Reliability, Availability and Maintainability (RAM) Analysis for Offshore High Pressure Compressor

by

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16029

Dissertation submitted in partial fulfilment of

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(Mechanical)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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Approved by,

____
(Dr. Masdi Bin Muhammad)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2016

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.

SITI NUR IZZAIDAH BINTI JUMALI

ABSTRACT

Reliability, Availability and Maintainability (RAM) helps in optimizing performance of equipment. The availability can be improved by the enhancement of the reliability and maintainability. Equipment failure in offshore facilities are difficult to be predicted hence sudden failure of an equipment lead to reduction in output, loss of production and high maintenance cost due to unplanned maintenance. This study examined and analysed the failure mode of high pressure compressor at offshore platform in order to identify its critical failure mode. Failure and repair data are utilized to determine reliability and maintainability of the high pressure compressor. Reliability and maintainability analysis was carried out with the aid of Reliasoft Weibull++ software to obtain the required parameters while ReliaSoft BlockSim software was used for reliability block diagram (RBD) construction and simulation to obtain the availability of the high pressure compressor. The developed model can improve the performance of the high pressure compressor since it is validated with the actual model. From this RAM analysis, the overall performance of high pressure compressor can be increase by conducting Root Cause Failure Analysis (RCFA) which focusing on the most critical failure mode. The optimization of maintenance schedule can lead to the reduction of maintenance cost.

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May Allah bless and pay them all.

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ABBREVIATIONS AND NOMENCLATURE

RAM	Reliability, Availability and Maintainability
RBD	Reliability Block Diagram
RDA	Repairable Data Analysis
CM	Corrective Maintenance
LDA	Life Data Analysis
OREDA	Offshore Reliability Data
PM	Preventive Maintenance
TTF	Time to Failure
TTR	Time to Repair

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Reliability, availability and maintainability (RAM) model is an engineering tool that delivers the safety in operation and production and aims to identify the component or failure modes within the system where improvement can be achieved [1]. RAM analysis are conducted on high pressure compressor at the offshore platform in order to identify the critical failure mode of the can be improved by optimizing the maintenance strategy. The probability of failure, equipment down time and availability of the high pressure compressor can be computed by RAM analysis. Adopting the RAM analysis into the plant are beneficial since it helps in identifying unreliable equipment, constraints in operation and improve the system availability. Failure modes involved in every failure event are identified with the reference to *Offshore Reliability Data* (OREDA) 2009 handbook.

Compressor is one of the vital equipment in an offshore platform. Compressor is a mechanical device used in order to increase the pressure of air/gas/vapour in the process of transferring from one location to another. In offshore field, there are two types of compressor that widely use in offshore: low pressure compressor and high pressure compressor. Low pressure compressor increasing the product's pressure from the low pressure vessel before going to the commingle line and export line. Likewise, high pressure compressor increasing the product's pressure from the high pressure vessel to the export line.

1.2 Problem Statement

In offshore facilities, it is difficult to predict the life of the high pressure compressor due to abrupt failure. Moreover, it may cause a loss of production because of sudden failure of the compressor. Corrective maintenance that only performed when there is a failure of component can be time consuming especially for an equipment in offshore facilities. This is because time consumption in the deliverances of the unavailability of manpower, tools and equipment spare part from the onshore. Unplanned maintenance activity eventually leads to high maintenance cost. This maintenance constraint affects the repair and maintenance of the compressor. High pressure compressor failure in the offshore facilities lead to reduction in output, loss of production and also creates unsafe working environment.

The developed RAM model performed the analysis on the failure mode level of the high pressure compressor to identify the most critical failure mode. The quantitative model evaluates the failure mode to improve the maintenance strategy by focusing on the component of the most critical failure mode. This action can increase the availability of the high pressure compressor.

1.3 Objective

In conjunction with above problem statement, the objectives of the project are:

i. To develop reliability, maintainability and RAM model of the failure mode for the high pressure compressor failure and downtime.
ii. To estimate availability of the high pressure compressor.
iii. Identify the critical failure mode and repair for the high pressure compressor.
iv. To propose mitigation action to improve availability through sensitivity analysis.

1.4 Scope of Study

To achieve the above mentioned objectives, this RAM analysis study are conducted by using Reliability Block Diagram (RBD) modelling approach based on high pressure compressor located offshore platform. This RAM analysis are identified in a failure mode level of the high pressure compressor. The reliability and maintainability analysis are carry out to determine the availability of the high pressure compressor using the failure and downtime data from the platform. Hence, this project is feasible to be conducted in a time scope of two semesters.

CHAPTER 2

LITERATURE REVIEW

2.1 Reliability, Availability and Maintainability (RAM) Analysis

Reliability is the probability that a machine or system will perform a required function, under specified conditions, for stated period of time. Thus, reliability is the probability of non-failure in a given period of time [1]. Availability is defined as the ability of an item (under combined aspects of its reliability, maintainability and maintenance support) to perform its required function at a stated instant of time or over a stated period of time [2] while maintainability is the probability that a failed machine or system will be restored to operational effectiveness within a given period of time when the repair action is performed in accordance with the prescribed procedures. In other word it is the probability of completing the repair at a given time [1]. The value of probability always lies in between 0 to 1. If the value approaching to 1 for the reliability, it indicates that the system or equipment are improbable to fail during stated period of time. One of the objective of every plant is to have high reliability of plant in order to minimize the expenditure and maximize the production.

RAM analysis is a method in accessing the production of the system and identifying possible causes of production losses. Furthermore, RAM analysis helps in identify the crucial point of the system to come out with optimum solution. Barabady, J. [2] reported that RAM analysis system has created remarkable changes in overall operating or production cost by predicting the failure and estimated the availability of the equipment. RAM analysis can be developing by assessing the failure modes, frequencies etc. in order to ensure the estimated production availability meets the requirements. Corrective maintenance result in significant higher repair costs than a preventive maintenance. High costs equipment and maintenance prompt engineering solutions to reliability problems in order to minimize the maintenance and operating expenditures while enhancing reliability. It also helps in increasing the equipment availability [2].

Availability analysis helps in identify items that affecting the system or operation. Availability of the item can be prolonging by considering the maintainability and reliability data. Wang et al. [3] found that the availability of a system is always higher than the reliability of the system because the availability is the probability that the component is currently in available/working state, even though it has a failure history and been restored to its operational state. Maintainability analysis can be performing in major RAM software and its help in specify the data in order to optimize the repair action and maintenance strategy [4]. Every repair and maintenance action is a downtime of the system since the system unable to operate during the period of time. Figure 2.1 shows the structure of the downtime and its element.

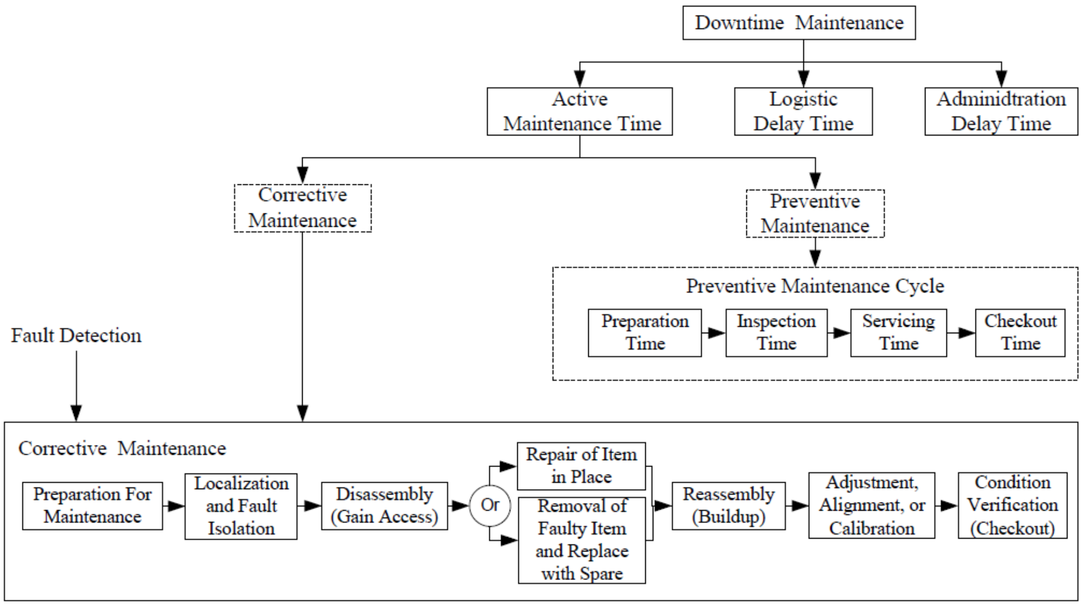


FIGURE 2.1: Structure of downtime maintenance [2]

Reliability and maintainability of the equipment or system can be enhanced by minimize the failure rate and repair time. Furthermore, the availability can be improved by the enhancement of the reliability and maintainability. As demonstrated in [5], reliability and availability analysis has helped to identify the critical components in the equipment that lead to a failure. One of the purposes of system reliability analysis is to identify the weakness in a system and to quantify the effectual related to the consequence of the failure.

As reported by Herder et al. [6] RAM analysis indicates that the improvement in reliability of the system will lead to reducing maintenance cost and manpower. It is considered as a valuable tool for availability optimization. Moreover, by using RAM analysis, there are increasing of efficiency and effectiveness of the preventive and corrective maintenance as well as resulting in higher plant reliability and less unexpected output shortfalls. The previous study by using RAM analysis specify that it can determine the critical equipment that require detail inspection to ensure sufficient plant shutdown duration and equipment reliability. Kumar et al. [7] had done the RAM approach by analyse the downtime of the equipment and it indicate that RAM analysis helped in identify the root cause of the production loss problem by developed model for various maintenance options.

2.2 RAM Modelling

RAM modelling can stimulate the configuration, operation, failure, repair and maintenance of the equipment. The result from the RAM modelling generates sufficient data to determine the decision making in order to increase the equipment/system efficiency [8],[9]. Equipment with high failure rate can be identified and the predicted reliability helps in upgrading the maintenance strategy. There are various techniques in RAM modelling such as: Markov chain, Petri-Net and reliability block diagrams (RBD).

2.2.1 Markov Chain

Markov chain develop by specify the state of the system. Each system state display whether the subsystem is functioning or failed. However, since Markov chain is a state-space analysis, the downside of this RAM modelling is every possible state of the system must be evaluate which makes Markov chain a complicated modelling especially for complex system. In fact, even though Markov chain commonly used where the constant failure rate can be applied to the system, the accuracy of Markov chain is debatable since the failure rate does not accurately represent the subsystem or component of the system.

2.2.2 Petri-Net

Similar to Markov chain, Petri-Net is a dynamic RAM modelling which also evaluate by using state-space analysis. Whereas, since it is a state-space analysis, the model developed by Petri-Net tend to become larger and complicated as the system become complex. Knezevic [10] mention that the application Petri-Net in reliability engineering is quite limited and its rarely been used because it a suitable RAM modelling approach for simpler model. In contrast from Markov chain, Petri-Net much more accurate as this modelling does not limited to constant failure rate.

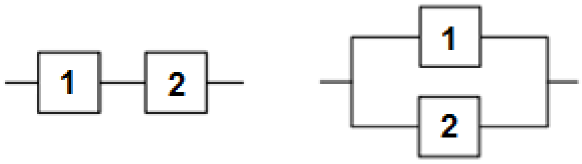
2.2.3 Reliability Block Diagram (RBD)

Meanwhile, in reliability block diagram (RBD), there are simple and complex system arrangement which using a top-down approach. RBD configuration and arrangement mostly represent the composition of the subsystem and its component. The arrangement accurately represents the entire system since RBD is a logic-based RAM modelling. The graphical designated system analyse and examine the reliability of the system. The major advantages of using RBD is that it is very convenient and has wide variable distribution as well as various arrangement including the applicability of redundancy in the system. Table 2.1 below shows the comparison between different approach of RAM modelling. Based on the Table 2.1, RBD is the most suitable RAM modelling for this study since it is static and logic-based modelling.

TABLE 2.1: Differences of RAM modelling types and its characteristic [10]

Characteristic	Markov Chain	Petri-Net	RBD
Static/Dynamic	Dynamic	Dynamic	Static
State-space/Logic-based	State-space	State-space	Logic-based
Top-down			X
Variable distribution		X	X

The RBD structure interpreted the relationship of failures within a system that are entails in order to sustain system operation [4],[9]. The blocks represent the groups of components or the smallest entities of the system. RBD analysis is crucial in determining the reliability, availability and down time of the system. Figure 2.2 shows basic arrangement of RBD method.



a) Series b) Parallel

FIGURE 2.2: Basic arrangement of reliability block diagram [11]

There are two general type of relationship between each component: series and parallel. If the components of a system are connected in series, the failure of any component causes the system to fail. Reliability of the series arrangement system based on Figure 2.1 expressed in the following formula shown in Equation 2.1:

$$R_s = R_1 \times R_2 \times \cdots \times R_N \tag{2.1}$$

When the components of a system are connected in parallel, the failures of all components cause the system to fail. If the failure of a component occurs, the other component will start to operate in order to fulfil the system requirement. The reliability of the parallel arrangement based on Figure 2.2 system shown in the following formula:

$$R_s = [1 - (1 - R_1) \times (1 - R_2) \times \cdots \times (1 - R_N)] \tag{2.2}$$

Parallel redundancy arrangement also called as k-out-of-n configuration. In the event of this arrangement, there are required number of the block/unit to be in the success state in order for the system to success. For instance, the system are in a k-out-of-n configuration where $k = 2$ and $n = 3$ so the system has a 2-out-of-3 configuration. This example is shown in the Figure 2.3 as an illustration of the situation. Since this type of arrangement consider to follow the general arrangement, it can also declare that k-out-of-n configuration tend to follow series arrangement due to the system behaviour follow the condition of the configuration.

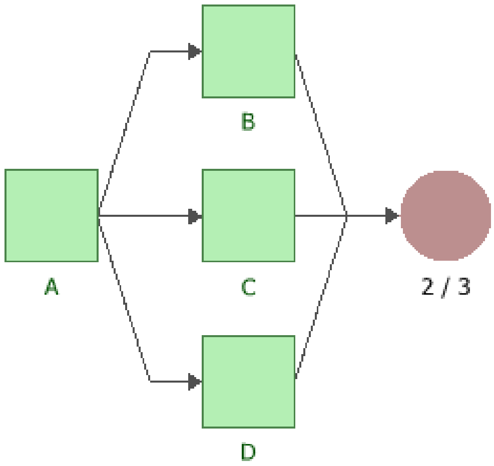


FIGURE 2.3: K-out-of-n arrangement of reliability block diagram

On the other hand, in many cases commonly in larger system, the general arrangement of parallel and series are hardly identified. It because in some cases, the system arrangement unable to be broken down into parallel or series arrangement due to the connectivity of each block diagram.

2.2.3.1 Simulation of RBD

In the event of the simulation, it is crucial to indicate the RBD assumptions to avoid mistakes during the simulations. This assumption also helps in proclaim the effect on the system when failure occurs. Prior to RAM analysis, each block of the failure modes in the RBD simulation exhibit the failure time and repair time. It is also necessary to specify failure mode that lead to the equipment failure or loss of production. The software tool use for the simulation of RBD is called BlockSim. This software created the RBD first then the input is assign to each block. The same level of details and input must be assign to each model to ensure the accuracy in the simulation [12]. Failure mode level are used for this RAM study.

Basically, there are two types of system that need to be consider in modelling and simulation phase: repairable and non-repairable. In non-repairable system, repair term mean replaces because if the failure occurs, the equipment is replaced with a new one [8]. Subsequently, the replacement time of non-repairable system is the same as the repair time in the repairable system.

2.3 Repairable System

Nachlas [13] addressed that repairable system is an equipment entity that is capable of being restored to an operating condition following a failure. For an equipment which repaired when failed, the reliability of the system can be categorize by the *Mean Time Between Failure* (MTBF) but this only applicable under certain condition of constant failure rate.

According to [14],[15], for a declining condition of repairable system known as *Non-Homogeneous Poisson Process* (NHPP), it is reasonable to assume that the successive working times of the system after repair will be decreasing while the consecutive repair times of the system after failure will become longer each times. Eventually, the system then become unrepairable and does not meeting the operating condition. It because the repairs effectiveness varies from restoring the system as a brand new system or restoring to the reliability of before the system last failed.

2.3.1 Crow-AMSAA

Based on Hamada [16], the distinguished feature of the repairable and non-repairable system is that the repairable system allows the reliability growth or decay of the system. In practice, most repairable systems are become worse in its operating condition because of the ageing effect and the accumulative wear.

Crow-AMSAA is a model in projecting reliability growth which helps in predict future failure and allowing reliability improvement of the system [17]. It also considered to be the best practice in determine the trend reliability. Crow-AMSSAA allow mixed failure modes and surfacing it in order to achieve higher reliability. This model also able to fit a power law distribution which gives a straight line on log-log paper. Moreover, Crow-AMSAA also able to analyse the changes of reliability level in a system. This model will be applied to this study in order to make the reliability growth or degradation more observable. Cumulative failures over cumulative time are plotted to display a graphical straight-line plot, with a goodness of fit test, and extrapolation of the data.

The parameter such as β and λ can be determine based on the plotted graph since β is the slope while λ is the y-intercept of the graph. The function of instantaneous failure for each cumulative point are expressed as Equation 2.3 [17].

$$\rho(t) = \lambda\beta t^{\beta-1} \quad (2.3)$$

Equation 2.4 are used in order to forecast the failure of the system and the line equation are defined as Equation 2.5.

$$n(t) = \lambda t^{\beta} \quad (2.4)$$

$$\ln n(t) = \ln\lambda + \beta \ln t \quad (2.5)$$

The trend of the data is determined conditional to the β parameter obtained from the Crow-AMSAA model which β indicate the life and failure of the system. The trend indicates whether the reliability of the system growth or follow degradation process.

2.3.1.1 Type of Failure (Bathtub Curve)

Every equipment or system that failed are describe in term of its failure. Predominantly, there are three type of failure expressed in a graph known as a bathtub curve. The failure is expressed in the β term. Bathtub curve are widely become a standard reliability term in describing type of failure and failure rates.

The bathtub curve consists of three different curve namely; an "early life" (burn-in) period, a "useful life" (random failure) period and a "wear-out" period. Figure 2.4 show the failure type described in term of bathtub curve. The causes lead to the failure also are identified and tabulated in Table 2.2.

FIGURE 2.4: Bathtub curve [1]

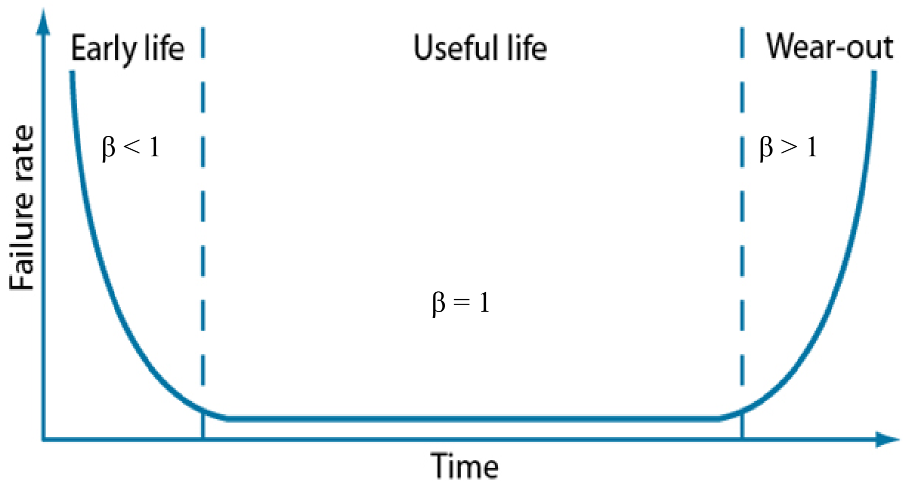


TABLE 2.2: Causes of failure characteristic [1]

Type of Failure	Failure Characteristic	Causes
Early life	Decreasing failure rate	Improper manufacturing, installation and poor materials
Useful life	Constant failure rate	Components or systems spend most of their lifetimes operating (normal operating life)
Wear-out	Increasing failure rate	Fatigue, corrosion, creep, friction and other aging factors

2.4 Non Repairable System

Opposite to the repairable system, non-repairable system is an equipment that unable to be restored to the operating condition after failure. The differences of repairable system and non-repairable system are shown in Table 2.3. A non-repairable are removed permanently after a failure. The system could be repair after undergo overhaul by replacing the failed part but the equipment performance is dwindling over time until the equipment completely failed. The life distribution is the best way to describe non-repairable system because the population is generally considered to be all of the possible unit lifetimes for all of the units.

TABLE 2.3: Differences of repairable system and non-repairable system

Characteristic	Non-repairable	Repairable
Time to Failure	Mean Time to Failure (MTTF)	Mean Time Between Failure (MTBF)
Maintainability	Not available	Maintainability downtime
Reliability Growth	Commonly not used	Used during development phase

2.4.1 Common Life Distribution

Reliability and maintainability of the system are defined by the probability of certain distribution. The reliability, given by the reliability function of $R(x)$ is expressed by the probability of no failure occur in the interval of 0 to x. Meanwhile for maintainability, O'Connor [18] stated that maintainability given by maintainability function of $M(x)$ tend to be in lognormal distribution.

On the other hand, since this study of RAM analysis are emphasis on failure modes, it is important to select correct distribution for the analysis in order to effectively analyse the data and reduce the frequency of the failure modes occurrence. There are several kinds of distribution used to represent the reliability and maintainability. The most commonly used in a reliability analysis are Weibull distribution and exponential distribution while for maintainability is lognormal distribution.

Life distribution used in a system are likely to change when there are changes of life (i.e., success or failed) of each unit in RBD and its affect the failure rate of the other unit. Furthermore, the condition and assumption of each unit must be state and consider clearly.

2.4.2 Exponential Distribution

Exponential distribution is common life distribution for modelling the reliability of system. This distribution is commonly used because of its simplicity to handle in term of algebraic and traceable. It is also represent the functional device life cycle or known as failure rate of engineering items or equipment during their useful life. The exponential distribution is the only probability distribution with constant hazard function [11]. The equation expression of exponential distribution shown in Equation 2.6:

$$R(t) = e^{-\lambda t} \qquad (2.6)$$

2.4.3 Weibull Distribution

Weibull Distribution developed by Waloodi Weibull in the early 1950. This distribution is one of the widely used distribution and very flexible with its positive and negative skewness. Research studies mainly only dealt with two-parameter Weibull distribution because it can fit many situations quite well with wide range of life distribution characteristic [19]. The equation of two perimeter Weibull distribution is:

$$R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}} \quad (2.7)$$

2.4.4 Lognormal Distribution

Lognormal distribution is a two parameter distribution that most likely to be used in determine the maintainability of the equipment or system. The lognormal distribution applies to most maintenance tasks and repair actions comprised of several subsidiary tasks of unequal frequency and time duration. The equation for maintainability for lognormal distribution are expressed in Equation 2.8 and Equation 2.9:

$$M(t) = \int_0^{\infty} t f_r(t)\, dt \quad (2.8)$$

$$M(t) = \frac{1}{\sigma\sqrt{2\pi}} \int_0^{\infty} e^{-\frac{1}{2(lnt-\beta)^2}}\, dt \quad (2.9)$$

Since maintenance tends to follow lognormal distribution, Figure 2.5 shows the skewness of maintainability function that the skews time to repair gravitate to the right. Points 1, 2, and 3 in the Figure 2.5 indicate the mean, median, and maximum corrective time-to-repair, respectively.

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 stochastic variable since every failure event occur at different downtime duration due to different failure modes, component failure, spare parts availability and the competency of the maintenance worker.

2.5 Offshore Facilities

Offshore platform is a huge structure with a lot of facilities which to drill wells in order to extract natural gas and oil from the subsea. The other function of an offshore platform is to temporarily store and process the product before it can be export to the onshore then continue with the refining and marketing. There are many equipment and a system required in the event of the temporary store and process the product. Figure 2.6 shows the general process flow and equipment of an offshore facilities. Main equipment such as separators, pumps, compressors, gas turbine, etc. are very crucial to make sure the overall stages of processing and exporting the product are running smoothly.

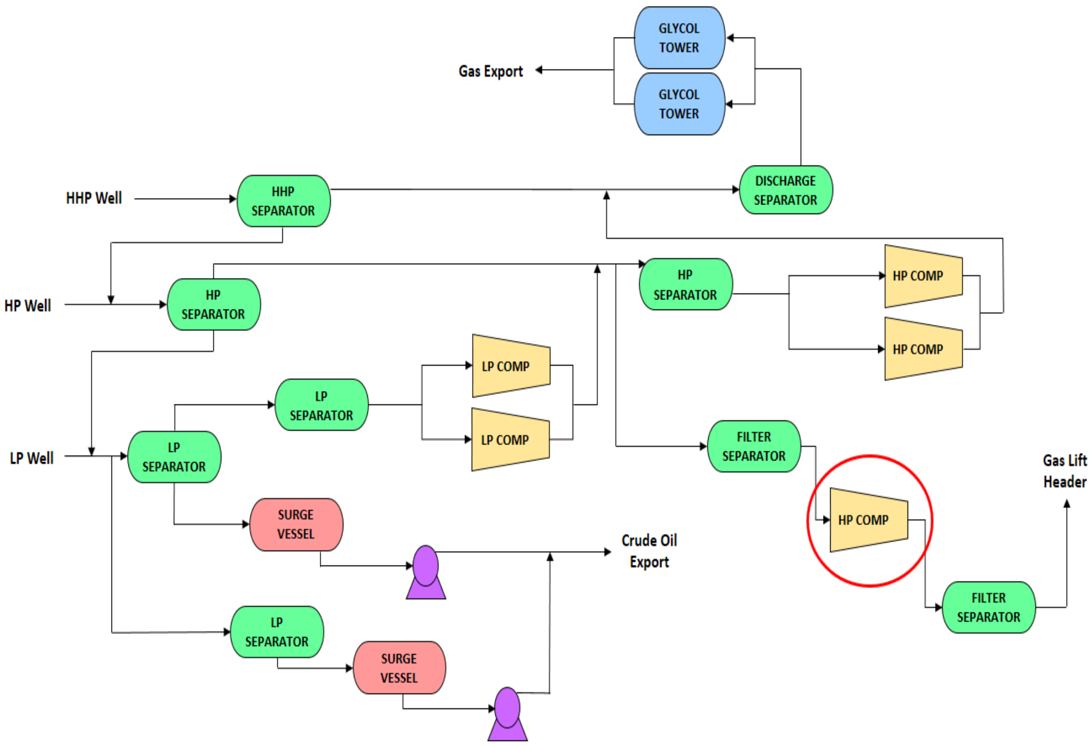


FIGURE 2.5: General process flow diagram of offshore facilities

2.5.1 High Pressure Compressor

In oilfield facilities, there are several of operations state and condition that require the usage of compressor. The most typical and frequent use of the compressor is recompression of the gas before going to the gas pipeline for further process and sale. The gas may have been at the low pressure for some reasons such as: multiple stage separation which may be necessary for proper fluid stabilization or other process requirements [20],[21]. The increment of pressure at the certain level are required to ensure the overall process meet the requirement. High pressure compressor operates after the product going through several of process. This high pressure compressor will increase the pressure of the gas from the process section into the exporting line. Aside from high pressure compressor, there is low pressure compressor which its functionality is to increase the pressure after the product undergo the gathering system and pipeline which lead to the pressure drop.

High pressure compressor is the equipment that are analyse in this RAM study and it is important to determine the boundary of the equipment in order to concentrate on the compressor itself. The high pressure compressor is a centrifugal-type and the equipment boundary of compressor based on OREDA is shown in Figure 2.7.

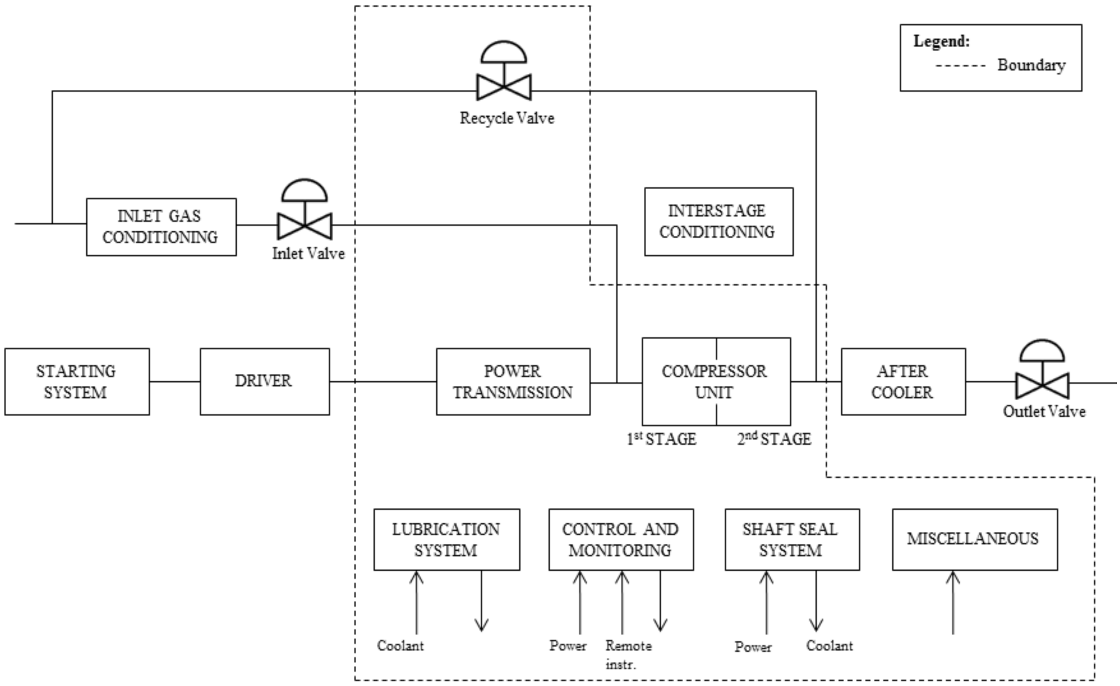


FIGURE 2.6: Boundary of compressor [22]

2.5.1.1 Failure Mode of high pressure compressor

As stated in book 'Compressor Handbook Principle and Practice' by Giampaolo [21], compressor has wide range of failure including mechanical, electrical and performance failure. The efficiency of the compressor reduces due to various reasons. 2% of the compressor efficiency affected by compressor fouling and 3% to 5% are due to reduction in capacity at constant compressor inlet temperature or ambient air temperature. With the continuous operation mode, high pressure compressor exposed to the unexpected failure and maintenance works.

This study is focusing on the failure modes of high pressure compressor. There are many situation that lead to the compressor failure and it's commonly are valve failure, bearing failure, surge damage and wear [20],[21]. Failure modes event demonstrate the failure of some component that impacts the availability of the high pressure compressor. OREDA [22] stated that there are 19 failure modes of compressor in offshore facilities consist of 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.

Through the RAM analysis, the critical failure mode of high pressure compressor is determine based on the failure modes stated by OREDA. Since every failure mode of the high pressure compressor are correlated to its component so it is crucial to identify the component and maintainable item of the compressor. Pursuant to the OREDA handbook, the components or the maintainable items of a compressor are shown in Table 2.4.

TABLE 2.4: Compressor subunit and maintainable items [22]

Subunit	Maintainable Item
Power transmission	Gearbox, Bearing, Seals, Lubrication, Couplings, Instruments
Compressor unit	Antisurge System, Casing, Cylinder Liner, Dummy Piston, Instruments, Shaft Seals, Radial Bearing, Thrust Bearing, Interstage Seals, Internal Piping, Valves, Piston, Packing, Rotor w/ Impellers
Control and monitoring	Instruments, Cabling/Junction Box etc., Control unit, Actuating Device, Monitoring, Internal Power Supply, Valves.

Lubrication system	Check Valves, Reservoir w/ Heating System, Piping, Pump w/ Motor, Filter, Cooler, Valves, Oil, Instruments, Seals
Shaft seal system	Buffer Gas System, Dry Gas Seal, Instruments, Overhead Tank, Reservoir, Scrubber, Pump w/ Motor/Gear, Filter, Valves, Seal Gas, Seal Oil
Miscellaneous	Base Frame, Cooler, Magnetic Bearing Control System, Piping, Purge Air, Silencers, Control/Isolating/Check Valves

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

This project work started through identifying the current problem and determines the objectives. In order to have better understanding on this project, research and related works are carried out using all types of publications such as books, journals and technical papers.

Based on reviewed P&ID and PFD of high pressure compressor at Semarang Platform, the failure modes of the high pressure compressor are identified by using OREDA as a preference. From the P&ID and PFD drawings, RBD model constructed by using failure modes of the high pressure compressor in Reliasoft BlockSim.

The failure and repair data of the high pressure compressor are used to develop reliability and maintainability model respectively. The reliability and maintainability model are generated by using Reliasoft's Weibull++. Based on both model, the RAM model then must be validated and the result must be less than 5% for the model to be accepted. Afterward, the availability of the system is estimate by assessing individual failure modes from the whole RAM model.

From the overall process, critical failure mode of high pressure compressor is identified and sensitivity analysis are conducted. Sensitivity analysis conducted to determine the impact of unlikely factors on the performance of the system by quantifying the alternative changes of the model.

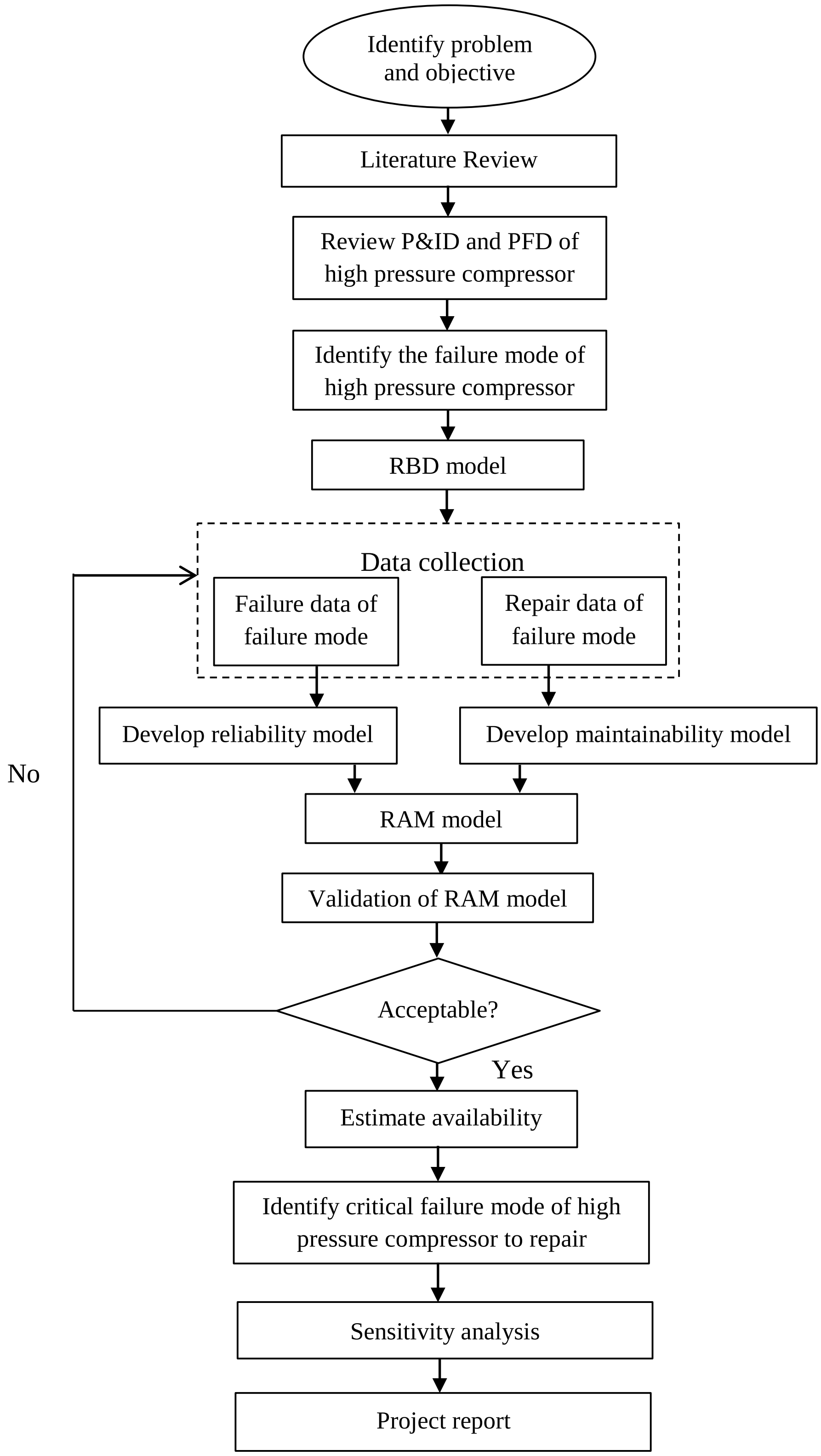


FIGURE 3.1 Flowchart of RAM analysis using RBD approach

3.2 Software/Tools Required

RAM analysis is utilize in order to develop to compute equipment failure, downtime and availability of the high pressure compressor and also to evaluate the high pressure compressor performance through the analysis. The software that will be used in order to achieve the objective of this project as an optimization tool is:

i. ReliaSoft Weibull++
ii. ReliaSoft BlockSim
iii. Microsoft Excel

3.3 Key Milestone

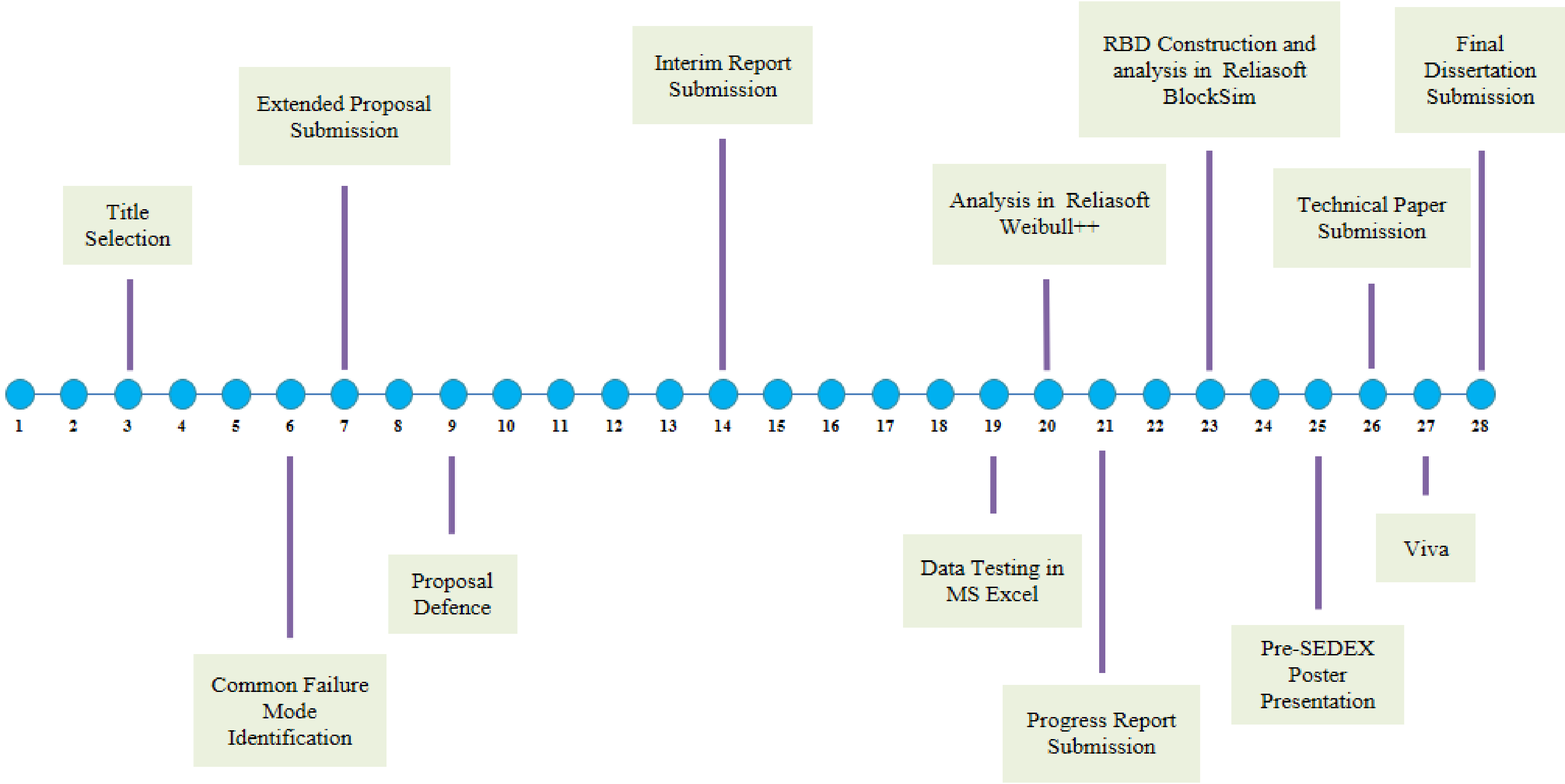


FIGURE 3.2: Key milestone of the project

3.4 Gantt Chart

TABLE 3.1: Gantt chart of RAM analysis using RBD approach

Activity	Week																											
	FYP 1														FYP 2 (Planned)													
	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
Project Title Selection	■	■	▲																									
Preliminary Research			■	■																								
Research on RAM Study			■	■	■	■	■	■	■																			
Research on high pressure compressor and its common failure				■	■	■	■	■	■	■																		
Analysis on common failure mode						■	■	■	■	■	▲																	
Software familiarization			■	■	■	■				■	■	■	■															
Extended Proposal				■	■	■	▲																					
Proposal Defence							■	■	▲																			
Interim Report									■	■	■	■	■	▲														
Data collection															■	■	■	■	■									
Data Testing																			■	■	■	▲						
Data Analysis by Weibull++																				■	■	■	▲					
Design and evaluate RBD by BlockSim																					■	■	■	▲				
Result evaluation and discussion																				■	■	■	■	■	■			
Progress Report															■	■	■	■	■	■	▲							
Pre-SEDEX																						■	■	■	▲			
Technical Report Preparation																							■	■	■	▲		
Viva																									■	■	▲	
Dissertation																									■	■	■	▲

CHAPTER 4

RESULT AND DISCUSSION

4.1 Failure Mode Statistics

Based on the failure and repair data of high pressure compressor from the offshore platform the data will be distributed by its identified failure mode. Table 4.1 shows the identified failure modes of the high pressure compressor. There are 7 failure modes involves in this RAM analysis.

TABLE 4.1 List of failure mode [22]

No.	Failure Mode	Failure Mode Code
1	Emergency Shutdown	ESD
2	External – Fuel	EXT (FUEL)
3	Gas Fuel Control Valve	GFCV
4	Fail to Start on demand	FTS
5	Instrument Protective System	IPS
6	Overheating	OHE
7	Other	OTH

Pertaining to the raw data, Figure 4.1 illustrate the failure mode frequency in order to view point the failures of each failure mode. As shown in Figure 4.1, ESD is the failure mode with the highest number of failure during the observation period of time. The observation period is done during the interval period of time from June 2011 until December 2014. To show the effect of each failure mode to the high pressure compressor, bar chart in Figure 4.2 are constructed.

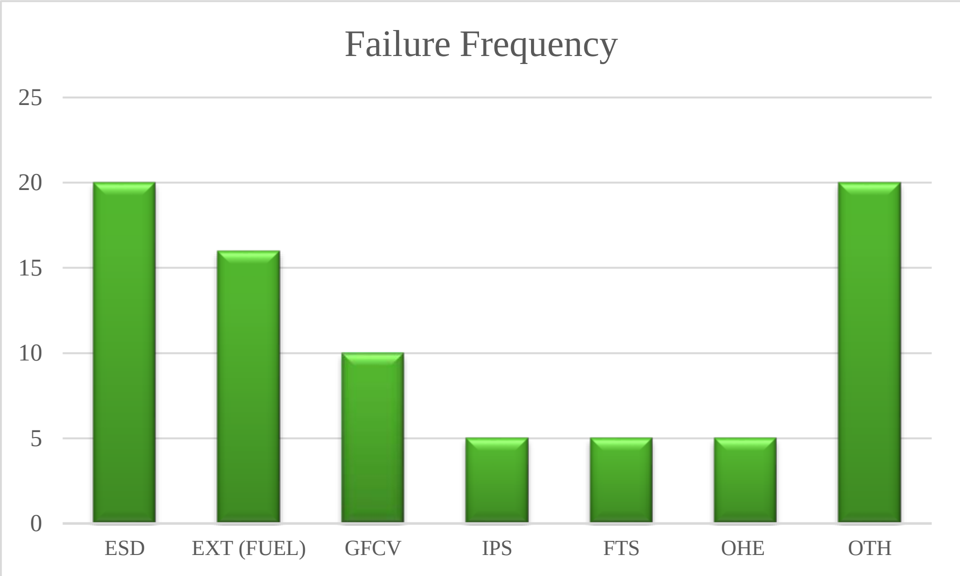


FIGURE 4.1: Failure mode frequency

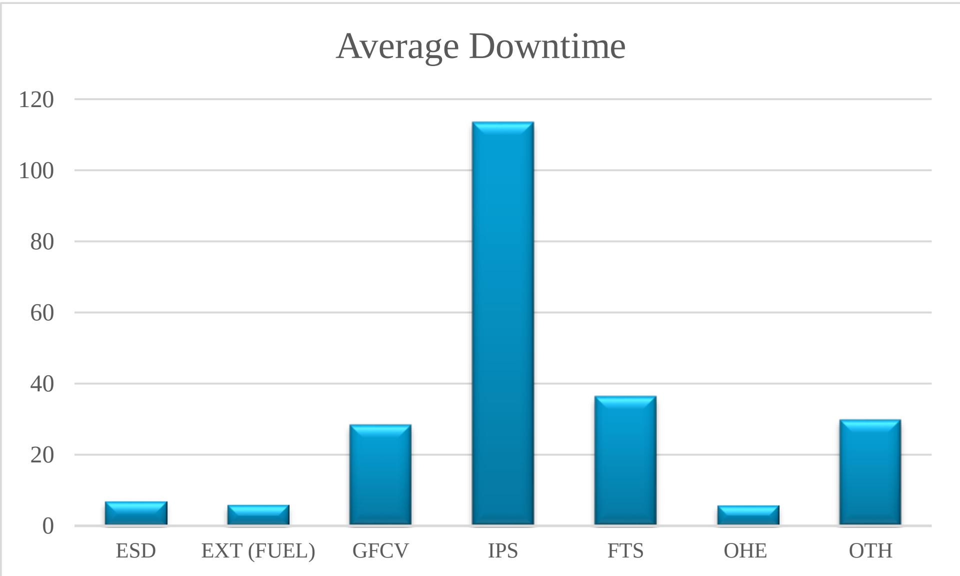


FIGURE 4.2: Average downtime

Since small set of data fits is difficult to fits statistically to any distribution, every failure mode with failures less than five are combined into one fixed failure mode named OTH.

Application of exponential distribution for small sets of data is robust because it only has one parameter. Distribution with two parameters are more likely to become uncertainties when applied to small data set. However, the disadvantage of applying exponential distribution as an assumption is also means that the failures occurrence is purely random and that is also not accurately valid. Since there are only 5% differences when applying exponential distribution to the small data sets with the best fit distribution which is two-parameter Weibull, it is acceptable to apply exponential distribution.

4.2 Data Analysis by ReliaSoft Weibull++

Before analysis in Weibull++ is carried out, trend test has shown no trend present for all of the failure modes. Since the data is free from the trend, it implies an identical distribution data set [19]. Hence, it is accepted to use a minimal repair assumption which indicates every repair action bring the system back to 'as bad as old' condition. It is assumed that the high pressure compressor receives preventive maintenance and all preventive maintenance tasks are assumed to bring the equipment back to 'as bad as old' condition.

OTH is assumed to have constant failure rate and fits exponential distribution. Since the difference of the assumed distribution with the best fit distribution for OTH is less than 5%. Thus it is acceptable to assume that fixed failure mode follow exponential distribution. In the Weibull++ software, the failure modes are analyse individually.

The data analysis is conducted by using Maximum Likelihood Method (MLE) since this study consists of huge data set. Data analysis in Weibull++ detects the distribution that fits the data. Based on the probability distribution prompted, the parameter for each suggested distribution are evaluated to identify the failure stage of the failure mode event as shown in Table 4.2 and Table 4.3.

4.2.1 Time Between Failure (TBF) Data

1-parameter exponential distribution, 2-parameter Weibull distribution and lognormal distribution are used to determine and modelling the failure data. All of the distribution used is suitable in modelling the failures of mechanical equipment and system since it able to cover every aspect of different characteristic of the data set. Table 4.2 listed the best fit distribution for each failure mode based on the time between failure (TBF) data.

TABLE 4.2 Best fit distribution for TBF data

Failure Mode	Distribution	Parameter
ESD	2P Weibull	β = 1.3934 η = 1718.570
EXT (FUEL)	2P Weibull	β = 0.7134 η = 1601.725
GFCV	Lognormal	μ = 7.601 σ = 0.980
IPS	1P Exponential	$\lambda = 1.9406 \times 10^{-4}$
FTS	Lognormal	μ = 8.594 σ = 0.469
OHE	Lognormal	μ = 8.010 σ = 1.256
OTH (assumed)	1P Exponential	$\lambda = 9.862 \times 10^{-5}$
OTH (best fit)	2P Weibull	β = 1.2999 η = 10869.624

4.2.2 Time to Repair (TTR) Data

Lognormal distribution has been used to determine and modelling the repair data of all the failure mode. Lognormal distribution is the best distribution to model repair data [23]. Table 4.3 shows the lognormal distribution for time to repair (TTR) data of each failure mode.

TABLE 4.3 Lognormal distribution for TTR data

Failure Mode	Distribution	Parameter
ESD	Lognormal	μ = 1.690 σ = 0.717
EXT (FUEL)	Lognormal	μ = 1.445 σ = 0.767
GFCV	Lognormal	μ = 2.693 σ = 1.333
IPS	Lognormal	μ = 2.557 σ = 1.982
FTS	Lognormal	μ = 3.392 σ = 0.836
OHE	Lognormal	μ = 1.670 σ = 0.451
OTH	Lognormal	μ = 1.968 σ = 1.448

4.3 ReliaSoft BlockSim Analysis of RBD

All the parameter determined in the Weibull++ then used in BlockSim. BlockSim used to emphasize the connection of the individual failure mode with each other by RBD [13]. The availability of the high pressure compressor can be evaluated in BlockSim. Based on the reliability and maintainability, availability of the high pressure compressor will be visualizing from the simulation of RBD of the system. In this 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 high pressure compressor system. The developed RAM model are validated with the actual data and it shows only 4% of difference. Thus, the allowable error for this RAM analysis is 4%.

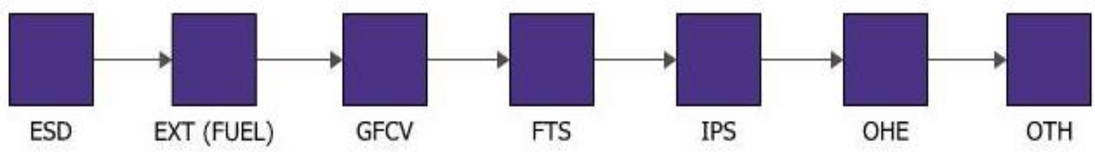


FIGURE 4.3: RBD for failure mode of high pressure compressor

Conducting a simulation for RAM analysis is need to be as accurate as possible. The number of simulations conducted must be adequate since the confidence of the simulation accuracy depends on the number of simulations. The simulation details listed in Table 4.4.

TABLE 4.4 Simulation details

Simulation detail	Parameter	Remarks
Simulation period	5 years (2015-2020)	Time perspective
No. of simulations	10 000	Simulation confidence
Failure distributions	See Table 4.2	Historical failure data
Repair distributions	See Table 4.3	Historical repair data
Corrective Maintenance (CM) task	When item fails	Continuing production
RAM model (allowable error)	4%	RAM model validation

The main results from the simulation are listed in Table 4.5. After 5 years of simulation, the mean availability of the high pressure compressor is 93.4%. Additionally, the expected number of failures for the next 5 years is 127 failures. The number of expected failures lead to the corrective maintenance downtime of 2899.279 hours. The availability of high pressure compressor drops during every maintenance works. It is dictate that every maintenance works brings the system to as bad as old condition.

TABLE 4.5 Simulation results

Performance measures	Result
Mean availability	0.934
System uptime (Hr)	40900.721
System downtime (Hr)	2899.279
Expected number of failures	127

RBD simulation in BlockSim able to identify the criticality of each failure mode. The criticality of each failure mode is determine by two factors: failure and downtime. From the analysis, it shows that ESD failure mode is the most critical failure mode while IPS is the most critical downtime of failure mode for high pressure compressor.

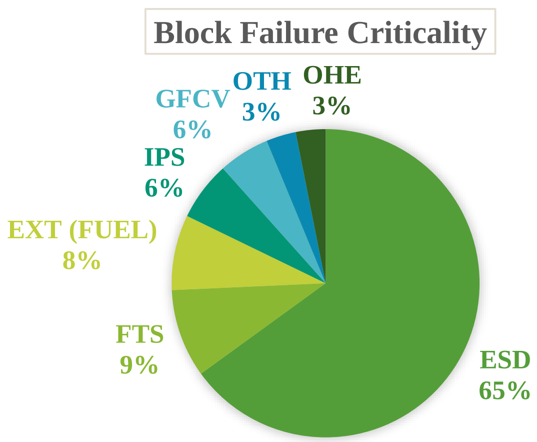


FIGURE 4.4: Failure mode failure criticality ranking

Figure 4.4 display the failure criticality ranking of the failure mode. ESD is the most critical failure mode with 65% followed by FTS (9%), EXT (FUEL) (8%), then IPS and GFCV with both of 6% criticality. The two least critical failure mode is OHE and OTH with only 3% each.

The second factor that determine the criticality and availability of the high pressure compressor is downtime of each failure mode. The most critical downtime is IPS with 49% followed by ESD (20%) and FTS (17%).

Even though the failure occurrence of IPS failure mode is quite low, but it leads to the highest downtime. Highest downtime of the IPS might be due to unavailability of the spare part and manpower that lead to the longer downtime of the high pressure compressor. The downtime of ESD failure mode is slightly unconventional since it only lead to 20% of the total downtime of the high pressure compressor. This situation might be because of the availability of spare part and manpower. The ESD repair also probably are not complex even though the failure occurrence is high. Failure mode with least downtime criticality is GFCV (8%), OTH (3%), EXT (Fuel) (2%) and OHE (1%).

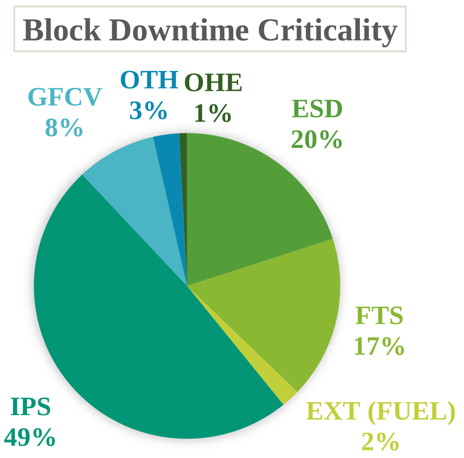


FIGURE 4.5: Failure mode downtime criticality ranking

The failure and downtime criticality of each failure mode affect its availability. Based on Figure 4.6, the result of the analysis indicate that IPS has the least availability while OHE has the most availability among all the identified failure mode. The least availability of the IPS is due to its highest downtime which is 49% criticality of the whole system.

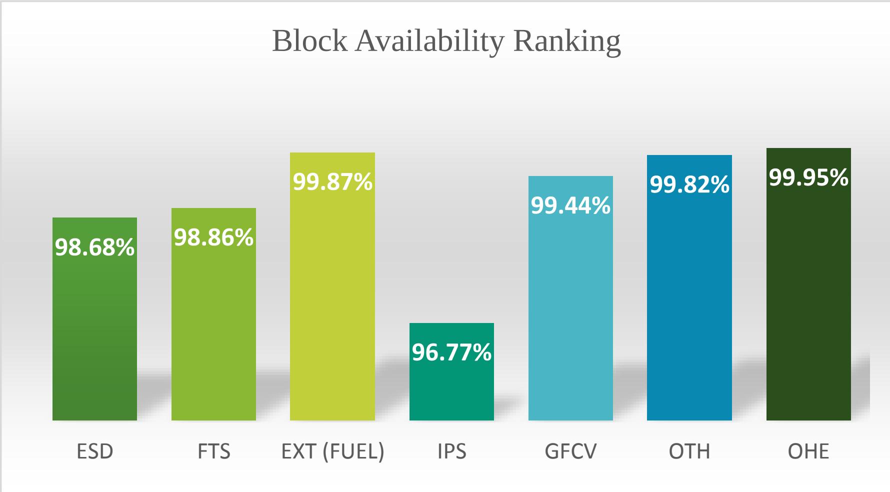


FIGURE 4.6: Failure mode availability ranking

4.4 Sensitivity Analysis

From the overall process, critical failure mode of high pressure compressor is identified and sensitivity analysis are conducted. Sensitivity analysis conducted to determine the impact of unlikely factors on the performance of the system by quantifying the alternative changes of the model. There are three cases conducted for the sensitivity analysis.

TABLE 4.6 Sensitivity analysis cases

Case 1	Assume ESD solved
Case 2	50% reduction of IPS downtime
Case 3	Exclude the external failure mode (GFCV & IPS)

Sensitivity analysis are conducted as per arrangement shown in Figure 4.3. Case 1 and 2 indicate that mean availability increment of high pressure compressor by approximately 2%. Meanwhile for case 3: exclusion of external failure mode which is IPS and GFCV, the mean availability of high pressure compressor shows an increment by 4%.

TABLE 4.7 Sensitivity analysis result

Performance measures	Parameter		
	Sensitivity case 1	Sensitivity case 2	Sensitivity case 3
Mean availability	0.9456	0.9486	0.9698

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Different research and studies have shown that RAM analysis helps in decreasing the maintenance cost by improving the equipment's availability, performance and its maintenance effectiveness. Remarkably this research is to study the failure and repair data of the high pressure compressor failure in order to develop the model of the system failure, down time and estimate availability of the high pressure compressor. The prospect of this study is identifying the critical equipment critical failure of high pressure compressor in order to improve maintenance and spare part strategy to increase the availability.

By conducting RAM analysis and related modelling, overall failure mode of the high pressure compressor is covered and it helps in identifying that can increase equipment productivity in term of reliability, availability and maintainability. The failure, repair and cost data are used in order to achieved the objectives. The modelling and the result of the analysis can easily tackle the compressor performance and come out with better maintenance strategy. The analysis also may save the cost of the company by prepare the amount of spare part for the next failure. Production loss due to a longer failure can be reduced automatically by the indication of time between the failures.

Based on this RAM analysis using RBD approach, the overall system availability for the next 5 years is 93.4% if the system running as per the current configuration. The performance of high pressure compressor can be increased by focusing on the identified highest critical failure mode which is ESD. It is predicted that the expected number of failure for the next 5 years is 127 failures. The analysis also can assist maintenance team in preparing the spare part for the most critical downtime of failure mode which is IPS for the next failure. The production loss due to a longer failure and repair can be reduce by tackle the most critical failure and downtime of the high pressure compressor.

Provided from the analysis, the improvement of the system can be achieved by identify and focus on the component level that lead to the most critical failure modes. The mitigation action can be taken by the facilities is performing the root cause failure analysis (RCFA) for the most critical failure mode: ESD and IPS. RCFA helps in determine the cause of the particular failure. The RCFA can be conducted by component level of the critical failure mode.

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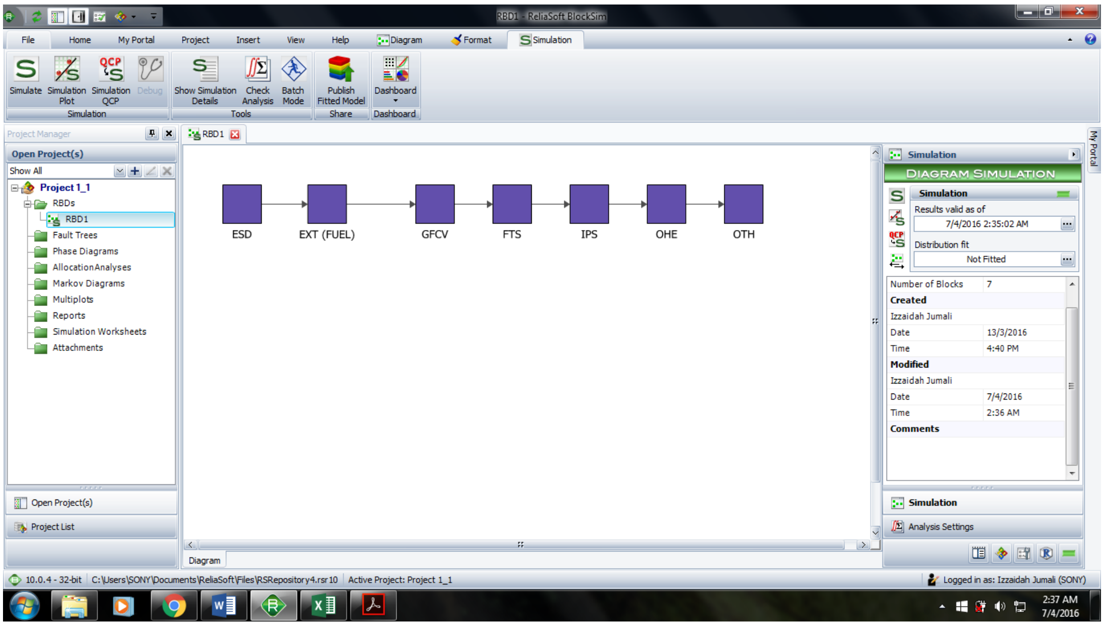
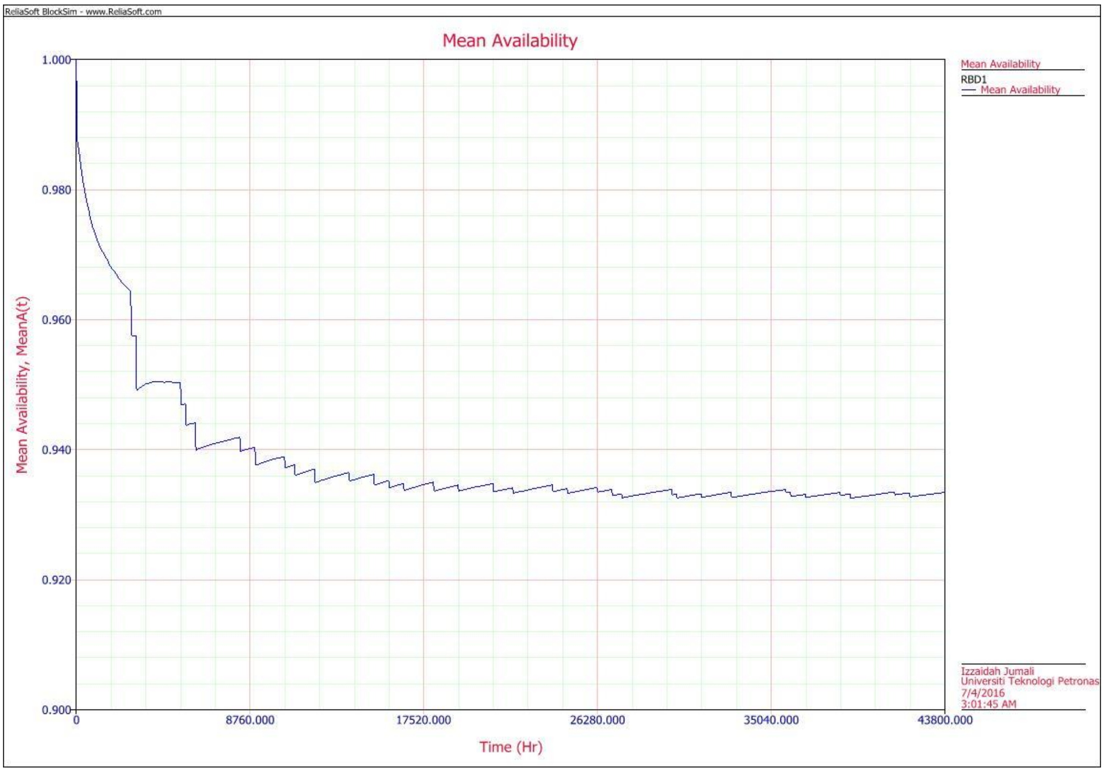
APPENDICES

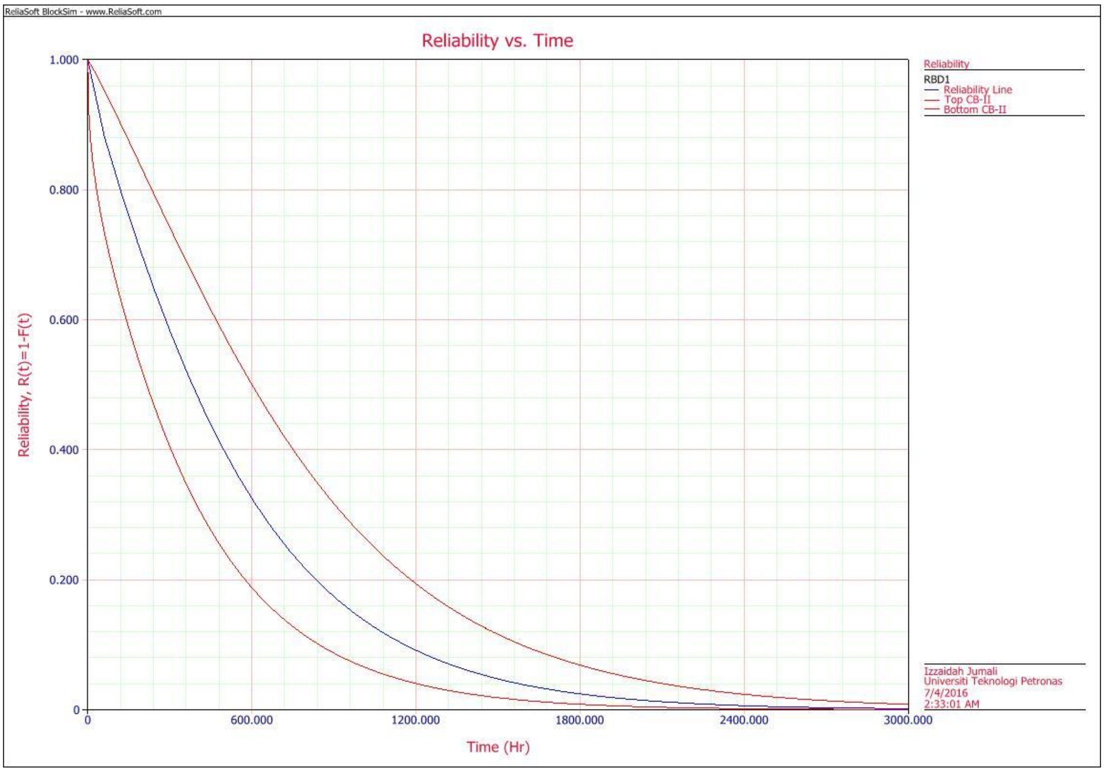
Appendix 1: Simulation of RBD in BlockSim



Appendix 2: Availability vs Time



Appendix 3: Reliability vs Time



Appendix 4: System Overview Result

System Overview	
General	
Mean Availability (All Events):	0.933806
Std Deviation (Mean Availability):	0.049776
Mean Availability (w/o PM, OC & Inspection):	0.933806
Point Availability (All Events) at 43800:	0.9337
Reliability(43800):	0
Expected Number of Failures:	127.4441
Std Deviation (Number of Failures):	12.805666
MTTFF (Hr):	512.760562
MTBF (Total Time) (Hr):	343.680092
MTBF (Uptime) (Hr):	320.930676
MTBE (Total Time) (Hr):	343.680092
MTBE (Uptime) (Hr):	320.930676
System Uptime/Downtime	
Uptime (Hr):	40900.72111
CM Downtime (Hr):	2899.278888
Inspection Downtime (Hr):	0
PM Downtime (Hr):	0
OC Downtime (Hr):	0
Waiting Downtime (Hr):	0
Total Downtime (Hr):	2899.278888
System Downing Events	
Number of Failures:	127.4441
Number of CMs:	127.4441
Number of Inspections:	0
Number of PMs:	0
Number of OCs:	0
Number of OFF Events by Trigger:	0
Total Events:	127.4441

Appendix 5: Block Criticality Summary

Block Summary										
Block Name	**RS FCI**	**RS DECI**	**RS DTCI**	**Mean Av. (All Events)**	**Mean Av. (w/o PM, OC & Insp.)**	**Expected # of Failures**	**Expected # of OFF Events by Trigger**	**System Downing Events**	**Block Downtime (Hr)**	**Block Uptime (Hr)**
ESD	64.11%	64.11%	19.40%	0.986819	0.986819	82.5473	0	82.5473	577.3059	43222.69
EXT (FUEL)	7.85%	7.85%	1.94%	0.998683	0.998683	10.1043	0	10.1043	57.68676	43742.31
GFCV	5.34%	5.34%	8.28%	0.994371	0.994371	6.8779	0	6.8779	246.5361	43553.46
FTS	9.12%	9.12%	16.59%	0.988727	0.988727	11.7384	0	11.7384	493.7409	43306.26
IPS	6.17%	6.17%	49.16%	0.966599	0.966599	7.9405	0	7.9405	1462.946	42337.05
OHE	3.10%	3.10%	0.79%	0.999462	0.999462	3.9963	0	3.9963	23.56848	43776.43
OTH	4.32%	4.32%	3.84%	0.997391	0.997391	5.5629	0	5.5629	114.2947	43685.71