ESTIMATING PUMP RELIABILITY USING RECURRENT DATA ANALYSIS FOR FAILURE MODES

by

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14870

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CERTIFICATION OF APPROVAL

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Approved by,

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TRONOH, PERAK

January 2015

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 specified sources or persons.

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(HADRI BIN HASNI)

ABSTRACT

Major equipment such as centrifugal pumps play an important role in oil and gas business. The main concern which is highlighted is the pumps' performance at site whether it is reliable or instead. In this study, the analysis is done in order to estimate pump reliability using recurrent data analysis (RDA) for failure modes. Thus four centrifugal pumps in Onshore Slugcatcher (OSC) terminal are used as the case study to verify the analysis done on repairable system. The reliability and availability of the centrifugal pumps could be determined using parametric recurrent data analysis approach. Thus the data regarding the centrifugal pumps operated in Onshore Slugcatcher terminal is collected from PETRONAS Carigali Sdn. Bhd before they will be further analysed using reliability software such as Weibull++ and BlockSim from ReliaSoft Corporation. Based on the explanatory results, the failure modes of respective centrifugal pumps are identified and categorized based on ISO 14224 standard. Next, Weibull++ software is used to determine the failure and repair distributions, while the reliability block diagram of the pump by failure modes is generated using BlockSim. The reliability and availability by failure modes and pump units are determined. The further analysis is hoped will benefit the maintenance team to come up with better maintenance strategy to improve the pumps' performance.

Keywords: Recurrent Data Analysis (RDA), Repairable System, Reliability Block Diagram, Centrifugal pump,

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ABBREVIATIONS AND NOMENCLATURES

The following are frequently used abbreviations in this document.

ELP	External Leakage- Process Medium
GRP	Generalised Renewal Process
HPP	Homogenous Poisson Process
INL	Internal Leakage
MTBF	Mean Time between Failures
NHPP	Non Homogenous Poisson Process
OHE	Overheating

CHAPTER 1: INTRODUCTION

1.1. BACKGROUND

A system is a combination of several assemblies or equipment to carry out specific functions with acceptable performance and reliability. Many companies worldwide spend a lot of money in order to improve equipment or system reliability [1]. Due to that, reliability analysis needs to be conducted to know the life-distribution of a certain component, assembly or system.

By knowing the time to failure of the component, the overall reliability may be predicted. Moreover, the system can be categorized into two which are repairable system and non-repairable system [2]. However in this project, the main focus of the analysis is on the repairable system. This is because, the components of the system will be reused even after maintenance or repairing process was done to the system [3].

In the aspect of exploration and production business, major equipment like gas turbine generator, electric motor, compressor and pump play a paramount role to the oil and gas production. The equipment as well as the whole system needs to be fully efficient and reliable to handle required task within specific period of time.

If the equipment does not achieve the required reliability, thus this will affect the production rate. In the context of this final year project, the main system that will be analysed is the condensate transfer system which comprises of pumps and other components.

Reliability analysis is a tool which assists statisticians and reliability engineers to analyse system performance and determining and predicting the system life span. Furthermore, the analysis of survival and recurrence data also contributes in other fields like pharmaceutical, medical research, social science and business [3]. Many specific reasons to look deeper into the recurrence data of few components, this is because, by assessing and analysing the data, the whole system reliability may be estimated.

1.2. OBJECTIVES

Since the centrifugal pump focused in this project had experienced many major failures in the past, thus the main objective of this project is to estimate the centrifugal pump reliability using recurrent data analysis for failure modes. The project given is totally relevant and reasonable to be completed within the two semester's period.

The project conducted is related to the mechanical engineering course as it focuses more onto reliability, availability and maintainability study. Thus, proper study and planning needs to be done and should be well executed according to the allocated time.

1.3. PROBLEM STATEMENT

In exploration and production business, major equipment and the whole system in site play a paramount role in total oil and gas production per day. Performance parameter such as reliability, availability, maintainability and safety ought to be built in during the design phase and will be sustained during the operation of the equipment or system [4].

If the system fails for a longer time or the frequency of the failure is high, this will surely cause a total production loss and the company would lose more than billions ringgit per day. In other to avoid this situation to happen, a reliability study needs to be done onto the system and its components.

By using the data from daily operation report (DOR), the reliability of each component in the condensate booster system may be estimated and evaluated for maintenance purposes. However, the data collected from site maybe insufficient or incomplete, therefore the needs of a general mathematical model and algorithms are required to solve the issue [5].

CHAPTER 2: LITERATURE REVIEW

2.1. ONSHORE SLUGCATCHER (OSC)

The project is conducted in a gas terminal in Kerteh, Terengganu. The terminal is called Onshore Slugcatcher (OSC). The terminal was first established in year 1992 by ExxonMobil for national oil and gas company, PETRONAS. In the early years, the terminal was operated by ExxonMobil operators before it was handed to PETRONAS in July 2008.

The objective of this terminal is to receive gas and condensate from three offshore platforms which are Angsi, Lawit and Jerneh. Moreover, the gas and condensate collected will be fully processed and separated from effluent such as mud and water. Hence, the terminal consists of many complex systems and each system play a major role in the gas and condensate processing. One of the systems that will be a major focus in predicting the reliability based on the recurrent field date is the condensate booster system.

2.2. CONDENSATE BOOSTER SYSTEM

The objective of condensate booster system is to receive condensate from offshore platforms and to boost the condensate pressure. The system is connected to the finger slugctacher in Onshore Slugcatcher (OSC). The condensate booster system is made up of four identical centrifugal pumps (P-5150, P-5151, P-5155 & P-5156) driven by four electric motors respectively. The design flow rate is 1250 kl/d each with 1986 kPa differential pressure while the minimum flow rate is 15 kl/hr. Moreover, the design pressure is 15037 kPa while design temperature ranges from -20 °C to 49 °C.

2.3. CONDENSATE TRANSFER PUMP-CENTRIFUGAL TYPE

The centrifugal pumps are the commonly used in most industries. These devices are simple however may be tricky in application [6]. The centrifugal pump is more preferred due to its high efficiency as compared to other types of pump aside of producing a steady flow process [6].The basic components of a centrifugal pump are volute, diffuser, impeller, wear ring, wear plate and mechanical seal. Normally, the centrifugal pump is driven by electric motor.

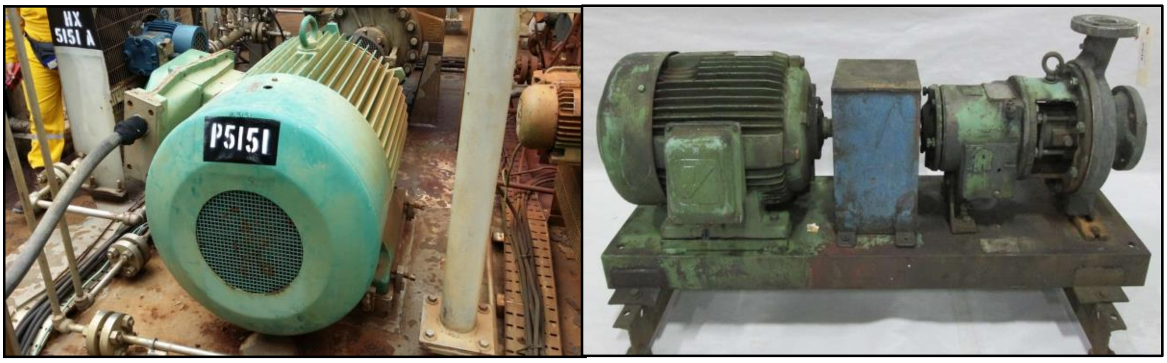


Figure 1: Condensate Transfer Pump: Centrifugal Type

The condensate transfer pumps (P-5150, P-5151, P-5155, P5156) in Onshore Slugcatcher (OSC) are of centrifugal-typed pump that have the same identical specifications. Those specifications are;

i. Impeller diameter: 347mm
ii. Suction flange: 4 inch
iii. Disc flange: 2 inch
iv. Speed: 2960 rpm
v. NPSH: 2.40 m
vi. Capacity: 57.30 m^3/h
vii. Head: 290.1 m
viii. Specific gravity: 0.732 kg/m^3

2.4. RELIABILITY ENGINEERING

Reliability engineering focuses on the following; application of engineering knowledge and techniques to reduce the frequency of failures, identification and correction of the causes of failures, determine ways to cope with failures if the causes can't be corrected for some time, and applying method of estimation while analysing reliability data [7].

During the design and development phase of a system, the performance parameters like reliability, availability, maintainability and safety are introduced and sustained throughout the system operation [4]. Reliability is a characteristic of an item expressed in terms of probability function such that the item will perform its required function for given conditions within a desired time interval [4], [7], [8].

From a qualitative perspective, reliability can be interpreted as the ability of the item to remain functional [4]. Quantitatively, reliability specifies the probability that no operational interruptions will occur during a stated time interval [4].

On the other hand, maintainability is defined as the probability of a failed item or system will be restored or repaired to a specified condition within a time interval when maintenance task is done following the recommended procedures and resources [4], [8], [9]. The recommended maintenance procedures may include number of maintenance crew for repair job, maintenance program, skill levels of maintenance crew and manner which the repair or maintenance to be implemented. Maintainability is divided into two which are preventive maintenance and corrective maintenance [4].

Furthermore, availability is described as the probability of an item or system is performing its required function at a given time interval. In another point of view, availability is the percentage of time an item or system is functioning over a specified time interval. This can also be expressed as the uptime divided over total time [4], [8], [9].

2.5. FAILURE

When an item or system fails, it will affect the performance or availability. Failure is defined as:

i. A loss of asset availability
ii. The unavailability of equipment
iii. Any loss that interrupts production
iv. Not meeting expected target

One way of analysing the failure and reliability is by conducting failure mode and effects analysis (FMEA) [6], [10]. By identifying and analysing the possible failure modes, the reliability of a certain item and system can be improved. Before any analysis process can be done, the data collection needs to be done. Two main failure data sources are from interviewing the engineer or maintenance personnel and gathering data from equipment maintenance database [6]. In the context of this project, the failure data is collected from OSC Daily Operational Report (DOR) and.

Data collection is considered as an important process before conducting any analysis on an item or system. The data gathered should be reliable and sufficient as this will determine the result of an analysis. For instance, two identical equipment may function differently from another or having different failure modes. Hence, both will not have the same amount of reliability. When the failure is understood, analysis can be carried out [6].

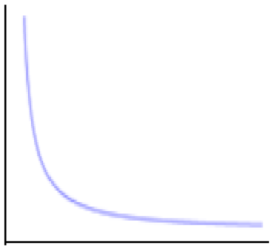
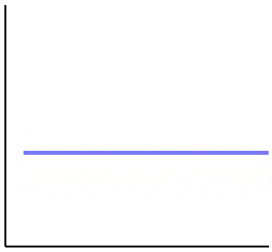
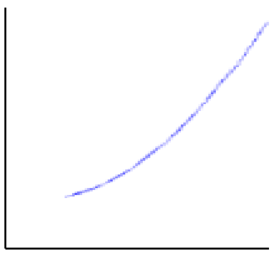
2.6. SOURCES OF FAILURE

When failure can be minimized, then the reliability of an item or system will increase [6]. If maintenance personnel could get a clear understanding regarding the failure data hence, an analysis and corrective measure can be carried out effectively [6]. Generally, the sources of failures can be divided into four categories:

i. Man as failure
ii. Machine as failure
iii. Methods of operation as failure
iv. Materials as failure

Meanwhile, the failure can be divided into three phases which are early life phase, useful life phase and wear out phase. These three phases are determined by their failure rates and failure characteristics. Below table shows the following regarding each phases and the characteristics.

Table 1: Failure Characteristics based on Failure Rate

Phase	Characterized by	Caused by	Reduced by
Early Life	Failure Rate  Time Decreasing Failure Rate	• Manufacturing defects • Welding flaws • Cracks • Defective parts • Poor quality control • Poor workmanship • Contamination	• Burn-in operation • Screening • Quality control • Acceptance testing
Useful-life	Failure Rate  Time Constant Failure Rate	• Environment • Random loads • Human error (in operation and maintenance) • Chance events	• Redundancy • Excess strength • Operation within design envelope • Strict adherence to operation and maintenance procedure
Wear-out	Failure Rate  Time Increasing Failure Rate	• Normal/abnormal fatigue • Corrosion • Aging • Cyclical loads	• Derating • Parts replacement (prior to failure)

2.7. SEVERITY CLASS TYPES-FAILURE

Failure can be categorized into four severity classes according to [11] which are:

i. Critical failure: Failure that causes an immediate and complete loss of equipment from performing its functions.
ii. Degraded failure: Failure which is not critical, however it prevents an equipment unit from providing its expected output within specifications. Such failure sometimes be gradual or partial and may develop into critical failure.
iii. Incipient failure: Failure which does not cause an immediate loss of equipment unit's capability of providing output but if it is not attended to, will lead to degraded or critical failure in the future.
iv. Unknown: Failure which can't be determined or deduced.

In the context of this project, the main focus will be on the critical failure which will affect the performance of the pump from providing its expected output.

2.8. FAILURE MODES

According to [11], [12] below are the following potential failure modes and their failure codes that could cause failure to the pump.

Table 2: Potential Failure Modes and FM codes

Failure Modes	**Failure Mode Codes**
Abnormal Instrument Reading	AIR
Breakdown	BRD
External Leakage-Process Medium	ELP
External Leakage- Utility Medium	ELU
Erratic Output	ERO
Fail to Start on Demand	FTS
High Output	HIO
Internal Leakage	INL
Low Output	LOO
Overheating	OHE

Structural Deficiency	STD
Fail to Stop on Demand	STP
Spurious Stop	UST
Noise	NOI
Vibration	VIB

2.9. EQUIPMENT BOUNDARY - PUMP

During the data analysis of the centrifugal pump, its equipment boundary need to be taken into consideration. According to [12] the importance of the boundary is to properly differentiate the subunit/component and maintainable item/part which are included within the boundary of particular equipment. In addition, each equipment has its own boundary. This is important, during the analysis the failure data needs to be revised properly and the listed maintainable parts of the pump that fail ought to be in the equipment boundary while those that are not within the equipment boundary should not be considered in the analysis as to avoid any inaccurate result while simulating using the software later. For pump, the boundary and the maintainable item are shown in figure and table below;

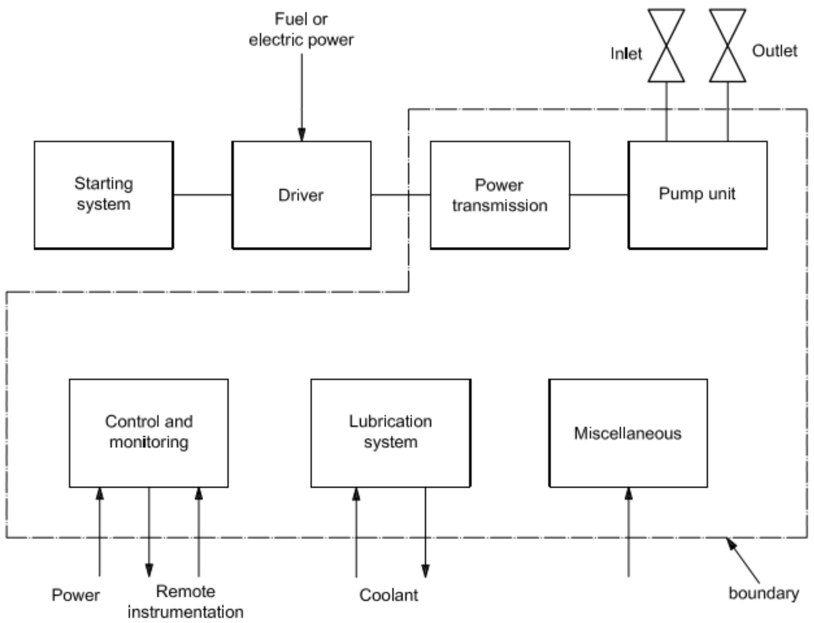


Figure 2: Pump Boundary according to ISO 14224

Table 3: Pumps Subunit and Maintainable Items

Equipment Unit	**Pumps**				
Subunit	**Power transmission**	**Pump unit**	**Control and monitoring**	**Lubrication system**	**Miscellaneous**
Maintainable items	- Gearbox/ variable drive - Bearing - Seals - Coupling to driver - Coupling to driven unit	- Support - Casing - Impeller - Shaft - Radial bearing -Thrust bearing - Seal - Valves - Piping - Cylinder liner - Piston Diaphragm	Actuating device Control unit Internal power supply Monitoring Sensors Valves Wiring Piping Seals	- Reservoir - Pump - Motor - Filter - Cooler - Valves - Piping - Oil - Seals	- Purge air -Cooling/heating system - Cyclone separator - Pulsation damper - Flange joint

2.10. REPAIRABLE AND NON-REPAIRABLE SYSTEM

System can be grouped into two types which are repairable and non-repairable [2]. There are distinct differences between both of them. For instance, a light bulb of a car failed, the owner will replace it with a new light bulb taking consideration that the light bulb is one-time usage or non-repairable system.

The component or system could be in a larger system. Furthermore, in another situation, the system is repaired or maintained but not replaced after each failure happened. For instance, if the systems that fail are the light bulb and the car itself, hence the owner would repair the car and just replace a new light bulb [2]. In terms of reliability perspective, repairable and non-repairable system could be classified into their own characteristics accordingly [8].

Table 4: Difference of Repairable and Non-Repairable System

Non-Repairable System Characteristics	**Repairable System Characteristics**
Expressed in terms of availability of the system only. No reliability functions.	Expressed in terms of reliability and availability of the system.
Taking consideration on the failure rate.	Taking consideration on both failure rate and repair rate.
Calculated in terms of Mean Time to Failure (MTTF)	Calculated in terms of Mean Time between Failure (MTBF)
One-Time Failure	Repeated Failure

Repairable systems will the main focus in this project. This is because, the first time failure of non-repairable does not show any significant but one is more interesting in the system failure probability [2].

2.11. RECURRENT DATA ANALYSIS

In repairable system, the failures may accumulate over time. Instead of replacing the whole system, it will be repaired to restore its function. Recurrent data analysis can be divided into two categories which are non-parametric and parametric. Two variables are taken into consideration which are the number of failure by for given age and the time between successive failures. The focus will be on parametric recurrent data analysis. The objective of conducting recurrent data analysis is to know and characterising the event occurrence like patterns or characteristics over certain period of time and the probability. Using the software Weibull++, the trend of the failures can be tracked as well as estimating the rate and giving predictions in terms of reliability and expected failures [13].

The parametric analysis is based on three models which are Homogenous Poisson Process (HPP), Non Homogenous Poisson Process (NHPP) and Generalized Renewal Process (GRP). Generally, there are two repair assumptions which are "as good as new" or "as bad as old", however in reality the equipment when repaired lies between these two assumptions [14].This is said as partial restoration. The models frequently used to predict such assumptions are Homogenous Poisson Process and Non Homogenous Poisson Process [15]. Homogenous Poisson obeys the repair assumption of "as good as new" is rarely happen in practice. On the other hand, the Non Homogenous Poisson Process will follow the repair assumption of "as bad as old". Meanwhile, the General Renewal Process (GRP) model is able to cover all the three repair assumptions [15]. This is by taking into account of the repair effect on succeeding failure. For instance, a repair work has been done to a system, but it does not make the system "as good as new" nor it makes the system "as bad as old". In simple word, the system is just partially rejuvenated after the repair [13].

In the project, the assumption of Non Homogenous Poisson Process is applied on the recurrent data analysis whereby the system is still at the same state after repair as just before the failure happened. Minimal repair assumption or as-bad-as-old after repair is applied here.

RELIABILITY BLOCK DIAGRAM

A system is made up of a collection of subsystems and components. Using a reliability block diagram, a graphical representation of the system could be generated. Based on the diagram generated, availability and reliability of whole system could be determined, provided each parameters of items' block diagram had been determined. The parameters are failure distributions, repair distributions and other maintenance requirements. Generating a reliability block diagram involves in segregating the system's items into elements with clearly defined tasks [4]. Be sensitive on the fact of the status (good or failed) and failure mode that could be considered for each elements [4]. A system configuration could be in series or parallel order with respect to its real configuration in site.

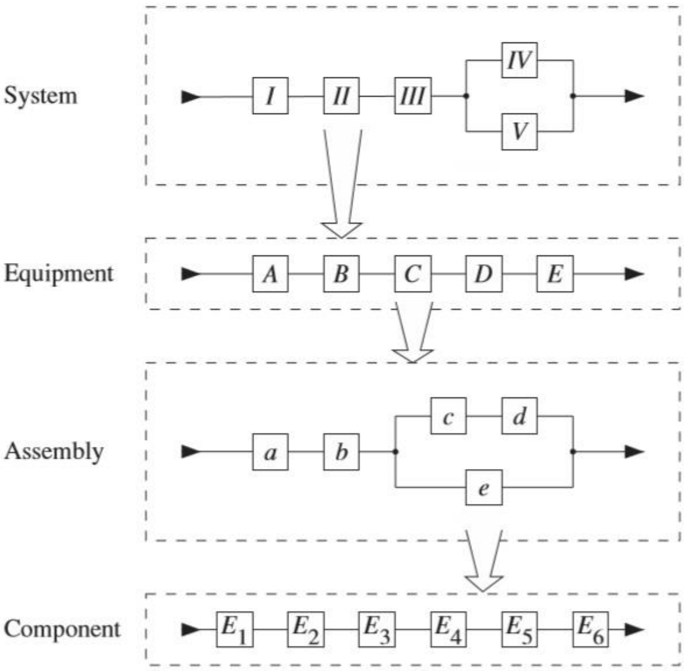


Figure 3: Reliability Block Diagram of System

CHAPTER 3: METHODOLOGY

3.1. PROJECT MILESTONES

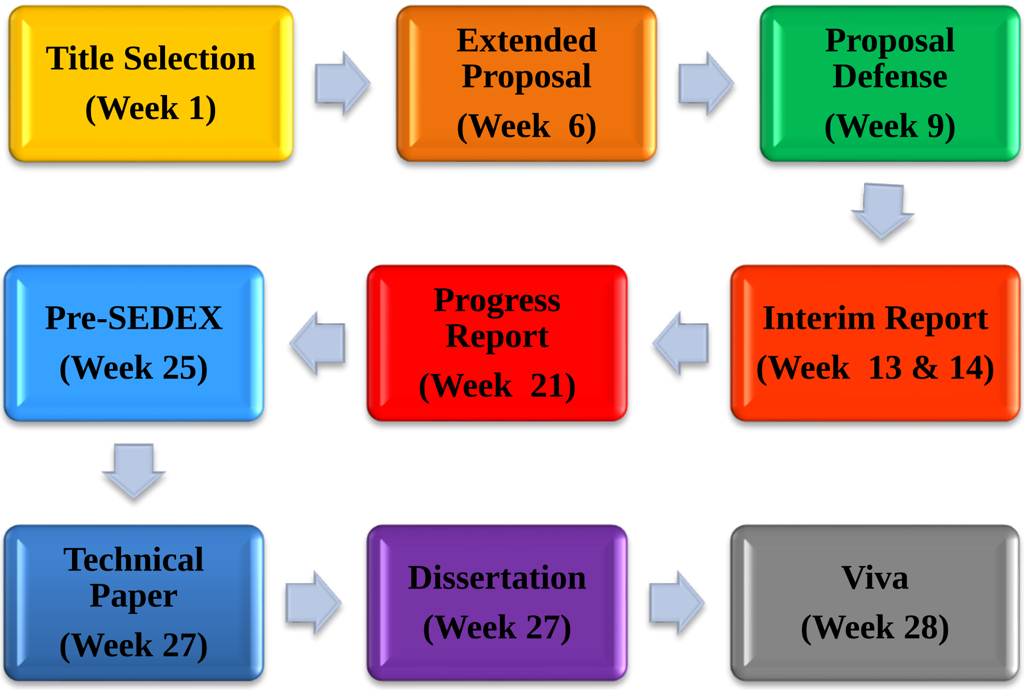


Figure 4: Key Milestone

Proper planning is important in order to ensure that the whole project progress is completed according to the allocated time. The tools like the key milestone and the Gantt chart are used so that there will be no delay happen during the project execution. The key milestone helps in highlighting the main events of the project that require attention meanwhile the Gantt chart is used to show details or process of the project starting from the commissioning until the end.

3.2. GANTT CHART

No.	Activities	Duration (Week)													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Selection of Project Topic & Supervisor	■	■												
2.	Preliminary Research Work on the Project		■	■	■	■									
	- Project Background & Problem Statement		■												
	- Objective & Scope of Study			■	■										
	- Critical Analysis of Literature			■	■	■									
3.	Data Collection of Centrifugal Pump from PETRONAS Carigali Sdn. Bhd.			■	■	■	■	■							
4.	Preparation of Extended Proposal				■	■									
5.	Submission of Extended Proposal						●								
6.	Presentation of Proposal Defence							■							
7.	Project Work Continues								■	■	■	■	■	■	
	- Preparation of Data Trending Template using Microsoft Excel								■	■					
	- Classification of Pump's Failure Modes										■	■			
	- Preliminary Data Analysis											■	■	■	
8.	Preparation of Interim Report												■	■	
9.	Submission of Interim Draft Report														●
10.	Submission of Interim Report														●

Figure 5: Gantt chart FYP1

No.	Activities	Duration (Week)													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Analysis of Pump Failure Data	■	■	■	■	■	■	■	■	■	■	■	■	■	
2.	Project Development	■	■	■	■	■	■	■							
	- Grouping the Data according to Failure Modes	■	■												
	- Analysing the Data Using Weibull++ Software			■	■	■	■								
	- Generation of the Preliminary Reliability Block Diagram							■							
3.	Submission of Progress Report							●							
4.	Project Work Continues								■	■	■	■	■	■	
	- Analyse the Data by Pump Unit.								■	■					
	- Analyse the Repair Data										■	■			
	- Generation of System Reliability Block Diagram											■	■		
	- Estimate the Reliability and Availability of Pump and the System												■	■	■
5.	Pre-SEDEX											●			
6.	Submission of Dissertation													●	
7.	Submission of Technical Paper													●	
8.	Viva														●
9.	Submission of Project Dissertation (Hard Bound)														●

Figure 6: Gantt chart FYP2

3.3. PROJECT FLOW

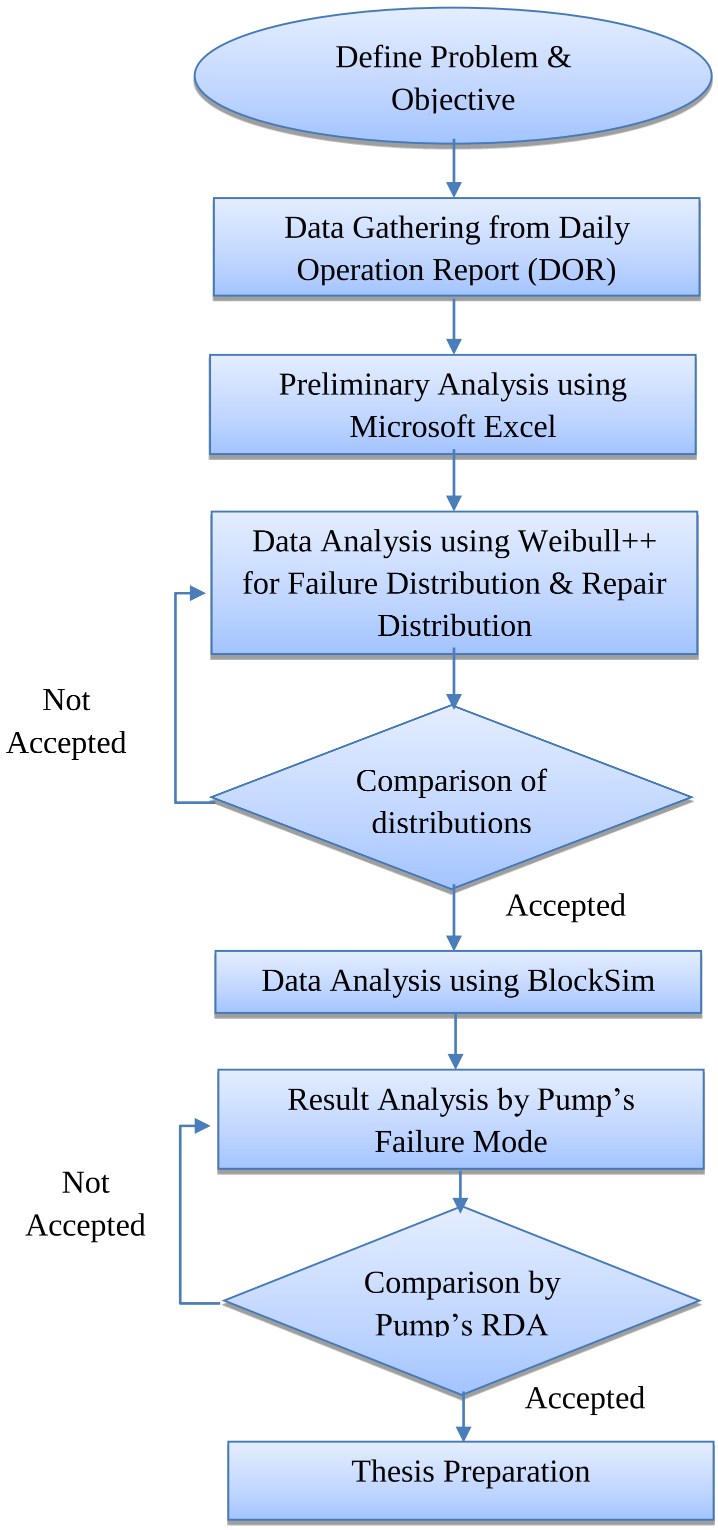


Figure 7: Project Flow

In conducting reliability analysis, the first task that needs to be done is to identify the problem and set an objective to be achieved. Estimating the pump reliability requires a sufficient and reliable data. These data are collected from the daily operation report of the centrifugal pump while integrating them with the data in system application product from PETRONAS Carigali Sdn. Bhd.

Using Microsoft Excel equipment trending template created, the failure data of the centrifugal pump will be grouped accordingly while analysing their respective failure modes according to ISO 14224 standards. A bar chart of respective failure modes according to each pumps will be developed as well as the line graph generated which will indicate cumulative failure of the centrifugal pump against period of data sample.

Next, by using recurrent data parametric folio in Weibull++ software, these data will be analysed to obtain the failure distributions and failure characteristics of the failure modes and the pump. Moreover, the repair distribution of the failure modes can be determined too. Thus, this will help in the analysis of the system reliability by using reliability block diagram later. Besides the reliability of each pump based on failure modes can be calculated using the software. A comparison can be made from both analysis of failure modes and the pump units.

Later, the data will be further analysed using BlockSim software whereby all the failure modes will be arranged in a series order of reliability block diagram to find out the overall system reliability. The data from the analysis will be compared with the data set collected for the pumps. If the results or findings found are feasible, thus proceed with the discussion. Finally after the result analysis, proceed with the dissertation report.

CHAPTER 4: RESULTS AND DISCUSSION

4.1. ASSUMPTIONS

In this project, the analysis is based on few assumptions:

i. The pumps are identical and of the same types and specifications.
ii. Only critical failures are considered in the analysis.
iii. Random failure is considered to follow exponential distribution.
iv. The repair assumption is as bad as old, which means that the pump undergoes minimal repair. Repair model used in Non-Homogenous Poisson Process.
v. The pump downtime is considered as the repair time which includes the administrative and logistic delay.
vi. The corrective task or maintenance is done upon pump failure.
vii. The pump failure mode reliability block diagram is arranged in series instead of parallel.
viii. The pump system reliability block diagram is arranged in parallel. Only, two pumps are running, while the others are in hot standby.

4.2. TOOLS

The tools used in order to come up with the preliminary analysis of the project is basically using the Microsoft Excel software. Initially, the author had collected sample of data from Onshore Slugcatcher (OSC) daily operation report. The reports consist of the four centrifugal pumps' failure data within 3 years period. However, without proper template, the data could not be arranged in proper order and this will make the analysis tedious. Thus, using Microsoft Excel, the author create a template that could ease the task of identifying and classifying each failure modes of centrifugal pumps.

With that, the cumulative running hour of pumps based on daily operation report is recorded and calculated in the template. It will show the running hour of each pumps and the downtime. Moreover, the bar chart of identified failure modes of each pumps is developed and cumulative failure versus time is plotted too.

Later, by using the Weibull++ software, the author is able to construct reliability growth model to analyse the failure characteristics of each failure modes of the pumps, provided that the data of the pumps' failure modes are sufficient in order to be input in the software. The model distribution of failure mode is determined using the distribution wizard tool in the software. It will show the best distribution based on the data input the parametric recurrent data folio.

This is because, failure data which are less than three can't be analysed using the software. The software will then analyse the data input and produce the distribution plotting and the parameters needed. The parameters are shape parameter, β and failure rate, λ. This will show the failure characteristics according to the failure modes. The other parameter that could be determined is the characteristics life, η.

Next, the reliability block diagram of failure modes is generated using the BlockSim software. Using this software, the author could determine the availability of a pump unit and the overall system. The software also enables the author to calculate the overall reliability of the pump and the system. The block up down diagram from this software could be used in order to determine the critical failure modes that cost the failure of the pump.

4.3. EXPLANATORY RESULTS

Identification of failure modes is an important step in the analysis, the failure mode must be critical failure, if not it will not be considered in this analysis Using the equipment performance trending template, the failure modes of the centrifugal pumps had been classified according to the standard hence the explanatory results of the preliminary analysis are shown in the table below:

Table 5: Failure Modes Identified and their occurrence

Failure Mode	FM Code	P-5150	P-5151	P-5155	P-5156	Total
External Leakage-Process Medium	ELP	5	2	2	-	9
Internal Leakage	INL	1	3	2	2	8
Spurious Stop	UST		1	-	1	2
Overheating	OHE	-	1	-	-	1
Subtotal		6	7	4	3	20

4.3.1. CENTRIFUGAL PUMP FAILURE MODES

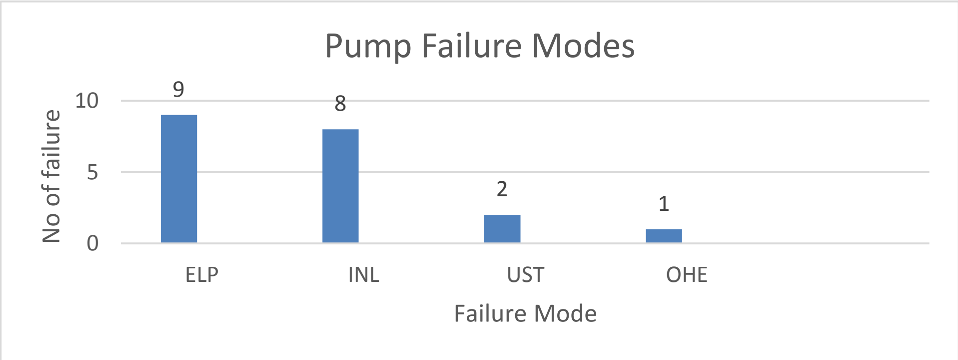


Figure 8: Pump Failure Modes

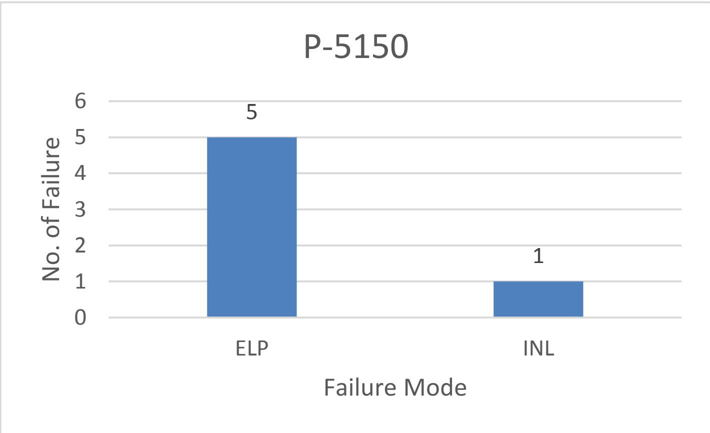


Figure 9: Pump P-5150 Failure Modes

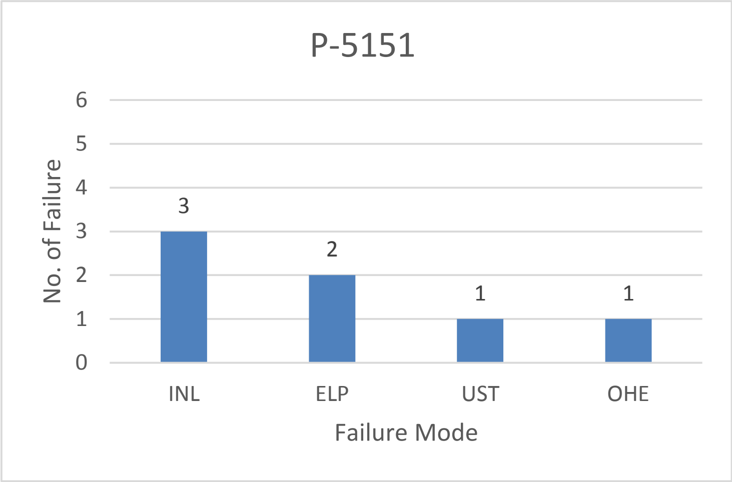


Figure 10: Pump P-5151 Failure Modes

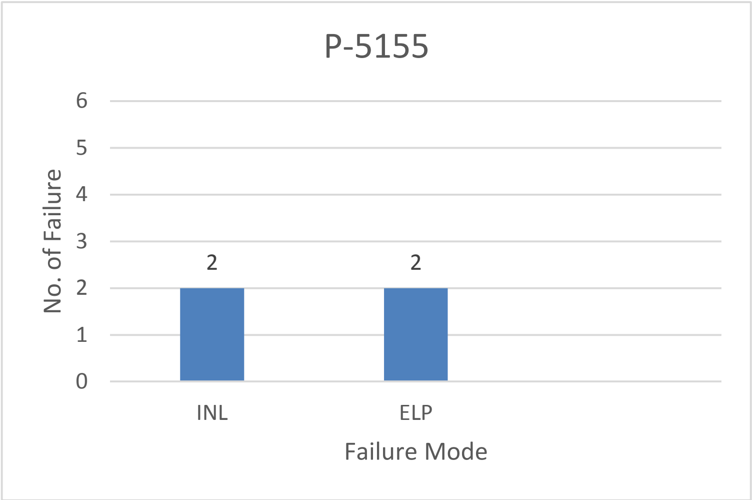


Figure 11: Pump P-5155 Failure Modes

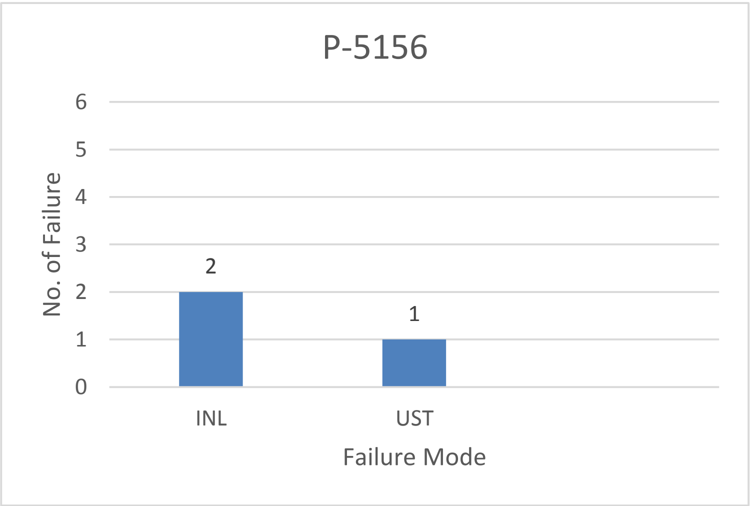


Figure 12: Pump P-5156 Failure Modes

4.3.2. CUMULATIVE FAILURE OF PUMP VERSUS TIME

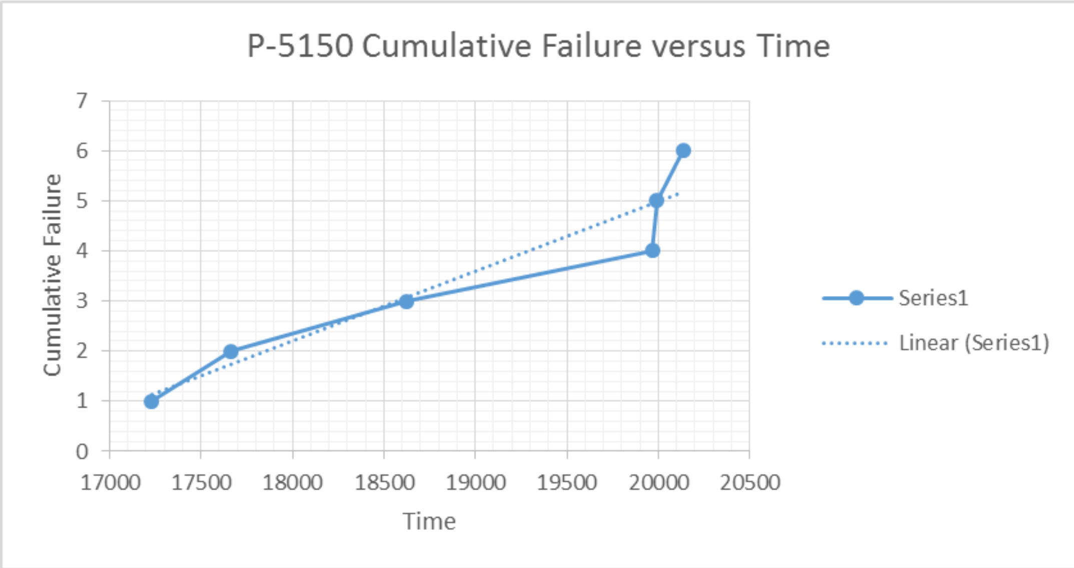


Figure 13: Cumulative Failure P-5150 versus Time

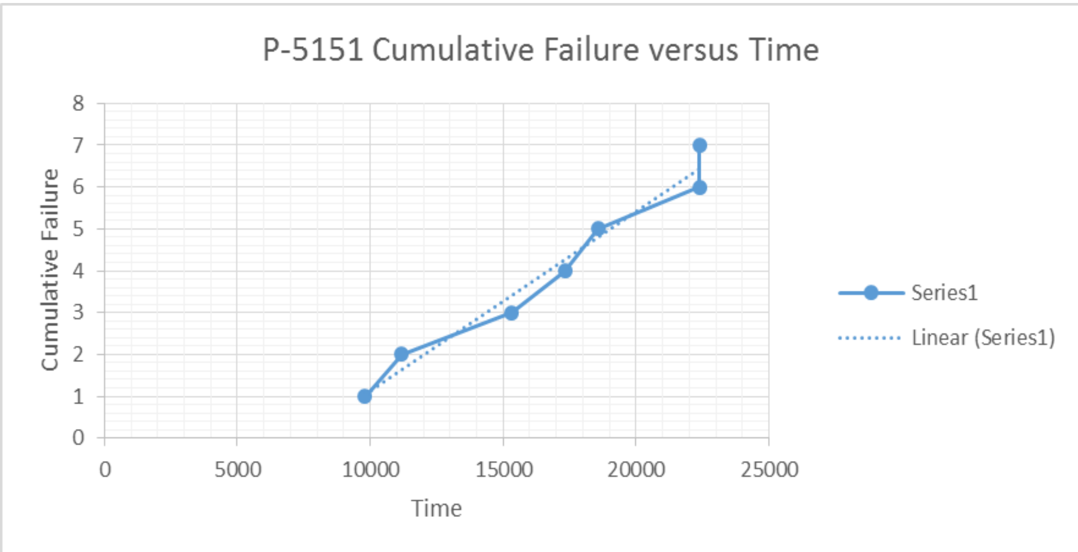


Figure 14: Cumulative Failure P-5151 versus Time

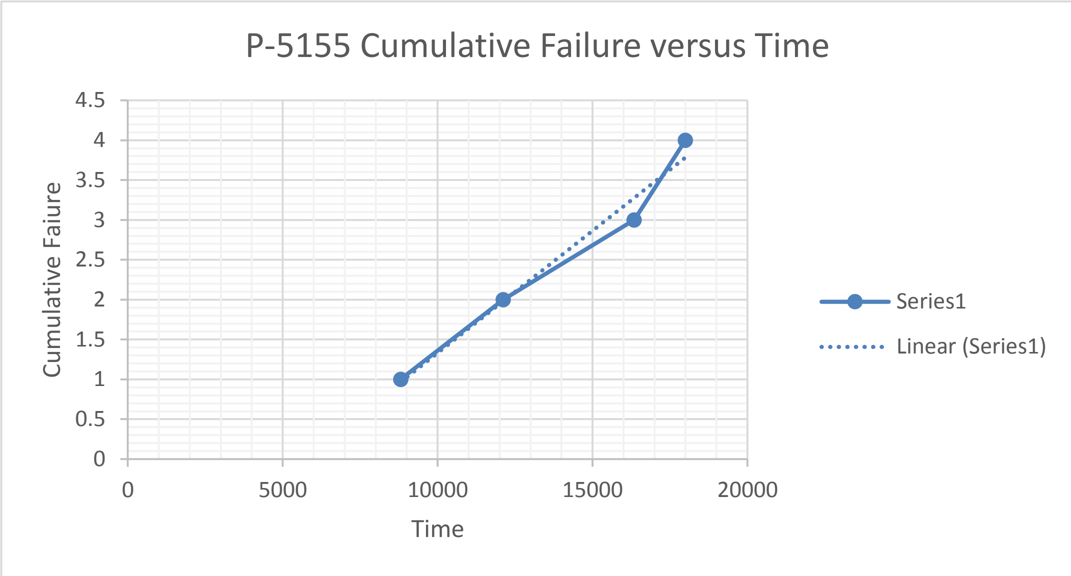


Figure 15: Cumulative Failure P-5155 versus Time

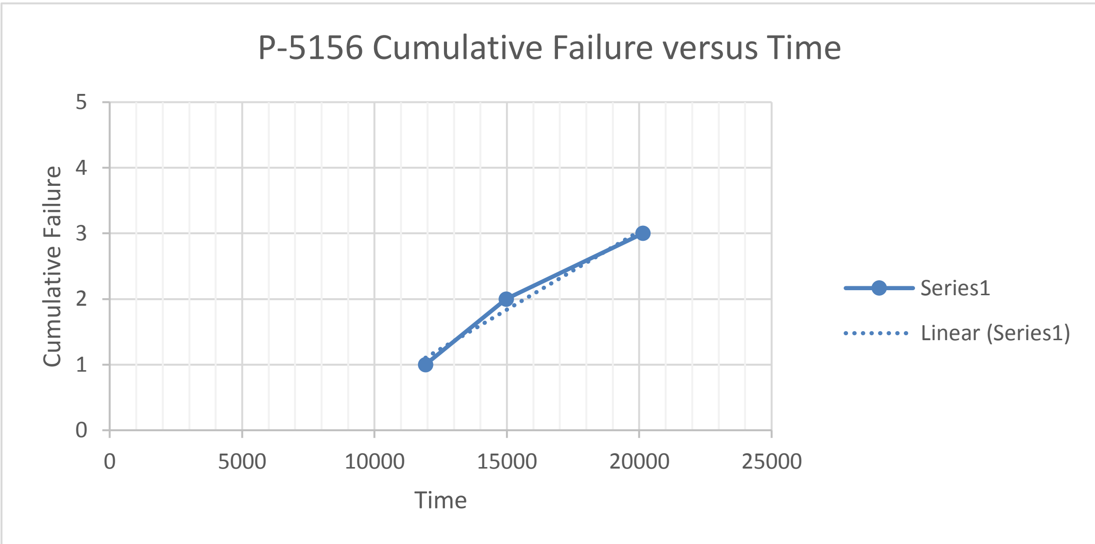


Figure 16: Cumulative Failure P-5156 versus Time

4.4. ANALYSIS USING THE WEIBULL++ SOFTWARE FOR FAILURE MODES

Previously, the failure data of the centrifugal pump are collected and being sorted using Microsoft Excel template, this is to ease the grouping and determination of time of failure (cumulative running hour) according to each failure modes of the pumps respectively. Hence, when this is done, the data will then be input into the Weibull++ parametric recurrent data analysis folio in order to determine the failure distributions, patterns and characteristic of the pump failure modes.

However, due to lack of data, only failure modes such as external leakage-process medium (ELP) and internal leakage (INL) can be analysed using the specialised folio. The other two failure modes which are spurious stop (UST) and overheating (OHE). These failure modes are assumed to exhibit constant failure rate. Below are the set of the cumulative running hours of the pump when the failure modes happened.

Table 6: Cumulative Running Hour of Pumps – External Leakage

Pump	Cumulative Running Hour
P-5150	17232
	17664
	19968
	19992
	20136
P-5151	11184
	22392
P -5155	16344
	18000

Table 7: Cumulative Running Hour of Pumps – Internal Leakage

Pump	Cumulative Running Hour
P-5150	18624
P-5151	9792
	15312
	17328
P-5155	8808
	12120
P-5156	11928
	14976

In the Weibull++ parametric recurrent data analysis folio, the unit is set to hour. The data for the failure modes in the table above is input in the folio and the pump is classified accordingly using system ID. For example pump P-5150 system ID is denoted as number 1. If failure happened, the data will be denoted with letter “F” as fail.

When the data observation ends for each system ID, a letter “E” is used to signal end. However, due to lack of data for the remaining two failure modes like spurious stop (UST) and overheating (OHE), the software cannot conduct the analysis, here the failure modes are assumed to exhibit constant failure rate, which the shape parameter, β is equal to value one. Thus failure distribution is considered as exponential distribution.

ELP INL

A1 1

	System ID	Event (F=Failure, E=End)	Time to Event (Hr)
1	1	F	17232
2	1	F	17664
3	1	F	19968
4	1	F	19992
5	1	F	20136
6	1	E	25176
7	2	F	11184
8	2	F	22392
9	2	E	22392
10	3	F	16344
11	3	F	18000
12	3	E	18000
13	4	E	25416
14			
15			

Figure 17: Data Analysed using Weibull++ Software

Assuming that the restoration is bad as old with minimal repair, the folio is set to power law which is one of the non-homogenous Poisson process model. The identification of failure distributions as well as the parameters like shape parameter, β and failure rate λ are important for further analysis using next software, BlockSim.

By generating reliability block diagram, the overall system's reliability and availability by failure modes could be determined. Besides, it is also important in order to determine the characteristics life, η. The parameter calculated from the data above are as follows:

Table 8: Failure Parameters – External Leakage

Model	Power Law
Beta	3.464403
Lambda (per hour)	1.69E-15
Eta (hour)	18356.33672

Table 9: Failure Parameters – Internal Leakage

Model	Power Law
Beta	1.79531
Lambda (per hour)	5.02E-08
Eta (hour)	11637.98725

Moreover, the software not only calculate the failure parameters, the plotting of the failure data is also showed whether it is in decreasing or in increasing failure pattern. There are two graphs that are generated using the software which are the cumulative number of failure versus time of external leakage and internal leakage.

The plot of cumulative number of failure versus time is shown in terms of linear plot, hence in order to determine its pattern, the option of logarithmic need to be switched off.

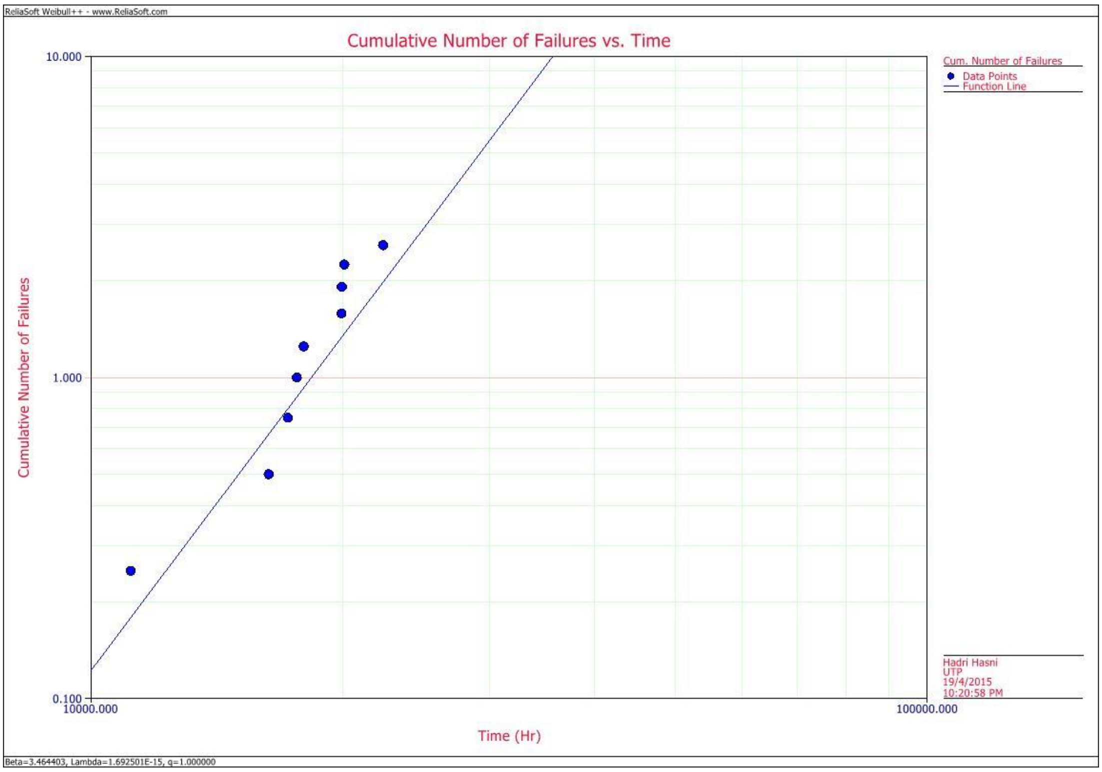


Figure 18: Cumulative Number of Failure versus Time – External Leakage (Using Logarithmic Axes)

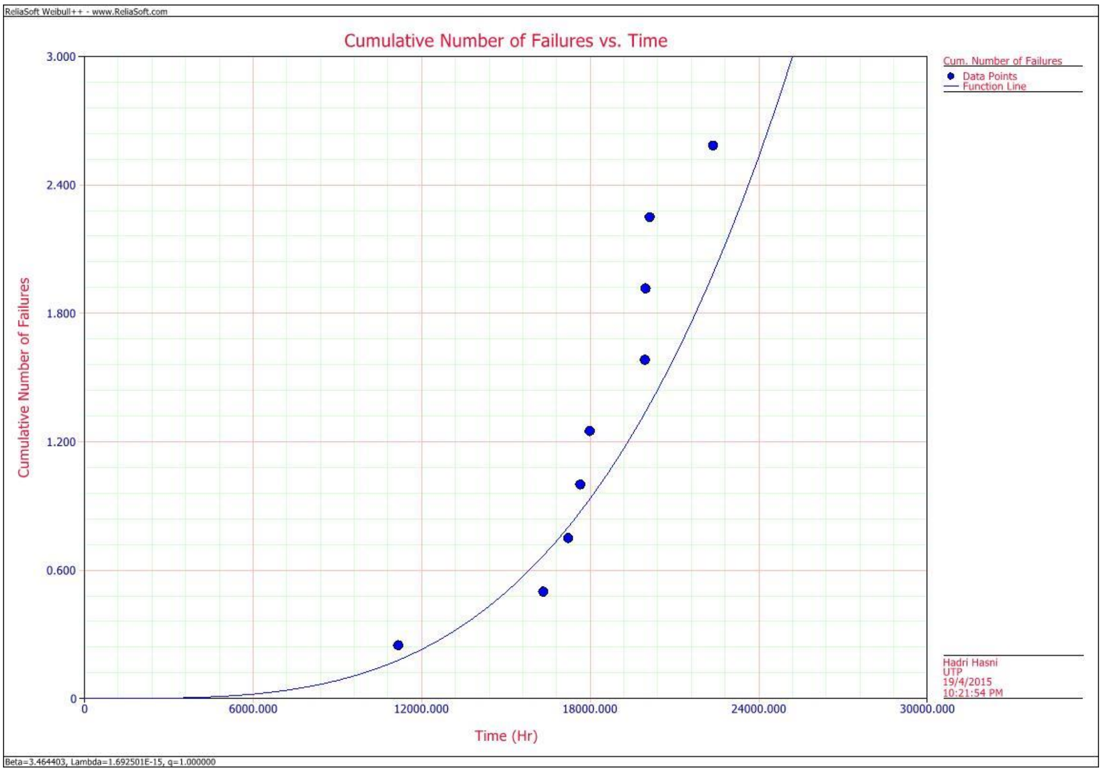


Figure 19: Cumulative Number of Failure versus Time – External Leakage

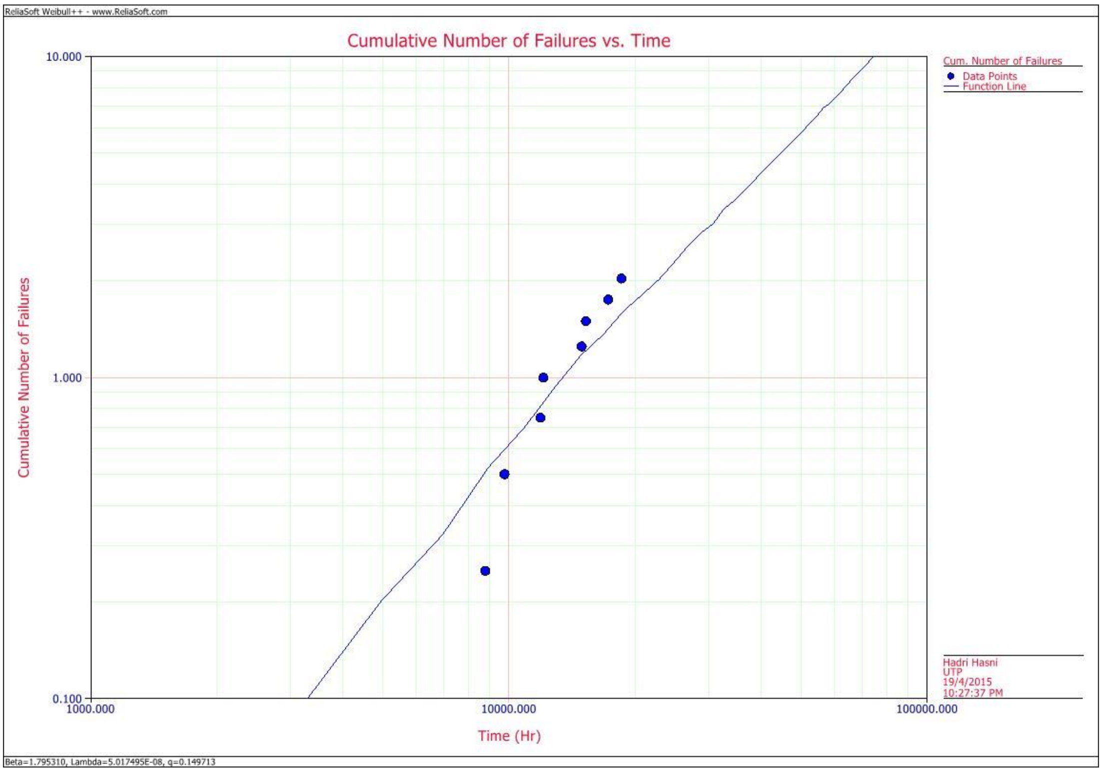


Figure 20: Cumulative Number of Failure versus Time – Internal Leakage (Using Logarithmic Axes)

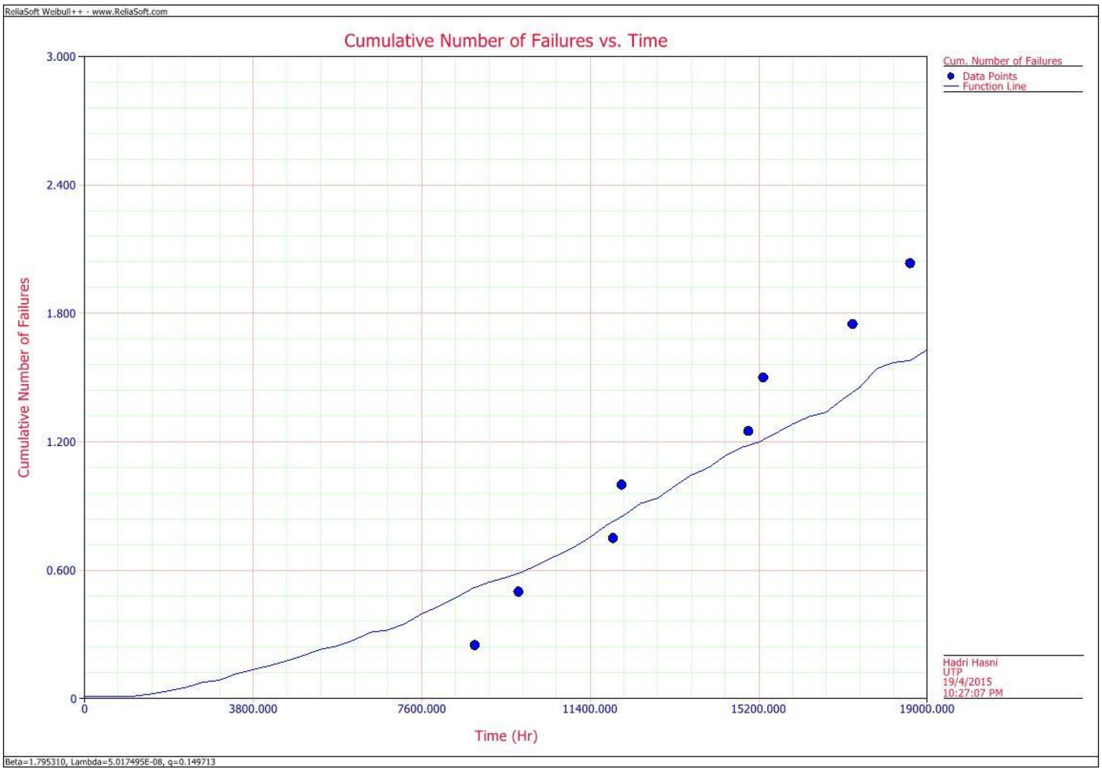


Figure 21: Cumulative Number of Failure versus Time- Internal Leakage

4.5. ANALYSIS USING THE WEIBULL++ SOFTWARE FOR PUMP UNIT

Using the same method as before, the software is used to analyse the data for pump unit regardless of any failure modes that happened. Now, the analysis is done by pump which the result will be compared with the results of analysis by failure modes arranged in reliability block diagram. The failure distribution of pump follows the Weibull 2-Parameter distribution. Below are the failure parameters of each pumps:

Table 10: Failure Parameters – Pump P-5150

Pump	P-5150
Beta	0.434536
Lambda (per hour)	0.036302
Eta (hour)	2060.767724

Table 11: Failure Parameters – Pump P-5151

Pump	P-5151
Beta	2.639443
Lambda (per hour)	4.43E-11
Eta (hour)	8370.421882

Table 12: Failure Parameters – Pump P-5155

Pump	P-5155
Beta	3.467086
Lambda (per hour)	3.14E-14
Eta (hour)	7845.553961

Table 13: Failure Parameters – Pump P-5156

Pump	P-5156
Beta	2.185464
Lambda (per hour)	2.16E-09
Eta (hour)	9223.696489

Using the “QCP” options, the reliability of each pump is calculated. Setting the mission start time as zero while the mission additional time to 8760 hours. Refer the appendix for the calculation picture and below is the reliability of each pumps;

Table 14: Pump Reliability Calculated using Weibull++

Pump	Reliability	Reliability (%)
P-5150	0.153293	15.33
P-5151	0.323816	32.38
P-5155	0.230947	23.09
P-5156	0.409264	40.92

4.6. ANALYSIS USING WEIBULL++ SOFTWARE FOR REPAIR DISTRIBUTION OF FAILURE MODES

Using the Weibull++ standard folio, the repair time of each failure modes are analysed. The reasons behind this is the analysis using the BlockSim simulation folio requires repair distributions in order to estimate the reliability and availability of the pump in terms of failure modes. The assumptions made earlier, the repair is immediate repair upon failure without and administrative or logistic delay.

After the analysis, all the repair distributions of failure modes follow lognormal distributions. However, the data for overheating (OHE) failure mode is insufficient. Thus with the assumption, it exhibits an exponential distribution. Below is the data of the repair distribution;

Table 15: Repair Distribution of External Leakage

Failure Mode	External Leakage
Distribution	Lognormal
Log-Mean (Hr)	5.76066
Log-Standard deviation	0.93405

Table 16: Repair Distribution of Internal Leakage

Failure Mode	Internal Leakage
Distribution	Lognormal
Log-Mean (Hr)	6.226752
Log-Standard deviation	1.168387

Table 17: Repair Distribution of Spurious Stop

Failure Mode	Spurious Stop
Distribution	Lognormal
Log-Mean (Hr)	5.265247
Log-Standard deviation	0.675649

Table 18: Repair Distribution of Overheating

Failure Mode	Overheating
Distribution	Exponential
Mean Time (Hour)	624

4.7. ANALYSIS OF RELIABILITY BLOCK DIAGRAM USING BLOCKSIM SOFTWARE

When all the parameters of each failure modes are complete. The failure modes are then arranged in series diagram. The diagram symbolises the pump, for each failure modes that occur will trigger the pump failure. Later, as the sub diagrams, the reliability block diagram of the pump system is generated. The reliability block diagram is shown below;

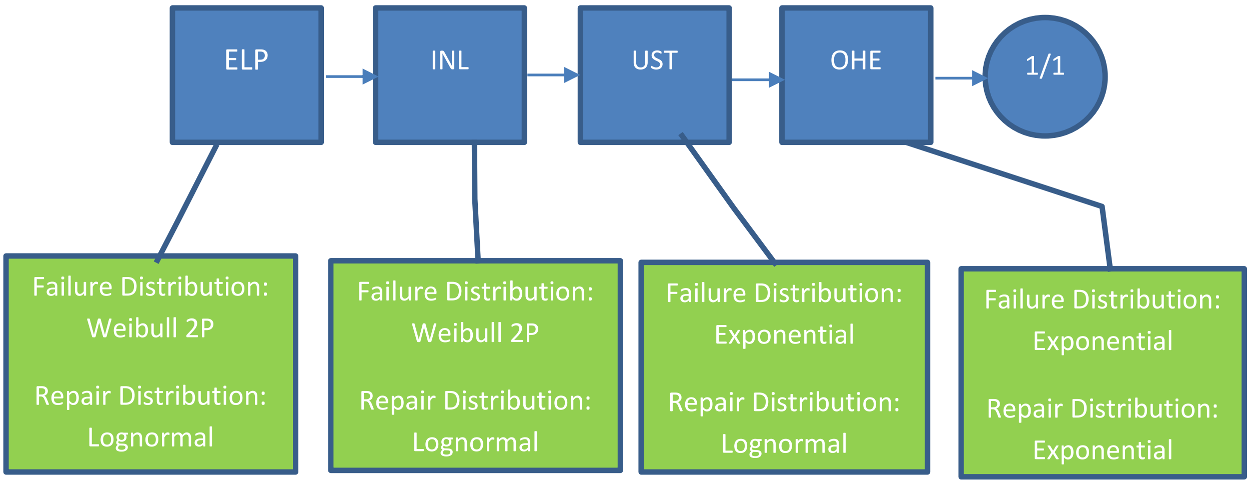


Figure 22: Reliability Block Diagram of Pump by Failure Modes

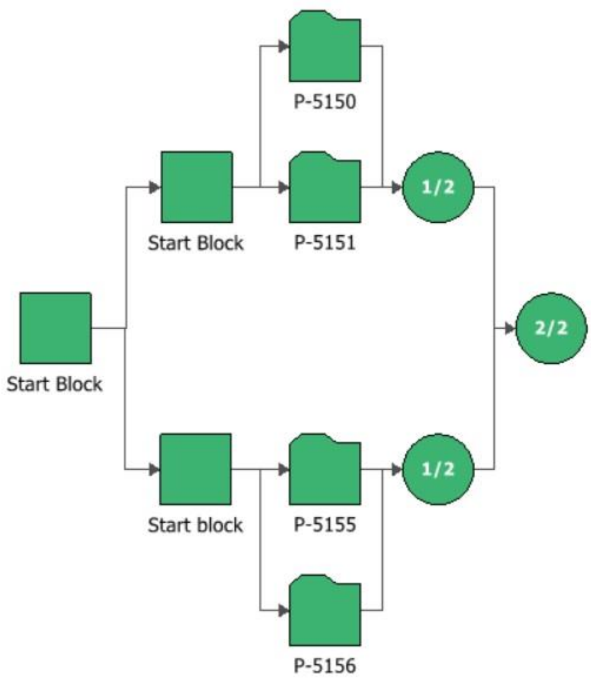


Figure 23: Reliability Block Diagram Generated Using BlockSim Software

Based on the diagram generated, the pump and system reliability is calculated by clicking the "QCP" button where the mission end time is set to 8760 hours that is equal to one year period. Moreover, the availability of the pump and the system in terms of failure modes is simulated for one year period. Below are the results of the analysis;

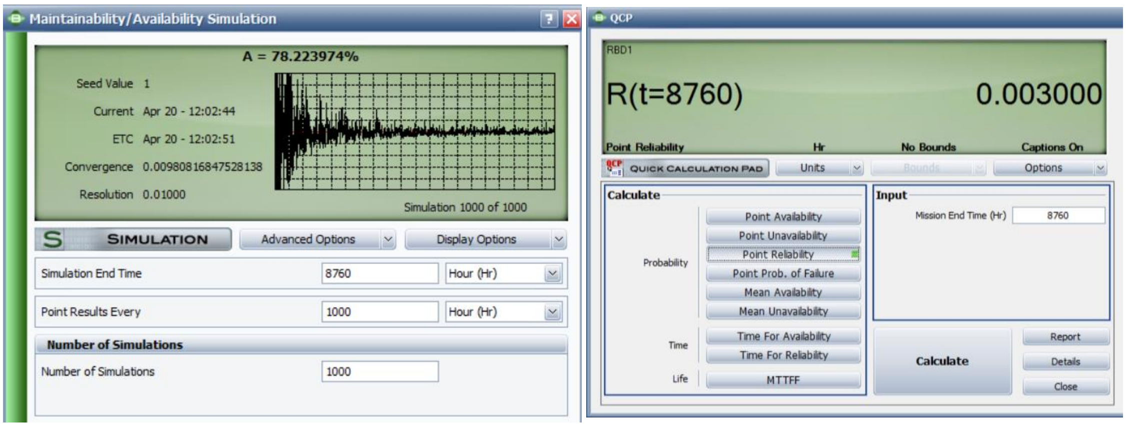


Figure 24: Pump Availability and Reliability

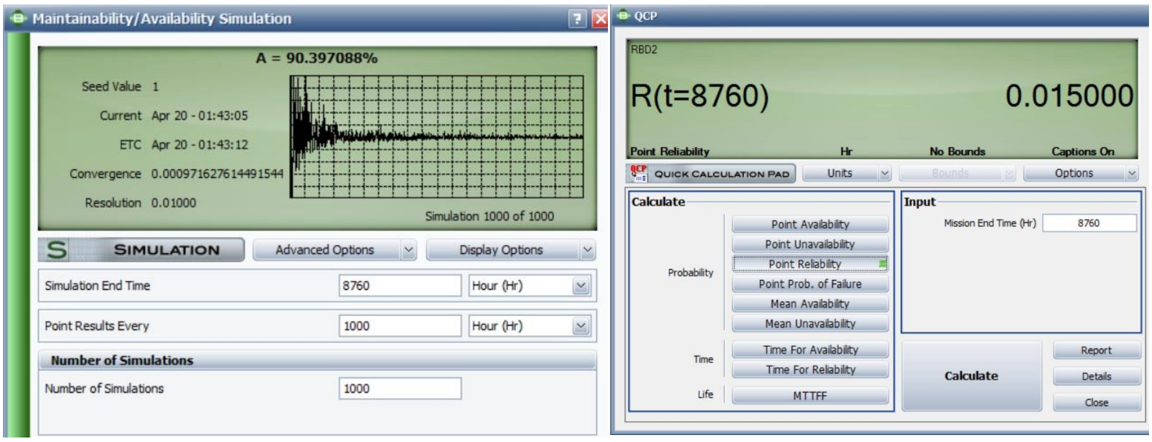


Figure 25: System Availability and Reliability

It is found that, the pump availability is 78% and the reliability is 0.3% for the next 1 year. Meanwhile, the system availability recorded a value of 90% and the reliability is 1.5%.

4.8. DISCUSSION

4.8.1. DISCUSSION ON THE EXPLANATORY ANALYSIS AND WEIBULL++ SOFTWARE RESULTS

Based on the explanatory results of the preliminary analysis, the centrifugal pumps experienced 20 failures over the time period of three years. The failures are identified and categorised according to the failure modes based on ISO 14224 standards. The failures too must be within the boundary specified in order to be further analysed. The results shown that the most occurring failure mode is external leakage-process medium (ELP), followed by internal leakage (INL). Other failure modes that were identified that had caused the pump failure are spurious stop (UST), and overheating (OHE) and). The tabulation of number of failure modes occurrence of respective pumps are recorded in the table 1.

Table 19: Failure Mode Identified based on ISO 14224

Failure Mode	FM Code	Number of Occurrence
External Leakage-Process Medium	ELP	9
Internal Leakage	INL	8
Spurious Stop	UST	2
Overheating	OHE	1

Next, the respective pumps' cumulative failure against time is plotted by using the gathered sets of data. Based on the results, it is determined that all the pumps shows an increasing trend of cumulative failure over time. The period of data collected is three years which from June 2011 until May 2014. A best fit graph is plotted in order to show the relationship of the cumulative failure and time. This is because, the failure can't be fully analysed unless using Weibull++ software. It enables the user to estimate the best distributions, parameters and characteristics of failure or repair data input. However, by using Microsoft Excel, the author are able to determine the trend only.

Based on the analysis using Weibull++ software, it is found out that the failure mode of the external leakage-process medium (ELP) and internal leakage (INL) are in wear out (increasing failure rate) stage of the bathtub curve. This is shown by the plotting and proven by the shape parameter, β which is more than value one.

The characteristics life is an important failure parameters .Using reliability formula of power law, the characteristics life, η could be determined from other parameters. The formula is:

$$\eta = \left(\frac{1}{\lambda}\right)^{\frac{1}{\beta}}$$

Later, the parameters will be input in the BlockSim software in order to find the system reliability based on the analysis done on the pump failure modes using Weibull++ software.

Each block diagrams will not be identical to each other and will have different parameters as the failure modes data analysed using software will follow the Weibull two parameter distribution for external leakage and internal leakage while the remaining two failure modes will follow exponential distribution as they are assumed to be having a constant failure rate.

Using mean time between failures from the data analysis, the failure rate of the failure modes that exhibit exponential distribution could be calculated such that from the template made, the mean time of the spurious stop failure is 3180 hours while the mean time for overheating is 3792 hours.

4.8.2. DISCUSSION ON BLOCKSIM RESULTS

When the all the parameters are finally determined including the repair distributions, the failure modes will be modelled into reliability block diagrams which are in series configuration to symbolise the pump unit. While the system diagram will be arranged in parallel configuration exactly like the real situation in the Onshore Slugcatcher (OSC) terminal.

Based on the analysis by failure modes, the reliability of the pump is 0.3%. However the analysis based on the pump data shows a larger value as compared to the analysis using the failure modes. Refer table 14 for the reliability of each pump units.

The pump availability simulated using the BlockSim for the next one year period gives an availability of 78%. The availability of the pump can be calculated manually in order to proof and make comparison with the result shown. Using the availability formula:

$$Availability = \frac{Uptime}{Uptime + Downtime} \times 100\%$$

From, this equation, the uptime plus with downtime will give the total year of observation which is three years. Below are the availability of each pump unit

Table 20: Pump Availability Calculated using Formula

Pump	Availability	Availability (%)
P-5150	0.957	96
P-5151	0.852	85
P-5155	0.684	68
P-5156	0.967	97

Meanwhile the reliability of the system shows a value of 1.5% for the period of 1 year and the availability of 90%. There big difference of the reliability value between estimation by failure modes and estimation by pump unit is due to the difference in assumption. This happens since BlockSim software the estimation is to the first failure of the failure modes whereas for non-homogenous Poisson process model used in Weibull++, the process is multiple failure with minimal repairs. Due to that, it causes a major difference in reliability value estimation for both by failure modes and by pump unit analysis.

4.8.3. STUDY LIMITATIONS

While conducting this project, the author had faced several limitations in order to complete the analysis within the time frame allocated. The limitations are:

i. *Understanding the concept of Reliability Engineering*

Since this is a new course, the author has known very little about the knowledge of reliability engineering. The concept of estimating pump reliability by failure modes using recurrent data analysis has never been done before in industry. Usually, the reliability of equipment is analysed by the mean time between failures of the equipment. With that, the author had to do some readings and research mostly on the parametric analysis, reliability block diagram and repairable system.

ii. *Obtaining reliable failure and repair data*

In order to obtain a good and feasible results, the first step is to gather reliable sets of data. However, during the data analysis phase, the author found out there are a lot of missing sets of data on the failure and repair time. In order to overcome that, the author had to make few assumptions before further analysis could be carried out.

iii. *Less information on how to use reliability software*

The software used in this project such as Weibull++ and BlockSim are totally new to author. In order to conduct the analysis, the author needs to learn the software by himself. There are less information or online tutorials on how to fully utilise these software. The seminar conducted on using the software are expensive and unaffordable since the author is still studying. In fact, the author had to get assistance from supervisor on the tutorials.

CHAPTER 5: CONCLUSION

There is growing concern regarding the equipment the availability and performance of major equipment such as centrifugal pumps in oil and gas industry. A loss of major equipment would be a loss of total production which will incur expensive cost. The main objective of the analysis is to estimate the centrifugal pump reliability using recurrent data analysis for failure modes. As stated in the explanatory result, there are 20 failures within three years period.

Meanwhile, based on the standards used, there are seven different failure modes identified from each centrifugal pumps (P-5150, P-5151, P-5155 & P-5156). The preliminary analysis is done to show the trending of the pumps' cumulative failure over time before the data will be further analysed using Weibull++ and BlockSim software in the future. The estimation of the pump reliability and availability is done through software analysis. Based on the results obtained, there is difference between the reliability values of estimation by failure modes and the estimation by pump unit. This is due to the difference in assumptions made by the software. Hopefully, the feasible results obtained from the analysis could be implemented to form a better maintenance strategy in terms of failure mitigation and inspection. Hence, the objective of the project had been achieved.

CHAPTER 6: RECOMMENDATIONS FOR FUTURE STUDIES

Based on the project analysis and results, the recommendations for future studies are described as follows:

i. *Gather a more reliable set of data*

   The data of the pumps are taken from the daily operation report of Onshore Slugcatcher (OSC) terminal in Kerteh, Terengganu. The observation time is for three years period. However, due to missing and incomplete descriptions in the daily operation report, the reliability of the data is affected. The author had to make assumption in order to fill the gap of missing data time in the equipment performance trending template. This is called "Engineering Judgement". The recommendation would be to gather more sets of data for a longer period of time as this will reduce the percentage of error. Moreover, the study should not rely on single source of data information. Further study should integrate the data from the daily operation report with the company's database. For instance, system application product (SAP).

ii. *Get a training on the software.*

   The problem arises when it comes to data analysis using the reliability software. For example, the author is confused on which folio should be used in order to analyse the data. Thus more time is spent on figuring out the application of the software.

iii. *The analysis could be carried out on repairable item in site*

   From the analysis, the results of this study could be used as a reference on how to fully analyse a repairable items or system by failure modes in site. For instance, the critical equipment like compressor, turbine and motor. Those equipments are repairable items which make up a large system. Currently, analysis using the mean time between failures may not give accurate results.

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APPENDIX A

OSC DAILY OPERATION REPORT

OSC DAILY OPERATION REPORT	DAY START 0600 HRS:	31/5/2014	DAY ENDING 0600 HRS:	1/6/2014

PRODUCTION DATA

TOTAL GAS NOMINATION	1,483.000	mmscfd	*white - do not change	*take figure from 0600 hrs metering print out and DCS
TOTAL GAS SALES	1,303.624	mmscfd	*green - input	
TOTAL GAS SALES MASS	31453.557	tonnes	1 km3/d = 0.03531338 mmscf/d	1 tonne = 1000 kg
TOTAL COND. SALES	3578.139	bbl/d	1 kl/d = 6.294 bbl/d	1 mmscf/d = 28.3178783792432 km3/d
TOTAL COND. SALES MASS	374.136	tonnes	1 m3/d = 35.301 ft3/d	

OPERATIONS DATA					
LANDING PRESSURE/TEMP JERNEH	7810/21	kPa/Celcius	GAS DENSITY (MT5700)	0.8500	kg/m3
LANDING PRESSURE/TEMP LAWIT	7694/24	kPa/Celcius	GAS DENSITY (MT5800)	0.8540	kg/m3
LANDING PRESSURE/TEMP ANGSI	7694/23	kPa/Celcius	CONDENSATE DENSITY (MT5710)	658.11	kg/kl

			GAS SALES		CONDENSATE SALES	
D/STREAM PRESSURE (MT5700/MT5800)	7524/7533	kPa	GAS	mmscf/d	CONDENSATE	kl/d
CONDENSATE LANDING PRESSURE/TEMP	7900	kPa/Celcius	TOTAL NOMINATION	1483	MT5710 SALES [kl/d]	568.50
FSC LEVEL (Finger A / Finger B)	17/2	%	MT5700 SALES	738.22		
MOISTURE CONTENT (MT5700/MT5800)	22/10	[lbs/mscf]	MT5800 SALES	565.41		
PRODUCED H_2O TANK LEVEL (T5540/5541)	5/2	m	MT5700 SALES [km3/d]	20869.6		
			MT5800 SALES [km3/d]	15984.1		
			TOTAL SALES [mmscfd]	1304	TOTAL SALES [bbls/	3578

INLET FINGERS PROTOCOL LINE UP

GAS INLET STATUS	Normal Protocol @ May 28, 2330 hrs		
	Finger A	Finger B	Train C
	Ang	JeA/LaA/Ang	LaA
GAS OULET TO TRAIN C	Close	Close	
REMARKS			

	GAS (mmM3)	COND. (kl)
MONTHLY		
YEARLY 2014		

HSE STATISTICS

ACTIVITIES	DATE LAST REPORTED	YTD
EMERGENCY DRILL	22-May-14	6
IIR	14-Apr-14	4
TOTAL DAYS WITHOUT LOST TIME INCIDENT (01/12/2011)	PCSB: 913	CONTRACTOR: 913

* START ACCUMULATIVE TOTAL MANHOUR on 01 Dec 2011

AREA OF CONCERN

1. MOV-304 terminal card control failure due to water ingress. WO:96371085.
2. RE-5100 JeA receiver door stud broken. WO:- 96465282.
3. Signboard lighting shorted - NO:23165989
4. MOV 122 Equalizing Valve Leak at packing stem. WO:- 96507505
5. Sight glass for V-5120 pinhole leak at union joint. WO:- 96542706
6. MOV-101 gear box problem . WO : 96544792. (Site survey done by PFCE on 28.04.2014)
7. MOV-132/33/34 unable to operate on motor (JeA 8" receiver). WO:96075646/PR:10089887.

OSC EQUIPMENT STATUS

EQPT TAG NO.	DATE RPT	DESCRIPTION OF FAILURE	ACTION PROGRESS	ACTION PARTY	NOTIFICATION / WORK ORDER NO
MOV-132/33/34	5/7/2012	unable to operate on motor (JeA 8" receiver)	To purchase spare parts	PRM5	WO:96075646/PR:10089887
SDV-1100	13/2/2013	Valve badly passing (inlet finger JeA to Tr-A)	To purchase new valve. Change from welded to flanges type. Require Jerneh SD	PRM6	WO:96181553
SDV-2100	13/2/2013	2ea 2" VG bypass valve jammed close (inlet finger LaA to Tr-A)	2" valve already purchase by Material Co. Operation to install 2" valve. Require Lawit & Train A SD	PRM6	WO:96181555
SDV-2150	13/2/2013	SDV & 2" bypass valve badly passing (inlet finger LaA to Tr-B)	2" valve already purchase by Material Co. Operation to install 2" valve. Require Lawit & Train B SD	PRM6	WO:96181736
BDV-7181	13/2/2013	BDV & isolation valves badly corroded (MT-5710)	WO:96573209: BDV-7181, BDV-1454 & BDV-1230	PRM6	WO:96181739
PSV-5320	3/10/2013	badly passing (P-5532 CDV pump)	PSV not in use since day one. Register FIP to study PSV to resize.	PRM6	WO:96217979
G-5415	31/3/2013	failed to start on "AUTO" during power failure	To revisit the issue (operation philosophy). Propose FIP	PRM5	WO:96218100
G-5416	8/11/2013	battery charger card kaput	To follow up quotation from PFCE CG for new card replacement	PRM5	WO:96408031
P-5475	6/10/2013	mech seal leaking (FWP)	rate of packing leak is within spec	PRM3	WO:96273096
MOV-304	29/9/2013	terminal card control failure due to water ingress	To follow up quotation from PFCE CG for new card replacement	PRM5	WO:96371085
PV-143A	7/8/2013	bypass indication faulty, to replace control panel	site survey done by MATCO	PRM6	WO:96304176
PV-143B	14/7/2013	bypass indication faulty, to replace control panel	site survey done by MATCO	PRM6	WO:96326908
PSV-1000	20/08/2013	PSV Isolation valve passing (JeA 28" receiver)	3" x 900# valve available. Operation to Install	Operation	WO:96339892
P-5156	18/12/2013	Abnormal sound at NDE bearing	Closed. No abnormal sound.	PRM3	WO:96445972

APPENDIX B

ISO 14224 EQUIPMENT SPECIFIC DATA – PUMPS

Table A.22 — Equipment-specific data — Pumps

Name	Description	Unit or code list	Priority
Type of driver	Equipment class, type and identification code	Specify	High
Fluid handled	Type	Oil, gas, condensate, freshwater, steam, sea water, crude oil, oily water, flare gas, fuel gas, water/glycol, methanol, nitrogen, chemicals, hydrocarbon-combined, gas/oil, gas/condensate, oil/water, gas/oil/water, LNG	High
Fluid corrosive/erosive	Classify as shown in footnote [a]	Benign, moderate, severe	Medium
Application – pump	Where applied	Booster, supply, injection, transfer, lift, dosage, disperse	Medium
Pump – design	Design characteristic	Axial, radial, composite, diaphragm, plunger, piston, screw, vane, gear, lobe	Medium
Power – design	Design/rated power of pump	Kilowatt	High
Utilization of capacity	Normal operating/design capacity	Percent	Medium
Suction pressure – design	Design pressure	Pascal (bar)	Medium
Discharge pressure – design	Design pressure	Pascal (bar)	High
Speed	Design speed	Revolutions per minute or strokes per minute	Medium
Number of stages	Centrifugal: number of impellers (in all stages) Reciprocating: number of cylinders Rotary: number of rotors	Number	Low
Body type	Barrel, split casing, etc.	Barrel, split case, axial split, cartridge,	Low
Shaft orientation	—	Horizontal, vertical	Low
Shaft sealing	Type	Mechanical, oil seal, dry gas, packed, gland, dry seal, labyrinth, combined	Low
Transmission type	Type	Direct, gear, integral	Low
Coupling	Coupling	Fixed, flexible, hydraulic, magnetic, disconnect	Low
Environment	Submerged or dry-mounted	—	Medium
Pump cooling	Specify if separate cooling system is installed	Yes/No	Low
Radial bearing	Type	Antifrictional, journal, magnetic	Low
Thrust bearing	Type	Antifrictional, journal, magnetic	Low
Bearing support	Type	Overhung, between bearings, pump casing, split sleeve	Low

[a] Benign (clean fluids, e.g. air, water, nitrogen).

Moderately corrosive/erosive (oil/gas not defined as severe, sea water, occasionally particles).

Severely corrosive/erosive [sour gas/oil (high H_2S), high CO_2, high sand content].

APPENDIX C

EQUIPMENT PERFORMANCE TRENDING TEMPLATE

	A	B	C	D	E	F	G	H	I	J	K
1	System/Package	Condensate Booster Pump									
2	Equipment Tag	P5150									
3	Description	Condensate Booster Pump									
4	Date	Equipment Status (hours)						Remarks in DOR/DMR	Remarks in SAP	Cumulative Running Hours	
5		Running	Standby	OOS	PPM	Total	Failure in Service				
63	05/10/13			24		24		Outboard mech seal leaking		19968	
64	06/10/13			24		24		Outboard mech seal leaking		19968	
65	07/10/13			24		24		Outboard mech seal leaking		19968	
66	08/10/13	24				24		Available		19992	
67	09/10/13			24		24	1	DE mechnical seal leak		19992	ELP
68	10/10/13			24		24		DE mechnical seal leak		19992	
69	11/10/13			24		24		DE mechnical seal leak		19992	
70	12/10/13			24		24		DE mechnical seal leak		19992	
71	13/10/13			24		24		DE mechnical seal leak		19992	
72	14/10/13			24		24		DE mechnical seal leak		19992	
73	15/10/13			24		24		DE mechnical seal leak		19992	
74	16/10/13			24		24		DE mechnical seal leak		19992	
75	17/10/13	24				24		Available		20016	
76	18/10/13	24				24		Available		20040	
77	19/10/13	24				24		Available		20064	
78	20/10/13	24				24		Available		20088	
79	21/10/13	24				24		Available		20112	
80	22/10/13	24				24		Available		20136	
81	23/10/13			24		24	1	NDE mechanical seal leak		20136	ELP
82	24/10/13			24		24		NDE mechanical seal leak		20136	
83	25/10/13			24		24		NDE mechanical seal leak		20136	
84	26/10/13			24		24		NDE mechanical seal leak		20136	

APPENDIX D

OSC PROCESS FLOW DIAGRAM