9246

Appendix 6: Block Criticality Summary

Block Failure Criticality Ranking	
Block Name (Diagram)	RS FCI
ELP	45.48%
BRD	27.46%
ELU	10.32%
VIB	9.85%
SER	6.88%

Block Downtime Criticality Ranking	
Block Name (Diagram)	RS DTCI
ELP	31.28%
BRD	26.31%
VIB	15.24%
ELU	14.08%
SER	13.09%

Block Availability Ranking	
Block Name (Diagram)	Availability
SER(RBD3)	91.31%
ELU(RBD3)	90.65%
VIB(RBD3)	89.89%
BRD(RBD3)	82.54%
ELP(RBD3)	79.24%

Block Failures Ranking	
Block Name (Diagram)	Expected # of Failures
ELP(RBD3)	0.8754
BRD(RBD3)	0.5285
ELU(RBD3)	0.1986
VIB(RBD3)	0.1896
SER(RBD3)	0.1325

Block System Downing Events	
Block Name (Diagram)	System Downing Events
ELP(RBD3)	0.8754
BRD(RBD3)	0.5285
ELU(RBD3)	0.1986
VIB(RBD3)	0.1896
SER(RBD3)	0.1325

Block Downtime Ranking	
Block Name (Diagram)	Block Downtime (Hr)
ELP(RBD3)	1818.232743
BRD(RBD3)	1529.227819
VIB(RBD3)	885.696435
ELU(RBD3)	818.684568
SER(RBD3)	761.054266

Block Uptime Ranking	
Block Name (Diagram)	Block Uptime (Hr)
SER(RBD3)	7998.945734
ELU(RBD3)	7941.315432
VIB(RBD3)	7874.303565
BRD(RBD3)	7230.772181
ELP(RBD3)	6941.767257