Abram Dionisius Antory

Optimum Maintenance Strategy Recommendation of Compressor Based on OREDA Failure Rate

Master's thesis in RAMS
Supervisor: Per Schjølberg
June 2023

Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
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Reliability, Availability, Maintainability, and Safety

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Preface

The thesis is titled "Optimum Maintenance Strategy Recommendation of Compressor Based on OREDA Failure Rate" and it is a part of Reliability, Availability, Maintainability, and Safety (RAMS) program at NTNU. This thesis of TPK4950 will fulfil the need of 30 credits and finishing the master's degree.

Sture Angelsen from DNV, who agreed to help supervisor Per Schjølberg, was involved in the early stage of the brainstorming. Hence, he introduced Lars and Peder who are working directly with Yinson on their floating production storage and offloading (FPSO). Yinson then decided to cancel the sharing of their data, which will be explained later on the writing.

The background of this report is how reliability and maintenance engineers calculate the maintenance strategy on design phase, where this is done before the running/production period of a facility. This report will only narrowed to one specific big equipment, electric driven screw compressor, which shortens the time of analysis and calculations due to the mishaps that happened before.

The report will rely heavily on The Offshore and Onshore Reliability Data (OREDA) and several standards such as ISO 14224 and IEC 60812 to name the least. Simple calculations are done using the formula from IEC 60812 regarding equipment's failure rate, criticality, and probability of failure during a certaing maintenance time interval. This will help engineers to decide how would they approach the maintenance strategy further.

Trondheim, 2023-06-11

Abram Dionisius Antory

Acknowledgment

I would like to thank Per Schjølberg as my supervisor for helping and guiding me from project specialisation through master thesis. Without his inputs and connections, I would not be as inspired as I am writing this thesis.

I would like to thank also my previous project team leader Chandra Salim, who is the CEO of PT. Cliste Rekayasa Indonesia (CRI) where I gained experience in reliability related projects before going to Norway. He and I had some discussions regarding my calculation in this writing and he also guided me through the standards of IEC and ISO in this writing.

I would also like to thank Sture Angelsen, for agreeing to help me and colleagues from project specialisation period through thesis, although the end result might not be in favour for us. Thank you for connecting me to Lars Tore Haug and Peder Andreas Vasset and your effort to put me in connection with Yinson for data sharing. Despite not the result we wanted, I thank you and DNV so much for the effort of helping graduating students.

A.D.A.

Executive Summary

In the oil and gas company, usually there will be preventive maintenance activities that rely on the interval time like daily, weekly, monthly, etc. This makes the writer wonder on how do they decide on that. How do they see the criticality and the probability of the equipment so that they will have their own maintenance interval?

From the datasheet that is available to be accessed, the writer decide to narrow down the equipment to electric driven screw compressor. This steps are usually done in the design phase of a project where the equipment is not yet running. This uses many historical data that are given on books and documentations. There are also some international standards that give the procedure and the equation how to calculate the needed probability of failure for this analysis.

The calculation resolves around the failure rate given from historical data and also the *alpha* and *beta* values for each failure mode that is related to the equipment where each equipment can have more than one failure modes. Then, each failure mode has maintainable items that needed to be taken care of. This will allow the user/company/engineer to decide what maintainable item should have a certain maintenance interval.

Many maintainable items are listed on the result later, but one of the more important result of this writing is that the pressure and temperature instrument are really probable in terms of probability of failure. They needed to be maintained daily to remain at *remote* probability of failure category.

Some of the results would be to proceed with the calculated maintenance strategy, and to focus to only one or two sample, *control unit* and *pressure and temperature instrument* are chosen, due to the several failure modes that control unit has and also the significant probability of failure that pressure and temperature instrument have. The decision would be decided by looking at the probability of failures table in which the failure probability with colour to the red is likely to be frequent.

Contents

Preface i
Acknowledgment ii
Executive Summary iii

1 Introduction **2**
1.1 Background 2
1.2 Objectives 3
1.3 Research Questions 3
1.4 Approach 4
1.5 Contributions 4
1.6 Limitations 5
1.7 What It Could Have Been 5
1.8 Outline 5

2 Maintenance in Oil and Gas Industry **9**
2.1 Preventive Maintenance 10
2.2 Corrective Maintenance 11
2.3 Maintenance Process Based on EN 17007 11
2.3.1 Required Function 13
2.4 Maintenance Policies 13
2.5 Phases of Oil and Gas Cycle 14
2.5.1 Types of Oil and Gas Facilities 15
2.6 Maintenance Trends 16
2.7 Value of Maintenance 16
2.7.1 Sample of Incidents Due to Maintenance Issue 17

3 Compressor for Air Instrumentation and Utility **19**
3.1 Screw Compressor 20
3.1.1 Oil-Lubricated Screw Compressor 21
3.1.2 Oil-Free Screw Compressor 21

4 OREDA **23**
4.1 OREDA Data . . . 23
4.2 OREDA Hierarchy . . . 24
4.3 Problems in OREDA Data . . . 26

5 Equipment Taxonomy **29**
5.1 ISO 14224 . . . 29
5.2 OREDA Taxonomy . . . 31

6 IEC 60812 **33**
6.1 Failure Mode and Effect Analysis (FMEA) . . . 33
6.1.1 System Structure . . . 33
6.1.2 Failure Mode Determination . . . 36
6.1.3 Failure Cause . . . 37
6.1.4 Failure Effects . . . 37
6.2 Failure Mode, Effects, and Criticality Analysis (FMECA) . . . 39
6.2.1 Failure Rate and Criticality Number . . . 40
6.2.2 Criticality Matrix . . . 41
6.2.3 Risk Acceptability . . . 42
6.2.4 Alternate Severity List . . . 43
6.2.5 Alternate Occurrence List . . . 44
6.2.6 Alternate Detection List . . . 44
6.2.7 Evaluating RPN Number . . . 46

7 Data Quality **47**
7.1 Problems in Data Quality . . . 48
7.1.1 Data Multiplication . . . 48
7.1.2 Manual Transfer and Manual Input . . . 48
7.1.3 Missing or Difficult Performance Indicators . . . 48
7.1.4 Poor Internal Data Movement . . . 49
7.1.5 Recycling of Knowledge . . . 49
7.2 Dealing with Data Quality Problems . . . 49

8 Methodology and Result **51**
8.1 Equipment Data Sheet . . . 51
8.1.1 Compressor Assumptions . . . 55
8.2 MTBF, Alpha, and Beta Calculation . . . 55
8.2.1 MTBF . . . 55
8.2.2 Alpha . . . 57

8.2.3 Beta 57
8.3 Failure Rate and Criticality 58
8.3.1 Failure Rate of Failure Modes 58
8.3.2 Criticality with Time Interval 58
8.4 Probability of Failure 60
8.4.1 Categorising PoF 61
8.5 Criticality and PoF of Actual Failure Rate 64
8.6 Result 64

9 Discussion **66**
9.1 Result Summary 66
9.2 Discussion 66
9.2.1 Pre-Analysis Parameters 67
9.2.2 Post-Analysis Discussion 68

10 Conclusion **71**

A Acronyms **73**

B Mail and Discussions with DNV (Confidential) **76**

C Data Sheet of Screw Compressor **77**

D OREDA Data of Electric Driven Screw Compressor **78**

E Criticality and Probability of Failures of Failure Modes **79**

F Probability of Failures of Maintainable Items **80**

G Maintainable Items Probability of Failures **81**

H Presentation for Quality Norway Smart Verdibasert Vedlikehold – Moderne Vedlikehold **82**

Bibliography **83**

Chapter 1

Introduction

1.1 Background

Maintenance has been around the since the birth of industrialisation. Two of the biggest industries are manufacturing and energy industries. There industries keep people live their lives in a way that they are supposed to live, a fulfilled life. To keep these industries running, preferably 24/7, processes are done to keep the manufacturing line or an energy platform goes continuously and produce what people in general need. One of the process is maintenance where companies maintain their equipment to be able to withstand the test of time and deliver to the people almost a hundred percent.

Maintenance process will vary to just lubricating a fan to overhauling engine of a turbine. Hence, a lot of things come along with maintenance to do it properly. A lot of data has been collected to make the running of an industry smoothly and without severe failures and death, especially in industry like oil and gas, which needs to be as little as possible to failure and accident. That is why this industry, alongside aviation, somewhat leads the world in the maintenance and reliability.

Doing maintenance in oil and gas industry has come a long way, but the basic one is to do Preventive Maintenance (PM), in which there is a time-based interval for an equipment to be checked, inspected, or even overhauled. This leads to the problem on how do personnel actually calculate this time interval for PM.

Problem Formulation

Norway has a renowned database that was first published in 1981 and continuously being updated. It is called The Offshore and Onshore Reliability Data (OREDA). OREDA has been the data oil and gas reliability engineer look up to, usually in design phases where it is impossible to gather real data.

Around this phase, maintenance engineer will also take a lot of OREDA data to calculate and formulate the proposed maintenance program as soon as equipment are ran. Although company's reliability and maintenance engineer has their calculations, Original Equipment Manufacturer (OEM) will also have their proposed maintenance program based on their respective data.

This writing will try to show to students, who have not get much real life project exposure, extract data from OREDA to be calculated to a maintenance strategies based on the Probability of Failure (PoF). Hence, to make it one-equipment-only analysis, this writing would narrowed down and focus to screw-type compressor with electrically driven motor.

1.2 Objectives

The main objectives of this Master's thesis are

1. To show basic maintenance strategy calculation using OREDA data such as Failure Rate and Failure Probability,

2. To use Criticality and Probability of Failures to decide how the maintenance strategy is decided,

3. To publish some of this steps and calculations as a learning tool for future students or companies,

4. Previous objective of the writing is to compare company's maintenance data to the calculated recommended maintenance strategy, but due to some problems that will be explained later in this chapter, this objective is not applicable now.

1.3 Research Questions

This thesis report will gladly answer some questions as the problem formulation stated, which are mostly in the field of energy or oil and gas companies. Those questions are:

1. How would the OREDA data be used to formulate maintenance strategy?

2. How does the number in OREDA data affect the criticality and probabiliy of failure (PoF) of a certain failure mode?

3. How to decide on the maintenance interval from the result of probability of failure?

1.4 Approach

The writer will take data from the OREDA, but a lot of information that can be gathered from there. With the narrowed down topic to screw-type compressor, the writer will start to gather the failure data and repair time of the specific equipment. Then, using recommendations and equations from ISO (2016) and International Electrotechnical Commission (2006), calculation and categorisation can be made. This means the equipment would be analysed for its *criticality* and *probability of failures*.

Criticality can be calculated by using OREDA (2002) data of failure rate for each failure mode. This requires alpha and beta values. Alpha values can be calculated directly from OREDA, and the beta values can a bit subjective due to the severity of failure mode to the equipment. Then *Probability of Failure* would be the continuation of the criticality, hence we would have probability of failures for all failure modes that are applicable to that specific equipment. All of them are explained on Chapter 3 later on.

The last objective point above mentioned the comparison of company's maintenance data and this recommended maintenance strategy. For the first three month of thesis writing (January - April, 2023), the writer had been in contact with DNV to communicate the possibility of acquiring actual maintenance data from one of their clients. Then, comparison should have been made from the recommended maintenance strategy to the actual strategy the company does.

1.5 Contributions

This topic will be useful in helping the design phase of oil and gas project and can be the foundation of the early preventive maintenance data that will be shown to the management. Using *criticality* and *probability of failures*, engineers can know the step by step procedure of calculating and deciding maintenance strategy, especially preventive maintenance where it is done in design phase (pre-production).

This writing will also hopefully give people who are starting to get into the world of reliability and maintenance, in which the preventive maintenance is the one thing they should know about. A lot of maintenance strategy are already be in the Computerised Maintenance Management System (CMMS) and new personnel might not even bother to know where is this interval coming from. Hence, it is somewhat important to know how the time interval for each maintenance strategy came from as a foundation for good operational phase.

In Appendix H, there will be presentation of very direct version of this writing that was presented on June 8th, 2023 in *Quality Norway Smart Verdibasert Vedlikehold - Moderne Vedlikehold*. The presentation was done under the request from Per Schjølberg.

1.6 Limitations

Several limitations for writing this thesis are:

- Big oil and gas or energy companies have really complex facilities and to specify the topic and methods, only one equipment will be analysed.
- Failure descriptor versus failure mode in OREDA can be quite confusing and might not be useful to the analysis.
- On March and April, DNV sent emails telling that the client declined the possibility of giving their data. This left the writer with no comparison to actual data and to just make a calculation of an equipment which is available in published article or books.
- This kind of topic usually is submitted as project documents inside companies and usually are confidential. Hence, the reference and literature for this writing are somehow limited and standards by OREDA, ISO, and IEC are paid, hence the only standards used in this writing are the free and might be older version of them.

1.7 What It Could Have Been

Supervised by Per Schjølberg and using his vast connections, DNV would want to help in acquiring company data for comparison. Having a quite intense contact in the months of January and February, they decided to help on acquiring maintenance data from Yinson. These mails can be seen in Appendix A. First conversations were done with Sture Angelsen who helped immensely in brainstorming ideas for the previous project specialisation and the current thesis. He then introduced Lars Tore Haug and Peder Andreas Vasset who are in the maintenance area and have connection to the actual data of the client. It was them who tried what they could to convince Yinson in giving data of their maintenance history.

On March 9, 2023, Lars sent an email that tells cancellation of Yinson permitting students to have their maintenance historical data. Thus, this writing would not have any comparison to the actual data from the field.

The writer would personally thank Lars and Peder for their help and immense effort to connecting Yinson, also to Sture who helped with the connecting people inside DNV. Without these chain of events, this writing would not be here in the first place.

1.8 Outline

An overview of this thesis report can be seen as list below:

- Preface
- Acknowledgments
- Executive Summary
- Chapter 1. Introduction
- Chapter 2. Maintenance in Oil and Gas Industry
  - 2.1 Preventive Maintenance
  - 2.2 Corrective Maintenance
  - 2.3 Maintenance Process Based on EN 17007
    - 2.3.1 Required Function
  - 2.4 Maintenance Policies
  - 2.5 Maintenance Trends
  - 2.6 Value of Maintenance
- Chapter 3. Compressor for Air Instrumentation and Utility
  - 3.1 Screw Compressor
    - 3.1.1 Oil-Lubricated Screw Compressor
    - 3.1.2 Oil-Free Screw Compressor
- Chapter 4. OREDA
  - 4.1 OREDA Data
  - 4.2 OREDA Hierarchy
  - 4.3 Problems in OREDA Data
- Chapter 5. Equipment Taxonomy
  - 5.1 ISO 14224
  - 5.2 OREDA Taxonomy
- Chapter 6. IEC 60812
  - 6.1 Failure Mode and Effect Analysis (FMEA)
    - 6.1.1 System Structure
    - 6.1.2 Failure Mode Determination

    * 6.1.3 Failure Cause
    * 6.1.4 Failure Effects
  - 6.2 Failure Mode, Effects, and Criticality Analysis (FMECA)
    * 6.2.1 Failure Rate and Criticality Number
    * 6.2.2 Criticality Matrix
    * 6.2.3 Risk Acceptability
    * 6.2.4 Alternate Severity List
    * 6.2.5 Alternate Occurrence List
    * 6.2.6 Alternate Detection List
    * 6.2.7 Evaluating RPN Number
- Chapter 7. Data Quality
  - 7.1 Problems in Data Quality
    * 7.1.1 Data Multiplication
    * 7.1.2 Manual Transfer and Manual Input
    * 7.1.3 Missing or Difficult Performance Indicators
    * 7.1.4 Poor Internal Data Movement
    * 7.1.5 Recycling of Knowledge
  - 7.2 Dealing with Data Quality Problems
- Chapter 8. Methodology and Result
  - 8.1 Equipment Data Sheet
    * **8.1.1 Compressor Assumptions**
  - 8.2 MTBF, Alpha, and Beta Calculation
    * 8.2.1 Mean Time Between Failures (MTBF)
    * 8.2.2 Alpha
    * 8.2.3 Beta
  - 8.3 Failure Rate and Criticality
    * 8.3.1 Failure Rate of Failure Modes
    * **8.3.2 Criticality with Time Interval**
  - 8.4 Probability of Failure
    * **8.4.1 Categorising PoF**

  - 8.5 Result

- Chapter 9. Discussion
  - 9.1 Result Summary
  - 9.2 Discussion
    * 9.2.1 Pre-Analysis Parameters
    * 9.2.2 Post-Analysis Discussion
- Chapter 10. Conclusions
- Appendix A (Acronyms)
- Appendix B (Mails and Communications with DNV)
  - Things to do and meeting requests
  - Cancellation of data permission
  - Supervisors' communications
- Appendix C (Data Sheet of Screw Compressor)
- Appendix D (OREDA Data of Electric Driven Screw Compressor)
- Appendix E (Criticality and Probability of Failures for Failure Modes)
- Appendix F (Probability of Failures for Maintainable Items)
- Appendix G (Maintainable Items Probability of Failures)
- Appendix H (Presentation for Quality Norway Smart Verdibasert Vedlikehold – Moderne Vedlikehold)
- Bibliography

Chapter 2

Maintenance in Oil and Gas Industry

Although it has been done billions of time since the birth of the industry itself, maintenance is somehow never perfected. Companies are always trying to find a way to somehow minimise financial outcomes and maximise their returns. This includes the risks of the workers doing the maintenance as people want to minimise their risks exposed to danger and maximise their work efficiency.

International Electrotechnical Commission (2004) explained phases that usually goes onto maintenance. They are:

1. Management process: developing and policing the maintenance, provide funding for maintenance, and also supervising maintenance.

2. Support planning: defining the maintenance, identification of the task, analysing the maintenance task, and resourcing maintenance support.

3. Preparation: plan specific maintenance task, scheduling task, and obtaining and assigning resources.

4. Execution: performance of maintenance, results to be recorded, and perform special safety and environmental procedures.

5. Assessment: maintenance measurement and analysis of the result, probably a report of actions to be taken.

6. Improvement: improving maintenance concept, improving resources, improving procedures, etc. based on maintenance assessment.

There are two major type of maintenance that have been done. These will be listed and explained in this section.

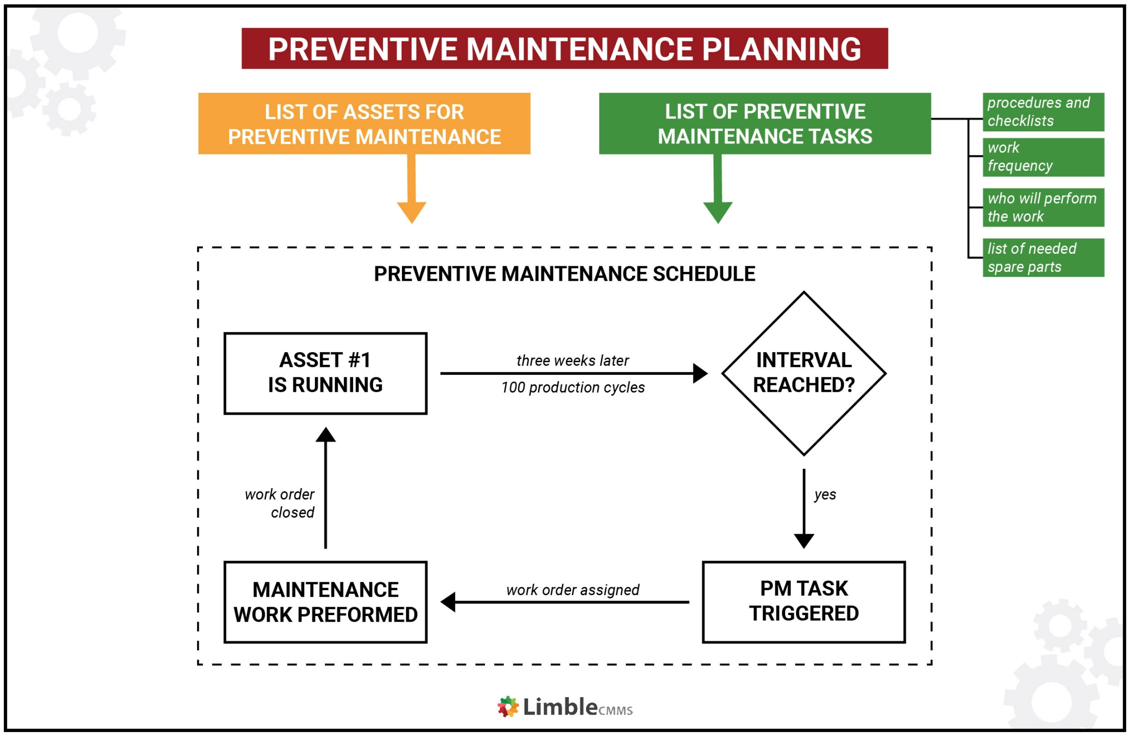

Figure 2.1: Typical Preventive Maintenance Strategy (Limble CMMS (2023))

2.1 Preventive Maintenance

According to its name, Preventive Maintenance (PM) is a method of maintenance where companies want to prevent accidents or catastrophic. This usually is done in a timely or in cycle manner and the maintenance package detail might be different each maintenance.

For example, a cooling fan of an air conditioning unit will have a daily inspection, monthly PM, and yearly PM (UpKeep (2023)). On the daily inspection, worker will only lubricate and inspect visual things. On monthly PM, they will do check and clean pulleys, blade, and filters. Other than that, alignments and tension of belts might needed to be checked. Then on the yearly PM, they will clean the most detailed components inside as well as major repair if it is found a faulty components such as cabling, coils, or insulation.

Calendars for preventive maintenance is most of the time given by the OEM of the equipment, but it is possible for user companies to formulate their own calendar interval. Some equipment that has cycle interval will be maintained when that specific cycle has passed, for example a pump will be overhauled after a thousand of production cycles.

From Figure 2.1, it is shown that PM is always generated by a Computerised Maintenance Management System (CMMS) and the details of the PM will be stored inside the respective tasks. These details include procedures, frequency, workforce, and list of consumables or spare parts needed. To be able to do that, CMMS will be connected to the list of equipment on the field and when the calendar interval is reached, the CMMS will send a job alert to the maintenance operator.

2.2 Corrective Maintenance

Corrective Maintenance (CM), different from PM, will be done after a failed equipment happen and usually will be done only if the failed equipment affect the overall production or function of the system or plant.

There are actually two type of CM. They are:

- Planned CM
- Unplanned CM

Planned CM is a bit confusing in term of the language use, but it is a common strategy to use especially for a smaller equipment that has a less significant safety measure. This is usually known as Run-To-Failure where the equipment is planned to be used until they fail and then workers will replace those equipment with the new one.

Figure 2.2 shows the unplanned CM, which on the other hand, is the one that most of people talk about, because it is scary in terms of economy, safety, and time. This usually happens in more significant equipment and it will usually affect the production cycle. To minimise the loss, to run it back quickly is crucial. Most companies have a redundancy on their significant equipment so that when one fails, there will be another identical or similar equipment to do its job. By this time, corrective maintenance will be done to the failed equipment.

2.3 Maintenance Process Based on EN 17007

From Johnsgaard (2021), maintenance process needs key activities that are related it. They include policies, strategies, developing actions, budgets, communication, and defining area for improvement. These can be seen in Figure 2.3 based on the EN17007:2017 standard.

The first important thing to initiate maintenance process is to determine the primary cause and effect so that the activity of the maintenance can be suited directly to the cause and effect of the failure. Then Europäische Norm (2010) would say that "collect, analyse, store and transmit all data needed to document and improve the maintenance process". This will be related to storing the data and evaluating reliability of the items.

Blue things on Figure 2.3 denote the external factor such as human resources, documentation, spare parts, infrastructure, etc. This will affect the process of maintenance and the overall result of it.

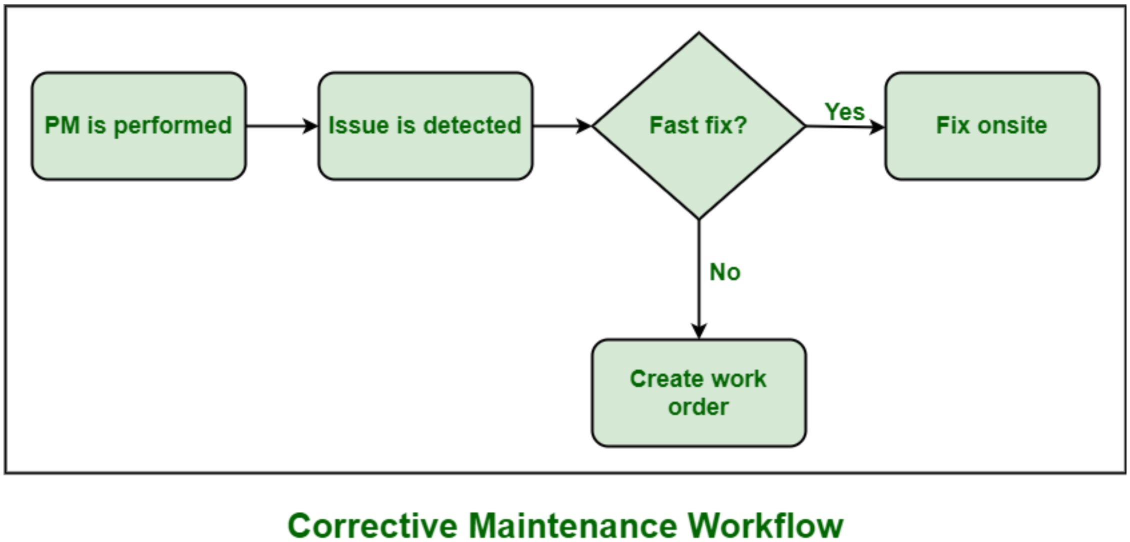

Figure 2.2: Typical Corrective Maintenance Flow (Adapted from Europäische Norm (2010))

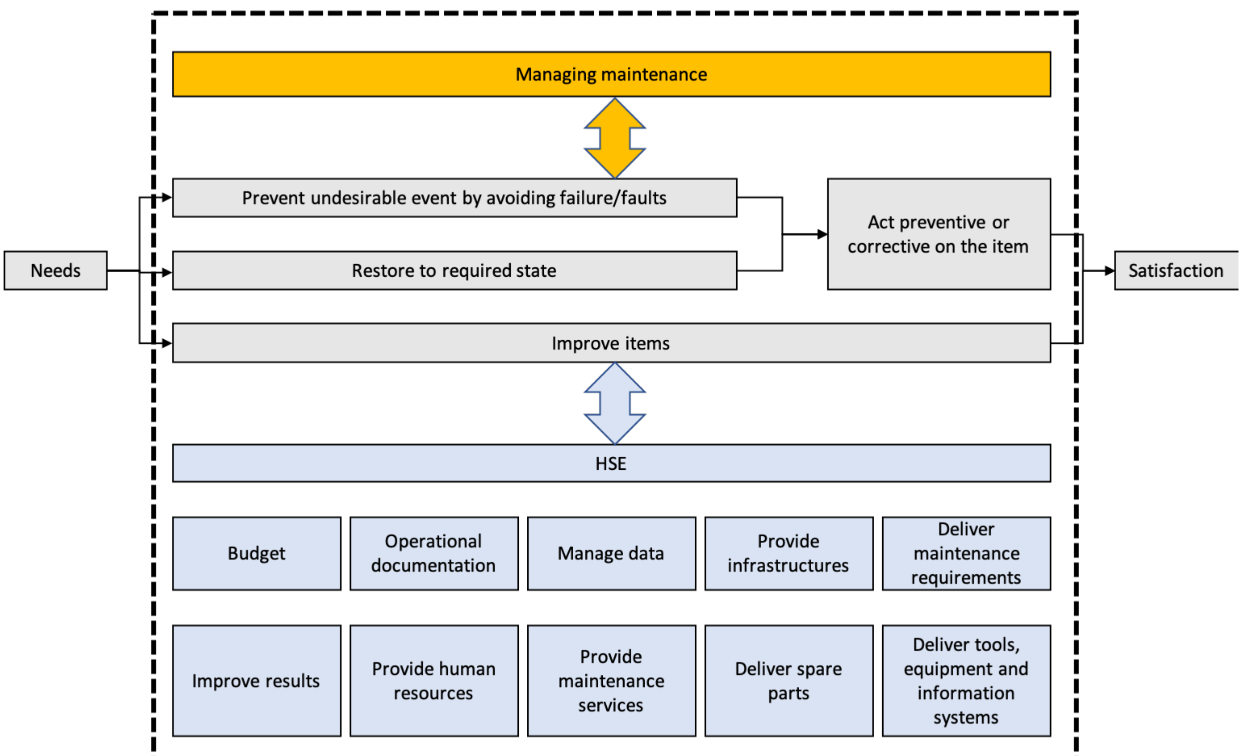

Figure 2.3: Maintenance Process (Adapted from European Committee for Standardization (2016))

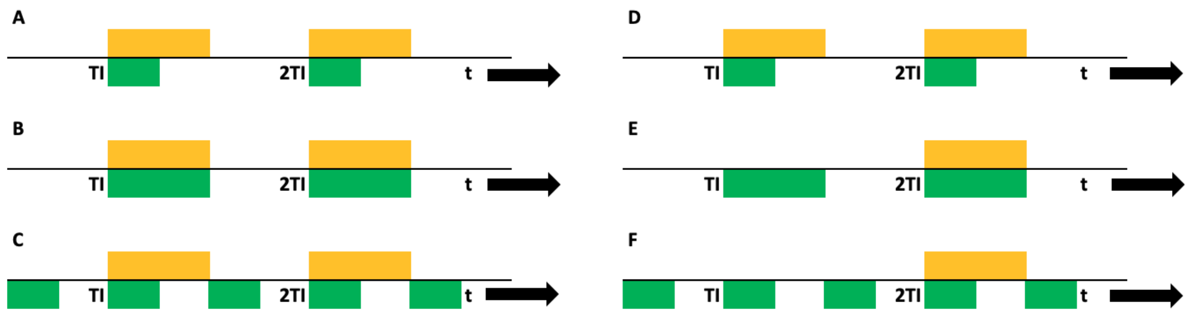

Figure 2.4: A and D are Parallel Testing, B and E are Sequential Testing, and C and F are Staggered Testing (Adapted from Redutskiy et al. (2021))

2.3.1 Required Function

The main function of maintenance is to restore an equipment or a system from failure to go back to their intended required function. Required function may have one or several functions that is necessary of an equipment or a system operate at a given phase. Failure itself means the inability of the equipment or system to do their required function. This means that it cannot do at least one of the function required at that phase.

Hierarchy in the upcoming section will make it easier for engineers to set the required function for designated equipment or system as they will know not only the items before and after, but also below and above the specified equipment (as it may be a quite small maintainable item under a big equipment or system).

2.4 Maintenance Policies

Maintenance at its core would have policies to be followed. These policies usually are for testing period and overhaul or downtime. This is specially written in Redutskiy et al. (2021), where they use safety instrumented system (SIS) to explain about several maintenance policies. They are:

- Parallel testing: testing of equipment that starts simultaneously. This requires facility shutdown for technology overhaul.
- Sequential testing: testing of equipment that is done one by one by the same maintenance engineer. This requires fewer workers, but takes longer.
- Staggered testing: testing of equipment that is separately tested at points within the test interval.

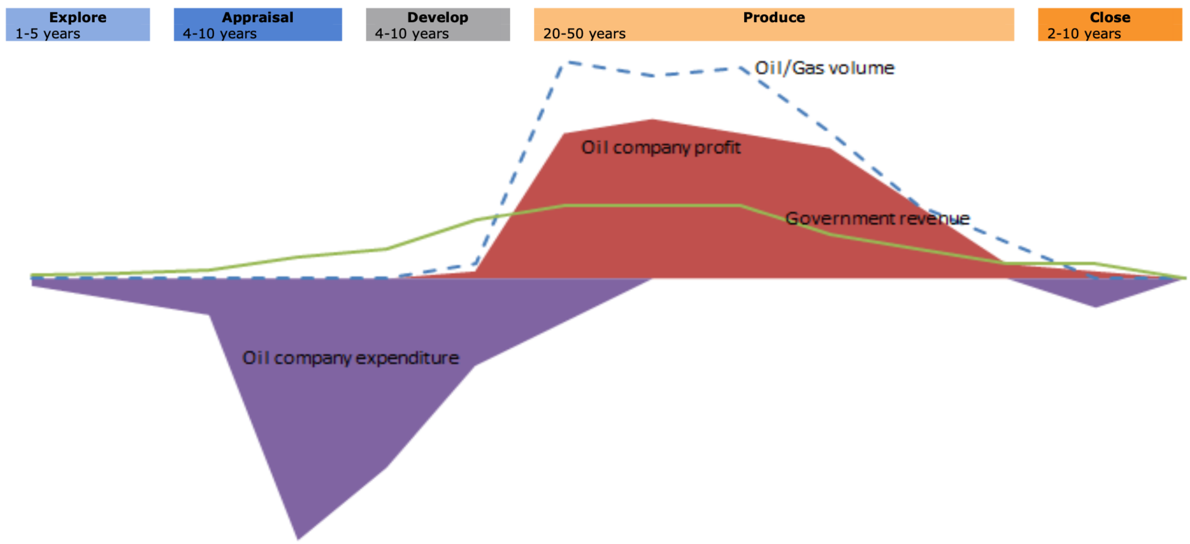

Figure 2.5: Phases of Oil and Gas Cycle Including the Revenue Graph (Darko (2014))

The visualisation of these maintenance and testing policies can be seen in Figure 2.4. The green blocks are testing period, and there is testing interval (TI) on the time line. A and D are parallel testing, B and E are sequential testing, and C and F are staggered testing. First thing to be noted is sequential testing takes longer (B and E are longer than A and D), but in E, the test does not require shutdown which denoted by orange block. The difference between A, B, C and D, E, F is noted by the overhaul or shutdown when the testing interval is 2TI. This shows also that D is unable to overhaul at 2TI only as it needs shutdown for testing, hence every testing is denoted with shutdown.

This will be used further to Markov modelling that will not be discussed in this writing, but from the result of the article there are several things to consider. They are:

- Result of the article prefers field devices (e.g., sensors and actuators) to be high in reliability although it can be expensive to purchase.
- Diverse redundancy will always be chosen if it is allowed. This will be calculated as higher system or facility reliability than having only one equipment for critical system.
- On the article, the highest possible redundancy is 2-out-of-8 system for fire detectors. This might be due to the low cost the device has.
- Low risk might be attributed by low average probability of failure on demand.

2.5 Phases of Oil and Gas Cycle

Phases of life-cycle in oil and gas industry are divided to five categories (Darko (2014)):

1. **Exploration, 1-5 years**: This is the phase where the company explore for potentially viable oil or gas sources with geological surveys. This phase will also include the government of the place for further work.

2. **Appraisal, 4-10 years**: This phase will make the companies engage more with the communities as the operation will impact the local environment and economy.

3. **Development, 4-10 years**: This phase will make contracts of what kind of facility will be made and designing and planning will be done.

4. **Production, 20-50 years**: This is the phase where everything is running and oil or gas is extracted.

5. **Closing/Termination, 2-10 years**: When the company finds the facility is not profitable anymore, the facility will be decommissioned and will be made as close as possible to the environment state before the project.

These phases can be seen alongside revenue graph in Figure 2.5. It shows also how much the oil companies have to spend on the first three stages before even making their first oil in the production.

2.5.1 Types of Oil and Gas Facilities

In the appraisal until closing phases of oil and gas, they might have some standards that works differently depending on the facilities that the companies have. Types of facility from DEQ Oklahoma (2023) are:

- Oil/NG – Well Site
- Central Tank Battery
- Produced Water Injection Facility
- NG – Gathering Compressor Station
- NG – Treatment Without Compression
- NG Plant – NGL Extraction and/or Fractionation
- NG – Transmission Compressor Station
- NG – Underground Storage Facility
- Oil – Pipeline Breakout Facility/Truck Station

- Oil – Tank Farm
- Oil/NGL/Refined Petroleum – Pipeline Pump Station
- Oil Refinery
- Refined Petroleum – Product Terminal
- Oil/NG/NGL – Other

In this writing, the facility that will be focused on is just the well site, which most of the people would know and visualise the shape and the function of it. It also has the type of compressor equipment that will be analysed in this writing, which is an electric-driven screw compressor.

2.6 Maintenance Trends

From the birth of industrialisation, maintenance can be divided on to four generations da Silva and de Souza (2021). They would be:

- Pre-1950s, **first generation**: Corrective maintenance (run to failure) and no planning,
- 1950s to mid 1970s, **second generation**: Preventive maintenance (time-based) with manual planning,
- Mid 1970s to mid 1990s, **third generation**: Predictive maintenance (condition-based) with computer-aided planning and reliability-oriented designs and analysis,
- Mid 1990s to 2020, **fourth generation**: Predictive maintenance (improved monitoring) and risk-based maintenance with maintenance optimisation and artificial intelligence. It also includes strengthening failure analysis and maintenance alignment with asset management.

2.7 Value of Maintenance

Maintenance, from the trends above, is now linked quite heavily to the asset management inside a company. According to da Silva and de Souza (2021) and referring to ISO (2014), asset management makes companies realising value from their assets. The benefits of this asset management are da Silva and de Souza (2021):

- Improvement of financial performance,
- Informed decisions about investments in assets,

- Risk management,
- Improvement of services and products,
- Social responsibility,
- Improvement of image, and
- Efficiency.

Improvement in financial performance will likely be debated at first between the engineering and economic department, because the nature of this is to spend quite a lot in the earlier phase of design and production so that the healthy period of the production should be longer. In the digital era like today, this usually means to spend a lot on conditional monitoring sensors for big equipment; e.g. pressure and temperature sensors. They have quite a big impact for pretty small things.

With these kind of conditional monitoring equipment, companies can make a good trend lines of the performance of the main equipment and hence make a better maintenance strategies that are not so frequent to splurge more money, but also frequent enough to have the main equipment in healthy state.

Overtime, companies will save money on unnecessary maintenance and spend efficiently for the important ones. This also makes the risk lower as now lesser people are exposed to the risk of maintaining equipment and if the equipment is going smoothly and very well maintained, it improves the social responsibility and image of the company between the oil and gas circles.

2.7.1 Sample of Incidents Due to Maintenance Issue

Major incidents due to maintenance issues tend to happen when it is not done right. According to PSA (2010), the key to an event to be considered as major incidents are:

- Mode or magnitude of event: *Acute incident*,
- Event type: *Major discharge/ emission or a fire/ explosion* and *Fire, explosion, dangerous release, loss of structural integrity and helicopter, diving and other work-related events.*
- Effect: *Several serious injuries and/or loss of human life, serious harm to the environment and/or loss of substantial material assets, serious danger or harm to a relevant person, an at-risk community, a property or the environment*, with examples of:
  - *Death or serious personal injury to persons in the vicinity of the installation,*
  - *Major damage to the structure of the installation,*

  - *Collision of a helicopter with the installation,*
  - *Critical failure of diving operations in connection to the installation, and*
  - *Death or serious personal injuries to five or more persons in the vicinity of the installation arising from other events, excluding hazards such as slips, trips and falls.*

- Timing of impact: *Immediate or delayed.*
- Impact location: *Vicinity of installation.*

According to Okoh and Haugen (2013), few incidents can be categorised as major incidents, they are:

1. USA - Texas City refinery explosion (March 23, 2005),
2. USA - Allied Terminals tank collapse (November 12, 2008),
3. USA - Hoeganaes metal dust flash fire (January 31, 2011),
4. USA - Hoeganaes hydrogen explosion (May 27, 2011),
5. USA - DuPont flammable vapor explosion (November 10, 2010),
6. USA - Goodyear ammonia release (June 11, 2008),
7. USA - Giant oil refinery fire and explosion (April 8, 2004),
8. USA - EEI hydrogen sulfide release (December 11, 2002),
9. USA - Kleen Energy gas explosion (February 7, 2010),
10. USA - ConAgra gas explosion (June 9, 2009),
11. USA - Bayer CropScience tank explosion (August 28, 2008), and
12. USA - DuPont toxic chemical release (January 23, 2010).

Incidents above have factors in which they are maintenance-specific, they can be noted as:

- *Lack of barriers*, which allows failure to breakthrough this barrier, e.g. corrosion of valves due to lack of maintenance.
- *Barrier maintenance error*, e.g. wrong calibration of safety devices.
- *New hazard*, in which this new hazard is triggered by maintenance, e.g. forgotten tool inside tank that is maintained would be source of localised corrosion.
- *Initiating event*, in which maintenance is the initiating event for an accident scenario, e.g. wrong valve operated causing loss of contamination.

Chapter 3

Compressor for Air Instrumentation and Utility

Throughout oil and gas process of exploration, drilling, transporting, and refining the oil, one of the vital role of those processes is the instrumentation air. Jobs that need this instrumentation air range from painting platform, sandblasting ship, cleaning vessel and pipe, or even kick-starting mechanical rotating equipment like gas turbine generator Arfalk (2015). For pneumatic control systems, instrument air is employed in the oil and gas sector. Systems for controlling valves, actuators, and other machinery are included in this. To achieve precise and dependable control, the air compressor utilized for instrumentation air must produce a steady, clean, and dry air supply. Air dryers and filters are included in instrumentation air compressors, which are generally oil-free compressors that remove moisture and impurities from the air.

In many oil and gas platform, this will be packed usually in an instrument skid package that includes multiple compressors (for redundancy) with dryers and filtration systems for good quality dry air that will be needed for actuating pneumatic for valves, buffer sealing gas, etc. There are several types of compressor to be assigned for this air utility and instrumentation application, they are:

- **Centrifugal compressors:** usually have electric motor with high speed configuration for driving the impellers.
- ***Screw compressors:*** usually are more reliable under bad conditions.
- **Tooth compressors:** they use a symmetrical and dynamically balanced rotor.

This writing and the analysis will solely focus on the *screw compressor* as the main equipment for the instrumentation air and utility system. One of the reason of choosing this type of equipment is because there are quite a number of analysis on the gas turbine compressor of axial, centrifugal, or even engine powered. That is because it is one the most important equipment of the oil and gas platform, but smaller type of compressor with completely different function might be beneficial to look at.

Air utility compressor will have a function that can be considered secondary as it will allow the instrumentation and utility such as valve to work. Although it might be less vital than the gas turbine compressor, failure in this compressor can also be impactful to the production.

3.1 Screw Compressor

Screw compressor works in two basic principle that are actually used in a a lot of compressor type. Its principal is that it uses rotary movements to compress the air. There is a set of different rotors (male and female) that usually has convex lobes and concave cavities so that *they can mesh together without touching to achieve compression* (CompAir (2023)). Step by step operation of a screw compressor would be:

1. Valve opening will suck gas into the compressor chamber where two screw rotors located. It will be going in high speed.
2. When they are rotating, they trap and isolate air and moving the air down the chamber.
3. The chamber getting smaller in size and moved away from the valve opening. The volume decreases, hence pressure increases.
4. Pressurisation creates condensed air.
5. The air pressure triggers compressor's discharge valve to open and allowing the pressurised air to get into a receiver on other tank.
6. Air will be compressed and transferred to the equipment such as dryers and separators for contamination removal.

Benefits of having a rotary screw air compressor are:

- **Continuous operation:** It is capable of continuous operation of airflow and pressurisation as they do not need to be shut on or off. This will create a very low downtime.
- ***Easy to maintain:*** It has less moving parts to other type of compressor, hence easier to maintain and this is going to be the talking point of this writing.
- **Powerful performance:** It can operate in challenging and harsh conditions, hence pneumatic tools and heavy equipment will be running efficiently in different conditions.
- **Energy-efficient:** It is durable and produce less heat, hence conserve more energy than other type.

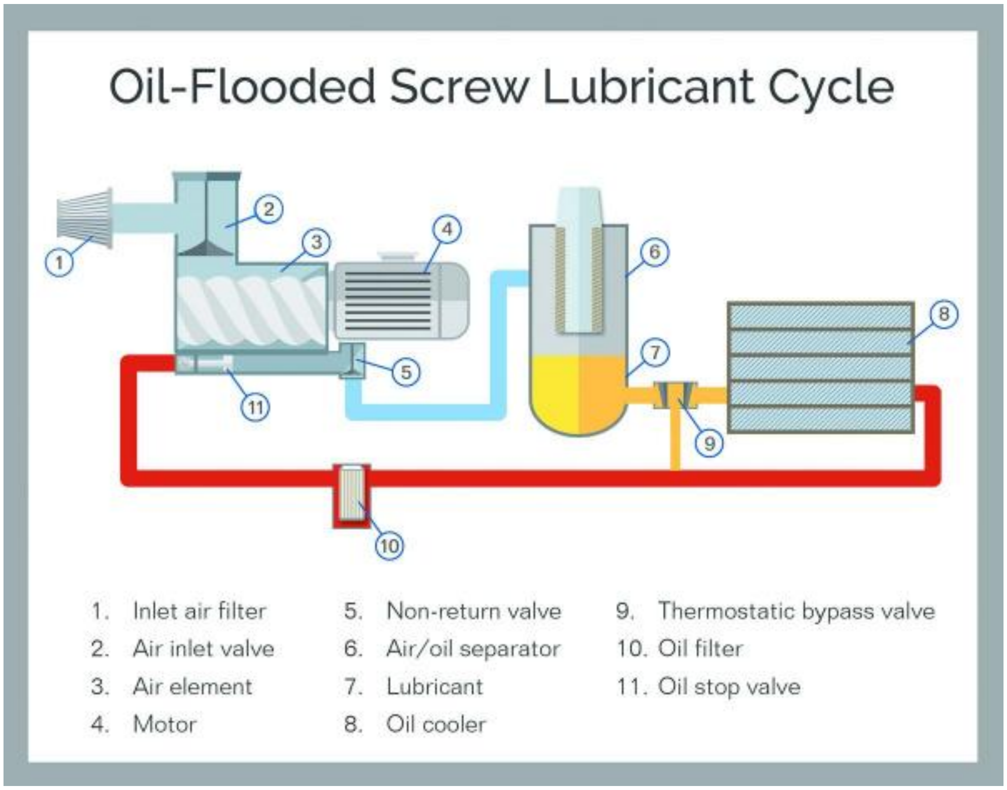

Figure 3.1: Oil-Lubricated Screw Compressor Brockett and Isel Inc. (2023)

- **Low noise:** Less moving parts mean less noise.

There are two types of screw compressor that is present around the industry; Oil lubricated screw compressors, and oil-free screw compressor.

3.1.1 Oil-Lubricated Screw Compressor

This type of compressor will sometimes be called flooded screw compressor. It uses lubricant in the compression chamber to cool and lubricate the element of the compressor. Other than that, lubricant creates seal and dampening for the noise. The illustration from Brockett and Isel Inc. (2023) can be seen on Figure 3.1.

3.1.2 Oil-Free Screw Compressor

Oil-free screw compressor will not use any type of oil in the compression chamber, hence removing risk of contamination. Usually, they will have a water-injected system to lubricate, cool, and seal the compressor as oil replacement. This will help with the dry air output for the utility and instrument air. This will be illustrated by Siddiqui (2013) on Figure 3.2.

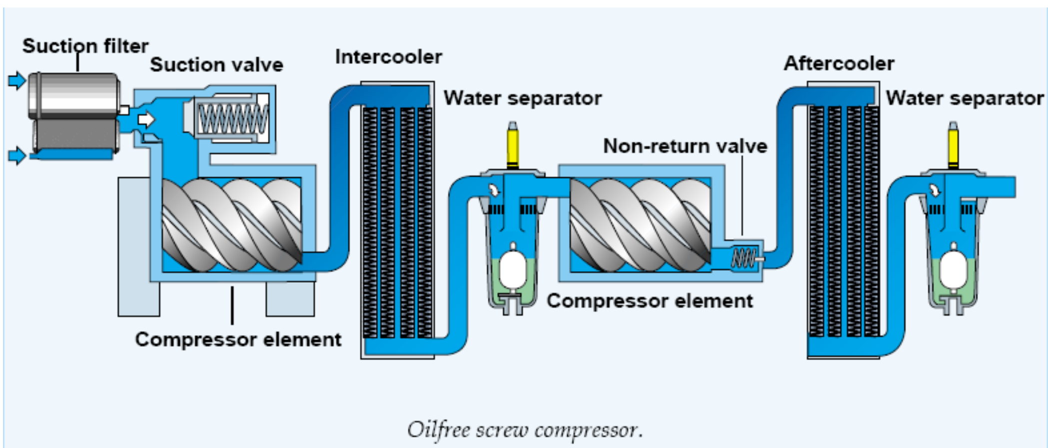

Figure 3.2: Oil-Free Screw Compressor Siddiqui (2013)

Chapter 4

Offshore and Onshore Reliability Data (OREDA)

First released in the 1980s, this database is the brainchild of many oil and gas companies. They are BP, Norsk Hydro, Shell, AGIP, Elf, Esso, Statoil, and Total. Data collected and shown in OREDA is mainly offshore equipment units with their respective failures. Many iterations have been done and the most recent one is Phase XIII (13) which released on 2018 with new companies participating in the data collection.

Since 1990, SINTEF has been the main contractor for OREDA and data collection of the equipment type is chosen by the oil companies. Primarily, it was used for risk and availability studies when the offshore project is in the early and engineering phases.

4.1 OREDA Data

Based on Sandtorv et al. (1996), OREDA has three basic part containing:

1. Inventory
2. Failure
3. Maintenance

The Inventory is the top category in OREDA that contains the used equipment of the offshore platform (e.g., a compressor) that the data was collected by companies. This contains also the description, technical data, and environmental parameters that the equipment work with.

Inside Inventory there will be Failure. It will contain all failure events experienced by those companies for the specific equipment during a length of specific time. Each section of the Inventory will have a dedicated page for the failures that the respective equipment has and this will usually be in abbreviations. Some of the most used example from them are:

- FTS = Fail to start on demand
- STP = Fail to stop on demand
- ELP = External leakage - process medium
- ELU = External leakage - utility medium
- etc.

These failure data would then be categorized according to different severity; Critical, Degraded, and Incipient. Each severity can have same failure modes, but the numerical data would differ from one to another. The numerical data itself has several headings to it such as lower, mean, upper, SD (Standard Deviation), and n/tau (which is a total number of failures divided by the total time in service, usually estimated failure rate used for a homogeneous sample). In many calculations, the mean failure rate is being used instead of the others.

Maintenance part of the Inventory will show the preventive and corrective maintenance. The PM will always be related to the inventory part and the CM will be related to the failure event or records. It shows active repair time and the repair time which is showed as Minimum, Mean, and Max repair hours. Active repair hours is the "clean" time of repair (OREDA (2002)) that does not include shutting down, waiting time, etc. Hence it should be lower than the average "dirty" repair time which is shown as mean on the table next to it.

These parts can be viewed as a whole in Figure 4.1.

4.2 OREDA Hierarchy

Many reliability standards come with equipment hierarchy to ease personnel to identify in what area or what bigger system an equipment work for. OREDA is no different than others. Usually there are three different levels per equipment category, which on this example, Compressor will have two lower levels of it. Highest level equipment will usually be a gas turbine, compressor, pump, etc.

From Figure 4.2, Compressor will be divided onto six different level two components; Power Transmission, Compressor Unit, Control and Monitoring, Lubrication System, Shaft Seal System, and Miscellaneous. Each of these six sub-level will have their respective sub-sub-level, which are the maintainable items.

It is shown on Figure 4.3 that there is a table of the maintainable items, which is the almost lowest level in the hierarchy, versus failure mode. Numbers shown on the table are percentage (probability), hence there should be a sum header and total row on the right corner (in the end of table) that should conclude all numbers to a hundred percent. These maintainable items will be crucial in later process in which Failure Modes and Effect Analysis (FMEA) takes place.

Taxonomy no		Item			
1.1		Machinery Compressors			
Population	**Installations**	**Aggregated time in service (10^6 hours)**		**No of demands**	
131	38	**Calendar time ***	**Operational time †**	82472	
		3.8235	2.4253		

Failure mode	**No of failures**	**Failure rate (per 10^6 hours).** Lower	Mean	Upper	SD	n/τ	**Active rep.hrs**	**Repair (manhours)** Min	Mean	Max
Critical	**595*** **595†**	**0.00** **0.08**	**166.07** **268.58**	**839.82** **1176.02**	**361.26** **459.51**	**155.62** **245.33**	**17.8**	**0.5**	**29.3**	**1818.0**
Abnormal instrument reading	3* 3†	0.00 0.00	1.11 6.03	4.88 29.41	1.91 12.28	0.78 1.24	7.0	16.0	16.5	17.0
Breakdown	5* 5†	0.01 0.00	1.28 6.20	4.17 34.23	1.51 17.26	1.31 2.06	61.5	25.5	367.0	1481.0
Erratic output	12* 12†	0.00 0.00	6.00 9.41	29.41 43.25	12.36 17.34	3.14 4.95	32.2	3.0	56.8	580.0
External leakage - Process medium	44* 44†	0.00 0.00	10.26 12.45	50.98 51.89	46.43 58.15	11.51 18.14	8.3	0.5	12.0	197.0
External leakage - Utility medium	31* 31†	0.00 0.01	11.80 24.22	58.78 105.90	25.04 41.33	8.11 12.78	12.6	1.0	23.6	123.5
Fail to start on demand	72* 72†	0.21 0.59	22.45 40.25	74.13 127.61	27.10 45.88	18.83 29.69	26.3	1.0	37.3	704.0
Fail to stop on demand	3* 3†	0.00 0.00	1.44 2.80	7.87 15.40	3.69 7.43	0.78 1.24	3.5	3.5	10.8	18.0
High output	1* 1†	0.00 0.00	0.27 0.45	1.52 2.42	0.90 1.56	0.26 0.41	7.0	14.0	14.0	14.0
Internal leakage	5* 5†	0.00 0.00	1.38 2.68	7.61 14.47	3.74 9.25	1.31 2.06	113.4	2.0	171.4	304.0

Figure 4.1: A Simple Compressor Data in OREDA

COMPRESSOR					
Power transmission	Compressor unit	Control and Monitoring	Lubrication system	Shaft seal system	Miscellaneous
• Gearbox • Bearing • Seals • Lubrication • Couplings • Instruments	• Antisurge system • Casing • Cylinder liner • Instruments • Shaft seals • Radial bearing • Thrust bearing • Interstage seals • Valves & • piping • Piston[4] • Packing • Rotor w/impellers	• Instruments • Cabling, junction box etc. • Control unit • Actuating device • Monitoring • Internal power supply • Valves	• Reservoir w/heating system • Pump w/motor • Filter • Cooler • Valves & piping • Oil • Instruments • Seals	• Buffer gas system • Dry gas seal • Instruments • Overhead tank • Reservoir • Scrubber • Pump w/motor/gear • Filter • Valves • Seal gas • Seal oil	• Base frame • Cooler • Valves • Magnetic bearing control system • Piping • Purge air • Silencers

Figure 4.2: Levels of Compressor Hierarchy

Maintainable item versus failure mode, to be continued
Item: Compressors

	AIR	BRD	ELP	ELU	ERO	FTS	HIO	INL	LOO	NOI
Actuating device	0.04	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
Antisurge system	0.22	0.00	0.04	0.13	0.35	0.18	0.04	0.18	0.00	0.00
Base frame	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bearing	0.00	0.00	0.00	0.18	0.00	0.04	0.00	0.00	0.00	0.00
Buffer gas system	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Cabling & junction boxes	0.22	0.00	0.00	0.04	0.00	0.09	0.00	0.00	0.00	0.00
Casing	0.00	0.02	0.04	0.18	0.00	0.00	0.00	0.00	0.00	0.00
Check valves	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Control unit	0.84	0.00	0.00	0.04	0.22	0.53	0.00	0.00	0.00	0.00
Control-, isolating & check valves	0.04	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00
Cooler(s)	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00
Coupling to driven unit	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00
Coupling to driver	0.00	0.00	0.00	0.11	0.18	0.00	0.00	0.00	0.00	0.00
Cylinder liner	0.13	0.00	1.94	0.62	0.00	0.04	0.00	0.04	5.78	0.00
Dry gas seal	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.04	0.00	0.00
Filter(s)	0.02	0.00	0.04	0.18	0.00	0.00	0.09	0.04	0.31	0.00
Gearbox/var.drive	0.09	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.09
Instrument, flow	0.57	0.00	0.00	0.09	0.00	0.04	0.00	0.00	0.00	0.00
Instrument, general	0.84	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.04	0.00
Instrument, level	2.07	0.00	0.00	0.22	0.00	0.04	0.00	0.04	0.00	0.00
Instrument, pressure	4.07	0.00	0.00	0.31	0.09	0.31	0.04	0.00	0.04	0.00
Instrument, speed	0.26	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00
Instrument, temperature	4.65	0.00	0.04	0.11	0.09	0.13	0.00	0.00	0.04	0.00
Instrument, vibration	1.08	0.00	0.00	0.11	0.04	0.00	0.00	0.00	0.00	0.00
Internal piping	0.02	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Internal power supply	0.22	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00
Interstage seals	0.00	0.00	0.09	0.11	0.00	0.00	0.00	0.04	0.04	0.00

Figure 4.3: Maintainable Items vs. Failure Mode of Compressor

On the other hand, failure descriptor table on Figure 4.4 will show the percentage of the reason causing the failure mode. The same with Figure 4.3, the total on the right bottom at the end of the table should conclude to a hundred percent.

4.3 Problems in OREDA Data

During the data collection, Sandtorv et al. (1996) faced some problems experienced that might be a limitation on using OREDA. They are:

- Difficult to develop complex equipment specifications that is interpreted differently by each data collector,
- Historical data collection makes it a bit hard to interpret information that is incomplete,
- Effect of PM on the reliability is hard to measure, hence it is hard to have the "naked" failure rate where no PM is done.

Due to these problems, several steps of quality control of the data was carried out, they are:

- Self-check routines done by the individual data collector (personal)
- After one platform or system is finished (contractor)

Failure descriptior versus failure mode, to be continued
Item: Compressors

	AIR	BRD	ELP	ELU	ERO	FTS	HIO	INL	LOO	NOI
Blockage/plugged	0.13	0.00	0.00	0.09	0.04	0.00	0.00	0.00	0.31	0.00
Breakage	0.26	0.04	0.09	0.09	0.00	0.04	0.00	0.00	0.00	0.00
Burst	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cavitation	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Clearance/ alignment failure	0.13	0.00	0.04	0.26	0.00	0.00	0.00	0.00	0.00	0.00
Combined causes	0.04	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.04
Contamination	0.09	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Control failure	0.40	0.00	0.00	0.09	0.18	0.49	0.00	0.04	0.04	0.00
Corrosion	0.09	0.00	0.00	0.04	0.00	0.04	0.00	0.04	0.00	0.00
Deformation	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04
Earth/isolation fault	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electrical failure - general	0.04	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.00
Erosion	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
External influence - general	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fatigue	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00
Faulty power/voltage	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
Faulty signal/indication/alarm	3.40	0.00	0.00	0.00	0.18	0.18	0.00	0.00	0.00	0.00
Instrument failure - general	6.27	0.00	0.09	0.35	0.35	0.75	0.09	0.04	0.62	0.00
Leakage	0.04	0.00	1.06	4.15	0.00	0.04	0.00	0.09	0.00	0.00
Looseness	0.18	0.00	0.09	0.44	0.09	0.13	0.00	0.00	0.00	0.04
Material failure - general	0.13	0.00	0.13	0.49	0.00	0.00	0.09	0.00	0.00	0.04
Mechanical Failure - general	0.44	0.09	3.18	2.56	0.13	0.35	0.04	0.13	9.14	0.13
Misc. external influences	0.18	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.26	0.00
Miscellaneous - general	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
No cause found	0.26	0.00	0.00	0.04	0.00	0.04	0.00	0.00	0.00	0.04
No power/ voltage	0.04	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
No signal/indication/alarm	0.71	0.00	0.00	0.04	0.00	0.13	0.00	0.00	0.00	0.00
Open circuit	0.40	0.00	0.04	0.04	0.00	0.09	0.00	0.00	0.00	0.00
Other	0.00	0.04	0.04	0.00	0.00	0.04	0.00	0.00	0.00	0.00
Out of adjustment	3.27	0.00	0.00	0.00	0.26	0.22	0.00	0.04	0.09	0.00
Overheating	0.00	0.00	0.13	0.04	0.04	0.00	0.00	0.00	0.00	0.00
Short circuiting	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Software failure	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sticking	0.18	0.04	0.00	0.00	0.04	0.09	0.00	0.13	0.00	0.00
Unknown	0.53	0.00	0.04	0.13	0.00	0.26	0.00	0.00	0.71	0.09
Vibration	0.31	0.00	0.04	0.18	0.00	0.00	0.00	0.00	0.04	0.13
Wear	0.18	0.00	0.09	1.50	0.26	0.00	0.00	2.38	0.40	0.13
Total	18.23	0.22	5.12	10.77	1.63	3.27	0.22	2.91	11.65	0.71

Figure 4.4: Failure Descriptor vs. Failure Mode

- Statistical check on selected data (project management)
- Final verification (project management)

But then, there will always be challenges doing these quality control; to harmonise interpretations between different data collectors, and dealing with changes such as plants, plans, codes, standards, etc. when data collecting.

Chapter 5

Equipment Taxonomy

5.1 ISO 14224

ISO 14224 (Petroleum, petrochemical and natural gas industries - Collection and exchange of reliability and maintenance data for equipment) shows pretty much everything for the maintenance and reliability management in an oil and gas industry. On this section, the writer will only focus how the OREDA connects to the taxonomy section of the ISO 14224.

On Figure 5.1, there shows nine components of the taxonomy pyramid where the equipment should be named. Usually, they are called functional location so that personnel can easily identify which system and what is the functions. The top five of the pyramid will tell personnel the management side of the functional location, such as the industry (if the company has a lot of different industries going on), business category (upstream, midstream, downstream, etc.), installation (type of the facility, e.g., transportation, oil and gas production), plant/unit (type of plant it is, e.g., semi-submersible plant, methanol plant, etc.), section/system (main systems of the plant).

While the bottom four of the pyramid is where the OREDA equipment comes in until the eighth component (maintainable item). In the reliability management of a business (company), usually a functional location will be named from the fourth level to prevent a very long tag number (as CMMS usually will take around thirty characters of naming system). This also means that in the each of the tag number will have an impact on failures and safety. On Figure 5.2, **X** denotes that it is a default that the data of an impact or failure will impact on some level of equipment. For example, Plant level will be impacted by a failure on safety, and then maintainable item will be impacted by component failure. **(X)** denotes that it is a possible alternatives, for example for failure impact on equipment will may be impacting a sub-unit or maintainable item, but it will not always happen.

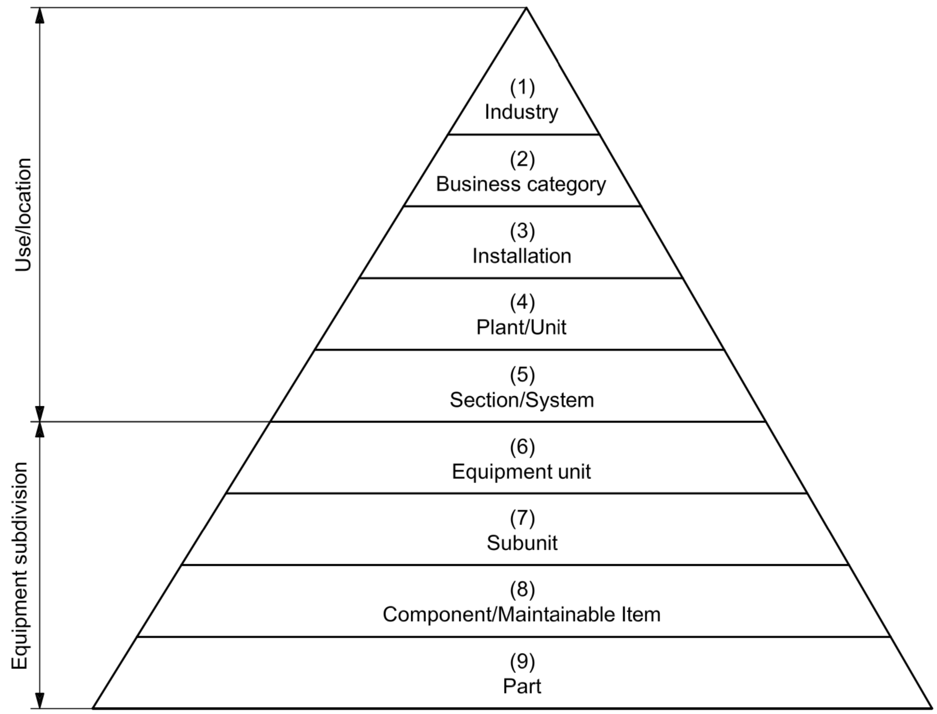

Figure 5.1: ISO 14224 Taxonomy

Recorded RM Data	Hierarchy Level				
	4	5	6	7	8
	Plant/Unit	Section/System	Equipment Unit	Subunit	Component/ Maintenable Item
Impact of failure on safety	X				
Impact of maintenance on safety	X				
Impact of failure on operations	X	(X)			
Impact of maintenance with regard to operations	X	(X)			
Failure impact on equipment			X	(X)	(X)
Failure mode		(X)	X	(X)	(X)
Failure mechanism			(X)	(X)	X
Failure cause				(X)	X
Detection method		(X)	X	(X)	(X)
Subunit failed				X	
Component/maintenable item failed					X
Down time	(X)	(X)	X		
Active maintenance time			X	(X)	(X)

Figure 5.2: Reliability and Maintenance Parameter to the Taxonomy

5.2 OREDA Taxonomy

Along with the hierarchy, similar equipment or typical item (e.g., piping) will be differentiated based on their taxonomy. With this taxonomy, it means that personnel on site can differentiate where is the equipment located within the system and what effect will it causes when a failure mode happens.

Equipment class will have three main taxonomy branches that will define their unique address to specify their failure rate and define the process and function they are doing. These are (Sandtorv et al. (1996)):

1. Use characteristics

2. Design characteristics

3. Identification

Use characteristics will give people sense where is the environment of the equipment, what operation it does, and the maintenance program it is going to be have. On the other hand, design characteristics will give people more technical data such as manufacturer data, design specifications (what is the parameter the equipment can withstand), and performance specification (the parameter used by the company's operation). Identification would be the record of the equipment itself, it can be the classification of the equipment and also the historical data such as installation parameters.

Different companies might have a different approach on whether on what systems do they have, but most of the time they will follow ISO 14224 in the taxonomy of the equipment. For example, to differentiate piping location and function, usually there will be a tag number to the pipe according to the system they are in. Two examples that the writer has seen are:

- A-ORF-50-FS-0001-XX

  - A denotes the business category, which can be seen later in Figure 5.1. This will depend solely on the business owner.
  - ORF denotes the installation within the business category, in this case ORF means Onshore Receiving Facility.
  - 50 denotes the diameter in millimeters (roughly two inches).
  - FS denotes Fire Safety system (there should be a company standard on what process gas fluids are and what systems do they have).
  - 0001 denotes the number (usually closest to the main equipment).
  - XX denotes other notes or class according to the standard the company follows (usually materials and thickness).

- B-WHP-500-PG-0003-AA
  - B denotes another business category than the one before.
  - WHP in this case means Wellhead Platform (offshore rig), then again this interpretation can be different according the company and business owners.
  - 500 denotes the diameter (roughly twenty inches).
  - PG denotes Process Gas system.
  - 0003 denotes the number within the system.
  - AA denotes other notes or class.

Chapter 6

IEC 60812

6.1 Failure Mode and Effect Analysis (FMEA)

Planning FMEA should have a clear definition of the purpose it intended to. There will be a specific focus on certain design elements that can be considered as risk because it does the function or because "immaturity if the technology used" (International Electrotechnical Commission (2006)). It should also identify which measures should be revised for the later revisions and also including experts of the respective equipment/item in the analysis.

6.1.1 System Structure

There are several items needed to be included for the system structure in FMEA:

- System elements with their respective characteristics, performances, roles, and functions;
- Logical connection between elements;
- Redundancy and the nature of the redundancies themselves;
- Position, location, and importance of the system within and to the whole facility;
- Inputs and outputs of the system;
- Changes in structure in different operational modes.

When engineers and experts agree on those items for system structure, they will need boundaries for the analysis. This can be influenced by the design, use, source of supply, or even commercial criteria. Creating boundaries will benefit engineers especially in a complex interconnected items that have many inputs and outputs or hardware and software, so that engineers can use other aspect like functional boundaries.

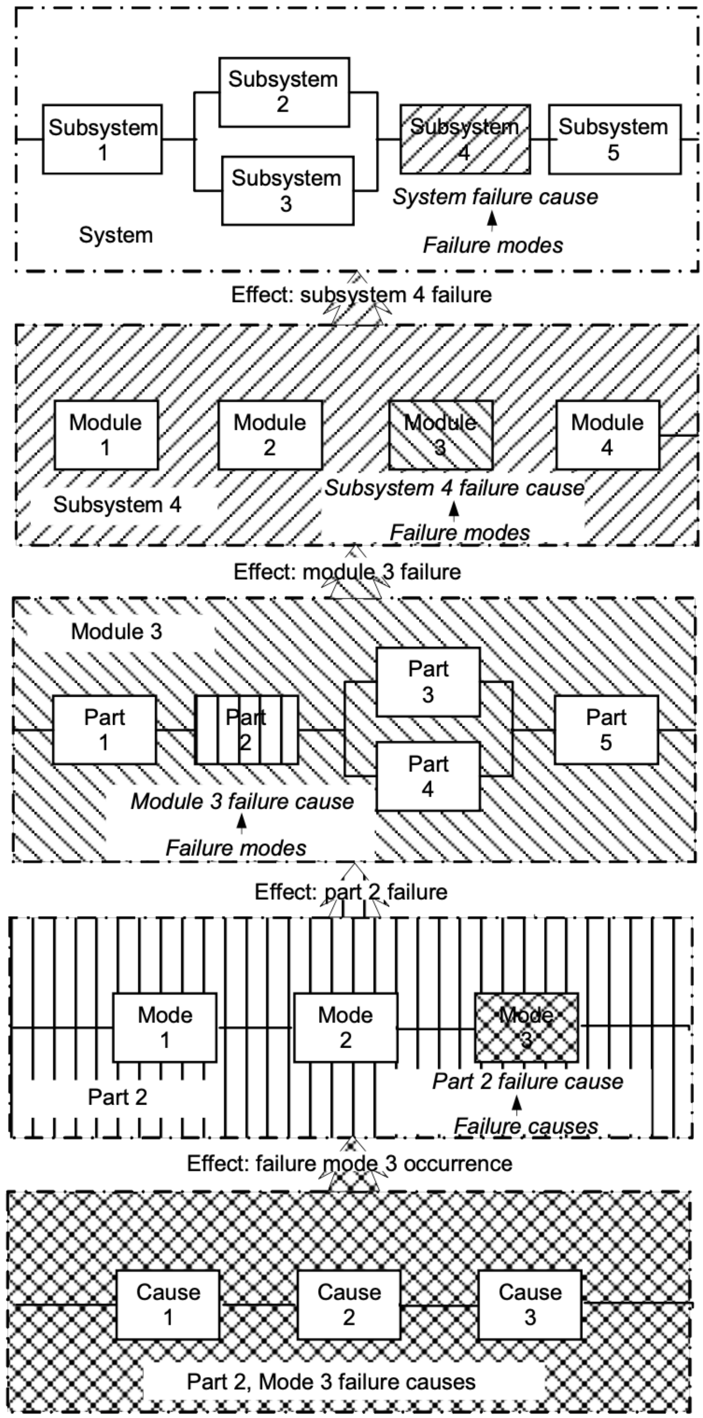

Figure 6.1: Relationship of Failure Modes and Failure Effects in System Hierarchy

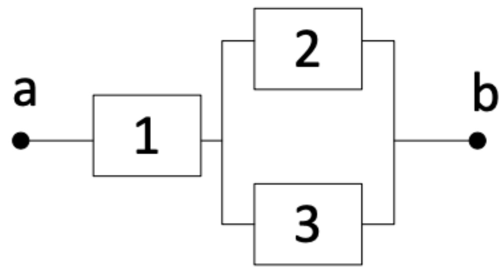

Figure 6.2: Simple RBD with Parallel Systems/Equipment (Vatn (2021))

Level requirements for the system structure states that the highest level of the system should be the design concept and the specified outputs requirement, while the lowest level of the analysed system is on the items which shows the function description. Hence it is better to specify the maintainable or repairable items in the lower system levels. Level of the details can vary due to the influence of previous experience.

The levels will influence the failure modes, failure causes, and failure effects later on as seen on Figure 6.1. The figure shows that the maintainable items (in this case would be the Part 2) would carry the failure mode and within that failure mode lies several failure causes that will impact higher levels such as the equipment, module, sub-system, and even system.

Representation of these systems or equipment will be done in a diagram to help easing the understanding. Most of the time, Reliability Block Diagram (RBD) would be used. This will enable the viewer to see the connectivity between systems or equipment and if there is redundancies within the system. Figure 6.2 shows the simple line of system with two equipment that have a redundancy in the second equipment. We can assume item 1 is a tank and item 2 and 3 are pumps. Pump will usually have redundancy to prevent inability to perform its function, so that when one fail, the redundant will directly take over.

After that, it is necessary to have a detailed information on initiation, operation, control, and maintenance. In details, they are:

- Duration of each function that is called to perform;
- Time interval between periodic tests;
- Time window for corrective maintenance before serious consequences happen;
- Facility personnel and environment including interactions between operators;
- Operating procedures document for system start-up, shut-down, and other operational transitions (e.g., decommissioning, etc.);

- Control within operational phases;
- PM and CM;
- Procedure of routine testing (periodic test), if available.

The system environment for the list above might not be full at design phase due to limited knowledge, but as the project progresses, usually there will be continuous update to the FMEA to deal with the interaction between operators and the facility.

6.1.2 Failure Mode Determination

The procedures in identifying failure modes can be helped by creating list of:

- System's use;
- System element involved;
- Operation mode;
- Pertinent operational specifications;
- Time constraints;
- Environmental stresses;
- Operational stresses.

From International Electrotechnical Commission (2006), the most general example of the failure modes would be something like these sentences:

1. Failure during operation
2. Failure to operate at a prescribed time
3. Failure to cease operation at a prescribed time
4. Premature operation

6.1.3 Failure Cause

This is the the identification and description of the causes of each failure mode because one failure mode can have more than one cause. The identification of the failure causes will be based on the failure effects and their respective severity as the higher the severity and effect a failure mode has, it would be more important to seek the causes of it.

These causes may be acquired by doing tests, but when the design is new, usually experts view and opinion will take a major role in this. After having the causes, recommended action will be recommended based on the probability of occurrence and the severity of the effect.

6.1.4 Failure Effects

Failure effects are the consequence of one or more failure modes on one or more equipment. The term "local effects" means the *effect of the failure mode to the system element under consideration* International Electrotechnical Commission (2006). Identifying this local effects is beneficial to formulate the recommended action that is usually a corrective action. When identifying the effects, there are impacts of the failure to the higher or highest level of the system. All effects in between should also be identified and the end effect might be the result of one or more failures. This should be indicated on the worksheets.

Detection of the failure effect is how the user or operator on-site are aware of the failing equipment. This might be done by test or established during maintenance activities. In FMEA, usually this will be called "Detectability" or "Detect-ability" and it will be given a number that cites how easy or hard it is to detect this failure.

There are identification feature in which they have the ability to prevent or reduce the effect of the failure mode. This should be shown clearly in FMEA. These includes:

- redundant equipment (allowing operation when one fails);
- alternative means of operation;
- monitoring or alarm devices;
- any other means of permitting effective operation or limiting effect.

This will usually be formulated in the design phase, but as the phase goes to another, FMEA should be updated or might be even repeated to have the closest as it can be to the real systems.

These effects will have their severity stored. There are factors consideration for the severity. They are the nature of the system, functional performance of the system, contractual requirements, government or industry requirements, and also requirements from the warranty. Overall, there are four classes of the severity that is used in FMEA and this classification of the severity can be shown like International Electrotechnical Commission (2006):

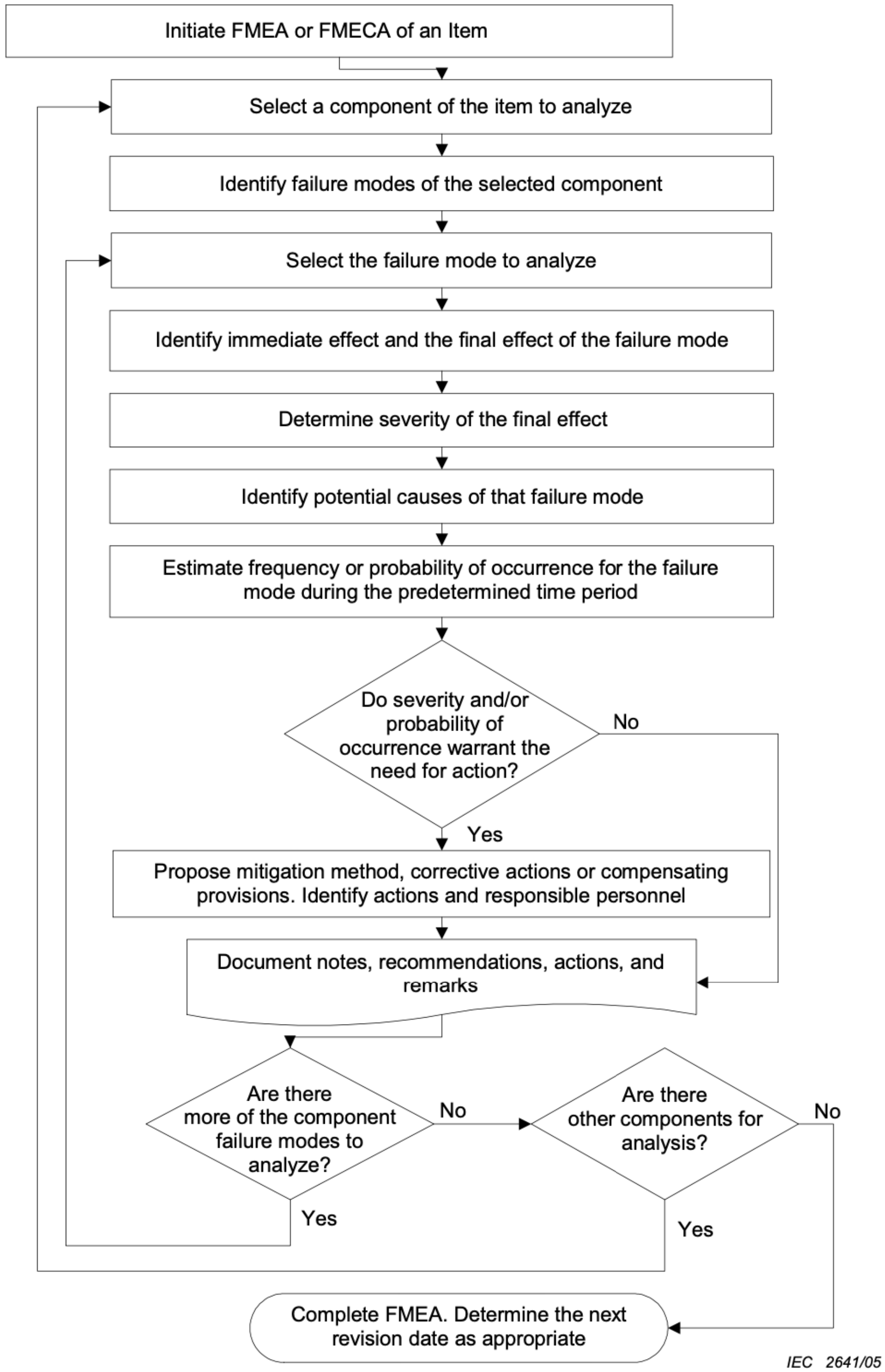

Figure 6.3: FMEA Flowchart as per International Electrotechnical Commission (2006)

- Level 1 (Insignificant or Negligible) - Failure mode which could potentially degrade system's function but will cause no damage to the system and does not constitute a threat to life or injury,
- Level 2 (Marginal) - Failure mode which could potentially degrade system's performance function(s) without appreciable damage to system or threat to life or injury,
- Level 3 (Critical) - Failure mode which could potentially result in the failure od the system's primary functions and therefore causes considerable damage to the system and its environment, but does not constitute a serious threat to life or injury,
- Level 4 (Catastrophic) - Failure mode which could potentially result in the failure of the system's primary functions and therefore causes serious damage to the system and its environment and/or personal injury.

Frequency of the failure would be the failure rate data. This is acquired by the life testing of the equipment (if it is newly designed), database for failure rate (e.g., OREDA (2002)), field failure data, and/or failure data for similar equipment. In the FMEA, each company or manufacturer usually have their own way of saying the probability such as "once in two to four years" and "once in more than twenty years".

Figure 6.3 show the flow how the initiation of FMEA go step by step in the reliability management. This shows that the step taken have to be for a specific equipment and its specific failure mode until severity and probability of occurrence need action to be taken or not. If yes, what is the recommended action for that specific failure mode. If not, if there are any other failure mode, they shall go with another failures mode and if they are done with one equipment's many failure modes, they shall go to the next equipment. This will take time but the reliability management will be benefited by the FMEA.

6.2 Failure Mode, Effects, and Criticality Analysis (FMECA)

FMECA is steps of analysis following the FMEA. Criticality analysis in this method will include Risk Priority Number (RPN). There is a general expression regarding basic potential risk. Basic equation of this basic potential risk is:

$$R = S \cdot P \tag{6.1}$$

- S denotes a non-dimensional number for severity, this will differ between companies or users, but the idea is there is a range (e.g., 1-5, or 1-10) that notes the how severe the failure will be in accordance to the effect to the system. The higher the number should means the more severe the effects are.

- P also denotes a non-dimensional number for probability of occurrence. This is a probability that ranges 0-1.

This will be developed onto RPN, which has *D*, which is a non-dimensional number for detection (detect-ability). The equation would be:

$$RPN = S \cdot O \cdot D \tag{6.2}$$

- O denotes an occurrence number that is ranged differently between companies and users. Like *S* in equation 6.1, it would be ranged 1-5 or 1-10 depending on the data needed. The higher the number should means that the failure are more probable to occur in a specific amount of time.

- D denotes the detection number which is also ranged depending on the companies and users. It should follow the same range as *O* and the higher the number should means that it is difficult to detect by the personnel on-site.

This RPN number will be used to prioritise which failure modes need more attention. Usually the higher the severity will be also high in RPN number and those are the failures that need attention. Because of the different ranges users can use, this RPN will differ and should not be compared with one another. If one company use 5 as their high limit, then an RPN number of 100 is really high. On the other hand, there are companies who use 10 as their high limit, and RPN of 100 is comparatively and figuratively low.

FMECA, as per International Electrotechnical Commission (2006), should not be used as the single basis of judging the risk of complex high-risk system is going to be acceptably low. This will be added up with criticality matrix approach that will be discussed in later section.

6.2.1 Failure Rate and Criticality Number

Failure rate is the rate over time in which an equipment will have a certain failure mode. Each failure mode of an equipment will have their own failure rate and in OREDA, this failure rate is shown as a number over one million hours. The general equation for the failure rate (λ) is shown in Equation 6.3 (International Electrotechnical Commission (2006)).

$$\lambda_{\mathrm{i}} = \lambda_{\mathrm{j}} \cdot \alpha_{\mathrm{i}} \cdot \beta_{\mathrm{i}} \tag{6.3}$$

- λ_{i} denotes the estimate of failure rate for failure mode i, which is assumed as constant.

- λ_{j} denotes the failure rate of the component j.

- α_i denotes the failure mode ratio, such as the probability of the equipment will have failure mode i.

- β_i denotes the conditional probability of the failure effect if failure mode i happens.

The drawback of this equation is that the failure rate is assumed to be constant and factors of the equation are based on best guesses and predictions. In some cases, quantitative approach to critical analysis will use number C instead of the failure rate. C is the criticality number that is not related to the term "Criticality" that have been written. Criticality number equation would be as follow:

$$C_\mathrm{i} = \lambda_\mathrm{j} \cdot \alpha_\mathrm{i} \cdot \beta_\mathrm{i} \cdot t_\mathrm{j} \tag{6.4}$$

Which also can be noted shortly as (refer to 6.3):

$$C_\mathrm{i} = \lambda_\mathrm{i} \cdot t_\mathrm{j} \tag{6.5}$$

The component t in the criticality number denotes the time of the operation of the equipment in the FMECA. Hence, when one equipment has m number of failure modes, it can be denoted as equation below:

$$C_\mathrm{j} = \sum_{i=1}^{m} \lambda_\mathrm{j} \cdot \alpha_\mathrm{i} \cdot \beta_\mathrm{i} \cdot t_\mathrm{j} \tag{6.6}$$

In this sum of criticality number, it does not translate to the probability of occurrence. It is calculated for relative measure of the consequence of the failure modes and its probability. Determining the probability of failure mode for time t would be as follow:

$$P_\mathrm{i} = 1 - \exp^{-C_\mathrm{i}} \tag{6.7}$$

6.2.2 Criticality Matrix

Criticality matrix will be presented in a table like in Figure 6.4. As section before stated, each company or user might have different range, but in the International Electrotechnical Commission (2006) case, it has four levels of severity and five levels of likelihood (probability of occurrence). In Figure 6.4, the severity is ascending from the least severe (I) to the most severe (IV) and also likelihood is ascending from low likelihood [E] to high likelihood [A], hence in this case it can be seen in IVA is the highest risk while IE is the least.

Usually the likelihood would be stated like these:

- 1 or E, Improbable, probability of occurrence: $0 \leq P_\mathrm{i} < 0.001$,

Likelihood - probability of occurrence					
	5 [A]				High risk
	4 [B]		Failure mode 1		
	3 [C]				
	2 [D]			Failure mode 2	
	1 [E]	Low risk			
		I	II	III	IV
		Severity			

Figure 6.4: Criticality Matrix per International Electrotechnical Commission (2006)

- 2 or D, Remote, probability of occurrence: $0.001 \leq P_\mathrm{i} < 0.01$,
- 3 or C, Occasional, probability of occurrence: $0.01 \leq P_\mathrm{i} < 0.1$,
- 4 or B, Probable, probability of occurrence: $0.1 \leq P_\mathrm{i} < 0.2$,
- 5 or A, Frequent, probability of occurrence: $P_\mathrm{i} \geq 0.2$.

Also, there are examples for failure modes in this case there are two failure modes, which one of them is more likely to occur in the B category while having less severe severity in II, while the other has more severe severity in III, but having a less likelihood in D. There will be discussion surrounding this kind of situation and it is up to the management to decide which failure should be noted as more critical as it might be dependant to a certain system or equipment that is more critical than the other or there are policy about the likelihood and severity factors. This leads to the next section of acceptability.

6.2.3 Risk Acceptability

Using Figure 6.4 as basis, this assessment will create another table of the acceptance regarding each severity and likelihood level.

Frequency of occurrence of failure effect	Severity levels			
	1 Insignificant	2 Marginal	3 Critical	4 Catastrophic
5: Frequent	Undesirable	Intolerable	Intolerable	Intolerable
4: Probable	Tolerable	Undesirable	Intolerable	Intolerable
3: Occasional	Tolerable	Undesirable	Undesirable	Intolerable
2: Remote	Negligible	Tolerable	Undesirable	Undesirable
1: Improbable	Negligible	Negligible	Tolerable	Tolerable

Figure 6.5: Risk Acceptability Matrix

Frequency of occurrence of failure effect	Severity levels			
	1 Insignificant	2 Marginal	3 Critical	4 Catastrophic
5: Frequent	Undesirable	Intolerable	Intolerable	Intolerable
4: Probable	Tolerable	Undesirable	Intolerable	Intolerable
3: Occasional	Tolerable	Undesirable	Undesirable	Intolerable
2: Remote	Negligible	Tolerable	Undesirable	Undesirable
1: Improbable	Negligible	Negligible	Tolerable	Tolerable

Figure 6.6: Colored Risk Acceptability Matrix

In Figure 6.5, it can be seen for each severity and likelihood they have classes of acceptance; Negligible, Tolerable, Undesirable, and Intolerable. This means that intolerable classes should be the one considered as critical failure, while negligible is the one that is least critical. Most companies or users can visualise this kind of table to a more striking visual with colors. They also usually opt for a less categories, so they will use only three categories for the color red, yellow, and green according to the acceptance classes (intolerable, undesirable, tolerable, and negligible). This can be seen in Figure 6.6 with the reds being the most severe, yellows are the in between, and greens are the least severe.

6.2.4 Alternate Severity List

With the help of SAE International (2002), RPN severity will be classified with ranking and the description for each ranking. This will help personnel to visualise or describe the failure mode they have. This will be seen on Figure 6.7.

Ranking will go from the low ranking 1 which usually has negligible effect in terms of severity until 10 which has severe effect, in this case it is hazardous to environment and without warning. While this helps with the describing failure, some of the severity level, such as in ranking 3 until 5, might be subjective and needs expert's view on them.

Severity	Criteria	Ranking
None	No discernible effect.	1
Very minor	Fit and finish/squeak and rattle item does not conform. Defect noticed by discriminating customers (less than 25%).	2
Minor	Fit and finish/squeak and rattle item does not conform. Defect noticed by 50% customers.	3
Very low	Fit and finish/squeak and rattle item does not conform. Defect noticed by most customers (greater than 75%).	4
Low	Vehicle/item operable but comfort/convenience item(s) opearable at a reduced level of performance. Customer somewhat dissatisfied.	5
Moderate	Vehicle/item operable but comfort/convenience item(s) inoperable. Customer dissatisfied.	6
High	Vehicle/item operable but at a reduced level of performance.	7
Very high	Vehicle/item inoperable (loss of primary function).	8
Hazardous with warning	Very high severity ranking when a potential failure made affects safe vehicle operation and/or involve non-compliance with government regulation with warning.	9
Hazardous without warning	Very high severity ranking when a potential failure made affects safe vehicle operation and/or involve non-compliance with government regulation without warning.	10

Figure 6.7: Failure Mode Severity as per SAE International (2002)

6.2.5 Alternate Occurrence List

As previous section helps with the description of the severity, this will help to also visualise and describe the occurrence needed for calculating RPN with the same range of 1 - 10. On Figure 6.8, ten rankings are shown within the five levels of failure mode occurrence; remote, low, moderate, high, and very high. Then, the ten rankings will have their respective frequency and probability.

Figure 6.8 also ranks from 1, which has the least occurring failure mode and least probability, to 10, which has the highest probability and very high occurrence level.

6.2.6 Alternate Detection List

The last thing needed for RPN number would be the ranking of detect-ability. This, like the severity, is a simple 1 - 10 ranking with the description for each ranking.

From Figure 6.9, it is shown that the lowest ranking 1 is when the failure mode is easily detected by the design control. Also when the ranking is at the highest (10), it means that the design control cannot detect the failure mode or even there is no design control. This means that it will make the failure more of an attention-seeker, hence will usually result in big RPN number.

Failure Mode Occurrence	Ranking	Frequency	Probability
Remote: Failure is unlikely	1	<= 0.010 per thousand vehicle/items	<= 1 x 10^-5
Low: Relatively few failures	2	0.1 per thousand vehicle/items	1 x 10^-4
	3	0.5 per thousand vehicle/items	5 x 10^-4
Moderate: Occasional failures	4	1 per thousand vehicle/items	1 x 10^-3
	5	2 per thousand vehicle/items	2 x 10^-3
	6	5 per thousand vehicle/items	5 x 10^-3
High: Repeated failures	7	10 per thousand vehicle/items	1 x 10^-2
	8	20 per thousand vehicle/items	2 x 10^-2
Very high: Failure is almost inevitable	9	50 per thousand vehicle/items	5 10^-2
	10	>= 100 in thousand vehicle/items	>= 1 10^-1

Figure 6.8: Occurrence of Failure Mode Related to Frequency and Probability

Detection	Criteria: Likelihood of Detection by Design Control	Ranking
Almost certain	Design Control will almost certainly detect a potential cause/mechanism and subsequent failure mode.	1
Very high	Very high chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.	2
High	High chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.	3
Moderately high	Moderately high chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.	4
Moderate	Moderate chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.	5
Low	Low chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.	6
Very low	Very low chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.	7
Remote	Remote chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.	8
Very remote	Very remote chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.	9
Absolutely uncertain	Design Control will not and/or cannot detect a potential cause/mechanism and subsequent failure mode; or there is no Design Control.	10

Figure 6.9: Detectability List

6.2.7 Evaluating RPN Number

There is a bit of ambiguity in the prioritizing the number due to the sensitive number change. One of the case would be:

- There is one failure which has high severity with low probability of occurrence and high detect-ability. We can say it has 10, 2, 2 respectively on the scale from figures above. Hence it has RPN of 40.

- On the other hand there is one failure which has medium severity, medium occurrence, and medium detect-ability. We can say it has 5, 4, 4. Hence, it has RPN number of 80, which is twice as the previous one.

In this case, companies and users usually has a policy of prioritising failures which have 9 or 10 or high severity first rather than the RPN number.

There are also some disadvantages using RPN, they are:

- Gaps - 88 percent of the range is empty as only 120 of 1000 numbers are generated International Electrotechnical Commission (2006).

- Several combinations might generate to the same RPN.

- Sensitive changes as one differences in number can create a big jump of RPN number.

RPN should be reviewed by experts with good judgements. Good practices would require thorough review of the values of the severity, occurrence, and detection. After that, measures would be made.

Chapter 7

Data Quality

Maintenance in this era require companies to interconnect their equipment or systems in the actual field with the accompanying data that comes along with them. They can be isometric drawing of a pipe, a parameter from a sensor on a pump, user manual of a compressor, etc. It is common for data to be misplaced, duplicated, or even place under the wrong place.

Data quality can be categorised as good (fit) if the data itself is usable in the context of the maintenance as per consumer/user perspective. Many techniques have been done to improve data quality over the years, some of them are data profiling, data standardisation, linking, and data cleaning (Al-Jumaili et al. (2011) Al-Jumaili et al. (2011)). As Al-Jumaili et al. (2011) mention, this topic also focus mainly on the data that affect and will have an impact to maintenance execution phase.

According to Wand and Wang (1996), there four types of data quality categories, they are:

1. Intrinsic: the quality of each data can be correct, example of this is mismatches of sources of the same data.

2. Contextual: it is required that data quality is considered within the context of the task, example of this is the incompleteness of data or wrongly defined data and that data should not be aggregated.

3. Representational: high quality data should be well represented, example of this is the interpret-ability, understand-ability, and consistent representation.

4. Accessibility: data must be accessible to the user or consumer in the most secure way possible.

Many of cases in this growing industry, personnel will have a hard time to do steps needed to see the data, extract and analyse, and transfer it to other accompanying departments. As Tretten et al. (2011) said that "Process industries are becoming more complex and at the same time greater demands are being placed upon the personnel", this means that there is a problem both sides. Instead of conducting training for personnel to be able to do the work, will it be better also if the data will be made and shown as easily extracted and transferred as possible.

7.1 Problems in Data Quality

According to the result of Al-Jumaili et al. (2011), it was found that there are few problems identified after conducting several interviews with maintenance personnel inside a Scandinavian mining company. Out of six problems they identified, this writing will focus only when the problem is suited to the data quality and not the problem with the CMMS system.

7.1.1 Data Multiplication

In many case, data related to maintained equipment would have to be acquired from company's file sharing system, whether it is a Microsoft Share Point or a linked server storage on the computer itself. Many times, several people will have these files on their own folder in the linked server storage, and then there are people who have it in the Share Point. It causes a confusion where people will not know which file is the most recent and updated one.

When updating has to be done, responsibility lies to people that have the data stored, and will not be clear as who is whom. This might create a prolonged activity and in the end of the day, it will not be updated.

7.1.2 Manual Transfer and Manual Input

This usually happen in the failure reporting and sometimes in the inspection of equipment. This is is caused by the data being transferred are varied in quality. There are cases where inspector see the parameter of an analog meter and he/she will take note of it on their notebook, but for the condition of the main equipment he/she inspects, he/she needs to write short descriptive sentences to best describe it and type it again later to the system.

Different inspectors on different days might resulted in different description for the same condition. Also, due to the manual transfer of this kind of data, missing and broken/corrupted can happen due to human error.

7.1.3 Missing or Difficult Performance Indicators

Status and efficiency of maintenance program are two of the parameters that could make the management happy or vice versa. To acquire data to be assessed to be efficiency might not as simple as it would be. CMMS would most of the time provide the material costs, salaries of the maintenance staff (usually per hour or day), cost and count of consumables, and also costs of subcontractors. This means the data is on the sub-process level, and not on equipment level. According to maintenance personnel interview results on Al-Jumaili et al. (2011), there is no available data that would assess the efficiency of the maintenance personnel or maintenance team.

7.1.4 Poor Internal Data Movement

CMMS will create a failure notice when there is a failure on site. The respective equipment is stored under a specific asset register data that it belongs to a certain department such as "Mechanical", "Electrical", "Rotating", etc. In real case, many failures will rooted in between those things and can only be done if several departments work together. This limits the information movement internally when only one department got noticed when a failure happens.

Also, communication wise, as separate departments personnel might have different area, information sharing can be limited as they are not together so often.

7.1.5 Recycling of Knowledge

In most sites, whenever there is a major unplanned shutdown (considered more than one hour), a Root Cause Failure Analysis (RCFA) will be conducted. Different companies might have different templates, but usually there are sets of questions of 5-whys leading to the unplanned shutdown. These would be stored in a word, excel, or as powerpoint presentation for the management to read. As time passes, these documents are rarely followed up to prevent similar problems in the future.

CMMS usage when a failure happens will have to be completed. It is checkout and a description will be made by the personnel in charge, example of this is like "valve has been replaced". More information can be stored such the root cause or the time details of the work but it is rarely done. Hence, it is a bit difficult to make this work order as a knowledge source for when a similar thing happen to similar equipment.

7.2 Dealing with Data Quality Problems

With several problems stated on the section above, several researchers have recommendations to accommodate those problems. Several of those of the source are Tretten et al. (2011) and Rasmussen (1983). Based on Tretten et al. (2011), there are four ways to minimise problems or errors in the data transfer quality. They are:

1. Simplifying tasks and give mental aids to methods. This could be made as an automated things to minimise unnecessary and complex work.

2. Training would be the simplest way to make personnel able to understand how the data flow from the equipment to users and finally to management.

3. System designs that should not allow personnel to misunderstand things to be done. Minimise systems that would make personnel do similar things that result in a different functions or contexts.

Chapter 8

Methodology and Result

In this chapter, the writer would like to show how the method for finding the maintenance strategy for a screw compressor. One of the first thing to do is requesting the manufacturer of the compressor itself for the data sheet. This allows the writer to see components and things to be taken care of. This could be aligned with the maintainable items.

The list of steps that can be used to do this are:

1. **Equipment Data Sheet** - Acquiring the type of equipment that is going to be analysed. This affects the OREDA page which has a lot of specific type of equipment.

2. **MTBF, Alpha, and Beta Calculation** - Acquiring the Mean Time Between Failures (MTBF), usually by company data or equipment-related published article. Alpha and beta would be acquired by the OREDA failure mode data and the expert's view of the impact of the failure mode respectively. This will be the basis of the calculation for criticality and probability of failure later on.

3. **Criticality** - This is a basic calculation from Equation 6.4. This step would also calculate the criticality of the maintenance time interval that would affect the probability of failure and the decision on the maintenance program for the designated maintainable item.

4. **Probability of Failure** - This is the continuation from criticality. It is derived from Equation 6.7. Each failure mode will have their own probability of failure.

5. **Decision** - Decision for the maintenance program that will be discussed in the Discussion of the next chapter.

8.1 Equipment Data Sheet

Data sheet provided by the manufacturer will usually look like Figure 8.1. The figure tells the reader about the compressor type and the driver type that would be the crucial differentiating

SERVICE CONDITION			
1	SERVICE : AIR		
2	DUTY : 2 x 100% (RUN/STAND BY & LEAD/LAG)		
3	TYPE : SCREW COMPRESSORS		
4	NUMBER OF STAGES : (*)		
5	CORROSIVE DUE TO : SALT LADEN ATMOSPHERIC		
OPERATING CONDITIONS			
6	ACTUAL CAPACITY PER COMPRESSOR	Sm³/h	(*)
7	SKID CAPACITY RATED (NOTE 19, 20)	Sm³/h	266.1 Sm³/hr @ 14.7 psia & 60°F (2 SETS)
8	**SUCTION CONDITIONS**		
9	RATIO OF SPECIFIC HEAT (Cp/Cv)		1.407
10	COMPRESSIBILITY, Z		0.9993
11	OPERATING TEMPERATURE (MIN/MAX)	°C	AMB (23 / 31)
12	OPERATING PRESSURE	barg	ATM
13	MASS FLOW	kg/h	325.2 (*)
14	ACTUAL INLET VOLUME	ACFM	(*)
15	**DISCHARGE CONDITIONS**		
16	RATIO OF SPECIFIC HEAT (Cp/Cv)		1.423 (*)
17	COMPRESSIBILITY, Z		0.997 (*)
18	OPERATING TEMPERATURE	°C	40 - 50 (*)
19	DISCHARGE PRESSURE	barg	10.6 barg (154 psig) (**)
20	TOTAL PRESSURE RATIO		(*)
21	POWER PER STAGE	kW	(*)
22	POWER DRIVER COUPLING	kW	(*)
23	DRIVER RATING	kW	(*)
24	DRIVER SPEED	rpm	(*)
25	DESIGN TEMPERATURE	°C	70 / 0
26	DESIGN PRESSURE **(Note 28)**	barg	12 barg (175 psig) (**)
ONDITION			
27	LOCATION ☐ INDOOR ■ OUTDOOR		
	☐ HEATED ■ UNHEATED		
28	TROPICALISATION REQUIRED : ■ YES ☐☐ NO		
29	AMBIENT TEMPERATURE	°C = 36 ; MIN = 18	
30	RELATIVE HUMIDITY	%	59 - 86
31	ELEVATION 0	m	22 (MEZZANINE DECK)
32	AREA CLASSIFICATION : UNCLASSIFIED		
33	NOISE LIMITATION : 85 dB (A) @ 1 m (as per PTS 12.01.02)		
34	WIND VELOCITY	m/s	14 (1 hour mean@ 2 years)
35	SEISMIC CONDITION : ELE : X= 0.085g; Y= 0.088g; Z= 0.220g		
35	0 ALE : X= 0.165g; Y= 0.163g; Z= 0.314g		
COMPRESSOR SKID CONNECTIONS			

PACKAGE SCOPE OF SUPPLY		
48	**COMPRESSOR TAG NO**	: K-5410 A/B
49	**COMPRESSOR TYPE**	: SCREW, OIL FREE TYPE
50	**DRIVER TYPE**	: ELECTRIC MOTOR
51	**COUPLING GUARD**	: ■ YES ☐ NO
52	**BASEPLATE :** ☐ SEPARATE	■ COMBINED ■ SKID
53	**LIFTING FRAMES**	: ■ YES ☐ NO
54	**INTAKE FILTER/SILENCER**	: ■ YES ☐ NO
55	**AIRCOOLER(S)**	: ■ YES ☐ NO
56	**PREFILTER** : YES	**AFTER FILTER** : YES
57	**OIL COOLER**	: ■ YES ☐ NO
58	**AUTO-CONDENSATE TRAP** :	■ YES (AUTOMATIC) ☐ NO
59	**AIR DRYER**	: ■ YES ☐ NO
60	DESICCANT CAGE	: ■ YES ☐ NO
61	BLOW OFF SILENCER	: ■ YES ☐ NO
62	VIBRATION MONITOR (ACCELEROMETER) :	☐ YES ■ NO
63	**INSTRUMENT SYSTEM OF PACKAGE :**	■ YES ☐ NO
64	WIRING CONTROLS & INSTRUMENTS :	■ YES ☐ NO
65	CONTROL PANEL :	■ YES ☐ NO
66	CONTROL PANEL TYPE :	■ LOCAL ☐ REMOTE
67	SPEC. REQUIRED : ISO 10440-2, BTP2B-EPCIC-BTJTB-M-SPC-0013	
68	PTS 12.11.35, PTS 14.10.02	
69	**ELECTRIC SYSTEM OF PACKAGE :**	■ YES ☐ NO
70	ELECTRIC MOTOR & ACCESSORIES	■ YES ☐ NO
71	ELECTRIC MOTOR POWER : kW	(*)
72	VOLTS : 400 PHASE : 3	Hz : 50
73	SPEC. REQUIRED : BTP2B-EPCIC-BTJTB-E-SPC-0001	
75	BTP2B-EPCIC-BTJTB-E-SPC-0011	
76	**INTERCONNECTING PIPEWORK AND VALVES :**	■ YES ☐ NO
77	MATERIALS : (*) BTP2B-EPCIC-BTJTB-P-SPC-0001	
78	PSV :	■ YES ☐ NO
79	**ENCLOSURE** : (*)	■ YES ☐ NO
80	ENCLOSURE TYPE : (*) ■ ACOUSTIC	■ WEATHERPROOF
81	AIR COOLING SYSTEM	■ YES ☐ NO
82	**PAINTING & COATING :**	■ YES ☐ NO
83	SPEC. REQUIRED : PTS 15.20.03, PROTECTIVE COATINGS AND LINING	
84	FOUNDATION BOLTS :	■ YES ☐ NO
85	COOLING WATER SUPPLY :	☐ YES ■ NO
86	LUBRICATION SYSTEM :	■ YES ☐ NO
CASING		
87	MODEL	(*)
88	MATERIAL AND GRADE	(*)

Figure 8.1: Mechanical Data Sheet of The Compressor

table in OREDA (2002).

This equipment data sheet shows that the writer will choose electric driven screw compressor from OREDA data. This will take the failure modes and maintainable items specific to the said equipment.

It is still missing MTBF data of the used compressor. MTBF data will usually be present from the company standard or requirement and be complied by the manufacturers of the said equipment. Due to the limitation of acquiring data from a company, the writer will use the published article. The data from Budiman (2015) shows the failure history of a compressor in Indonesian oil and gas facility from 2006 and 2010. This failure data would then be calculated to acquire the MTBF, alpha, and beta that would be required in Equation 6.4.

Taxonomy no		Item				
1.1.3.2		Machinery Compressors Screw Electric driven				
Population	**Installations**	**Aggregated time in service (10^6 hours)**				**No of demands**
		Calendar time *		**Operational time** †		
33	16	1.0800		0.5894		38694

Failure mode	**No of failures**	**Failure rate (per 10^6 hours).**					**Active rep.hrs**	**Repair (manhours)**		
		Lower	**Mean**	**Upper**	**SD**	**n/τ**		**Min**	**Mean**	**Max**
Critical	**79***	**0.00**	**119.07**	**623.23**	**280.02**	**73.15**	**14.7**	**1.0**	**23.2**	**163.0**
	79†	**0.00**	**140.31**	**771.01**	**373.65**	**134.04**				
Erratic output	4*	0.00	7.43	41.04	20.71	3.70	6.8	7.0	9.8	15.0
	4†	0.00	9.79	53.91	26.83	6.79				
External leakage - Process medium	2*	0.43	2.02	4.58	1.33	1.85	17.5	12.0	29.0	46.0
	2†	0.00	3.55	15.81	6.24	3.39				
External leakage - Utility medium	7*	0.00	12.91	71.93	37.34	6.48	14.1	13.0	38.9	96.0
	7†	0.00	16.30	92.72	49.64	11.88				
Fail to start on demand	12*	0.01	19.39	85.34	33.45	11.11	5.9	1.0	8.7	32.0
	12†	0.03	27.31	112.65	42.77	20.36				
Low output	11*	0.00	18.32	100.68	48.26	10.19	16.2	2.0	26.7	163.0
	11†	0.00	22.95	126.63	63.80	18.66				
Noise	1*	0.00	1.14	6.30	3.17	0.93	73.0	76.0	76.0	76.0
	1†	0.00	1.64	7.89	3.25	1.70				
Other	1*	0.00	1.14	6.30	3.17	0.93	7.0	7.0	7.0	7.0
	1†	0.00	1.64	7.89	3.25	1.70				
Overheating	4*	0.00	5.69	25.77	10.24	3.70	20.1	2.0	20.5	70.0
	4†	0.05	7.60	26.23	9.67	6.79				
Parameter deviation	2*	0.01	2.90	11.70	4.40	1.85	10.8	11.0	21.5	32.0
	2†	0.00	4.42	21.89	9.28	3.39				
Spurious stop	34*	0.00	49.58	255.89	111.67	31.48	15.8	2.0	23.6	148.0
	34†	0.00	60.15	320.06	146.70	57.69				
Structural deficiency	1*	0.00	1.64	8.64	3.90	0.93	21.5	43.0	43.0	43.0
	1†	0.01	1.96	7.64	2.83	1.70				
Degraded	**92***	**0.00**	**145.57**	**800.25**	**391.94**	**85.19**	**9.2**	**1.0**	**15.2**	**111.0**
	92†	**0.00**	**163.88**	**929.89**	**529.52**	**156.10**				
Abnormal instrument reading	1*	0.00	1.14	6.30	3.17	0.93	5.0	5.0	5.0	5.0
	1†	0.00	1.64	7.89	3.25	1.70				
Erratic output	5*	0.00	8.39	44.63	20.45	4.63	6.9	2.0	10.6	35.0
	5†	0.00	11.16	58.06	25.82	8.48				

Figure 8.2: OREDA Page for Electric Driven Screw Compressor

Maintainable item versus failure mode, to be continued
Item: Compressors - Screw

	AIR	BRD	ELP	ELU	ERO	FTS	HIO	INL	LOO	NOI
Base frame	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bearing	0.00	0.00	0.00	1.37	0.00	0.00	0.00	0.00	0.00	0.00
Cabling & junction boxes	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Casing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Control unit	0.00	0.00	0.00	0.00	0.69	0.34	0.00	0.00	0.00	0.00
Cooler(s)	0.00	0.00	0.00	0.86	0.00	0.00	0.00	0.00	0.00	0.00
Coupling to driver	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00
Dry gas seal	0.00	0.00	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.00
Filter(s)	0.17	0.00	0.00	0.69	0.00	0.00	0.00	0.00	0.69	0.00
Instrument, flow	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Instrument, general	1.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Instrument, level	0.69	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00
Instrument, pressure	6.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Instrument, speed	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Instrument, temperature	9.28	0.00	0.00	0.00	0.00	1.03	0.00	0.00	0.00	0.00
Instrument, vibration	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Internal piping	0.17	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Internal power supply	0.34	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00
Interstage seals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lube oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.69	0.00
Monitoring	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.34	0.34	0.00	0.00	0.00	0.00	0.34	0.00
Piping	0.00	0.00	0.00	3.26	0.00	0.00	0.00	0.00	0.00	0.00
Piping, pipe support + bellows	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pump w/motor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Purge air	0.00	0.00	0.00	0.34	0.00	0.34	0.00	0.00	0.00	0.00
Radial bearing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reservoir w/heating system	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rotor w/ impellers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
Seals	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00
Shaft seals	0.00	0.00	0.34	3.44	0.00	0.00	0.00	0.00	0.00	0.00
Subunit	0.69	0.00	0.34	0.69	0.00	0.00	0.00	0.34	1.03	0.34
Unknown	0.00	0.00	0.34	0.69	0.00	0.69	0.00	0.00	0.00	0.00
Valves	0.69	0.00	1.03	0.69	2.41	1.03	0.00	0.00	3.09	0.00
Total	22.68	0.00	2.75	13.75	3.09	4.12	0.00	0.34	5.84	0.69

Figure 8.3: Sample of Maintainable Item vs. Failure Mode of Screw Compressor

From OREDA (2002), the equipment the writer acquired is screw compressor that is electric driven. This is shown in Figure 8.2 that will be shown in full in Appendix D. The figure includes the failure mode of the electric driven screw compressor and the repair hours in which the writer will only use the **mean** failure rate per one million hours.

From Figure 8.3, it shows the maintainable item versus failure mode that the screw compressor has. This is the specific version of screw compressor from the previous general compressor from Figure 4.3. The writer would not use the failure descriptor part of the screw compressor as shown on Figure 4.4 as it is not needed to the calculation.

8.1.1 Compressor Assumptions

Note that the writer will have several assumptions regarding this electric driven screw compressor, they are:

1. The writer will assume that the compressor will work full shift without break. That means in OREDA, failure rate that will be acquired for each failure mode is the calendar time, instead of the operational time. This is denoted by the star symbol rather than the cross symbol.

2. Compressor failure data from Budiman (2015) is not so clear on what type of compressor it is. The writer will use it nonetheless.

3. The electric driven screw compressor is only viewed as an equipment without effects to the surrounding systems. So the impact for beta values will be analysed for the impact of the failure to the own equipment, not to the parenting system nor the surrounding systems.

8.2 MTBF, Alpha, and Beta Calculation

These three parameter can be calculated through several methods. This section would be split to each parameter and how the writer get the number until the step that will be taken to the next calculation. All of the calculation in this section onwards will be done using Microsoft Excel using the equation that are given in Chapter 2. No special software or features needed.

8.2.1 MTBF

Mean Time Between Failure (MTBF) means that the writer needs to have failures data to calculate the average time between those failures. Data is sourced from Budiman (2015) that acquired the data from an Indonesian oil and gas company.

FAILURE HISTOR				
No	Fail Time (Date & Time)	Start to Repair (Date & Time) [*optional]	Finish to Repair (Date & Time) [*optional]	Start to Run Time (Date & Time)
1	28 Jan 2006 - 15.00			31 Jan 2006 - 09.00
2	19 Feb 2006 - 00.00			19 Feb 2006 - 19.00
3	21 Jun 2006 - 00.00			21 Jun 2006 - 18.30
4	08 Jul 2006 - 00.00			08 Jul 2006 - 03.00
5	18 Dec 2006 - 00.00			22 Dec 2006 - 15.15
6	01 Jan 2007 - 00.00			01 Jan 2007 - 03.00
7	13 Mar 2007 - 00.00			13 Mar 2007 - 20.20
8	23 Mar 2007 - 00.00			23 Mar 2007 - 17.00
9	15 Jul 2007 - 00.00			15 Jul 2007 - 14.00
10	15 Aug 2007 - 00.00			15 Aug 2007 - 07.30
11	27 Oct 2007 - 00.00			27 Oct 2007 - 12.15
12	18 Nov 2007 - 00.00			18 Nov 2007 - 03.30
13	15 Dec 2007 - 00.00			15 Dec 2007 - 02.40
14	17 Sep 2008 - 00.00			17 Sep 2008 - 13.30
15	10 Nov 2008 - 00.00			10 Nov 2008 - 09.30
16	30 May 2009 - 00.00			14 Jul 2009 - 09.00
17	28 Dec 2009 - 00.00			13 Jan 2010 - 07.00
18	29 Jun 2010 - 00.00			14 Aug 2010 - 04.00
19	04 Sep 2010 - 00.00			15 Sep 2010 - 20.00
20	15 Oct 2010 - 00.00			28 Nov 2010 - 08.00
21	15 Dec 2010 - 00.00			16 Dec 2010 - 00.00

Figure 8.4: Failure History Adapted from Budiman (2015)

Time to Repair TTR (Hours)	Overall Delay Time (Hours)	Total Downtime (Hours)	Time to Fail TTF / Time Between Failure TBF (Hours)
66	0	66	663
19	0	19	447
18,5	0	18,5	2909
3	0	3	389,5
111,25	0	111,25	3909
3	0	3	224,75
20,33333333	0	20,33333333	1701
17	0	17	219,6666667
14	0	14	2719
7,5	0	7,5	730
12,25	0	12,25	1744,5
3,5	0	3,5	515,75
2,67	0	2,67	644,5
13,5	0	13,5	6645,33
9,5	0	9,5	1282,5
1089	0	1089	4814,5
391	0	391	3999
1108	0	1108	4001
284	0	284	500
1064	0	1064	700
24	0	24	400

Figure 8.5: Time Between Failures

MTBF	1864,714127
Failure Rate (1/MTBF)	**0,000536275**

Figure 8.6: Failure Rate from Real MTBF

The actual data from the article shows the date of shutdown and the running time in between failures, so in this case Time Between Failure (TBF). Time To Repair (TTR) and the time of starting again is not really important in this whole situation. MTBF would then be calculated by averaging those TBF values.

This MTBF would be used to calculate actual failure rate by dividing it from 1 as equated below:

$$\lambda = 1/MTBF \tag{8.1}$$

Figure 8.6 shows the actual failure rate value from the data acquired. This value would then be crucial for criticality and probability of failure calculation as it follows through the next several sections.

8.2.2 Alpha

Alpha number is decided from the number in Figure 8.3 and Appendix D. Each of the failure mode like AIR, ELP, ELU, etc. will have total number on the bottom of the table. Then this number would then be divided by the total of the table that should be 100, but due to several rounding offs, the exact number the writer got is 99.85. So in this case, AIR total of 22.68 would be divided by 99.85 to get AIR designated alpha value. This applies to all of the failure mode, so the next one for ELP would be 2.75 divided by 99.85 for its alpha value. This means that the sum of all of the alphas should be 1. This would be shown in Figure 8.8.

8.2.3 Beta

Beta number is a bit difficult to acquire because of the semi-quantitative nature of it. It needs the understanding of each failure mode (FM) and how impactful the failure mode is to the equipment. To make matter easier, the beta value could be divided onto four values between 0 to 1.

On Figure 8.7, beta number is divided onto 0.1, 0.25, 0.75, and 1. These are categorised as negligible, less impact, impactful, and failed respectively. Negligible means that the FM has

FM Severity	Description	Beta
NEGLIGIBLE	No effect to the equipment.	0,1
LESSIMPACT	Prolonged effect. No direct effect to performance.	0,25
IMPACTFUL	Effect to performance. Reduced.	0,75
FAILED	Failed equipment.	1

Figure 8.7: Beta Values Table

no effect to the equipment. Less Impact means that the FM has some indirect impact to the equipment such as corrosion. Impactful means that the FM can impact to the performance of the equipment. Failed means that the FM will directly make the equipment fail to do its function.

8.3 Failure Rate and Criticality

8.3.1 Failure Rate of Failure Modes

OREDA data that acquired for screw compressor will then be used in the Equation 6.4 for seeing how critical are the failures. This would allow the writer to sort the most critical failure to the least critical failure, which then decide how the interval of maintenance and maintenance activities will be done to the maintainable items.

Figure 8.8 shows all the Failure Mode on the first column with their respective probability number to be used for the alpha. The alpha is column two value divided by the total on the bottom of column two. Failure rates per one million hours are acquired from OREDA, but to be able to do the calculation, the writer needs the failure mode in per hour. The failure rates from OREDA are divided by one million to have the failure rates per hour that we call Lambda. Then, based on Figure 8.7, each failure mode will be categorised for their impact to the equipment. Thus, the beta value will show according to the categorisation. The last column shows the failure rate per failure mode from Equation 6.3.

8.3.2 Criticality with Time Interval

Criticality is derived from the failure rate that the writer got in Figure 8.8, but before proceeding to the calculation, this Equation 6.4 needs time interval. This time interval is the maintenance time interval companies apply in the real world. It usually will be something like; daily, weekly, monthly, yearly. In this case, the writer will list the time intervals for this calculation below.

- Daily (24 hours)

Failure Mode	FM	Alpha	Failure Rate per 10^6 Hours	Lambda (per hour)	FM Severity	Beta	Lambda.A.B
AIR	22,670	0,227	109,46	0,0000109460	IMPACTFUL	0,75	1,86389E-06
BRD	0,000	0,000	0,00	0,0000000000	NEGLIGIBLE	0,1	0
ELP	2,730	0,027	12,52	0,0000012520	FAILED	1	3,42309E-08
ELU	13,740	0,138	65,46	0,0000065460	FAILED	1	9,00772E-07
ERO	3,100	0,031	15,82	0,0000015820	IMPACTFUL	0,75	3,68368E-08
FTS	4,110	0,041	19,39	0,0000019390	LESSIMPACT	0,25	1,99532E-08
HIO	0,000	0,000	0,00	0,0000000000	NEGLIGIBLE	0,1	0
INL	0,340	0,003	1,14	0,0000001140	IMPACTFUL	0,75	2,91137E-10
LOO	5,840	0,058	24,23	0,0000024230	IMPACTFUL	0,75	1,06287E-07
NOI	0,680	0,007	2,28	0,0000002280	LESSIMPACT	0,25	3,88182E-10
OHE	2,390	0,024	8,86	0,0000008860	FAILED	1	2,12072E-08
OTH	5,480	0,055	23,29	0,0000023290	IMPACTFUL	0,75	9,58657E-08
PDE	13,390	0,134	68,41	0,0000068410	IMPACTFUL	0,75	6,88039E-07
SER	10,640	0,107	51,24	0,0000051240	LESSIMPACT	0,25	1,36503E-07
STD	1,700	0,017	6,61	0,0000006610	IMPACTFUL	0,75	8,44041E-09
STP	0,000	0,000	0,00	0,0000000000	NEGLIGIBLE	0,1	0
UNK	1,370	0,014	9,62	0,0000009620	LESSIMPACT	0,25	3,2998E-09
UST	11,670	0,117	49,58	0,0000049580	IMPACTFUL	0,75	4,34601E-07
VIB	0,000	0,000	0,00	0,0000000000	NEGLIGIBLE	0,1	0
Total	**99,85**	**1**	**467,91**	**0,0000467910**			**0,0000043506**

Figure 8.8: Failure Mode to Failure Rate Calculation

- Weekly (168 hours)
- Bi-weekly (336 hours)
- Monthly (730 hours)
- 2-monthly (1460 hours)
- 3-monthly (2190 hours)
- 6-monthly (4380 hours)
- Yearly (8760 hours)
- 2-yearly (17520 hours)

This will allow the writer to see which time interval would create the highest or lowest criticality and then the same thing would be done to the calculation of Probability of Failure at the end.

Figure 8.9 shows several failure modes if their failure rate is multiply by several time interval listed above. The full table of the criticality calculations can be seen on Appendix E. From the sample it can be seen that the higher the time interval would result in the higher number of criticality. This is due to the fact that the maintainable item is not maintained in that time interval, hence the longer the interval period, the more worn and tired the item will be.

Maintenance Interval	Time	AIR	BRD	ELP	ELU	ERO	FTS
Daily	24	4,47333E-05	0	8,21543E-07	2,16185E-05	8,84082E-07	4,78876E-07
Weekly	168	0,000313133	0	5,7508E-06	0,00015133	6,18857E-06	3,35213E-06
Bi-weekly	336	0,000626267	0	1,15016E-05	0,000302659	1,23771E-05	6,70426E-06
Monthy	730	0,001360639	0	2,49886E-05	0,000657563	2,68908E-05	1,45658E-05
2-monthly	1460	0,002721279	0	4,99772E-05	0,001315126	5,37817E-05	2,91316E-05
3-monthly	2190	0,004081918	0	7,49658E-05	0,00197269	8,06725E-05	4,36974E-05
6-monthly	4380	0,008163836	0	0,000149932	0,003945379	0,000161345	8,73948E-05
Yearly	8760	0,016327672	0	0,000299863	0,007890759	0,00032269	0,00017479
2-yearly	17520	0,032655344	0	0,000599726	0,015781518	0,00064538	0,000349579

Figure 8.9: Sample of Criticality Calculation

Maintenance Interval	Time	AIR	BRD	ELP	ELU	ERO	FTS
Daily	24	4,47323E-05	0	8,21542E-07	2,16183E-05	8,84082E-07	4,78876E-07
Weekly	168	0,000313084	0	5,75078E-06	0,000151318	6,18856E-06	3,35212E-06
Bi-weekly	336	0,000626071	0	1,15015E-05	0,000302613	1,23771E-05	6,70424E-06
Monthy	730	0,001359714	0	2,49883E-05	0,000657347	2,68905E-05	1,45657E-05
2-monthly	1460	0,002717579	0	4,99759E-05	0,001314262	5,37802E-05	2,91312E-05
3-monthly	2190	0,004073598	0	7,4963E-05	0,001970745	8,06692E-05	4,36965E-05
6-monthly	4380	0,008130602	0	0,00014992	0,003937607	0,000161332	8,7391E-05
Yearly	8760	0,016195098	0	0,000299818	0,007859709	0,000322638	0,000174774
2-yearly	17520	0,032127915	0	0,000599546	0,015657642	0,000645172	0,000349518

Figure 8.10: Sample of Probability of Failures

The actual highest criticality number would be the Abnormal Instrument Reading (**AIR**) failure mode with 2-yearly interval (17520 hours), while the lowest of them is Internal Leakage (**INL**) failure mode with daily (24 hours) interval. They have criticality of 0.032127915 and 6.98728E-09 respectively by excluding several failure modes that have 0 values.

8.4 Probability of Failure

Calculation of Probability of Failure will use Equation 6.7. This means that the result of the equation would be a percentage number. The result can be seen on Figure 8.10.

The full table can be seen also in Appendix E and Appendix F with the Criticality. Due to small numbers, the result of probability is not so far from the criticality. The highest probability of failure is also from failure mode Abnormal Instrument Reading (**AIR**) in the 2-yearly (17520 hours) interval with value 0.032127915 while the lowest is from failure mode Internal Leakage (**INL**) in daily (24 hours) interval with the value of 6.98728E-09.

Probability of Failue		Quantitative Range
At least once every < 6 months	**Frequent**	> 2.28E-04
At least once every 6 months to 2 years	**Probable**	2.28E-04 to 5.70776E-05
At least once every 2 to 4 years	**Rare**	5.70776E-05 to 2.85388E-05
At least once very 4 to 20 years	**Remote**	2.85388E-05 to 5.70776E-06
At least once every > 20 years	**Improbable**	5.70776E-06 >

Figure 8.11: Qualitative and Quantitative Categories of PoF

8.4.1 Categorising PoF

From the numbers above, it is hard for people to know which one is good and which one is best because the number is quite abstract in a way that it is a percentage or probability and they are very small in quantity. To make life easier, categories would be needed to group these PoF numbers to good or bad numbers using the qualitative versus quantitative range. The time description each company or standards have will differ one to another, but the basic idea is to group the number to a group of frequency. In this case the qualitative categories are:

- At least once every less than six months,
- At least once every six months to two years,
- At least once every two to four years,
- At least once every four to twenty years,
- At least once every more than twenty years.

To group the PoF numbers, the writer would change these qualitative categories to quantitative by dividing one to the time frame in hours. The first example would be once every less than six months. Six months would have six times of 730 hours per month, which results to 4380 hours. The probability of it happening once every less than six months would be 1/4380 hours. So the quantitative probability range would be > (1/4380). Each group would have each number as shown in Figure 8.11.

From the sample results in Figure 8.10, the five colours would be applied to the numbers. Hence, the higher the number would results in a spectrum towards red colour, but as it can be seen on Figure 8.12, **AIR** failure mode is quite critical as it possesses red colour even on the weekly interval.

To have a better view on how these probabilities of failures stack with their respective severity (beta value), Figure 8.13 gives an visual representation on how the failure modes are placed in the criticality matrix as per Figure 6.6. One thing to consider is that this is the average value

Maintenance Interval	Time	AIR	BRD	ELP	ELU	ERO	FTS
Daily	24	4,47323E-05	0	8,21542E-07	2,16183E-05	8,84082E-07	4,78876E-07
Weekly	168	0,000313084	0	5,75078E-06	0,000151318	6,18856E-06	3,35212E-06
Bi-weekly	336	0,000626071	0	1,15015E-05	0,000302613	1,23771E-05	6,70424E-06
Monthy	730	0,001359714	0	2,49883E-05	0,000657347	2,68905E-05	1,45657E-05
2-monthly	1460	0,002717579	0	4,99759E-05	0,001314262	5,37802E-05	2,91312E-05
3-monthly	2190	0,004073598	0	7,4963E-05	0,001970745	8,06692E-05	4,36965E-05
6-monthly	4380	0,008130602	0	0,00014992	0,003937607	0,000161332	8,7391E-05
Yearly	8760	0,016195098	0	0,000299818	0,007859709	0,000322638	0,000174774
2-yearly	17520	0,032127915	0	0,000599546	0,015657642	0,000645172	0,000349518

Figure 8.12: Categorising Probability of the Failure Mode

Likelihood - probability of occurrence		Negligible	Less Impact	Impactful	Failed
	5 [A]		SER	AIR LOO OTH PDE UST	ELU
	4 [B]		FTS	ERO	ELP OHE
	3 [C]			STD	
	2 [D]		UNK		
	1 [E]		NOI	INL	

Figure 8.13: Average FM PoF vs. Beta Severity

No.	Failure Mode	Failure Mode Code	Beta	Maintainable Item (Failure Cause)	Probability	Alpha
1	Abnormal Instrument Reading	AIR	0,75	Cabling & junction boxes	0,34	0,003405108
		AIR	0,75	Filter(s)	0,17	0,001702554
		AIR	0,75	Instrument, flow	0,34	0,003405108
		AIR	0,75	Instrument, general	1,72	0,017225839
		AIR	0,75	Instrument, level	0,69	0,006910366
		AIR	0,75	Instrument, pressure	6,53	0,065398097
		AIR	0,75	Instrument, speed	0,34	0,003405108
		AIR	0,75	Instrument, temperature	9,28	0,092939409
		AIR	0,75	Instrument, vibration	0,34	0,003405108
		AIR	0,75	Internal piping	0,17	0,001702554
		AIR	0,75	Internal power supply	0,34	0,003405108
		AIR	0,75	Monitoring	0,69	0,006910366
		AIR	0,75	Reservoir w/ heating system	0,34	0,003405108
		AIR	0,75	Subunit	0,69	0,006910366
		AIR	0,75	Valves	0,69	0,006910366

Figure 8.14: Sample of AIR Failure Mode with its Maintainable Items

of each failure mode's probability of failure from Figure 8.12. This might not give the actual representation of the failure mode and how to mitigate them. The answer would take us back to Figure 8.3 of maintainable items of the equipment.

For failure mode **AIR**, it is shown that it has fifteen (15) maintainable item applicable for the failure. The writer listed them all in order as per OREDA (2002) and alongside the maintainable items are the respective probability. This is due to the fact that the Alpha value before is for the whole failure mode, so in this case Alpha would be lower as it is divided per maintainable item and each number would be divided by 99.85 as done before. To double check the Alpha value, the total of the maintainable items' Alpha per failure mode should be equal to the previously calculated failure mode's Alpha in Figure 8.8 of the Failure Rate of Failure Modes sub-section. Using excel, the total of this AIR maintainable items Alpha is 0.227040561, which should be the same as Figure 8.8 with the round off to 0.227.

Continuing from the alpha and beta values for each maintainable item, using the failure rate from OREDA table for electric driven screw compressor, the criticality of each failure mode for each maintainable item can be calculated using Equation 6.4. The time used would be the same categories; Daily (24 hours) and up to 2-yearly (17520 hours). Then, using Equation 6.7, we can get numbers of Probability of Failure for each maintainable item. This sample for **AIR** failure mode is shown on Figure 8.15.

According to Figure 8.11, here are the colour categories for the result in Figure 8.15:

1. Dark green would mean that the failure of the specific maintainable item would be *improbable*,

2. Light green would mean that the failure of the specific maintainable item is *remote*,

Maintenance Interval Time								
Daily	Weekly	Bi-Weekly	Monthly	2-monthly	3-monthly	6-monthly	Yearly	2-yearly
6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
3,35451E-07	2,34815E-06	4,6963E-06	1,02032E-05	2,04064E-05	3,06094E-05	6,12179E-05	0,000122432	0,000244849
6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
3,39397E-06	2,37575E-05	4,75145E-05	0,000103228	0,000206445	0,000309652	0,000619208	0,001238033	0,002474533
1,36153E-06	9,5307E-06	1,90613E-05	4,14125E-05	8,28233E-05	0,000124232	0,000248449	0,000496837	0,000993427
1,28852E-05	9,01927E-05	0,000180377	0,00039185	0,000783546	0,001175089	0,002348797	0,004692076	0,009362137
6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
1,83115E-05	0,000128173	0,00025633	0,000556825	0,001113339	0,001669544	0,003336301	0,006661471	0,013278568
6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
3,35451E-07	2,34815E-06	4,6963E-06	1,02032E-05	2,04064E-05	3,06094E-05	6,12179E-05	0,000122432	0,000244849
6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
1,36153E-06	9,5307E-06	1,90613E-05	4,14125E-05	8,28233E-05	0,000124232	0,000248449	0,000496837	0,000993427
6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
1,36153E-06	9,5307E-06	1,90613E-05	4,14125E-05	8,28233E-05	0,000124232	0,000248449	0,000496837	0,000993427
1,36153E-06	9,5307E-06	1,90613E-05	4,14125E-05	8,28233E-05	0,000124232	0,000248449	0,000496837	0,000993427

Figure 8.15: Sample of AIR Failure Mode with its Maintainable Items PoF

3. Yellow result would mean that the maintainable item failure is *rare*,
4. Orange result would mean that the failure of the maintainable item would be *probable*, and
5. Red would mean that the failure of the specific maintainable item is *frequent*.

From Figure 8.14 and Figure 8.15, the sixth and eighth row of the maintainable item are pressure and temperature instruments respectively. They are in *probable* probability even when they are maintained weekly. This is where the maintenance activities will be assigned to maintainable items and the interval they need to stay available and reliable.

8.5 Criticality and PoF of Actual Failure Rate

Using the same method, but using real failure rate from Figure 8.6 and directly multiplying it to the maintenance time interval, we would get Figure 8.16. The MTBF value of 1864,71 hours or equivalent to 77 days resulted to these criticality and probability of failure values. These values are only derived from one big equipment, so there is no maintainable items section here, hence the values generated are relatively big, noted with all red even with daily maintenance interval.

The decision regarding what to do when the result colour is all red as this will be discussed on the result and discussion.

8.6 Result

Full result of figures above are attached on Appendix E, Appendix F, and Appedix G. From the results, there are a few take-away:

CRITICALITY				PROBABILITY		
Maintenance Interval	Time	Total		Maintenance Interval	Time	Total
Daily	24	0,012870606		Daily	24	0,012788134
Weekly	168	0,090094239		Weekly	168	0,086154939
Bi-weekly	336	0,180188478		Bi-weekly	336	0,164887204
Monthy	730	0,391480919		Monthy	730	0,32394505
2-monthly	1460	0,782961838		2-monthly	1460	0,542949704
3-monthly	2190	1,174442757		3-monthly	2190	0,691008885
6-monthly	4380	2,348885514		6-monthly	4380	0,904524491
Yearly	8760	4,697771027		Yearly	8760	0,990884427
2-yearly	17520	9,395542055		2-yearly	17520	0,999916906
				Average		0,524117749

Figure 8.16: Criticality and PoF of Actual Failure Rate

- The failure rate acquired from OREDA for failure mode **AIR**, **PDE**, and **ELU** are the two highest, hence the three have the highest probability of failure in the end when it comes to the calculation with the *alpha* and *beta*.

- Criticality number and the probability of failure will not be so much of a difference.

- There are items that appear in more than one failure mode such as pressure and temperature instrument. The decision in this kind of situation is to choose the one with higher probability of failure, in this case pressure and temperature instrument have the highest probability of failure in AIR failure mode. Hence companies should decide on maintain that failure mode only, in sense that other failure modes would then be eliminated by chosen the maintenance interval.

- As stated above, probability of failure of temperature and pressure instrument in **AIR** failure mode are the two most probable. Hence the users might have to think about making maintenance strategies that are quite strict around these instruments. The closest call might be creating a daily visual inspection to these instruments.

Chapter 9

Discussion

In this chapter, the writer will shortly show the result of the analysis and calculation and then discuss what affected the result and what will it affect afterwards.

9.1 Result Summary

Here are short summary of the result we had in the previous chapter:

1. Abnormal Instrument Reading (**AIR**) has the highest probability of happening.

2. The highest values of maintainable item for **AIR** are Pressure and Temperature instrument. This can be seen with orange colour even in weekly maintenance interval on Figure 8.15.

3. The most applicable strategies for the two highest probability of failure would be to have a daily inspection or maintenance to maintain the probability of failure in the *remote* category.

4. Actual failure rate gives a high probability of failure, coloured red even on daily maintenance interval.

9.2 Discussion

Topics to discuss around the area of this maintenance strategy is what affected the analysis and what comes after the analysis. This means parameters that happened before the analysis will be **Pre-Analysis Parameters** and what comes after is **Post-Analysis Discussion**.

9.2.1 Pre-Analysis Parameters

Data Sheet

Availability and confidentiality of specific equipment data sheet might have an effect in this kind of analysis. On the other hand, this kind of analysis usually is done within a company with third-party contractor who has access to the confidential documents of the clients. In this case, data sheet Petronas Carigali Muriah ltd. (2020) is used for determining the specific failure table from OREDA (2002) as each equipment type (e.g., compressor, pump, etc.) will have a lot of different variability like electric motor with a certain power, or even what fluid it processes. Keep it mind that we have to be very specific to be able to choose to closest as possible OREDA data from the actual historical field data.

Actual Failure Rate

Actual failure rate from actual MTBF acquired from field data might be good for big equipment, but it might be unclear to which components to maintain. As the result in Figure 8.16 shows, red colour dominates from the lowest maintenance interval. This means that it must be maintained properly at the lowest maintenance interval possible or this can also suggest that it is better to change the whole compressor specification to higher MTBF.

Beta Value Limitation

Creating a beta value in Figure 8.7 is limited to only four values. In the real analysis with experts doing it, these value might vary according to the experts' view. The numbers that the experts will come with will be usually a lot more closer to the actual severity of the failure mode due to more experience with the field.

Probability Categories

Categories of the probability of failures; *improbable, remote, rare, probable,* and *frequent* are the basic time allocation for oil and gas companies. In this case, Petronas Carigali Muriah ltd. (2019) has them in this kind of order and time (6 months, 2 years, 4 years, and 20 years). This kind of categories might vary for every company, but then they will know that this is just to make it easier for the top management and the economy people to see how the risk of failure and the probability work in an equipment.

9.2.2 Post-Analysis Discussion

Numerical Results

Results that are made from the equation are attached on Appendix E and Appendix F. Appendix E contains the data acquired from OREDA (2002) and are tabulated with *alpha* and *beta* values. This will create calculation of Lambda.A.B (lambda x alpha x beta) from Equation 6.3. This will then be continued onto the table below with the addition of the maintenance time interval making it criticality from Equation 6.4. Then the bottom table are the probability of failures for the specific failure mode. This is calculated from Equation 6.7.

Appendix F is the continuation of the probability of failure on Appendix E with more detailed look on the maintainable items. This will allow the viewers to see which item is more probable to failures and the users to decide how the maintenance strategy would be.

Actual Failure Rate Result

The result in Figure 8.16 shows that the current MTBF of the actual compressor is not so good. At the moment, it has MTBF value of 77 days and by our categorisation of probability that would be under once every six months. Few take-away shall be listed below:

- The decision of the engineers/company would have to be so strict that they will keep this compressor running without problem,
- This usually means that they will opt for condition monitoring where they will have sensors that sense performance parameters, usually every ten or twenty seconds over the running period. This will create data trends that could be used for further analytical methods or just to know whether or not there is a deviation in the usual performance,
- And other thing to consider for them is to change the specification of the compressor entirely by choosing another compressor with better starting MTBF from the manufacturer's data sheet.

Maintenance Strategy

Looking at Appendix F and Appendix G, all of these maintainable items would have their designated maintenance interval that suits them based on the analysis and the colour result on the table. On Appendix G, they were all sorted by maintainable items alphabetically. Sample of the sorted maintainable item can be seen on Figure 9.1 where it is angled counter-clockwise to see a bit more of these maintainable items. Some of the take-away that can be stated are:

- Maintainable items can have more than one failure mode,

No.	Failure Mode	Failure Mode Code	Beta	Maintainable Item (Failure Cause)	Probability	Alpha	Maintenance Interval Time								
							Daily	Weekly	Bi-Weekly	Monthly	2-monthly	3-monthly	6-monthly	Yearly	2-yearly
93	Structural Deficiency	STD	0,8	Base frame	0,34	0,00340511	4,0514E-08	2,836E-07	5,672E-07	1,2323E-06	2,4646E-06	3,6969E-06	7,3938E-06	1,4787E-05	2,9575E-05
22	External Leakage - Utility Medium	ELU	1	Bearing	1,37	0,01372058	2,1556E-06	1,5089E-05	3,0177E-05	6,5563E-05	0,00013112	0,00019668	0,00039331	0,00078647	0,00157232
94	Structural Deficiency	STD	0,8	Bearing	0,34	0,00340511	4,0514E-08	2,836E-07	5,672E-07	1,2323E-06	2,4646E-06	3,6969E-06	7,3938E-06	1,4787E-05	2,9575E-05
1	Abnormal Instrument Reading	AIR	0,8	Cabling & junction boxes	0,34	0,00340511	6,709E-07	4,6963E-06	9,3926E-06	2,0406E-05	4,0812E-05	6,1218E-05	0,00012243	0,00024485	0,00048964
58	Other	OTH	0,8	Cabling & junction boxes	0,69	0,00691037	2,897E-07	2,0279E-06	4,0557E-06	8,8116E-06	1,7623E-05	2,6434E-05	5,2868E-05	0,00010573	0,00021146
78	Minor In-Service Problems	SER	0,3	Casing	0,69	0,00691037	2,1245E-07	1,4872E-06	2,9743E-06	6,4621E-06	1,2924E-05	1,9386E-05	3,8772E-05	7,7542E-05	0,00015508
35	Erratic Output	ERO	0,8	Control unit	0,69	0,00691037	1,9678E-07	1,3775E-06	2,7549E-06	5,9854E-06	1,1971E-05	1,7956E-05	3,5912E-05	7,1822E-05	0,00014364
37	Fail to Start on Demand	FTS	0,3	Control unit	0,34	0,00340511	3,9615E-08	2,7731E-07	5,5461E-07	1,205E-06	2,4099E-06	3,6149E-06	7,2297E-06	1,4459E-05	2,8919E-05
59	Other	OTH	0,8	Control unit	0,34	0,00340511	1,4275E-07	9,9924E-07	1,9985E-06	4,3419E-06	8,6839E-06	1,3026E-05	2,6051E-05	5,2102E-05	0,0001042
68	Parameter Deviation	PDE	0,8	Control unit	0,34	0,00340511	4,193E-07	2,9351E-06	5,8702E-06	1,2754E-05	2,5507E-05	3,826E-05	7,6519E-05	0,00015303	0,00030604
101	Spurious Stop	UST	0,8	Control unit	0,69	0,00691037	6,1671E-07	4,317E-06	8,6339E-06	1,8758E-05	3,7516E-05	5,6273E-05	0,00011254	0,00022507	0,0004501
23	External Leakage - Utility Medium	ELU	1	Cooler(s)	0,86	0,00861292	1,3531E-06	9,4718E-06	1,8944E-05	4,1157E-05	8,2312E-05	0,00012346	0,00024691	0,00049377	0,00098729
52	Overheating	OHE	1	Cooler(s)	0,34	0,00340511	7,2406E-08	5,0684E-07	1,0137E-06	2,2024E-06	4,4047E-06	6,607E-06	1,3214E-05	2,6428E-05	5,2855E-05
60	Other	OTH	0,8	Cooler(s)	0,34	0,00340511	1,4275E-07	9,9924E-07	1,9985E-06	4,3419E-06	8,6839E-06	1,3026E-05	2,6051E-05	5,2102E-05	0,0001042
69	Parameter Deviation	PDE	0,8	Cooler(s)	0,34	0,00340511	4,193E-07	2,9351E-06	5,8702E-06	1,2754E-05	2,5507E-05	3,826E-05	7,6519E-05	0,00015303	0,00030604
102	Spurious Stop	UST	0,8	Cooler(s)	0,46	0,00460691	4,1114E-07	2,878E-06	5,7559E-06	1,2505E-05	2,5011E-05	3,7516E-05	7,503E-05	0,00015005	0,00030009
24	External Leakage - Utility Medium	ELU	1	Coupling to driver	0,34	0,00340511	5,3496E-07	3,7447E-06	7,4894E-06	1,6271E-05	3,2543E-05	4,8814E-05	9,7625E-05	0,00019524	0,00039044
25	External Leakage - Utility Medium	ELU	1	Dry gas seal	0,69	0,00691037	1,0856E-06	7,5995E-06	1,5199E-05	3,3021E-05	6,6041E-05	9,906E-05	0,00019811	0,00039618	0,00079221
95	Structural Deficiency	STD	0,8	Dry gas seal	0,34	0,00340511	4,0514E-08	2,836E-07	5,672E-07	1,2323E-06	2,4646E-06	3,6969E-06	7,3938E-06	1,4787E-05	2,9575E-05
2	Abnormal Instrument Reading	AIR	0,8	Filter(s)	0,17	0,00170255	3,3545E-07	2,3482E-06	4,6963E-06	1,0203E-05	2,0406E-05	3,0609E-05	6,1218E-05	0,00012243	0,00024485
26	External Leakage - Utility Medium	ELU	1	Filter(s)	0,69	0,00691037	1,0856E-06	7,5995E-06	1,5199E-05	3,3021E-05	6,6041E-05	9,906E-05	0,00019811	0,00039618	0,00079221
45	Low Output	LOO	0,8	Filter(s)	0,69	0,00691037	3,0139E-07	2,1097E-06	4,2194E-06	9,1672E-06	1,8334E-05	2,7501E-05	5,5002E-05	0,00011	0,00021999
61	Other	OTH	0,8	Filter(s)	0,34	0,00340511	1,4275E-07	9,9924E-07	1,9985E-06	4,3419E-06	8,6839E-06	1,3026E-05	2,6051E-05	5,2102E-05	0,0001042
70	Parameter Deviation	PDE	0,8	Filter(s)	1,72	0,01722584	2,1212E-06	1,4848E-05	2,9696E-05	6,4516E-05	0,00012903	0,00019354	0,00038704	0,00077392	0,00154725
79	Minor In-Service Problems	SER	0,3	Filter(s)	0,69	0,00691037	2,1245E-07	1,4872E-06	2,9743E-06	6,4621E-06	1,2924E-05	1,9386E-05	3,8772E-05	7,7542E-05	0,00015508
103	Spurious Stop	UST	0,8	Filter(s)	0,11	0,00110165	9,8316E-08	6,8821E-07	1,3764E-06	2,9904E-06	5,9809E-06	8,9713E-06	1,7942E-05	3,5885E-05	7,1768E-05
3	Abnormal Instrument Reading	AIR	0,8	Instrument, flow	0,34	0,00340511	6,709E-07	4,6963E-06	9,3926E-06	2,0406E-05	4,0812E-05	6,1218E-05	0,00012243	0,00024485	0,00048964
4	Abnormal Instrument Reading	AIR	0,8	Instrument, general	1,72	0,01722584	3,394E-06	2,3758E-05	4,7514E-05	0,00010323	0,00020645	0,00030965	0,00061921	0,00123803	0,00247453
80	Minor In-Service Problems	SER	0,3	Instrument, general	0,34	0,00340511	1,0469E-07	7,3281E-07	1,4656E-06	3,1842E-06	6,3684E-06	9,5526E-06	1,9105E-05	3,821E-05	7,6418E-05
5	Abnormal Instrument Reading	AIR	0,8	Instrument, level	0,69	0,00691037	1,3615E-06	9,5307E-06	1,9061E-05	4,1413E-05	8,2823E-05	0,00012423	0,00024845	0,00049684	0,00099343
38	Fail to Start on Demand	FTS	0,3	Instrument, level	0,34	0,00340511	3,9615E-08	2,7731E-07	5,5461E-07	1,205E-06	2,4099E-06	3,6149E-06	7,2297E-06	1,4459E-05	2,8919E-05
81	Minor In-Service Problems	SER	0,3	Instrument, level	0,69	0,00691037	2,1245E-07	1,4872E-06	2,9743E-06	6,4621E-06	1,2924E-05	1,9386E-05	3,8772E-05	7,7542E-05	0,00015508
6	Abnormal Instrument Reading	AIR	0,8	Instrument, pressure	6,53	0,0653981	1,2885E-05	9,0193E-05	0,00018038	0,00039185	0,00078355	0,00117509	0,0023488	0,00469208	0,00936214
71	Parameter Deviation	PDE	0,8	Instrument, pressure	1,03	0,01031547	1,2702E-06	8,8915E-06	1,7783E-05	3,8635E-05	7,7269E-05	0,0001159	0,00023179	0,00046353	0,00092684
82	Minor In-Service Problems	SER	0,3	Instrument, pressure	0,69	0,00691037	2,1245E-07	1,4872E-06	2,9743E-06	6,4621E-06	1,2924E-05	1,9386E-05	3,8772E-05	7,7542E-05	0,00015508
104	Spurious Stop	UST	0,8	Instrument, pressure	1,72	0,01722584	1,5373E-06	1,0761E-05	2,1522E-05	4,6759E-05	9,3515E-05	0,00014027	0,00028052	0,00056096	0,0011216
7	Abnormal Instrument Reading	AIR	0,8	Instrument, speed	0,34	0,00340511	6,709E-07	4,6963E-06	9,3926E-06	2,0406E-05	4,0812E-05	6,1218E-05	0,00012243	0,00024485	0,00048964

Figure 9.1: Sorted Maintainable Item Sample (angled)

- Decision from engineers/company is that they should choose the most probable failure mode,
- With that maintenance time interval, they then will eliminate other failure modes as well,
- Example would be in control unit item, it has five failure modes and the strategy that should have been done is that they take bi-weekly or monthly interval as a starter if they wanted to have a *remote* failure, also
- This will varies also in how they approach the item and the economy that goes with it, some smaller and cheaper item could be decided in the *rare* or *probable* so that they can just replace it later and will not bother doing a quite frequent maintenance. If they decide to do this on control unit item, they can probably take the 3-monthly to 6-monthly maintenance interval.

Chapter 10

Conclusion

There are several things that concludes this writing from the analysis and results that have been formulated throughout. Conclusion concluding this writing would be listed as follow:

- If possible, knowing the detail of the equipment would be very beneficial for the accurateness of the data from OREDA (2002). This will be obtained from the manufacturer's data sheet for the equipment. Some information might not be stated in the data sheet, so communication between engineers and the manufacturer should happen here. The general page will always be available to use, but it will maybe take away the accurateness. For example in this electric driven screw compressor alone, there are categories in which they are divided by the power with range of the kilowatts it runs on.

- The maintenance strategy should look at the smallest maintainable items as possible. OREDA would be the industry standard when it comes to finding reliability data and maintainable items for each equipment.

- Failure rate (lambda) from OREDA will have to be calculated with their respective alpha and beta values, while if actual data is present, direct calculation can be done for the criticality and further.

- Deciding beta values might need a more experienced person to know the detailed beta number or categories of a failure mode. This should make the probability of failure more accurate to the field data, hence create a better classification or categories for the probability of failures.

- Categorising the probability of failure can be different for each company because every company usually have their own standard. This is usually done to help the top management and non-technical department to understand the visual categorisation of failures in an equipment.

- Design phase of a project usually will take OREDA data to clearly sort the maintainable items of the equipment, as discussed on previous chapter. This will make the decision relatively easier for the engineers to choose the maintenance time interval.

- When maintainable items have more than one failure modes, the most probable failure modes should be chosen for maintenance time interval, so that the remaining failure modes will be eliminated by doing the maintenance.

Appendix A

Acronyms

AIR Abnormal instrument reading

BRD Breakdown

CM Corrective maintenance

CMMS Computerised maintenance management system

ECTS European credit transfer system

ELP External leakage - process medium

ELU External leakage - utility medium

EN Europäische norm (European standard)

ERO Erratic output

FM Failure mode

FMEA Failure mode and effect analysis

FMECA Failure mode and effect criticality analysis

FTS Fail to start on demand

HIO High output

IEC International electro-technical commission

INL Internal leakage

ISO International organization for standardization

LOO Low output

MTBF Mean time between failure

MTTF Mean time to failure

NOI Noise

OEM Original equipment manufacturer

OHE Overheating

OREDA The offshore and onshore reliability data

ORF Onshore receiving facility

OTH Other

PDE Parameter deviation

PM Preventive maintenance

PoF Probability of failure

RAMS Reliability, availability, maintainability, and safety

RCFA Root cause failure analysis

RPN Risk priority number

SAE Society of automotive engineers

SER Minor in-service problems

SD Standard deviation

SIS Safety instrumented system

STD Structural deficiency

STP Fail to stop on demand

TBF Time between failures

TI Testing interval

TTR Time to repair

UNK Unknown

UST Spurious stop

VIB Vibration

WHP Wellhead platform

Appendix B

Mail and Discussions with DNV (Confidential)

From: **Abram Dionisius Antory** abramda@stud.ntnu.no
Subject: Re: NTNU Master 3. Mars Update
Date: 4 March 2023 16.13
To: Haug, Lars Tore Lars.Tore.Haug@dnv.com
Cc: Per Schjølberg per.schjolberg@ntnu.no

Hei Lars,

Apologise for the late reply, yes you can share that to Yinson for necessary background, if that is not sufficient, please tell me so that I can revise.

As for the data, until now I will need the maintenance data, also the event log (ESD and planned shut down), but will this eliminate the possibility to request other data (alarm log) in the future?

Best Regards,

> On 3 Mar 2023, at 16.40, Haug, Lars Tore <Lars.Tore.Haug@dnv.com> wrote:
>
> Hi Abram
> Thank for the document. I will have a look at this. I had a meeting with Yinson yesterday to ask them if we can use the data they have shared with us in the Prod Analytics pilot project. They are considering this, but wanted us to send them the title and an abstract of the scope of the thesis.
>
> The data we have received now and as discussed. What data would you be interested in?
>
> 1. Maintenance data for a gas compression system – around 1000 tasks. Not the complete vessel. We are discussing to extend this to cover major safety critical elements on the FPSO.
> 2. Event log from emergency shut-down – one day of cause and effects.
> 3. Alarm log – one year og alarm logs
>
> Can I share the document you submitted with Yinson to give the necessary background ?
>
> Best regards
> for DNV AS
>
> **Lars Tore Haug M.Sc.**
> Head of Section, Offshore Class, Safety and systems
> DNV
> E-mail lars.tore.haug@dnv.com
> Mobile +47 922 22 811
> www.dnv.com | LinkedIn
>
> ---
>
> **From:** Abram Dionisius Antory <abramda@stud.ntnu.no>
> **Sent:** fredag 3. mars 2023 14:35
> **To:** Haug, Lars Tore <Lars.Tore.Haug@dnv.com>
> **Cc:** Per Schjølberg <per.schjolberg@ntnu.no>
> **Subject:** NTNU Master 3. Mars Update
>
> Dear Lars,
>
> I hope this mail will find you in a good condition. I just wanted to ask how is the agreement going as per today? If necessary, would it be possible to have a meeting some time next week?

I attached a revised chapter 1 and a bit of chapter 2 that will be added over time. Let me know if you have any feedback on the writing or things to do.

Best regards,

Abram Dionisius Antory
NTNU
abramda@stud.ntnu.no

Abram Dionisius Antory
NTNU
abramda@stud.ntnu.no

From: **Haug, Lars Tore** Lars.Tore.Haug@dnv.com
Subject: Shating of data
Date: 9 March 2023 12.52
To: abramda@stud.ntnu.no, Vasset, Peder Andreas Peder.Andreas.Vasset@dnv.com

---

Hi Abram.
Just got a call from Yinson. Unfortunately they responded negatively on sharing maintenance data with you.
We have to look for alternative solutions.

Lars Tore

Sendt fra [Outlook for Android]

From: **Per Schjølberg** per.schjolberg@ntnu.no
Subject: Fwd: DNV Connect - NTNU Master thesis
Date: 25 April 2023 09.07
To: Abram Dionisius Antory abramda@stud.ntnu.no

Sendt fra min iPhone

Videresendt melding:

> **Fra:** "Haug, Lars Tore" <Lars.Tore.Haug@dnv.com>
> **Dato:** 8. februar 2023 kl. 16:48:41 CET
> **Til:** Per Schjølberg <per.schjolberg@ntnu.no>
> **Kopi:** "Angelsen, Sture Olav" <Sture.Angelsen@dnv.com>, "Vasset, Peder Andreas" <Peder.Andreas.Vasset@dnv.com>, "Pedersen, Eirik Edland" <Eirik.Edland.Pedersen@dnv.com>
> **Emne: RE: DNV Connect - NTNU Master thesis**
>
> Hei Per,
> Jeg tror det nok er best å jobbe med Abraham både kompetansemessig og for å få lov til å dele av data.
>
> Innspill på tema som vi kan diskutere videre på fredag:
>
> - Digital assurance of technical integrity of floating production and drilling units.
> - Using digital tools for assurance of safety systems onboard floating production and drilling units in the operation phase.
> - Focus on the Classification scope
> - Assurance of maintenance system and barrier management systems
> - Assessment of integrity of safety systems
>
> Er det en kobling mellom deres milø og miljøet som jobber med denne rapporten?

Report

Potential for automated follow-up of safety equipment

An APOS project report

Author(s):

Shenae Lee, Maria Vatshaug Ottermo, Stein Hauge, Solfrid Håbrekke, (all SINTEF), Mary Ann Lundteigen (NTNU)

Report No:

<ReportNo> - Internal

Client(s)

Multiclient

From: Per Schjølberg <per.schjolberg@ntnu.no>
Sent: onsdag 8. februar 2023 10:01
To: Haug, Lars Tore <Lars.Tore.Haug@dnv.com>
Cc: Angelsen, Sture Olav <Sture.Angelsen@dnv.com>; Vasset, Peder Andreas <Peder.Andreas.Vasset@dnv.com>
Subject: Re: DNV Connect - NTNU Master thesis

Hei

Takk for positivt møte og en utfordrende mulighet for studenter. Det er et alternativ å kun jobbe med Abraham. Det kan jeg ta videre hvis du ønsker det.

Mvh

Per s

Sendt fra min iPhone

> 8. feb. 2023 kl. 09:28 skrev Haug, Lars Tore <Lars.Tore.Haug@dnv.com>:
>
> Hei Per
> Takk for en interessant mulighet til samarbeid med dere rund bruk av data på vedlikehold og teknisk integritet. Dataene vi sitter på nå kommer fra Yinson (de har base i Malaysia og Singapore) og er knyttet til nødavstengningssystemet til deres produksjonsinretninger. Som nevnt ser jeg noen utfordringer med å dele disse dataene spesielt med studenten fra Iran. Vi må gjennom noen runder med referansesjekker og så må vi få tillatelse fra Yinson også som eier disse dataene.
>
> Er det et alternativ bare å jobbe med studenten fra Malysia, Abraham

Dionisi Antony ? Etter det jeg skjønner har han også jobbet i Petronas med RAMs og teknsk integritet og det vil være en betydlig fordel i dette arbeidet i forhold til en som ikke har noe forkunnskap om petroleumsnæringen.

Det ville være greit å avklare dete spørsmålet først før vi går videre. Dernest, er spørsmålet om dette en dyktig studet med rimelig gode resultater ?

Best regards
for DNV AS

Lars Tore Haug M.Sc.
Head of Section, Offshore Class, Safety and systems
DNV
E-mail lars.tore.haug@dnv.com
Mobile +47 922 22 811
www.dnv.com | LinkedIn

-----Original Appointment-----
From: Vasset, Peder Andreas <Peder.Andreas.Vasset@dnv.com>
Sent: mandag 6. februar 2023 11:13
To: Vasset, Peder Andreas; per.schjolberg@ntnu.no; haniehra@stud.ntnu.no; abramda@stud.ntnu.no; Haug, Lars Tore
Cc: Angelsen, Sture Olav
Subject: DNV Connect - NTNU Master thesis
When: fredag 10. februar 2023 09:00-09:50 (UTC+01:00) Amsterdam, Berlin, Bern, Rome, Stockholm, Vienna.
Where: Microsoft Teams Meeting

Dear All,

As agreed; we touch base on Friday.
Students: If you have any input/suggestions on scope or want to communicate interests/competencies that may be relevant, please feel free to drop us an e-mail.
We will discuss internally with the rest of the team (Aberdeen/Trondheim) and provide some initial feedback/thoughts by end of week.

Thanks and have a good week!

Best Regards,
For DNV

Peder Andreas Vasset
Principal Engineer
Drilling Systems & Lifting Appliances
Maritime

DNV AS
peder.andreas.vasset@dnv.com

Mobile +4799738906
dnv.com

DNV

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****

Appendix C

Data Sheet of Screw Compressor

PROJECT : **PROVISION OF ENGINEERING, PROCUREMENT, CONSTRUCTION, INSTALLATION AND COMMISSIONING OF BTJT-B WELLHEAD PLATFORM, INFIELD PIPELINES AND HOST TIE IN MODIFICATION FOR BUKIT TUA PHASE 2B DEVELOPMENT PROJECT**

CLIENT : **PC KETAPANG II LTD**

CONTRACT NO. : **4850000373**

DOCUMENT TITLE : **MECHANICAL DATASHEET - INSTRUMENT AIR COMPRESSOR AND DRYER PACKAGE (A-5410)**

PC KETAPANG II LTD (PCK2L)
BUKIT TUA PHASE 2B PROJECT
(EPCIC OF BTJT-B WELLHEAD PLATFORM, INFIELD PIPELINES AND HOST TIE IN MODIFICATION)

Return Code	Date	Initial & Sign
CODE 1		
CODE 2		
CODE 3		
CODE 4		

CODE 1 Approved to proceed
CODE 2 Accepted with Comments
CODE 3 Reject And Resubmit
CODE 4 For Information/Reference

PCK2L APPROVAL DOES NOT RELIEVE THE CONTRACTOR RESPONSIBILITY TO MEET REQUIREMENTS OF THE CONTRACT

0	10-Jan-20	Approved for Construction	SPM	BSJ/RSD	AS	RL/BW	SAE/IG
B	06-Dec-19	Issued for Approval	SPM	BSJ	FM/RSD	RL/BW	SAE/IG
A	08-Nov-19	Issued for Review	SPM	BSJ	FM/RSD	RL/BW	SAE/IG
Rev	Date	Description	Prepared By	Approved By	Reviewed By	Reviewed By	Approved By
			PT MEINDO ELANG INDAH			**PC KETAPANG II LTD**	

REVISION LIST

SECTION	REV	DATE	DESCRIPTION
All Pages	A	8-Nov-19	Issued for Review
All Pages	B	6-Dec-19	Issued for Approval
All Pages	0	10-Jan-20	Approved for Construction

COMMENT RESPONSE SHEET

No	Document/Page Ref.	Owner Comments	Contractor Response	Remarks
1	3 of 10	Ensure capacity has been aligned with latest process datasheet, to account for drier regeneration. Ensure that the capacity has satisfied both max/min pressure conditions.	CTR confirmed that indicated capacity has been aligned with the latest process data sheet	
2	3 of 10	Add "Note 18"	Noted & incorporated	
3	6 of 10	Refer comment on page 3. Please add "(Note 3)"	Noted & incorporated	
4	6 of 10	Add "Note 21"	Noted & incorporated	
5	8 of 10	Add "Note 18"	Noted & incorporated	
6	8 of 10	To add: "... as specified in this datasheet."	Noted & incorporated	
7	8 of 10	Add: "Refer PTS 12.11.35 para 3.2.8 for intake filter requirements." Contractor to ensure that air intake is located in non-hazardous area.	Noted & incorporated. CTR confirmed that air intake will be located in non-hazardous area	
8	8 of 10	Note 28 ==> Recheck with updated Process datasheet	Noted. CTR confirmed that indicated pressure (lead-lag condition) has been aligned with the latest process data sheet	
9	4 of 10	CTR to review and incorporate HAZID & HAZOP recommendation into this datasheet HAZOP Recommendation No.12 "Review the requirement for inhibiting the lead/ lag startup of the air compressors K-5410A/B when the power supply is only through EDG, since the EDG cannot cater for both compressors running simultaneously".	Noted. CTR confirmed that the package will be provided adjustable operating control "auto and manual mode". The both of compressors may operate individually or sequently throught selecting selector switch on Local Control Panel directly. Select to Manual means that Compressor will manually operate on Load unload setting and as auto run and individually. Otherwise, select to Auto means that Compressor will operate in sequent or Lead lag operation base on their load unload setting. During emergency condition when the power supply is only through EDG, the operating mode of the package can be change to "manual" so that only one unit of the air compressor will be running. Control philosophy and detail schematic diagram will be provided during detail (after PO).	
10	4 of 10	add code for compressor	Noted & incorporated	
11	4 of 10	specify deck name	Noted & incorporated	
12	4 of 10	see comment on compressor scrubber vessel	Noted & Updated as per CPY comment	
13	5 of 10	pls add one row mention the equipment --> air compressor?	Noted & Updated as per CPY comment	
14	7 of 10	CTR to make sure air output quality shall meet PTS requirement	Noted. CTR confirmed that air quality requirement shall meet PTS as already stated in NOTE-14	

PETRONAS	PT. MEINDO ELANG INDAH Engineering and Construction	Doc. No.	: BTP2B-EPCIC-BTJTB-M-TDS-0013
		Revision	: 0
PROVISION OF EPCIC OF BTJT-B WELLHEAD PLATFORM, INFIELD PIPELINES AND HOST TIE IN MODIFICATION FOR BUKIT TUA PHASE 2B DEVELOPMENT PROJECT		Page	: 4 of 11

MECHANICAL DATASHEET
INSTRUMENT AIR COMPRESSOR AND DRYER PACKAGE (A-5410)

Applicable to	: ○ Proposal	● Purchase	○ As Built
Client	: PC KETAPANG II LTD	**Equipment Name**	: AIR COMPRESSOR AND DRYER PACKAGE
Project	: PROVISION OF EPCIC OF BTJT-B WELLHEAD PLATFORM, INFIELD PIPELINE & HOST TIE IN MODIFICATION FOR BUKIT TUA PHASE 2B DEVELOPMENT PROJECT	**Tag Number**	: SEE BELOW (NOTE 18)
		No. Required	: ONE (1) PACKAGE
Location	: WHP - BTJT-B	**SPEC. REF.**	: BTP2B-EPCIC-BTJTB-M-SPC-0013
Contract No.	: 4850000373		& PTS 12.11.35 (COMPRESSOR & DRYER SPEC)

SERVICE CONDITION

1	SERVICE	:	AIR
2	DUTY	:	2 x 100% (RUN/STAND BY & LEAD/LAG)
3	TYPE	:	SCREW COMPRESSORS
4	NUMBER OF STAGES	:	(*)
5	CORROSIVE DUE TO	:	SALT LADEN ATMOSPHERIC

OPERATING CONDITIONS

6	ACTUAL CAPACITY PER COMPRESSOR	Sm³/h	(*)
7	SKID CAPACITY RATED (NOTE 19, 20)	Sm³/h	266.1 Sm³/hr @ 14.7 psia & 60°F (2 SETS)
8	**SUCTION CONDITIONS**		
9	RATIO OF SPECIFIC HEAT (Cp/Cv)		1.407
10	COMPRESSIBILITY, Z		0.9993
11	OPERATING TEMPERATURE (MIN/MAX)	°C	AMB (23 / 31)
12	OPERATING PRESSURE	barg	ATM
13	MASS FLOW	kg/h	325.2 (*)
14	ACTUAL INLET VOLUME	ACFM	(*)
15	**DISCHARGE CONDITIONS**		
16	RATIO OF SPECIFIC HEAT (Cp/Cv)		1.423 (*)
17	COMPRESSIBILITY, Z		0.997 (*)
18	OPERATING TEMPERATURE	°C	40 - 50 (*)
19	DISCHARGE PRESSURE	barg	10.6 barg (154 psig) (**)
20	TOTAL PRESSURE RATIO		(*)
21	POWER PER STAGE	kW	(*)
22	POWER DRIVER COUPLING	kW	(*)
23	DRIVER RATING	kW	(*)
24	DRIVER SPEED	rpm	(*)
25	DESIGN TEMPERATURE	°C	70 / 0
26	DESIGN PRESSURE **(Note 28)**	barg	12 barg (175 psig) (**)

ONDITION

27	LOCATION	☐ INDOOR	■ OUTDOOR	
		☐ HEATED	■ UNHEATED	
28	TROPICALISATION REQUIRED :	■ YES	☐ NO	
29	AMBIENT TEMPERATURE	°C	= 36 ; MIN = 18	
30	RELATIVE HUMIDITY	%	59 - 86	
31	ELEVATION	m	22 (MEZZANINE DECK)	
32	AREA CLASSIFICATION	:	UNCLASSIFIED	
33	NOISE LIMITATION	:	85 dB (A) @ 1 m	(as per PTS 12.01.02)
34	WIND VELOCITY	m/s	14 (1 hour mean@ 2 years)	
35	SEISMIC CONDITION	:	ELE : X= 0.085g; Y= 0.088g; Z= 0.220g	
35			ALE : X= 0.165g; Y= 0.163g; Z= 0.314g	

Revision 0 (triangle marks at rows 30–31 and 35)

COMPRESSOR SKID CONNECTIONS

36	**NOZZLES**	**SIZE**	**RATING**	**FACING**	**POSITION**
37	INLET	(*)	(*)	(*)	(*)
38	SKID AIR OUTLET	DN50 (*)	150#	RF	(*)
39	BYPASS	N/A	N/A	N/A	N/A
40	COOLING WATER	N/A	N/A	N/A	N/A
		INSIDE SKID, VENT TO ATMOSPHERE			
41	PSV	(*)	(*)	(*)	(*)
42	SKID DRAIN	(*)	150#	RF	(*)

ELECTRICAL INFORMATION (Note 26)

43	ELECTRICAL CERTIFIED AREA CLASS.	:	ZONE 2
44	MOTOR PROTECTION RATING	:	IP 56

INSTRUMENT INFORMATION (Note 8, 9)

45	INSTRUMENT CERTIFIED AREA CLASS.	:	ZONE 1, GAS GROUP IIA, T3
46	CONTROL PANEL	:	YES, Ex'd', IIA, T3 , IP 65
47	CONTROL PANEL LOCATION	:	LOCAL (NOTE 9)

PACKAGE SCOPE OF SUPPLY

48	**COMPRESSOR TAG NO**	: K-5410 A/B		
49	**COMPRESSOR TYPE**	: SCREW, OIL FREE TYPE		
50	**DRIVER TYPE**	: ELECTRIC MOTOR		
51	**COUPLING GUARD**	:	■ YES	☐ NO
52	**BASEPLATE :** ☐ SEPARATE		■ COMBINED	■ SKID
53	**LIFTING FRAMES**	:	■ YES	☐ NO
54	**INTAKE FILTER/SILENCER**	:	■ YES	☐ NO
55	**AIRCOOLER(S)**	:	■ YES	☐ NO
56	**PREFILTER**	: YES	**AFTER FILTER**	: YES
57	**OIL COOLER**	:	■ YES	☐ NO
58	**AUTO-CONDENSATE TRAP**	:	■ YES (AUTOMATIC)	☐ NO
59	**AIR DRYER**	:	■ YES	☐ NO
60	DESICCANT CAGE	:	■ YES	☐ NO
61	BLOW OFF SILENCER	:	■ YES	☐ NO
62	VIBRATION MONITOR (ACCELEROMETER)	:	☐ YES	■ NO
63	**INSTRUMENT SYSTEM OF PACKAGE :**		■ YES	☐ NO
64	WIRING CONTROLS & INSTRUMENTS :		■ YES	☐ NO
65	CONTROL PANEL :		■ YES	☐ NO
66	CONTROL PANEL TYPE :		■ LOCAL	☐ REMOTE
67	SPEC. REQUIRED :	ISO 10440-2, BTP2B-EPCIC-BTJTB-M-SPC-0013		
68		PTS 12.11.35, PTS 14.10.02		
69	**ELECTRIC SYSTEM OF PACKAGE :**		■ YES	☐ NO
70	ELECTRIC MOTOR & ACCESSORIES		■ YES	☐ NO
71	ELECTRIC MOTOR POWER :	kW	(*)	
72	VOLTS : 400	PHASE : 3	Hz : 50	
73	SPEC. REQUIRED :	BTP2B-EPCIC-BTJTB-E-SPC-0001		
75		BTP2B-EPCIC-BTJTB-E-SPC-0011		
76	**INTERCONNECTING PIPEWORK AND VALVES :**		■ YES	☐ NO
77	MATERIALS	: (*) BTP2B-EPCIC-BTJTB-P-SPC-0001		
78	PSV	:	■ YES	☐ NO
79	**ENCLOSURE**	: (*)	■ YES	☐ NO
80	ENCLOSURE TYPE : (*)		■ ACOUSTIC	■ WEATHERPROOF
81	AIR COOLING SYSTEM		■ YES	☐ NO
82	**PAINTING & COATING :**		■ YES	☐ NO
83	SPEC. REQUIRED :	PTS 15.20.03, PROTECTIVE COATINGS AND LINING		
84	FOUNDATION BOLTS	:	■ YES	☐ NO
85	COOLING WATER SUPPLY	:	☐ YES	■ NO
86	LUBRICATION SYSTEM	:	■ YES	☐ NO

CASING

87	MODEL		(*)
88	MATERIAL AND GRADE		(*)
89	CASING THICKNESS	inch	(*)
90	CORROSION ALLOWANCE	inch	(*)
91	DESIGN PRESSURE	psig	(*)
92	MAXIMUM OPERATING TEMP.	°F	(*)
93	MINIMUM OPERATING TEMP.	°F	(*)
94	RADIOGRAPHY (*)	: **Per Code**	☐ YES ☐ NO

SPEED

95	MAXIMUM ALLOWABLE	rpm	(*)			
96	TRIP SPEED	rpm	(*)			
97	CRITICAL SPEED	rpm	1st (*)	2nd (*)	LATERAL	
98			1st (*)	2nd (*)	TORSIONAL	
99	MAX. TRIP SPEED AT RATED SPEED	rpm	(*)			
100	MAX. TRIP SPEED AT MAX.ALLOW.SPEED	rpm	(*)			
101	ROTATION VIEWED FROM DRIVEN	(*)	☐ CW	☐ CCW		
102						
103						

PETRONAS	PT. MEINDO ELANG INDAH Engineering and Construction	Doc. No. : BTP2B-EPCIC-BTJTB-M-TDS-0013
		Revision : 0
PROVISION OF EPCIC OF BTJT-B WELLHEAD PLATFORM, INFIELD PIPELINES AND HOST TIE IN MODIFICATION FOR BUKIT TUA PHASE 2B DEVELOPMENT PROJECT		Page : 5 of 11

MECHANICAL DATASHEET
INSTRUMENT AIR COMPRESSOR AND DRYER PACKAGE (A-5410)

Client	: PC KETAPANG II LTD	**Equipment Name**	: AIR COMPRESSOR AND DRYER PACKAGE
Project	: PROVISION OF EPCIC OF BTJT-B WELLHEAD PLATFORM, INFIELD PIPELINE & HOST TIE IN MODIFICATION FOR BUKIT TUA PHASE 2B DEVELOPMENT PROJECT	**Tag Number**	: SEE BELOW
		No. Required	: ONE (1) PACKAGE
Location	: WHP - BTJT-B	**SPEC. REF.**	: BTP2B-EPCIC-BTJTB-M-SPC-0013
Contract No.	: 4850000373		& PTS 12.11.35 (COMPRESSOR & DRYER SPEC)

AIR COMPRESSOR 0

	ROTORS		
1	DIAMETER	mm	(*)
2	TYPE	-	(*)
3	TYPE FABRICATION	-	(*)
4	MATERIAL	-	(*)
5	ROTOR CLEARANCE	mm	(*)
6	MAXIMUM DEFLECTION	mm	(*)
	SHAFT		
7	MATERIAL	mm	(*)
8	DIAMETER	mm	(*)
9	AT COUPLING : (*)		
10	SHAFT END : (*) ☐ TAPERED ☐ CYLINDRICAL		
11	SLEEVE MATERIAL : (*)		
	TIMING GEARS		
13	SIZE : (*)		
14	MATERIAL : (*)		
	SHAFT SEALING		
15	TYPE : (*)		
16	SYSTEM TYPE : (*)		
17	INNER OF LEAKAGE : (*)		
	BEARING HOUSING		
18	TYPE : (*)		
19	SPLIT : (*)		
20	MATERIAL : (*)		
	RADIAL BEARINGS		
21	TYPE :		(*)
22	AREA	mm^2	(*)
23	LOADING ALLOWABLE	kg/cm^2	(*)
24	ACTUAL	kg/m^3	(*)
	THRUST BEARINGS		
25	TYPE :		(*)
26	AREA	mm^2	(*)
27	LOADING ALLOWABLE	kg/cm^2	(*)
28	ACTUAL	kg/m^3	(*)

	COMPRESSOR CONNECTIONS				
29	NOZZLE	SIZE (in)	RATING	FACING	POSITION
30	INLET	(*)	150	RF	(*)
31	DISCH. OUTLET	(*)	150	RF	(*)
32	COOLING WATER	(*)	150	RF	(*)
33	BY PASS	(*)	150	RF	(*)

	CONTROL PANEL (NOTE 9) 0	
34	OPERATING CONTROL	: MANUAL - AUTO SELECT
35	CAPACITY CONTROL METHOD	: (*)
36	VARIABLE SPEED/BY PASS	: (*)
37	STOP/START ON RECEIVER PRESSURE :	(*)

	INTAKE AIR FILTER/SILENCER (Note 21)	
38	EQUIPMENT No.	: -
39	QUANTITY	: TWO (2)
40	No. REQ'D (EACH COMPRESSOR)	: ONE (1)
41	SILENCER RATING	: (*)
42	MFR/SUPPLIER	: (*)
43	SIZE	: (*)
44	MODEL	: (*)
45	TYPE	: (*)
46	MTG.ARRANGEMENT	: (*)
47	WEIGHT	: (*) kg
	LUBRICATION	
48	LUBE SYSTEM : (*) ☐ DRIVER ☐ GEAR	
49	■ OIL FREE TYPE	
50	■ INTEGRAL WITH COMPRESSOR SKID ☐ SEPARATE CONSOLE	
51	LUBE OIL PUMP DRIVE : (*) ☐ SHAFT ☐ ELECTRIC MOTOR	
52	SYSTEM OIL CAPACITY	kW (*)
53	TYPE OF OIL GRADE	(*)
54	ELECTRICAL HEATER WITH THERMOSTAT	kW (*)
55	LUBE OIL COOLER	: (*)
56	LUBE OIL FILTER	: (*)

	AIR RECEIVER (SUPPLIED BY OTHER)			
57	EQUIPMENT No. :			
58	QUANTITY :			
59	DESIGN CODE/SPECS. : N/A			
60	No. REQ'D :			
61	MFR/MFR SUPPLIED BY: (*)			
62	MATERIAL OF CONSTRUCTION : (*)			
63	CORROSION ALLOWANCE	in		(*)
64	RECEIVER CAPACITY	ft^3		(*)
65	MOUNTING ARRANGEMENT (*)			
66	DIAMETER (in) : (*)	LENGTH (in) : (*)		
67	RELIEF VALVE REQ'D ☐ YES ☐ NO			
68	TYPE : (*)	MFR : (*)		
69	SIZE (in) : (*)	SETTING (psig) : (*)		
70	DRAIN VALVE ON TRAP REQ'D (*)			
71	TYPE : (*)	MFR :		
72	SIZE (in) : (*)	RELIEF LIQUID : MANUAL		
73	DESIGN PRESSURE	psig	##	(*)
74	DESIGN TEMPERATURE	°F	##	(*)
75	HYDROTEST PRESSURE	psig	##	(*)
76	NOZZLE	SIZE (in)	RATING	FACING
77	INLET	(*)	150	RF
78	OUTLET	(*)	150	RF
79	PSV	(*)	150	RF

PETRONAS	PT. MEINDO ELANG INDAH Engineering and Construction	Doc. No. : BTP2B-EPCIC-BTJTB-M-TDS-0013
		Revision : 0
PROVISION OF EPCIC OF BTJT-B WELLHEAD PLATFORM, INFIELD PIPELINES AND HOST TIE IN MODIFICATION FOR BUKIT TUA PHASE 2B DEVELOPMENT PROJECT		Page : 6 of 11

MECHANICAL DATASHEET
INSTRUMENT AIR COMPRESSOR AND DRYER PACKAGE (A-5410)

Client	: PC KETAPANG II LTD	**Equipment Name**	: AIR COMPRESSOR AND DRYER PACKAGE
Project	: PROVISION OF EPCIC OF BTJT-B WELLHEAD PLATFORM, INFIELD PIPELINE & HOST TIE IN MODIFICATION FOR BUKIT TUA PHASE 2B DEVELOPMENT PROJECT	**Tag Number**	: SEE BELOW (NOTE 18)
		No. Required	: ONE (1) PACKAGE
Location	: WHP - BTJT-B	**SPEC. REF.**	: BTP2B-EPCIC-BTJTB-M-SPC-0013
Contract No.	: 4850000373		& PTS 12.11.35 (COMPRESSOR & DRYER SPEC)

COMPRESSOR AFTER COOLERS (Note 22)

1	EQUIPMENT No. :	E-5410 A/B		
2	QUANTITY :	2		
3	LIQUID OR AIR COOLED :	AIR COOLED (MOTOR DRIVEN FAN)		
4	DESIGN CODE :	MFR. STD.		
5	No. REQ'D (EACH COMPRESSOR) :	1		
6	MFR/MFR SUPPLIED BY :	(*)		
7	HEAT TRANSFER CONF. :	(*)		
8	CAPACITY :	(*)		
9	MOUNTING ARRANGEMENT :	(*)		
10	SHELL MATERIAL :	(*)		
11	DIA (m) : (*)	OAL (m) : (*)		
12	TUBE CONSTRUCTION MATERIAL :	(*)		
13	DIA (m) : (*)	LENGTH (m) (*)	PITCH (*)	
14	COOLING LIQUID :	N/A		
15	TEMP IN/OUT (^{o}C) : N/A	INLET PRESS (barg) : N/A		
16	DIFFERENTIAL PRESSURE (psig) :	NA		
17	FLOW CONTROL	☐ MANUAL	☐ AUTO	
18	CONN.	SIZE (in)	RATING	FACING
19	INLET	(*)	150 #	RF
20	OUTLET	(*)	150 #	RF
21	COMPRESSED AIR TEMP. (^{o}C)	IN : (*)	OUT : (*)	
22	DIFFERENTIAL PRESSURE (barg) :	(*)		
23	**MOISTURE SEPARATOR REQ'D :**	**(S-5410 A/B)**	(Note 23)	
24	TYPE : (*)	MFR : (*)		
25	NOZZLE	SIZE (in)	RATING	FACING
26	INLET	(*)	(*)	(*)
27	OUTLET	(*)	(*)	(*)
28	DRAINTRAP TYPE :	AUTOMATIC/ BLOW DOWN		
29	SIZE : (*)	RELIEF VALVE REQ'D : (*)		
30	RELIEF VALVE	(*)		
31	TYPE :	(*)	MFR : (*)	
32	SIZE (in) :	(*)	SETTING (psig) : (*)	
33	TIP SPEED :	(*)	Max : (*)	
34	NOISE :	85 dB (A) @ 1 m	(as per PTS 12.01.02)	

INSTRUMENTATION

35		INDICATOR	ALARM (Note 27)	SHUT DOWN (Note 27)
36				
37	Discharge Pressure	YES	YES	YES
38	Discharge Temperature	YES	YES	YES
39	Lube Oil Pressure	YES	YES	YES
40	Lube Oil Temperature	YES	YES	YES
41	Lube Oil Filter DP	YES	YES	(*)
42	Air Inlet Filter DP	YES	YES	(*)
43	Lube Oil Level	YES	YES	(*)
44				

INSPECTION AND TESTING

45		Required	Witness
46	Shop Inspection	●	○
47	Hydrotest	●	●
48	Leak Test	●	○
49	Function Test	●	●
50	Compressor & Driver Performance Test	●	●
51	Material Certification	●	○
52	Certification and Inspection Records	●	○
53	Mechanical Run Test	●	●

WEIGHT AND DIMENSIONS

54			L		W		H		
55	Compressor Unit	: (*) kg	(*)	x	(*)	x	(*)	m	
56	Compressor Driver	: (*) kg	(*)	x	(*)	x	(*)	m	
57	Skid Control Panel UCP	: (*) kg	(*)	x	(*)	x	(*)	m	
58	Air Cooler	: (*) kg	(*)	x	(*)	x	(*)	m	
59	Instrument Air Pre Filters	: (*) kg	(*)	x	(*)	x	(*)	m	
60	Instrument Air Dryers	: (*) kg	(*)	x	(*)	x	(*)	m	
61	Instrument Air After Filters	: (*) kg	(*)	x	(*)	x	(*)	m	
62	Dryer Logic System	: (*) kg	(*)	x	(*)	x	(*)	m	
63	Total Package	: (*) kg	(*)	x	(*)	x	(*)	m	
64									
65									
66									

NOTES

(1) (*) = Indicates Vendor to advise ; (**) = Indicates Vendor to confirm

(2) Applicable specifications, including referenced documents specified therein;
Project Specification for Instrument Air Compressor Package (BTP2B-EPCIC-BTJTB-M-SPC-0013) & Company Specification (PTS 12.11.35)

(3) VENDOR shall clearly state and guarantee the following :

- Minimum stable flow (max. turndown)
- Outlet water dewpoint
- Maximum pressure drop
- Maximum air losses from package
- Maximum regeneration time
- Maximum dry air capacity
- Dessicant lifetime
- Power consumption

(4) The Electric motor driver shall comply with BTP2B-EPCIC-BTJTB-E-SPC-0011, Specification for LV Induction Motors

(5) All necessary controls, instruments, and dew-point analyzers shall be provided as part of this package.

(6) Provision for inspection of dryer dessicant and removal facilities to be provided.

(7) VENDOR to confirm suitable material of construction for equipment and internals.
Selected materials of construction shall be the Selection of all components, materials, etc. suitable for the service and environmental conditions encountered and in accordance with COMPANY specification.

(8) Instrumentation shall be as per Instrument Design Basis, BTP2B-EPCIC-BTJTB-I-DES-0001; Specification for PMCS & SIS, BTP2B-EPCIC-BTJTB-I-SPC-0001; Specification for Instrument Requirement for Package, BTP2B-EPCIC-BTJTB-I-SPC-0008; and PTS 14.10.03 “Instrumentation for Equipment Packages” , PTS 14.10.02 “Instruments for Measurement and Control”

PETRONAS	PT. MEINDO ELANG INDAH Engineering and Construction	Doc. No. : BTP2B-EPCIC-BTJTB-M-TDS-0013
		Revision : 0
PROVISION OF EPCIC OF BTJT-B WELLHEAD PLATFORM, INFIELD PIPELINES AND HOST TIE IN MODIFICATION FOR BUKIT TUA PHASE 2B DEVELOPMENT PROJECT		Page : 7 of 11

MECHANICAL DATASHEET
INSTRUMENT AIR COMPRESSOR AND DRYER PACKAGE (A-5410)

Client	: PC KETAPANG II LTD	**Equipment Name**	: AIR COMPRESSOR AND DRYER PACKAGE
Project	: EPCIC OF BTJT-B WELLHEAD PLATFORM, INFIELD PIPELINE & HOST	**Tag Number**	: SEE BELOW (NOTE 18)
	TIE IN MODIFICATION FOR BUKIT TUA PHASE 2B DEVELOPMENT PROJECT	**No. Required**	: ONE (1) PACKAGE
Location	: WHP - BTJT-B	**SPEC. REF.**	: BTP2B-EPCIC-BTJTB-M-SPC-0013
Contract No.	: 4850000373		& PTS 12.11.35 (COMPRESSOR & DRYER SPEC)

AIR DRYER

1	EQUIPMENT No.	-	S-5412 A/B	13	INSULATION OF PRESSURE VESSEL : N/A
2	No. REQ'D	-	DUAL TOWER	14	MOISTURE REMOVAL METHOD : ADSORPTION BY DESICCANT
2	AIR DRYER TYPE	-	HEATLESS DESICCANT	15	DESICCANT CONTAINER NUMBER : (*)
3	REQUIRED AIR QUALITY	-	NOTE 14	16	DESICCANT TYPE : ACTIVATED ALUMINA (*)
4	DELIV'D CAPACITY	Sm³/h	266.1 (NOTE 3)	17	MFR/MFR SUPPLIER : (*) SIZE : (*)
5	DEW POINT	°C	-40	18	REGEN. CYCLE (hrs) : (*) OR BY DEMAND
6	AIR FLOW VELOCITY	fpm	(*)	19	DRYING PERIOD : (*) HEATER RATING (HP) : N/A
7	PRESSURE VESSEL DESIGN		ASME Sec VIII Div 1	20	BLOWER RATING (HP : N/A
8	INLET PRESSURE	barg	10 barg (145 psig)	21	NOZZLE — SIZE — RATING — FACING
9	INLET TEMPERATURE	°C	40 - 50	22	INLET — DN 50 (*) — 150 # — RF
10	DESIGN PRESSURE (Note 28)	barg	12 barg (175 psig)	23	OUTLET — DN 50 (*) — 150 # — RF
11	DESIGN TEMPERATURE	°C	70/0	24	WEIGHT — kg — (*)
12	HYDROTEST PRESSURE	barg	AS PER PTS 12.20.01	25	SPEC. REQUIRED : BTP2B-EPCIC-BTJTB-M-SPC-0013 & PTS 12.11.35

AIR DRYER ACCESSORIES

26	DUAL VESSELS/TWIN TOWERS	■ YES □ NO	46	INTAKE FILTER & SILENCER (NOTE 21)	□ YES ■ NO
27	SYSTEMS SEQUENCE ANNUNCIATOR	■ YES □ NO	47	AUTOMATIC CONDENSATE TRAP	■ YES □ NO
28	CONTROL PANEL	■ YES □ NO	48	AIR DRYER DESSICANT CAGE	■ YES □ NO
29	PNEUMATIC SWITCHING VALVES	■ YES □ NO	49	BLOW-OFF SILENCER	■ YES □ NO
30	INSULATIONS	□ YES ■ NO	50	LIFTING FRAME	■ YES □ NO
31	PRESSURE EQUALIZATION	■ YES □ NO	51	ENCLOSURE (WEATHERPROOF & ACCOUSTIC)	□ YES ■ NO
32	CONTROL AIR FILTER	■ YES □ NO	52	DEW POINT ANALYZER	■ YES □ NO
33	OVER TEMPERATURE SAFETY CONTROL	□ YES ■ NO	53	SPECIAL TOOLS (IF REQUIRED)	■ YES □ NO
34	SEPARATE TOWER SAFETY VALVES	■ YES □ NO	54	LIFTING LUGS AND PADEYES	■ YES □ NO
35	SEPARATE TOWER FILL/DRAIN PORTS	■ YES □ NO	55		
36	CHECK VALVES	□ YES ■ NO	56		
37	PURGE FLOW REGULATOR	■ YES □ NO	57		
38	PRE-FILTER x 2	■ YES □ NO	58		
39	AFTER FILTER x 2	■ YES □ NO	59		
40	FILTERS DRAIN VALVES	■ YES □ NO	60		
41	FILTER ELEMENT VISUAL INDICATOR	■ YES □ NO	61		
42	STAINLESS STEEL DIFFUSER SCREENS	■ YES □ NO	62		
43	PURGE FLOW INDICATOR	■ YES □ NO	63		
44	MOISTURE INDICATOR	■ YES □ NO	64		
45	FAILURE TO SWITCH ALARMS	■ YES □ NO	65		

FILTERS (NOTE 14, 24)

66	PRE FILTER		S-5411 A/B
67	INSTALLED AT		DRYER INLET
68	PRESSURE DROP	psia	< 1 (**)
69	FILTER TYPE		CARTRIDGE
70	FILTER SIZE	microns	REMOVE SOLIDS GREATER THAN 0.6 MICRONS, MAX 1 PPM OIL / HC CONTENT (*) **(NOTE-14)**
71	EFFICIENCY	%	99.9
72	DESIGN CODE		ASME SECTION VIII DIV. 1
73	AFTER FILTER		S-5413 A/B
74	INSTALLED AT		DRYER OUTLET
75	PRESSURE DROP	psia	< 0.5 (**)
76	FILTER TYPE		CARTRIDGE
77	FILTER SIZE	microns	REMOVE SOLIDS GREATER THAN 2 MICRONS (*) **(NOTE-14)**
78	EFFICIENCY	%	99.9
79	DESIGN CODE		ASME SECTION VIII DIV. 1
80	NOISE LEVEL	dBA	85 dB (A) @ 1 m (as per PTS 12.01.02)
81	MATERIAL		SS 316L

MECHANICAL DATASHEET
INSTRUMENT AIR COMPRESSOR AND DRYER PACKAGE (A-5410)

Client	: PC KETAPANG II LTD	**Equipment Name**	: AIR COMPRESSOR AND DRYER PACKAGE
Project	: PROVISION OF EPCIC OF BTJT-B WELLHEAD PLATFORM, INFIELD PIPELINE & HOST TIE IN MODIFICATION FOR BUKIT TUA PHASE 2B DEVELOPMENT PROJECT	**Tag Number**	: SEE BELOW (NOTE 18)
		No. Required	: ONE (1) PACKAGE
Location	: WHP - BTJT-B	**SPEC. REF.**	: BTP2B-EPCIC-BTJTB-M-SPC-0013
Contract No.	: 4850000373		& PTS 12.11.35 (COMPRESSOR & DRYER SPEC)

DESIGN DATA OF VESSELS FOR AIR DRYER (S-5412 A/B)

1	DESIGN CODE		ASME Sec VIII Div 1	28	VESSEL CAPACITY	m^3	(*)
2	NO. OF VESSEL		2	29	CORROSION ALLOWANCE	mm	Nil
3	DESIGN PRESSURE (Note 28)	barg	12 barg (175 psig)	30	BASE TYPE	■ ON SKID	☐ CONCRETE
4	DESIGN TEMPERATURE	°C	70/0	31		☐ RINGWALL	☐ OTHER
5	OPERATING PRESSURE	barg	10 barg (145 psig)	32	INSULATION THICKNESS	mm	N/A
6	OPERATING TEMPERATURE	°C	40 - 50	33	WIND VELOCITY	m/s	ELE : X= 0.085g; Y= 0.088g; Z= 0.220g
7	SERVICE		AIR	34	EARTHQUAKE ZONE :		N/A
8	DENSITY	kg/m^3	1	35	WELD EXAMINATION	■ RADIOGRAPHIC	☐ ULTRASONIC
9	VESSEL TYPE ☐ HORIZONTAL		■ VERTICAL	36		☐ OTHERS	
10	VESSEL SIZE:			37	WELD HEAT TREATMENT :		N/A
11	INTERNAL DIAMETER OF VESSEL	m	(*)	38	IMPACT TEST :		(*)
12	LENGTH BETWEEN TANGENT LINES	m	(*)	39	INSPECTION AUTHORITY :		(*)
13	WALL THICKNESS, SHELL/HEADS	mm	(*)	40	TEST PRESSURE :		AS PER PTS 12.20.01
14	TYPE OF HEADS		(*)	41	MILL TEST REQ'D	■ YES	☐ NO
15	OVERALL HEIGHT OF VESSELS	mm	(*)	42	PACKED TOWER		(*)
16	TRAYS			43	TOTAL HEIGHT OF PACKING		(*)
17	SPACING No.REQ'D		N/A	44	SIZE AND TYPE OF PACKING		(*)
18	TYPE		N/A	45	No. OF PACKED SECTION		(*)
19	LAYOUT IN ACCORDANCE WITH SHEET		N/A	46	No.OF REDISTRIBUTORS		(*)
20	FURNISHED BY		N/A	47	HEIGHT PER BED	mm	(*)
21	INSTALLED BY		N/A	48			
22	DEMISTER TYPE		N/A	49			
23	FURNISHED BY		N/A	50			
24	INSTALLED BY		N/A	51			
25	MAX ALLOWABLE PRESSURE DROP	barg	(*)	52			
26				53			
27				54			

WEIGHTS

55	ERECTION WEIGHT (SHIPPING WEIGHT)	kg	(*)	59	WEIGHT OF INSULATION	kg	N/A
56	TOTAL WEIGHT OPERATING	kg	(*)	60	WEIGHT OF FIREPROOFING	kg	N/A
57	TOTAL WEIGHT FULL OF WATER	kg	(*)	61	TOTAL WEIGHT	kg	(*)
58	WEIGHT OF INTERNALS (INCLUDING PACKING)	kg	(*)	62			

MATERIALS

63	SHELL	SS 316L	83	SKID MOUNTED	A-36
64	HEADS	SS 316L	84	BASE RING & CHAIRS	(*)
65	JACKET SHELL	(*)	85	BASE PLATES	(*)
66	JACKET HEADS	(*)	86	LEGS	A-36 (*)
67	CLADDING LINING	Not Required	87	STUD BOLTS EXTERNAL	A193 B8M class 2 / A194 Gr 8MA
68	SHELL	Not Required	88	NUTS EXTERNAL	
69	HEADS	Not Required	89	ANCHOR BOLTS	(*)
70	NOZZLES		90	BOLTS INTERNAL	SS 316
71	LINE PIPE	A 312 TP 316L	91	NUTS INTERNAL	SS 316
72	FLANGE	A 182 F 316L	92	INTERNAL PARTS	
73	REINF PLATES	(*)	93	BAFFLES	N/A
74	STIFFENING RINGS	(*)	94	TRAYS	N/A
75	FLANGES BOLT & NUT	A193 B8M class 2 / A194 Gr 8MA	95	TRAY SUPPORTS	N/A
76	GUSSETS	(*)	96	DEMISTER SUPPORT	N/A
77	PLATFORM	(*)	97	PIPE FITTING	N/A
78			98	CLEATS	N/A
79			99	WEAR PLATES	N/A
80			100	GASKETS EXTERNAL	Non CAF Flat Gasket
81			101		
82			102		

PETRONAS	PT. MEINDO ELANG INDAH Engineering and Construction	Doc. No. : BTP2B-EPCIC-BTJTB-M-TDS-0013
		Revision : 0
PROVISION OF EPCIC OF BTJT-B WELLHEAD PLATFORM, INFIELD PIPELINES AND HOST TIE IN MODIFICATION FOR BUKIT TUA PHASE 2B DEVELOPMENT PROJECT		

MECHANICAL DATASHEET
INSTRUMENT AIR COMPRESSOR AND DRYER PACKAGE (A-5410)

Client	: PC KETAPANG II LTD	**Equipment Name**	: AIR COMPRESSOR AND DRYER PACKAGE
Project	: PROVISION OF EPCIC OF BTJT-B WELLHEAD PLATFORM, INFIELD PIPELINE & HOST TIE IN MODIFICATION FOR BUKIT TUA PHASE 2B DEVELOPMENT PROJECT	**Tag Number**	: SEE BELOW (NOTE 18)
		No. Required	: ONE (1) PACKAGE
Location	: WHP - BTJT-B	**SPEC. REF.**	: BTP2B-EPCIC-BTJTB-M-SPC-0013 & PTS 12.11.35
Contract No.	: 4850000373		

FABRICATION AND INSPECTION REQUIREMENTS

1	CONSTRUCTION CODE	:	ASME Sec VIII Div 1	8	OTHER NDT	:	N/A
2	DESIGN APPROVAL	:	MIGAS	9	CHEMICAL ANALYSIS	:	-
3	INSPECTION	:	(*)	10	MANUFACTURER'S CERTIFICATE	:	(*)
4	INSPECTION AUTHORITY	:	MIGAS	11	CHEMICAL ANALYSIS	:	YES
5	STRESS RELIEVING	:	PER CODE	12	MECHANICAL DATA	:	YES
6	SPECIAL HEAT TREATMENT	:	N/A	13	ULTRASONIC TESTING	:	(*)
7	RADIOGRAPHY	:	PER CODE	14	PNEUMATIC TESTING	:	(*)

PROTECTIVE COATING

15	INTERNAL SURFACE	N/A
16	EXTERNAL SURFACE	As per PTS 15.20.03 , Protective Coating & Linings

AIR DRYER SKID CONNECTIONS

17		**Reqd.**	**Size.**	**Rating**	**Flange**	**SCH**	**Service Description**	**Remarks**
18		**No.**		**(#)**	**Type**			
19		1	DN 50	150	RF WN		AIR INLET	
20		1	DN 50	150	RF WN		AIR OUTLET	
21		1	DN 50	150	RF WN		DRAIN	
22		(*)	(*)	(*)	(*)		VENT	

NOTES (CONTINUED)

(9) VENDOR to provide a skid mounted Local Control Panel.
The alarm signal from the package shall include as minimum:
- High compressor discharge pressure
- High compressor discharge temperature
- Compressor tripped
- Compressor mechanical faults (by Vendor)
- Low/High instrument air pressure
- Load Control
- Common alarms

Local Control Panel (LCP) located at skid and shall suitable for Hazardous Area.
Controller supplied shall be comply with SIL Requirement which defined by IPF Studies.

(10) VENDOR shall specify spare parts for start up and commissioning, 2 (two) years operation and special tools requirements.

(11) Design life for the equipment shall be 10 years.

(12) VENDOR shall include all instrumentation, valves, fitting and piping as shown in P&ID 11-BTJT-B-B-PID-1541 / 1542.
VENDOR shall include pressure control valves

(13) All cables inside the skid shall be provided as per Specification for Electrical Cable, BTP2B-EPCIC-BTJTB-E-SPC-0005 and Specification for Electrical Requirements on Package Equipment, BTP2B-EPCIC-BTJTB-E-SPC-0001.

(14) Air quality shall be as per PTS. 16.39.07 Instrument Air System or ISA S7.0.01 Quality Standard for Instrument Air.

(15) Two welded earthing bosses with M10 SS studbolts shall be installed on diagonally opposite corners of the structural steel skid as per Electrical Typical Installation Details - Earthing, 11-BTJT-B-E-DWG-5002.

(16) Material certification shall be in accordance with BS EN 10474 type 3.1 for all major parts and load bearing parts. Type 2.2 certification shall apply to all other materials.

(17) Lifting lugs with safety factor of 2.0 shall be provided at skid, suitable for single point lifting by crane

(18) SS316 name plate c/w bracket shall be provided for the package and major equipment as specified in this datasheet.

(19) Delivered capacity of package which is at skid outlet. Additional capacity of compressors are required for dessicant regeneration.

(20) Instrument Air Package Capacity refer to Process Data Sheet, BTP2B-EPCIC-BTJTB-B-TDS-0012 and P&ID Instrument /Utility Air Compressor, 11-BTJT-B-B-PID-1541 and P&ID Instrument Air Dryer, 11-BTJT-B-B-PID-1542.

(21) The intake filter is to be fitted with a differential pressure gauge. Refer to PTS 12.11.35 para 3.2.8 for intake filter requirements.

(22) The air cooled coolers shall be thermally rated for a maximum possible inlet ambient air temperature as per specified in datasheet/specification.
A minimum of 10% shall be added to the calculated surface area requirement of the air coolers to cater for any fouling in service.

(23) Moisture separator (SS material) shall be design to ensure that the separator can remove 70% to 80% of moisture with an air quality of not more than 5% over saturated at outlet of separator under any operating conditions. An automatic draining facility with level alarm shall be provided for the moisture separator.

(24) Pre- and After-filter to be completed with pressure gauge and isolation valves, and/or switchover valve as required.
The size of each air filter shall be designed for six months of continuous operation in offshore/marine environment condition without replacement of The filter cartridge.

(25) Relief valve shall be provided to maintain minimum inlet pressure to filter dryer to avoid overloading.

(26) Electrical shall be as per Electrical Requirement for Package Equipment, BTP2B-EPCIC-BTJTB-E-SPC-0001.

(27) The alarm/shutdown requirement to be integrated with the SIS/ESD and will be indicated in P&ID.

(28) Design pressure : 12 barg is used as basis. Lead compressor starts at 8 barg and stop at 9.5 barg. Lag compressor starts at 7 barg and stop at 9 barg. The lead/lag control is driven by the pressure high/low setting at air receiver.

Type of equipment	: *		Mechanical Power :	*	kW
VENDOR/Manufacturer :	*		Speed :	*	r/min
Type no. :	*		Size l x b x h :	* x * x *	m

1. **GENERAL**

   This requisition cover the noise limits of equipment, given below. For definitions, method of measuring etc. reference is made to EEMUA specification no. 140 : Noise procedure specification.

2. **NOISE LIMITS TO BE MET BY THE EQUIPMENT**

   The noise generated by the equipment shall not exceed the more stringent of the noise limits given in the table below for any of the conditions of operation for which the equipment may normally be expected to be used.

   Lp is the maximum (A-weighted) sound pressure level, dB re 20 uPa at any location at 1 m from the equipment surface.

   Lw is the maximum (A-weighted) sound power level. dB re 1 pW.

   If the equipment generates noise with tonal or impulsive components the limits shall be taken 5 dB(A) more stringent.

3. **INFORMATION TO BE SUBMITTED WITH THE TENDER**

   This noise data sheet shall be returned with the tender and with guaranteed noise data filled in.

   VENDOR shall state which silencing measures were taken to meet the noise requirements.

   Where applicable the completed silencer and / or acoustic enclosure data requisition sheet shall also be returned.

Equipment Items / Locations	a		Noise levels guaranteed by VENDOR in dB(A) (upper tolerance + 0 dB)									b Noise limit dB (A)	Remarks Silencing measures
			63	125	250	500	1k	2k	4k	8k	Total		
INSTRUMENT AIR COMPRESSOR AND DRYER PACKAGE (A-5410)	1	Lp										**85**	
		Lw											
		Lp											
		Lw											
		Lp											
		Lw											
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		Lp											
		Lw											
		Lp											
		Lw											

COMPANY/CONTRACTOR shall indicate :

- In column "b", the noise limit
- In column "a" using the appropriate number, which of the following applies to the required noise levels :

  1) without acoustic provisions
  2) with acoustic provisions and / or special low noise design.
  3) VENDOR best estimate, not necessarily guaranteed.
  4) Without accoustic enclosure, refer remarks **'*'**.

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Doc. No.	: BTP2B-EPCIC-BTJTB-M-TDS-0013
Revision	: 0
Page	: 11 of 11

PROVISION OF EPCIC OF BTJT-B WELLHEAD PLATFORM, INFIELD PIPELINES AND HOST TIE IN MODIFICATION FOR BUKIT TUA PHASE 2B DEVELOPMENT PROJECT

Data/Requisition sheet for

MASS/CENTRE OF MASS OF EQUIPMENT

EQUIPMENT DESCRIPTION

AIR COMPRESSOR AND DRYER PACKAGE

INFORMATION STATUS (Tick as necessary)	
Tender est.	
Design est.	
Design update	
As supplied	

Heaviest component to be handled during maintenance:-

Description	mass KG

WEIGHT DATA (KG)

NOTES:

1/ One sheet shall be completed for each separately installed skid or item.

2/ As supplied equipment shall be weighted by VENDOR and witnessed by COMPANY/CONTRACTOR or nominee.

3/ VENDOR shall provide current calibration certificate of weighing equipment. Calibration methods shall be to BS 1610.

4/ VENDOR shall submit design update for significant changes in mass.

Dry	Kg	Operating	Kg	Test	Kg

Other temporary masses	Description	Kg

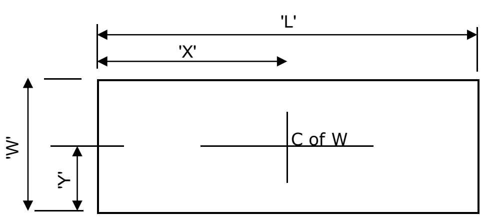
Certified final mass	Date	Name	Company
COMPANY/CONTRACTOR inspector			
VENDOR			

DIMENSIONAL DATA (mm)

NOTES:

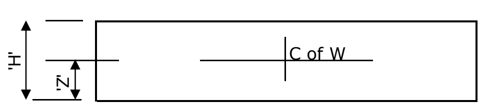
1/ Equipment orientation on each skid or item to be indicated.

2/ C of M Coordinates to be clearly shown on G.A. drawings.



Plan

OVERALL SIZES	
DIMENSION 'L'	
DIMENSION 'W'	
DIMENSION 'H'	



Elevation

CENTRE OF WEIGHT		
Dimension	Dry	Operating
'X'		
'Y'		
'Z'		

Appendix D

OREDA Data of Electric Driven Screw Compressor

Maintainable item versus failure mode, to be continued
Item: Compressors - Screw

	AIR	BRD	ELP	ELU	ERO	FTS	HIO	INL	LOO	NOI
Base frame	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bearing	0.00	0.00	0.00	1.37	0.00	0.00	0.00	0.00	0.00	0.00
Cabling & junction boxes	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Casing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Control unit	0.00	0.00	0.00	0.00	0.69	0.34	0.00	0.00	0.00	0.00
Cooler(s)	0.00	0.00	0.00	0.86	0.00	0.00	0.00	0.00	0.00	0.00
Coupling to driver	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00
Dry gas seal	0.00	0.00	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.00
Filter(s)	0.17	0.00	0.00	0.69	0.00	0.00	0.00	0.00	0.69	0.00
Instrument, flow	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Instrument, general	1.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Instrument, level	0.69	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00
Instrument, pressure	6.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Instrument, speed	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Instrument, temperature	9.28	0.00	0.00	0.00	0.00	1.03	0.00	0.00	0.00	0.00
Instrument, vibration	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Internal piping	0.17	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Internal power supply	0.34	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00
Interstage seals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lube oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.69	0.00
Monitoring	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.34	0.34	0.00	0.00	0.00	0.00	0.34	0.00
Piping	0.00	0.00	0.00	3.26	0.00	0.00	0.00	0.00	0.00	0.00
Piping, pipe support + bellows	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pump w/motor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Purge air	0.00	0.00	0.00	0.34	0.00	0.34	0.00	0.00	0.00	0.00
Radial bearing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reservoir w/heating system	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rotor w/ impellers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
Seals	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00
Shaft seals	0.00	0.00	0.34	3.44	0.00	0.00	0.00	0.00	0.00	0.00
Subunit	0.69	0.00	0.34	0.69	0.00	0.00	0.00	0.34	1.03	0.34
Unknown	0.00	0.00	0.34	0.69	0.00	0.69	0.00	0.00	0.00	0.00
Valves	0.69	0.00	1.03	0.69	2.41	1.03	0.00	0.00	3.09	0.00
Total	22.68	0.00	2.75	13.75	3.09	4.12	0.00	0.34	5.84	0.69

The figures are percentages of the total failure rate for the actual maintainable item/failure mode combination.

Maintainable item versus failure mode, continued
Item: Compressors - Screw

	OHE	OTH	PDE	SER	STD	STP	UNK	UST	VIB	Sum
Base frame	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.34
Bearing	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	1.72
Cabling & junction boxes	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.03
Casing	0.00	0.00	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.69
Control unit	0.00	0.34	0.34	0.00	0.00	0.00	0.00	0.69	0.00	2.41
Cooler(s)	0.34	0.34	0.34	0.00	0.00	0.00	0.00	0.46	0.00	2.35
Coupling to driver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
Dry gas seal	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	1.03
Filter(s)	0.00	0.34	1.72	0.69	0.00	0.00	0.00	0.11	0.00	4.41
Instrument, flow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
Instrument, general	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	2.06
Instrument, level	0.00	0.00	0.00	0.69	0.00	0.00	0.00	0.00	0.00	1.72
Instrument, pressure	0.00	0.00	1.03	0.69	0.00	0.00	0.00	1.72	0.00	9.97
Instrument, speed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
Instrument, temperature	0.00	0.00	0.69	0.34	0.00	0.00	0.00	2.41	0.00	13.75
Instrument, vibration	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.69
Internal piping	0.34	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	1.20
Internal power supply	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	1.03
Interstage seals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.34
Lube oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.69
Monitoring	0.00	0.34	0.00	0.34	0.00	0.00	0.00	0.00	0.00	1.37
Oil	0.00	0.34	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.69
Other	0.00	0.69	0.00	1.37	0.34	0.00	0.69	0.00	0.00	4.12
Piping	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.11	0.00	3.89
Piping, pipe support + bellows	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17
Pump w/motor	0.86	0.00	1.72	0.34	0.00	0.00	0.34	0.00	0.00	3.26
Purge air	0.00	0.00	2.06	1.03	0.00	0.00	0.00	0.00	0.00	3.78
Radial bearing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.34
Reservoir w/heating system	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
Rotor w/ impellers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.69	0.00	1.03
Seals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
Shaft seals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	4.12
Subunit	0.34	1.03	0.00	0.34	0.00	0.00	0.00	1.37	0.00	6.53
Unknown	0.00	1.03	0.34	0.00	0.00	0.00	0.34	2.06	0.00	5.50
Valves	0.34	0.34	4.81	2.58	0.34	0.00	0.00	0.69	0.00	18.04
Total	2.41	5.50	13.40	10.65	1.72	0.00	1.37	11.68	0.00	100.0

The figures are percentages of the total failure rate for the actual maintainable item/failure mode combination.

Failure descriptior versus failure mode, to be continued
Item: Compressors - Screw

	AIR	BRD	ELP	ELU	ERO	FTS	HIO	INL	LOO	NOI
Blockage/plugged	0.34	0.00	0.00	0.34	0.34	0.00	0.00	0.00	0.34	0.00
Breakage	0.69	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cavitation	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Clearance/ alignment failure	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Contamination	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Control failure	0.00	0.00	0.00	0.00	0.00	1.03	0.00	0.00	0.34	0.00
Corrosion	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Deformation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Earth/isolation fault	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electrical failure - general	0.34	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00
External influence - general	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Faulty signal/indication/alarm	1.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Instrument failure - general	12.03	0.00	0.00	0.34	1.72	1.37	0.00	0.00	1.03	0.00
Leakage	0.00	0.00	1.37	3.44	0.00	0.34	0.00	0.00	0.00	0.00
Looseness	0.00	0.00	0.34	0.69	0.00	0.00	0.00	0.00	0.00	0.00
Material failure - general	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mechanical Failure - general	0.69	0.00	0.00	6.87	0.69	0.00	0.00	0.00	1.37	0.00
Misc. external influences	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00
No signal/indication/alarm	1.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Open circuit	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Out of adjustment	3.09	0.00	0.00	0.00	0.34	0.69	0.00	0.00	0.00	0.00
Overheating	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Short circuiting	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Software failure	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sticking	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unknown	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.34	0.00
Vibration	0.69	0.00	0.34	0.34	0.00	0.00	0.00	0.00	0.00	0.00
Wear	0.00	0.00	0.00	1.72	0.00	0.00	0.00	0.34	2.06	0.69
Total	22.68	0.00	2.75	13.75	3.09	4.12	0.00	0.34	5.84	0.69

The figures are percentages of the total failure rate for the actual failure descriptor/failure mode combination.

Failure descriptior versus failure mode, continued
Item: Compressors - Screw

	OHE	OTH	PDE	SER	STD	STP	UNK	UST	VIB	Sum
Blockage/plugged	0.34	0.34	1.72	0.00	0.00	0.00	0.00	0.69	0.00	4.47
Breakage	0.00	0.00	0.00	1.37	0.00	0.00	0.00	0.00	0.00	2.41
Cavitation	0.00	0.34	0.00	0.34	0.34	0.00	0.00	0.00	0.00	1.37
Clearance/ alignment failure	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
Contamination	0.00	0.34	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.69
Control failure	0.00	0.00	0.69	0.34	0.00	0.00	0.00	0.00	0.00	2.41
Corrosion	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
Deformation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.34
Earth/isolation fault	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.69
Electrical failure - general	0.00	0.69	0.34	0.34	0.00	0.00	0.00	0.34	0.00	2.41
External influence - general	0.00	1.72	1.03	0.00	0.00	0.00	0.00	0.34	0.00	3.09
Faulty signal/indication/alarm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	1.37
Instrument failure - general	0.00	0.00	3.78	2.75	0.00	0.00	0.00	3.78	0.00	26.80
Leakage	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.34	0.00	5.84
Looseness	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.03
Material failure - general	0.00	0.34	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.69
Mechanical Failure - general	0.69	0.69	3.09	4.12	1.03	0.00	0.00	2.41	0.00	21.65
Misc. external influences	0.34	0.00	0.69	0.69	0.00	0.00	0.00	0.34	0.00	3.09
No signal/indication/alarm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.03
Open circuit	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.69
Other	0.00	0.34	0.00	0.00	0.00	0.00	0.69	0.00	0.00	1.03
Out of adjustment	0.69	0.00	0.69	0.00	0.00	0.00	0.00	0.69	0.00	6.19
Overheating	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.69
Short circuiting	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.34
Software failure	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
Sticking	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.34
Unknown	0.00	0.00	0.34	0.00	0.00	0.00	0.69	1.03	0.00	2.75
Vibration	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	1.72
Wear	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.69	0.00	5.84
Total	2.41	5.50	13.40	10.65	1.72	0.00	1.37	11.68	0.00	100.0

The figures are percentages of the total failure rate for the actual failure descriptor/failure mode combination.

Taxonomy no	Item
1.1.3.2	Machinery Compressors Screw Electric driven

Population	Installations	Aggregated time in service (10⁶ hours)		No of demands
		Calendar time *	Operational time †	
33	16	1.0800	0.5894	38694

Failure mode	No of failures	Failure rate (per 10⁶ hours). Lower	Mean	Upper	SD	n/τ	Active rep.hrs	Repair (manhours) Min	Mean	Max
Critical	**79***	**0.00**	**119.07**	**623.23**	**280.02**	**73.15**	**14.7**	**1.0**	**23.2**	**163.0**
	79†	**0.00**	**140.31**	**771.01**	**373.65**	**134.04**				
Erratic output	4*	0.00	7.43	41.04	20.71	3.70	6.8	7.0	9.8	15.0
	4†	0.00	9.79	53.91	26.83	6.79				
External leakage - Process medium	2*	0.43	2.02	4.58	1.33	1.85	17.5	12.0	29.0	46.0
	2†	0.00	3.55	15.81	6.24	3.39				
External leakage - Utility medium	7*	0.00	12.91	71.93	37.34	6.48	14.1	13.0	38.9	96.0
	7†	0.00	16.30	92.72	49.64	11.88				
Fail to start on demand	12*	0.01	19.39	85.34	33.45	11.11	5.9	1.0	8.7	32.0
	12†	0.03	27.31	112.65	42.77	20.36				
Low output	11*	0.00	18.32	100.68	48.26	10.19	16.2	2.0	26.7	163.0
	11†	0.00	22.95	126.63	63.80	18.66				
Noise	1*	0.00	1.14	6.30	3.17	0.93	73.0	76.0	76.0	76.0
	1†	0.00	1.64	7.89	3.25	1.70				
Other	1*	0.00	1.14	6.30	3.17	0.93	7.0	7.0	7.0	7.0
	1†	0.00	1.64	7.89	3.25	1.70				
Overheating	4*	0.00	5.69	25.77	10.24	3.70	20.1	2.0	20.5	70.0
	4†	0.05	7.60	26.23	9.67	6.79				
Parameter deviation	2*	0.01	2.90	11.70	4.40	1.85	10.8	11.0	21.5	32.0
	2†	0.00	4.42	21.89	9.28	3.39				
Spurious stop	34*	0.00	49.58	255.89	111.67	31.48	15.8	2.0	23.6	148.0
	34†	0.00	60.15	320.06	146.70	57.69				
Structural deficiency	1*	0.00	1.64	8.64	3.90	0.93	21.5	43.0	43.0	43.0
	1†	0.01	1.96	7.64	2.83	1.70				
Degraded	**92***	**0.00**	**145.57**	**800.25**	**391.94**	**85.19**	**9.2**	**1.0**	**15.2**	**111.0**
	92†	**0.00**	**163.88**	**929.89**	**529.52**	**156.10**				
Abnormal instrument reading	1*	0.00	1.14	6.30	3.17	0.93	5.0	5.0	5.0	5.0
	1†	0.00	1.64	7.89	3.25	1.70				
Erratic output	5*	0.00	8.39	44.63	20.45	4.63	6.9	2.0	10.6	35.0
	5†	0.00	11.16	58.06	25.82	8.48				
External leakage - Process medium	5*	0.00	8.86	46.23	20.66	4.63	2.5	1.0	4.6	15.0
	5†	0.00	11.83	60.47	26.16	8.48				
External leakage - Utility medium	28*	0.00	45.81	252.37	126.02	25.93	10.7	1.0	18.0	111.0
	28†	0.00	53.70	311.42	169.53	47.51				
Internal leakage	1*	0.00	1.14	6.30	3.17	0.93	48.0	48.0	48.0	48.0
	1†	0.00	1.64	7.89	3.25	1.70				
Low output	6*	0.00	5.91	33.01	19.44	5.56	6.5	2.0	6.5	12.0
	6†	0.00	8.05	44.37	22.22	10.18				
Noise	1*	0.00	1.14	6.30	3.17	0.93	15.0	15.0	15.0	15.0
	1†	0.00	1.64	7.89	3.25	1.70				

Comments

(cont.)

Taxonomy no		Item			
1.1.3.2		Machinery Compressors Screw Electric driven			
Population	Installations	Aggregated time in service (10⁶ hours)		No of demands	
		Calendar time *	Operational time †		
33	16	1.0800	0.5894	38694	

Failure mode	No of failures	Failure rate (per 10⁶ hours). Lower	Mean	Upper	SD	n/τ	Active rep.hrs	Repair (manhours) Min	Mean	Max
Other	7*	0.00	12.12	62.14	26.92	6.48	10.0	1.0	17.5	46.0
	7†	0.00	16.03	80.33	34.37	11.88				
Overheating	3*	0.00	3.17	16.69	7.58	2.78	11.0	16.0	20.0	24.0
	3†	0.00	5.15	21.87	8.42	5.09				
Parameter deviation	33*	0.00	58.96	332.10	175.64	30.56	8.4	2.0	15.7	101.0
	33†	0.00	67.80	360.97	238.56	55.99				
Structural deficiency	2*	0.00	3.67	20.15	9.58	1.85	6.3	8.0	12.5	17.0
	2†	0.00	4.93	25.68	11.43	3.39				
Incipient	**107***	**0.00**	**179.22**	**985.45**	**484.37**	**99.08**	**10.3**	**1.0**	**18.8**	**961.0**
	107†	**0.00**	**205.40**	**1177.72**	**656.93**	**181.55**				
Abnormal instrument reading	64*	0.00	108.32	600.47	307.63	59.26	6.2	1.0	10.2	176.0
	64†	0.00	122.36	663.52	417.49	108.59				
External leakage - Process medium	1*	0.00	1.64	8.64	3.90	0.93	1.0	2.0	2.0	2.0
	1†	0.01	1.96	7.64	2.83	1.70				
External leakage - Utility medium	5*	0.01	6.74	28.31	10.85	4.63	5.5	1.0	10.4	38.0
	5†	0.29	9.74	29.63	10.25	8.48				
Minor in-service problems	30*	0.00	51.24	285.27	147.80	27.78	3.1	1.0	5.5	23.0
	30†	0.00	59.42	325.43	199.95	50.90				
Other	2*	0.00	3.80	17.66	7.15	1.85	480.5	1.0	481.0	961.0
	2†	0.00	6.96	33.79	14.02	3.39				
Parameter deviation	4*	0.00	6.55	29.66	11.80	3.70	4.3	2.0	5.7	8.0
	4†	0.02	8.82	34.52	12.83	6.79				
Structural deficiency	1*	0.00	1.30	6.11	2.49	0.93	5.0	10.0	10.0	10.0
	1†	0.00	2.01	11.08	5.54	1.70				
Unknown	**6***	**0.06**	**15.73**	**60.80**	**22.46**	**5.56**	**5.0**	**8.0**	**11.7**	**16.0**
	6†	**0.15**	**32.54**	**119.59**	**44.18**	**10.18**				
Other	2*	0.00	6.23	32.72	14.79	1.85	-	8.0	9.0	10.0
	2†	0.00	14.83	73.04	30.82	3.39				
Unknown	4*	0.00	9.62	43.68	17.39	3.70	5.0	8.0	13.0	16.0
	4†	0.00	18.10	81.74	32.47	6.79				
All modes	**284***	**0.00**	**459.38**	**2500.47**	**1166.09**	**262.97**	**11.2**	**1.0**	**18.8**	**961.0**
	284†	**0.00**	**535.36**	**3002.40**	**1577.16**	**481.86**				

Comments

On demand probability for consequence class: Critical and failure mode: Fail to start on demand = 1.8 $\cdot 10^{-4}$

Appendix E

Criticality and Probability of Failures of Failure Modes

Failure Mode	FM	Alpha	Failure Rate per 10^6 Hours	Lambda (per hour)	FM Severity	Beta	Lambda.A.B
AIR	22,670	0,227	109,46	0,0000109460	IMPACTFUL	0,75	1,86389E-06
BRD	0,000	0,000	0,00	0,0000000000	NEGLIGIBLE	0,1	0
ELP	2,730	0,027	12,52	0,0000012520	FAILED	1	3,42309E-08
ELU	13,740	0,138	65,46	0,0000065460	FAILED	1	9,00772E-07
ERO	3,100	0,031	15,82	0,0000015820	IMPACTFUL	0,75	3,68368E-08
FTS	4,110	0,041	19,39	0,0000019390	LESSIMPACT	0,25	1,99532E-08
HIO	0,000	0,000	0,00	0,0000000000	NEGLIGIBLE	0,1	0
INL	0,340	0,003	1,14	0,0000001140	IMPACTFUL	0,75	2,91137E-10
LOO	5,840	0,058	24,23	0,0000024230	IMPACTFUL	0,75	1,06287E-07
NOI	0,680	0,007	2,28	0,0000002280	LESSIMPACT	0,25	3,88182E-10
OHE	2,390	0,024	8,86	0,0000008860	FAILED	1	2,12072E-08
OTH	5,480	0,055	23,29	0,0000023290	IMPACTFUL	0,75	9,58657E-08
PDE	13,390	0,134	68,41	0,0000068410	IMPACTFUL	0,75	6,88039E-07
SER	10,640	0,107	51,24	0,0000051240	LESSIMPACT	0,25	1,36503E-07
STD	1,700	0,017	6,61	0,0000006610	IMPACTFUL	0,75	8,44041E-09
STP	0,000	0,000	0,00	0,0000000000	NEGLIGIBLE	0,1	0
UNK	1,370	0,014	9,62	0,0000009620	LESSIMPACT	0,25	3,2998E-09
UST	11,670	0,117	49,58	0,0000049580	IMPACTFUL	0,75	4,34601E-07
VIB	0,000	0,000	0,00	0,0000000000	NEGLIGIBLE	0,1	0
Total	**99,85**	**1**	**467,91**	**0,0000467910**			**0,0000043506**

FM Severity	Description	Beta
NEGLIGIBLE	No effect to the equipment.	0,1
LESSIMPACT	Prolonged effect. No direct effect to performance.	0,25
IMPACTFUL	Effect to performance. Reduced.	0,75
FAILED	Failed equipment.	1

Probability of Failue		Quantitative Range
At least once every < 6 months	**Frequent**	> 2.28E-04
At least once every 6 months to 2 years	**Probable**	2.28E-04 to 5.70776E-05
At least once every 2 to 4 years	**Rare**	5.70776E-05 to 2.85388E-05
At least once very 4 to 20 years	**Remote**	2.85388E-05 to 5.70776E-06
At least once every > 20 years	**Improbable**	5.70776E-06 >

CRITICALITY

Maintenance Interval	Time	AIR	BRD	ELP	ELU	ERO	FTS	HIO	INL	LOO	NOI	OHE	OTH	PDE	SER	STD	STP	UNK	UST	VIB	Total
Daily	**24**	4,47333E-05	0	8,21543E-07	2,16185E-05	8,84082E-07	4,78876E-07	0	6,98728E-09	2,55088E-06	9,31637E-09	5,08973E-07	2,30078E-06	1,65129E-05	3,27608E-06	2,0257E-07	0	7,91952E-08	1,04304E-05	0	**0,00010441**
Weekly	**168**	0,000313133	0	5,7508E-06	0,00015133	6,18857E-06	3,35213E-06	0	4,8911E-08	1,78562E-05	6,52146E-08	3,56281E-06	1,61054E-05	0,000115591	2,29325E-05	1,41799E-06	0	5,54366E-07	7,30129E-05	0	**0,0007309**
Bi-weekly	**336**	0,000626267	0	1,15016E-05	0,000302659	1,23771E-05	6,70426E-06	0	9,78219E-08	3,57124E-05	1,30429E-07	7,12562E-06	3,22109E-05	0,000231181	4,58651E-05	2,83598E-06	0	1,10873E-06	0,000146026	0	**0,0014618**
Monthy	**730**	0,001360639	0	2,49886E-05	0,000657563	2,68908E-05	1,45658E-05	0	2,1253E-07	7,75894E-05	2,83373E-07	1,54813E-05	6,9982E-05	0,000502269	9,96473E-05	6,1615E-06	0	2,40885E-06	0,000317259	0	**0,00317594**
2-monthly	**1460**	0,002721279	0	4,99772E-05	0,001315126	5,37817E-05	2,91316E-05	0	4,2506E-07	0,000155179	5,66746E-07	3,09625E-05	0,000139964	0,001004538	0,000199295	1,2323E-05	0	4,81771E-06	0,000634517	0	**0,00635188**
3-monthly	**2190**	0,004081918	0	7,49658E-05	0,00197269	8,06725E-05	4,36974E-05	0	6,37589E-07	0,000232768	8,50119E-07	4,64438E-05	0,000209946	0,001506806	0,000298942	1,84845E-05	0	7,22656E-06	0,000951776	0	**0,00952782**
6-monthly	**4380**	0,008163836	0	0,000149932	0,003945379	0,000161345	8,73948E-05	0	1,27518E-06	0,000465536	1,70024E-06	9,28876E-05	0,000419892	0,003013613	0,000597884	3,6969E-05	0	1,44531E-05	0,001903552	0	**0,01905565**
Yearly	**8760**	0,016327672	0	0,000299863	0,007890759	0,00032269	0,00017479	0	2,55036E-06	0,000931073	3,40048E-06	0,000185775	0,000839784	0,006027226	0,001195768	7,3938E-05	0	2,89062E-05	0,003807103	0	**0,0381113**
2-yearly	**17520**	0,032655344	0	0,000599726	0,015781518	0,00064538	0,000349579	0	5,10072E-06	0,001862145	6,80095E-06	0,00037155	0,001679567	0,012054452	0,002391535	0,000147876	0	5,78125E-05	0,007614207	0	**0,07622259**

PROBABILITY

Maintenance Interval	Time	AIR	BRD	ELP	ELU	ERO	FTS	HIO	INL	LOO	NOI	OHE	OTH	PDE	SER	STD	STP	UNK	UST	VIB	Total
Daily	**24**	4,47323E-05	0	8,21542E-07	2,16183E-05	8,84082E-07	4,78876E-07	0	6,98728E-09	2,55088E-06	9,31637E-09	5,08973E-07	2,30077E-06	1,65128E-05	3,27607E-06	2,0257E-07	0	7,91952E-08	1,04304E-05	0	**0,00010441**
Weekly	**168**	0,000313084	0	5,75078E-06	0,000151318	6,18856E-06	3,35212E-06	0	4,8911E-08	1,7856E-05	6,52146E-08	3,56281E-06	1,61053E-05	0,000115584	2,29323E-05	1,41799E-06	0	5,54366E-07	7,30103E-05	0	**0,00073083**
Bi-weekly	**336**	0,000626071	0	1,15015E-05	0,000302613	1,23771E-05	6,70424E-06	0	9,78219E-08	3,57117E-05	1,30429E-07	7,1256E-06	3,22104E-05	0,000231155	4,5864E-05	2,83597E-06	0	1,10873E-06	0,000146015	0	**0,00146152**
Monthy	**730**	0,001359714	0	2,49883E-05	0,000657347	2,68905E-05	1,45657E-05	0	2,1253E-07	7,75864E-05	2,83373E-07	1,54811E-05	6,99795E-05	0,000502143	9,96423E-05	6,16148E-06	0	2,40885E-06	0,000317208	0	**0,00317461**
2-monthly	**1460**	0,002717579	0	4,99759E-05	0,001314262	5,37802E-05	2,91312E-05	0	4,25059E-07	0,000155167	5,66746E-07	3,0962E-05	0,000139954	0,001004033	0,000199275	1,23229E-05	0	4,8177E-06	0,000634316	0	**0,00634657**
3-monthly	**2190**	0,004073598	0	7,4963E-05	0,001970745	8,06692E-05	4,36965E-05	0	6,37589E-07	0,000232741	8,50119E-07	4,64427E-05	0,000209924	0,001505672	0,000298897	1,84843E-05	0	7,22654E-06	0,000951323	0	**0,00951587**
6-monthly	**4380**	0,008130602	0	0,00014992	0,003937607	0,000161332	8,7391E-05	0	1,27518E-06	0,000465428	1,70024E-06	9,28833E-05	0,000419804	0,003009077	0,000597705	3,69683E-05	0	1,4453E-05	0,001901741	0	**0,01900789**
Yearly	**8760**	0,016195098	0	0,000299818	0,007859709	0,000322638	0,000174774	0	2,55035E-06	0,000930639	3,40047E-06	0,000185758	0,000839431	0,006009099	0,001195053	7,39353E-05	0	2,89058E-05	0,003799866	0	**0,03792067**
2-yearly	**17520**	0,032127915	0	0,000599546	0,015657642	0,000645172	0,000349518	0	5,1007E-06	0,001860413	6,80093E-06	0,000371481	0,001678157	0,011982088	0,002388678	0,000147865	0	5,78108E-05	0,007585292	0	**0,07546348**
Average		0,007287599	0	0,000135254	0,003541429	0,000145548	7,88458E-05	0	1,15057E-06	0,000419788	1,53409E-06	8,38006E-05	0,000378652	0,002708374	0,000539036	3,33549E-05	0	1,30406E-05	0,001713245	0	0,01708065

Appendix F

Probability of Failures of Maintainable Items

No.	Failure Mode	Failure Mode Code	Beta	Maintainable Item (Failure Cause)	Probability	Alpha	Maintenance Interval Time								
							Daily	Weekly	Bi-Weekly	Monthly	2-monthly	3-monthly	6-monthly	Yearly	2-yearly
1	Abnormal Instrument Reading	AIR	0,75	Cabling & junction boxes	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
		AIR	0,75	Filter(s)	0,17	0,001702554	3,35451E-07	2,34815E-06	4,6963E-06	1,02032E-05	2,04064E-05	3,06094E-05	6,12179E-05	0,000122432	0,000244849
		AIR	0,75	Instrument, flow	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
		AIR	0,75	Instrument, general	1,72	0,017225839	3,39397E-06	2,37575E-05	4,75145E-05	0,000103228	0,000206445	0,000309652	0,000619208	0,001238033	0,002474533
		AIR	0,75	Instrument, level	0,69	0,006910366	1,36153E-06	9,5307E-06	1,90613E-05	4,14125E-05	8,28233E-05	0,000124232	0,000248449	0,000496837	0,000993427
		AIR	0,75	Instrument, pressure	6,53	0,065398097	1,28852E-05	9,01927E-05	0,000180377	0,00039185	0,000783546	0,001175089	0,002348797	0,004692076	0,009362137
		AIR	0,75	Instrument, speed	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
		AIR	0,75	Instrument, temperature	9,28	0,092939409	1,83115E-05	0,000128173	0,00025633	0,000556825	0,001113339	0,001669544	0,003336301	0,006661471	0,013278568
		AIR	0,75	Instrument, vibration	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
		AIR	0,75	Internal piping	0,17	0,001702554	3,35451E-07	2,34815E-06	4,6963E-06	1,02032E-05	2,04064E-05	3,06094E-05	6,12179E-05	0,000122432	0,000244849
		AIR	0,75	Internal power supply	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
		AIR	0,75	Monitoring	0,69	0,006910366	1,36153E-06	9,5307E-06	1,90613E-05	4,14125E-05	8,28233E-05	0,000124232	0,000248449	0,000496837	0,000993427
		AIR	0,75	Reservoir w/ heating system	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
		AIR	0,75	Subunit	0,69	0,006910366	1,36153E-06	9,5307E-06	1,90613E-05	4,14125E-05	8,28233E-05	0,000124232	0,000248449	0,000496837	0,000993427
		AIR	0,75	Valves	0,69	0,006910366	1,36153E-06	9,5307E-06	1,90613E-05	4,14125E-05	8,28233E-05	0,000124232	0,000248449	0,000496837	0,000993427
2	External Leakage - Process Medium	ELP	1	Internal piping	0,34	0,003405108	1,02317E-07	7,16216E-07	1,43243E-06	3,11213E-06	6,22425E-06	9,33635E-06	1,86726E-05	3,73449E-05	7,46884E-05
		ELP	1	Other	0,34	0,003405108	1,02317E-07	7,16216E-07	1,43243E-06	3,11213E-06	6,22425E-06	9,33635E-06	1,86726E-05	3,73449E-05	7,46884E-05
		ELP	1	Shaft seals	0,34	0,003405108	1,02317E-07	7,16216E-07	1,43243E-06	3,11213E-06	6,22425E-06	9,33635E-06	1,86726E-05	3,73449E-05	7,46884E-05
		ELP	1	Subunit	0,34	0,003405108	1,02317E-07	7,16216E-07	1,43243E-06	3,11213E-06	6,22425E-06	9,33635E-06	1,86726E-05	3,73449E-05	7,46884E-05
		ELP	1	Unknown	0,34	0,003405108	1,02317E-07	7,16216E-07	1,43243E-06	3,11213E-06	6,22425E-06	9,33635E-06	1,86726E-05	3,73449E-05	7,46884E-05
		ELP	1	Valves	1,03	0,010315473	3,09959E-07	2,16971E-06	4,33942E-06	9,42789E-06	1,88557E-05	2,82834E-05	5,6566E-05	0,000113129	0,000226245
3	External Leakage - Utility Medium	ELU	1	Bearing	1,37	0,013720581	2,15556E-06	1,50888E-05	3,01774E-05	6,55627E-05	0,000131121	0,000196675	0,000393312	0,000786469	0,00157232
		ELU	1	Cooler(s)	0,86	0,008612919	1,35312E-06	9,47182E-06	1,89436E-05	4,11567E-05	8,23117E-05	0,000123465	0,000246915	0,000493768	0,000987293
		ELU	1	Coupling to driver	0,34	0,003405108	5,34956E-07	3,74469E-06	7,48936E-06	1,62714E-05	3,25426E-05	4,88135E-05	9,76247E-05	0,00019524	0,000390442
		ELU	1	Dry gas seal	0,69	0,006910366	1,08565E-06	7,59949E-06	1,51989E-05	3,30212E-05	6,60413E-05	9,90603E-05	0,000198111	0,000396182	0,000792208
		ELU	1	Filter(s)	0,69	0,006910366	1,08565E-06	7,59949E-06	1,51989E-05	3,30212E-05	6,60413E-05	9,90603E-05	0,000198111	0,000396182	0,000792208
		ELU	1	Other	0,34	0,003405108	5,34956E-07	3,74469E-06	7,48936E-06	1,62714E-05	3,25426E-05	4,88135E-05	9,76247E-05	0,00019524	0,000390442
		ELU	1	Piping	3,26	0,032648973	5,12927E-06	3,59043E-05	7,18074E-05	0,000156004	0,000311983	0,000467938	0,000935656	0,001870437	0,003737376
		ELU	1	Purge air	0,34	0,003405108	5,34956E-07	3,74469E-06	7,48936E-06	1,62714E-05	3,25426E-05	4,88135E-05	9,76247E-05	0,00019524	0,000390442
		ELU	1	Seals	0,34	0,003405108	5,34956E-07	3,74469E-06	7,48936E-06	1,62714E-05	3,25426E-05	4,88135E-05	9,76247E-05	0,00019524	0,000390442
		ELU	1	Shaft seals	3,44	0,034451678	5,41248E-06	3,78868E-05	7,57721E-05	0,000164617	0,000329206	0,000493768	0,000987293	0,001973611	0,003943327
		ELU	1	Subunit	0,69	0,006910366	1,08565E-06	7,59949E-06	1,51989E-05	3,30212E-05	6,60413E-05	9,90603E-05	0,000198111	0,000396182	0,000792208
		ELU	1	Unknown	0,69	0,006910366	1,08565E-06	7,59949E-06	1,51989E-05	3,30212E-05	6,60413E-05	9,90603E-05	0,000198111	0,000396182	0,000792208
		ELU	1	Valves	0,69	0,006910366	1,08565E-06	7,59949E-06	1,51989E-05	3,30212E-05	6,60413E-05	9,90603E-05	0,000198111	0,000396182	0,000792208
4	Erratic Output	ERO	0,75	Control unit	0,69	0,006910366	1,9678E-07	1,37746E-06	2,75491E-06	5,98536E-06	1,19707E-05	1,7956E-05	3,59116E-05	7,1822E-05	0,000143639
		ERO	0,75	Valves	2,41	0,024136204	6,87302E-07	4,81111E-06	9,62219E-06	2,09052E-05	4,181E-05	6,27144E-05	0,000125425	0,000250834	0,000501605
5	Fail to Start on Demand	FTS	0,25	Control unit	0,34	0,003405108	3,9615E-08	2,77305E-07	5,5461E-07	1,20496E-06	2,40991E-06	3,61486E-06	7,22972E-06	1,44594E-05	2,89185E-05
		FTS	0,25	Instrument, level	0,34	0,003405108	3,9615E-08	2,77305E-07	5,5461E-07	1,20496E-06	2,40991E-06	3,61486E-06	7,22972E-06	1,44594E-05	2,89185E-05
		FTS	0,25	Instrument, temperature	1,03	0,010315473	1,2001E-07	8,40071E-07	1,68014E-06	3,6503E-06	7,30059E-06	1,09509E-05	2,19016E-05	4,38028E-05	8,76036E-05
		FTS	0,25	Internal power supply	0,34	0,003405108	3,9615E-08	2,77305E-07	5,5461E-07	1,20496E-06	2,40991E-06	3,61486E-06	7,22972E-06	1,44594E-05	2,89185E-05
		FTS	0,25	Purge air	0,34	0,003405108	3,9615E-08	2,77305E-07	5,5461E-07	1,20496E-06	2,40991E-06	3,61486E-06	7,22972E-06	1,44594E-05	2,89185E-05
		FTS	0,25	Unknown	0,69	0,006910366	8,03952E-08	5,62766E-07	1,12553E-06	2,44535E-06	4,8907E-06	7,33603E-06	1,4672E-05	2,93438E-05	5,86868E-05
		FTS	0,25	Valves	1,03	0,010315473	1,2001E-07	8,40071E-07	1,68014E-06	3,6503E-06	7,30059E-06	1,09509E-05	2,19016E-05	4,38028E-05	8,76036E-05
6	Internal Leakage	INL	0,75	Subunit	0,34	0,003405108	6,98728E-09	4,8911E-08	9,78219E-08	2,1253E-07	4,25059E-07	6,37589E-07	1,27518E-06	2,55035E-06	5,1007E-06
7	Low Output	LOO	0,75	Filter(s)	0,69	0,006910366	3,01389E-07	2,10972E-06	4,21943E-06	9,1672E-06	1,83343E-05	2,75013E-05	5,50019E-05	0,000110001	0,00021999
		LOO	0,75	Lube oil	0,69	0,006910366	3,01389E-07	2,10972E-06	4,21943E-06	9,1672E-06	1,83343E-05	2,75013E-05	5,50019E-05	0,000110001	0,00021999
		LOO	0,75	Other	0,34	0,003405108	1,4851E-07	1,03957E-06	2,07914E-06	4,51718E-06	9,03434E-06	1,35515E-05	2,71028E-05	5,42048E-05	0,000108407
		LOO	0,75	Subunit	1,03	0,010315473	4,49899E-07	3,14929E-06	6,29857E-06	1,36843E-05	2,73685E-05	4,10524E-05	8,21032E-05	0,0001642	0,000328372
		LOO	0,75	Valves	3,09	0,03094642	1,3497E-06	9,44784E-06	1,88956E-05	4,10524E-05	8,21032E-05	0,000123152	0,000246289	0,000492518	0,000984794
8	Noise	NOI	0,25	Rotor w/ impellers	0,34	0,003405108	4,65819E-09	3,26073E-08	6,52146E-08	1,41687E-07	2,83373E-07	4,25059E-07	8,50119E-07	1,70024E-06	3,40047E-06
		NOI	0,25	Subunit	0,34	0,003405108	4,65819E-09	3,26073E-08	6,52146E-08	1,41687E-07	2,83373E-07	4,25059E-07	8,50119E-07	1,70024E-06	3,40047E-06
9	Overheating	OHE	1	Cooler(s)	0,34	0,003405108	7,24062E-08	5,06843E-07	1,01369E-06	2,20235E-06	4,4047E-06	6,60704E-06	1,3214E-05	2,64279E-05	5,28551E-05
		OHE	1	Internal piping	0,34	0,003405108	7,24062E-08	5,06843E-07	1,01369E-06	2,20235E-06	4,4047E-06	6,60704E-06	1,3214E-05	2,64279E-05	5,28551E-05
		OHE	1	Piping, pipe support + bellows	0,17	0,001702554	3,62031E-08	2,53422E-07	5,06843E-07	1,10118E-06	2,20235E-06	3,30353E-06	6,60704E-06	1,3214E-05	2,64279E-05
		OHE	1	Pump w/ motor	0,86	0,008612919	1,83145E-07	1,28202E-06	2,56403E-06	5,57065E-06	1,11413E-05	1,67119E-05	3,34234E-05	6,68457E-05	0,000133687
		OHE	1	Subunit	0,34	0,003405108	7,24062E-08	5,06843E-07	1,01369E-06	2,20235E-06	4,4047E-06	6,60704E-06	1,3214E-05	2,64279E-05	5,28551E-05
		OHE	1	Valves	0,34	0,003405108	7,24062E-08	5,06843E-07	1,01369E-06	2,20235E-06	4,4047E-06	6,60704E-06	1,3214E-05	2,64279E-05	5,28551E-05
10	Other	OTH	0,75	Cabling & junction boxes	0,69	0,006910366	2,89696E-07	2,02787E-06	4,05574E-06	8,81156E-06	1,7623E-05	2,64344E-05	5,28682E-05	0,000105734	0,000211456
		OTH	0,75	Control unit	0,34	0,003405108	1,42749E-07	9,99242E-07	1,99848E-06	4,34194E-06	8,68386E-06	1,30258E-05	2,60513E-05	5,2102E-05	0,000104201
		OTH	0,75	Cooler(s)	0,34	0,003405108	1,42749E-07	9,99242E-07	1,99848E-06	4,34194E-06	8,68386E-06	1,30258E-05	2,60513E-05	5,2102E-05	0,000104201
		OTH	0,75	Filter(s)	0,34	0,003405108	1,42749E-07	9,99242E-07	1,99848E-06	4,34194E-06	8,68386E-06	1,30258E-05	2,60513E-05	5,2102E-05	0,000104201
		OTH	0,75	Monitoring	0,34	0,003405108	1,42749E-07	9,99242E-07	1,99848E-06	4,34194E-06	8,68386E-06	1,30258E-05	2,60513E-05	5,2102E-05	0,000104201
		OTH	0,75	Oil	0,34	0,003405108	1,42749E-07	9,99242E-07	1,99848E-06	4,34194E-06	8,68386E-06	1,30258E-05	2,60513E-05	5,2102E-05	0,000104201
		OTH	0,75	Other	0,69	0,006910366	2,89696E-07	2,02787E-06	4,05574E-06	8,81156E-06	1,7623E-05	2,64344E-05	5,28682E-05	0,000105734	0,000211456
		OTH	0,75	Subunit	1,03	0,010315473	4,32445E-07	3,02711E-06	6,05422E-06	1,31535E-05	2,63067E-05	3,94599E-05	7,89181E-05	0,00015783	0,000315635
		OTH	0,75	Unknown	1,03	0,010315473	4,32445E-07	3,02711E-06	6,05422E-06	1,31535E-05	2,63067E-05	3,94599E-05	7,89181E-05	0,00015783	0,000315635
		OTH	0,75	Valves	0,34	0,003405108	1,42749E-07	9,99242E-07	1,99848E-06	4,34194E-06	8,68386E-06	1,30258E-05	2,60513E-05	5,2102E-05	0,000104201
11	Parameter Deviation	PDE	0,75	Control unit	0,34	0,003405108	4,19298E-07	2,93508E-06	5,87016E-06	1,27536E-05	2,5507E-05	3,82602E-05	7,6519E-05	0,000153032	0,000306041
		PDE	0,75	Cooler(s)	0,34	0,003405108	4,19298E-07	2,93508E-06	5,87016E-06	1,27536E-05	2,5507E-05	3,82602E-05	7,6519E-05	0,000153032	0,000306041
		PDE	0,75	Filter(s)	1,72	0,017225839	2,12115E-06	1,4848E-05	2,96957E-05	6,45164E-05	0,000129029	0,000193537	0,000387036	0,000773922	0,001547245
		PDE	0,75	Instrument, pressure	1,03	0,010315473	1,27023E-06	8,89155E-06	1,7783E-05	3,86353E-05	7,72691E-05	0,000115901	0,00023179	0,000463525	0,000926836
		PDE	0,75	Instrument, temperature	0,69	0,006910366	8,50928E-07	5,95648E-06	1,19129E-05	2,58821E-05	5,17635E-05	7,76442E-05	0,000155282	0,000310541	0,000620985
		PDE	0,75	Instrument, vibration	0,34	0,003405108	4,19298E-07	2,93508E-06	5,87016E-06	1,27536E-05	2,5507E-05	3,82602E-05	7,6519E-05	0,000153032	0,000306041
		PDE	0,75	Pump w/ motor	1,72	0,017225839	2,12115E-06	1,4848E-05	2,96957E-05	6,45164E-05	0,000129029	0,000193537	0,000387036	0,000773922	0,001547245
		PDE	0,75	Purge air	2,06	0,020630946	2,54045E-06	1,7783E-05	3,55657E-05	7,72691E-05	0,000154532	0,00023179	0,000463525	0,000926836	0,001852812
		PDE	0,75	Unknown	0,34	0,003405108	4,19298E-07	2,93508E-06	5,87016E-06	1,27536E-05	2,5507E-05	3,82602E-05	7,6519E-05	0,000153032	0,000306041
		PDE	0,75	Valves	4,81	0,048172258	5,93182E-06	4,1522E-05	8,30422E-05	0,00018041	0,000360788	0,000541134	0,001081974	0,002162778	0,004320878
12	Minor In-Service Problems	SER	0,25	Casing	0,69	0,006910366	2,12452E-07	1,48716E-06	2,97433E-06	6,46207E-06	1,29241E-05	1,93861E-05	3,87718E-05	7,75421E-05	0,000155078
		SER	0,25	Filter(s)	0,69	0,006910366	2,12452E-07	1,48716E-06	2,97433E-06	6,46207E-06	1,29241E-05	1,93861E-05	3,87718E-05	7,75421E-05	0,000155078
		SER	0,25	Instrument, general	0,34	0,003405108	1,04687E-07	7,32806E-07	1,46561E-06	3,18421E-06	6,36842E-06	9,55261E-06	1,91051E-05	3,82099E-05	7,64183E-05
		SER	0,25	Instrument, level	0,69	0,006910366	2,12452E-07	1,48716E-06	2,97433E-06	6,46207E-06	1,29241E-05	1,93861E-05	3,87718E-05	7,75421E-05	0,000155078
		SER	0,25	Instrument, pressure	0,69	0,006910366	2,12452E-07	1,48716E-06	2,97433E-06	6,46207E-06	1,29241E-05	1,93861E-05	3,87718E-05	7,75421E-05	0,000155078
		SER	0,25	Instrument, temperature	0,34	0,003405108	1,04687E-07	7,32806E-07	1,46561E-06	3,18421E-06	6,36842E-06	9,55261E-06	1,91051E-05	3,82099E-05	7,64183E-05
		SER	0,25	Internal piping	0,34	0,003405108	1,04687E-07	7,32806E-07	1,46561E-06	3,18421E-06	6,36842E-06	9,55261E-06	1,91051E-05	3,82099E-05	7,64183E-05
		SER	0,25	Monitoring	0,34	0,003405108	1,04687E-07	7,32806E-07	1,46561E-06	3,18421E-06	6,36842E-06	9,55261E-06	1,91051E-05	3,82099E-05	7,64183E-05
		SER	0,25	Oil	0,34	0,003405108	1,04687E-07	7,32806E-07	1,46561E-06	3,18421E-06	6,36842E-06	9,55261E-06	1,91051E-05	3,82099E-05	7,64183E-05
		SER	0,25	Other	1,37	0,013720581	4,21825E-07	2,95277E-06	5,90554E-06	1,28304E-05	2,56607E-05	3,84908E-05	7,69802E-05	0,000153954	0,000307885
		SER	0,25	Piping	0,52	0,005207812	1,60109E-07	1,12076E-06	2,24152E-06	4,86997E-06	9,73991E-06	1,46098E-05	2,92195E-05	5,84381E-05	0,000116873
		SER	0,25	Pump w/ motor	0,34	0,003405108	1,04687E-07	7,32806E-07	1,46561E-06	3,18421E-06	6,36842E-06	9,55261E-06	1,91051E-05	3,82099E-05	7,64183E-05
		SER	0,25	Purge air	1,03	0,010315473	3,17139E-07	2,21997E-06	4,43993E-06	9,64626E-06	1,92924E-05	2,89385E-05	5,78762E-05	0,000115749	0,000231485
		SER	0,25	Subunit	0,34	0,003405108	1,04687E-07	7,32806E-07	1,46561E-06	3,18421E-06	6,36842E-06	9,55261E-06	1,91051E-05	3,82099E-05	7,64183E-05
		SER	0,25	Valves	2,58	0,025838758	7,94386E-07	5,56069E-06	1,11214E-05	2,41623E-05	4,8324E-05	7,24852E-05	0,000144965	0,000289909	0,000579734
13	Structural Deficiency	STD	0,75	Base frame	0,34	0,003405108	4,0514E-08	2,83598E-07	5,67195E-07	1,2323E-06	2,4646E-06	3,69689E-06	7,39377E-06	1,47875E-05	2,95748E-05
		STD	0,75	Bearing	0,34	0,003405108	4,0514E-08	2,83598E-07	5,67195E-07	1,2323E-06	2,4646E-06	3,69689E-06	7,39377E-06	1,47875E-05	2,95748E-05
		STD	0,75	Dry gas seal	0,34	0,003405108	4,0514E-08	2,83598E-07	5,67195E-07	1,2323E-06	2,4646E-06	3,69689E-06	7,39377E-06	1,47875E-05	2,95748E-05
		STD	0,75	Other	0,34	0,003405108	4,0514E-08	2,83598E-07	5,67195E-07	1,2323E-06	2,4646E-06	3,69689E-06	7,39377E-06	1,47875E-05	2,95748E-05
		STD	0,75	Valves	0,34	0,003405108	4,0514E-08	2,83598E-07	5,67195E-07	1,2323E-06	2,4646E-06	3,69689E-06	7,39377E-06	1,47875E-05	2,95748E-05
14	Unknown	UNK	0,25	Other	0,69	0,006910366	3,98866E-08	2,79206E-07	5,58413E-07	1,21322E-06	2,42643E-06	3,63965E-06	7,27928E-06	1,45585E-05	2,91168E-05
		UNK	0,25	Pump w/ motor	0,34	0,003405108	1,96543E-08	1,3758E-07	2,7516E-07	5,97818E-07	1,19563E-06	1,79345E-06	3,5869E-06	7,17379E-06	1,43475E-05
		UNK	0,25	Unknown	0,34	0,003405108	1,96543E-08	1,3758E-07	2,7516E-07	5,97818E-07	1,19563E-06	1,79345E-06	3,5869E-06	7,17379E-06	1,43475E-05
15	Spurious Stop	UST	0,75	Control unit	0,69	0,006910366	6,16708E-07	4,31695E-06	8,63388E-06	1,8758E-05	3,75157E-05	5,62731E-05	0,000112543	0,000225073	0,000450096
		UST	0,75	Cooler(s)	0,46	0,00460691	4,11139E-07	2,87797E-06	5,75593E-06	1,25054E-05	2,50106E-05	3,75157E-05	7,50301E-05	0,000150055	0,000300087
		UST	0,75	Filter(s)	0,11	0,001101652	9,83159E-08	6,88211E-07	1,37642E-06	2,99044E-06	5,98086E-06	8,97128E-06	1,79425E-05	3,58847E-05	7,1768E-05
		UST	0,75	Instrument, pressure	1,72	0,017225839	1,5373E-06	1,07611E-05	2,1522E-05	4,67585E-05	9,35149E-05	0,000140269	0,000280518	0,000560958	0,001121602
		UST	0,75	Instrument, temperature	2,41	0,024136204	2,15401E-06	1,5078E-05	3,01557E-05	6,55157E-05	0,000131027	0,000196534	0,00039303	0,000785905	0,001571193
		UST	0,75	Internal power supply	0,34	0,003405108	3,03885E-07	2,1272E-06	4,25439E-06	9,24314E-06	1,84862E-05	2,77292E-05	5,54576E-05	0,000110912	0,000221812
		UST	0,75	Interstage seals	0,34	0,003405108	3,03885E-07	2,1272E-06	4,25439E-06	9,24314E-06	1,84862E-05	2,77292E-05	5,54576E-05	0,000110912	0,000221812
15	Spurious Stop	UST	0,75	Piping	0,11	0,001101652	9,83159E-08	6,88211E-07	1,37642E-06	2,99044E-06	5,98086E-06	8,97128E-06	1,79425E-05	3,58847E-05	7,1768E-05
		UST	0,75	Radial bearing	0,34	0,003405108	3,03885E-07	2,1272E-06	4,25439E-06	9,24314E-06	1,84862E-05	2,77292E-05	5,54576E-05	0,000110912	0,000221812
		UST	0,75	Rotor w/ impellers	0,69	0,006910366	6,16708E-07	4,31695E-06	8,63388E-06	1,8758E-05	3,75157E-05	5,62731E-05	0,000112543	0,000225073	0,000450096
		UST	0,75	Shaft seals	0,34	0,003405108	3,03885E-07	2,1272E-06	4,25439E-06	9,24314E-06	1,84862E-05	2,77292E-05	5,54576E-05	0,000110912	0,000221812
		UST	0,75	Subunit	1,37	0,013720581	1,22448E-06	8,57132E-06	1,71426E-05	3,72439E-05	7,44864E-05	0,000111728	0,000223443	0,000446835	0,000893471
		UST	0,75	Unknown	2,06	0,020630946	1,84119E-06	1,28882E-05	2,57763E-05	5,60012E-05	0,000111999	0,000167994	0,00033596	0,000671808	0,001343165
		UST	0,75	Valves	0,69	0,006910366	6,16708E-07	4,31695E-06	8,63388E-06	1,8758E-05	3,75157E-05	5,62731E-05	0,000112543	0,000225073	0,000450096

Appendix G

Maintainable Items Probability of Failures

No.	Failure Mode	Failure Mode Code	Beta	Maintainable Item (Failure Cause)	Probability	Alpha	Maintenance Interval Time								
							Daily	Weekly	Bi-Weekly	Monthly	2-monthly	3-monthly	6-monthly	Yearly	2-yearly
93	Structural Deficiency	STD	0,75	Base frame	0,34	0,003405108	4,0514E-08	2,83598E-07	5,67195E-07	1,2323E-06	2,4646E-06	3,69689E-06	7,39377E-06	1,47875E-05	2,95748E-05
22	External Leakage - Utility Medium	ELU	1	Bearing	1,37	0,013720581	2,15556E-06	1,50888E-05	3,01774E-05	6,55627E-05	0,000131121	0,000196675	0,000393312	0,000786469	0,00157232
94	Structural Deficiency	STD	0,75	Bearing	0,34	0,003405108	4,0514E-08	2,83598E-07	5,67195E-07	1,2323E-06	2,4646E-06	3,69689E-06	7,39377E-06	1,47875E-05	2,95748E-05
1	Abnormal Instrument Reading	AIR	0,75	Cabling & junction boxes	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
58	Other	OTH	0,75	Cabling & junction boxes	0,69	0,006910366	2,89696E-07	2,02787E-06	4,05574E-06	8,81156E-06	1,7623E-05	2,64344E-05	5,28682E-05	0,000105734	0,000211456
78	Minor In-Service Problems	SER	0,25	Casing	0,69	0,006910366	2,12452E-07	1,48716E-06	2,97433E-06	6,46207E-06	1,29241E-05	1,93861E-05	3,87718E-05	7,75421E-05	0,000155078
35	Erratic Output	ERO	0,75	Control unit	0,69	0,006910366	1,9678E-07	1,37746E-06	2,75491E-06	5,98536E-06	1,19707E-05	1,7956E-05	3,59116E-05	7,1822E-05	0,000143639
37	Fail to Start on Demand	FTS	0,25	Control unit	0,34	0,003405108	3,9615E-08	2,77305E-07	5,5461E-07	1,20496E-06	2,40991E-06	3,61486E-06	7,22972E-06	1,44594E-05	2,89185E-05
59	Other	OTH	0,75	Control unit	0,34	0,003405108	1,42749E-07	9,99242E-07	1,99848E-06	4,34194E-06	8,68386E-06	1,30258E-05	2,60513E-05	5,2102E-05	0,000104201
68	Parameter Deviation	PDE	0,75	Control unit	0,34	0,003405108	4,19298E-07	2,93508E-06	5,87016E-06	1,27536E-05	2,5507E-05	3,82602E-05	7,6519E-05	0,000153032	0,000306041
101	Spurious Stop	UST	0,75	Control unit	0,69	0,006910366	6,16708E-07	4,31695E-06	8,63388E-06	1,8758E-05	3,75157E-05	5,62731E-05	0,000112543	0,000225073	0,000450096
23	External Leakage - Utility Medium	ELU	1	Cooler(s)	0,86	0,008612919	1,35312E-06	9,47182E-06	1,89436E-05	4,11567E-05	8,23117E-05	0,000123465	0,000246915	0,000493768	0,000987293
52	Overheating	OHE	1	Cooler(s)	0,34	0,003405108	7,24062E-08	5,06843E-07	1,01369E-06	2,20235E-06	4,4047E-06	6,60704E-06	1,3214E-05	2,64279E-05	5,28551E-05
60	Other	OTH	0,75	Cooler(s)	0,34	0,003405108	1,42749E-07	9,99242E-07	1,99848E-06	4,34194E-06	8,68386E-06	1,30258E-05	2,60513E-05	5,2102E-05	0,000104201
69	Parameter Deviation	PDE	0,75	Cooler(s)	0,34	0,003405108	4,19298E-07	2,93508E-06	5,87016E-06	1,27536E-05	2,5507E-05	3,82602E-05	7,6519E-05	0,000153032	0,000306041
102	Spurious Stop	UST	0,75	Cooler(s)	0,46	0,00460691	4,11139E-07	2,87797E-06	5,75593E-06	1,25054E-05	2,50106E-05	3,75157E-05	7,50301E-05	0,000150055	0,000300087
24	External Leakage - Utility Medium	ELU	1	Coupling to driver	0,34	0,003405108	5,34956E-07	3,74469E-06	7,48936E-06	1,62714E-05	3,25426E-05	4,88135E-05	9,76247E-05	0,00019524	0,000390442
25	External Leakage - Utility Medium	ELU	1	Dry gas seal	0,69	0,006910366	1,08565E-06	7,59949E-06	1,51989E-05	3,30212E-05	6,60413E-05	9,90603E-05	0,000198111	0,000396182	0,000792208
95	Structural Deficiency	STD	0,75	Dry gas seal	0,34	0,003405108	4,0514E-08	2,83598E-07	5,67195E-07	1,2323E-06	2,4646E-06	3,69689E-06	7,39377E-06	1,47875E-05	2,95748E-05
2	Abnormal Instrument Reading	AIR	0,75	Filter(s)	0,17	0,001702554	3,35451E-07	2,34815E-06	4,6963E-06	1,02032E-05	2,04064E-05	3,06094E-05	6,12179E-05	0,000122432	0,000244849
26	External Leakage - Utility Medium	ELU	1	Filter(s)	0,69	0,006910366	1,08565E-06	7,59949E-06	1,51989E-05	3,30212E-05	6,60413E-05	9,90603E-05	0,000198111	0,000396182	0,000792208
45	Low Output	LOO	0,75	Filter(s)	0,69	0,006910366	3,01389E-07	2,10972E-06	4,21943E-06	9,1672E-06	1,83343E-05	2,75013E-05	5,50019E-05	0,000110001	0,00021999
61	Other	OTH	0,75	Filter(s)	0,34	0,003405108	1,42749E-07	9,99242E-07	1,99848E-06	4,34194E-06	8,68386E-06	1,30258E-05	2,60513E-05	5,2102E-05	0,000104201
70	Parameter Deviation	PDE	0,75	Filter(s)	1,72	0,017225839	2,12115E-06	1,4848E-05	2,96957E-05	6,45164E-05	0,000129029	0,000193537	0,000387036	0,000773922	0,001547245
79	Minor In-Service Problems	SER	0,25	Filter(s)	0,69	0,006910366	2,12452E-07	1,48716E-06	2,97433E-06	6,46207E-06	1,29241E-05	1,93861E-05	3,87718E-05	7,75421E-05	0,000155078
103	Spurious Stop	UST	0,75	Filter(s)	0,11	0,001101652	9,83159E-08	6,88211E-07	1,37642E-06	2,99044E-06	5,98086E-06	8,97128E-06	1,79425E-05	3,58847E-05	7,1768E-05
3	Abnormal Instrument Reading	AIR	0,75	Instrument, flow	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
4	Abnormal Instrument Reading	AIR	0,75	Instrument, general	1,72	0,017225839	3,39397E-06	2,37575E-05	4,75145E-05	0,000103228	0,000206445	0,000309652	0,000619208	0,001238033	0,002474533
80	Minor In-Service Problems	SER	0,25	Instrument, general	0,34	0,003405108	1,04687E-07	7,32806E-07	1,46561E-06	3,18421E-06	6,36842E-06	9,55261E-06	1,91051E-05	3,82099E-05	7,64183E-05
5	Abnormal Instrument Reading	AIR	0,75	Instrument, level	0,69	0,006910366	1,36153E-06	9,5307E-06	1,90613E-05	4,14125E-05	8,28233E-05	0,000124232	0,000248449	0,000496837	0,000993427
38	Fail to Start on Demand	FTS	0,25	Instrument, level	0,34	0,003405108	3,9615E-08	2,77305E-07	5,5461E-07	1,20496E-06	2,40991E-06	3,61486E-06	7,22972E-06	1,44594E-05	2,89185E-05
81	Minor In-Service Problems	SER	0,25	Instrument, level	0,69	0,006910366	2,12452E-07	1,48716E-06	2,97433E-06	6,46207E-06	1,29241E-05	1,93861E-05	3,87718E-05	7,75421E-05	0,000155078
6	Abnormal Instrument Reading	AIR	0,75	Instrument, pressure	6,53	0,065398097	1,28852E-05	9,01927E-05	0,000180377	0,00039185	0,000783546	0,001175089	0,002348797	0,004692076	0,009362137
71	Parameter Deviation	PDE	0,75	Instrument, pressure	1,03	0,010315473	1,27023E-06	8,89155E-06	1,7783E-05	3,86353E-05	7,72691E-05	0,000115901	0,00023179	0,000463525	0,000926836
82	Minor In-Service Problems	SER	0,25	Instrument, pressure	0,69	0,006910366	2,12452E-07	1,48716E-06	2,97433E-06	6,46207E-06	1,29241E-05	1,93861E-05	3,87718E-05	7,75421E-05	0,000155078
104	Spurious Stop	UST	0,75	Instrument, pressure	1,72	0,017225839	1,5373E-06	1,07611E-05	2,1522E-05	4,67585E-05	9,35149E-05	0,000140269	0,000280518	0,000560958	0,001121602
7	Abnormal Instrument Reading	AIR	0,75	Instrument, speed	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
8	Abnormal Instrument Reading	AIR	0,75	Instrument, temperature	9,28	0,092939409	1,83115E-05	0,000128173	0,00025633	0,000556825	0,001113339	0,001669544	0,003336301	0,006661471	0,013278568
39	Fail to Start on Demand	FTS	0,25	Instrument, temperature	1,03	0,010315473	1,2001E-07	8,40071E-07	1,68014E-06	3,6503E-06	7,30059E-06	1,09509E-05	2,19016E-05	4,38028E-05	8,76036E-05
72	Parameter Deviation	PDE	0,75	Instrument, temperature	0,69	0,006910366	8,50928E-07	5,95648E-06	1,19129E-05	2,58821E-05	5,17635E-05	7,76442E-05	0,000155282	0,000310541	0,000620985
83	Minor In-Service Problems	SER	0,25	Instrument, temperature	0,34	0,003405108	1,04687E-07	7,32806E-07	1,46561E-06	3,18421E-06	6,36842E-06	9,55261E-06	1,91051E-05	3,82099E-05	7,64183E-05
105	Spurious Stop	UST	0,75	Instrument, temperature	2,41	0,024136204	2,15401E-06	1,5078E-05	3,01557E-05	6,55157E-05	0,000131027	0,000196534	0,00039303	0,000785905	0,001571193
9	Abnormal Instrument Reading	AIR	0,75	Instrument, vibration	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
73	Parameter Deviation	PDE	0,75	Instrument, vibration	0,34	0,003405108	4,19298E-07	2,93508E-06	5,87016E-06	1,27536E-05	2,5507E-05	3,82602E-05	7,6519E-05	0,000153032	0,000306041
10	Abnormal Instrument Reading	AIR	0,75	Internal piping	0,17	0,001702554	3,35451E-07	2,34815E-06	4,6963E-06	1,02032E-05	2,04064E-05	3,06094E-05	6,12179E-05	0,000122432	0,000244849
16	External Leakage - Process Medium	ELP	1	Internal piping	0,34	0,003405108	1,02317E-07	7,16216E-07	1,43243E-06	3,11213E-06	6,22425E-06	9,33635E-06	1,86726E-05	3,73449E-05	7,46884E-05
53	Overheating	OHE	1	Internal piping	0,34	0,003405108	7,24062E-08	5,06843E-07	1,01369E-06	2,20235E-06	4,4047E-06	6,60704E-06	1,3214E-05	2,64279E-05	5,28551E-05
84	Minor In-Service Problems	SER	0,25	Internal piping	0,34	0,003405108	1,04687E-07	7,32806E-07	1,46561E-06	3,18421E-06	6,36842E-06	9,55261E-06	1,91051E-05	3,82099E-05	7,64183E-05
11	Abnormal Instrument Reading	AIR	0,75	Internal power supply	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
40	Fail to Start on Demand	FTS	0,25	Internal power supply	0,34	0,003405108	3,9615E-08	2,77305E-07	5,5461E-07	1,20496E-06	2,40991E-06	3,61486E-06	7,22972E-06	1,44594E-05	2,89185E-05
106	Spurious Stop	UST	0,75	Internal power supply	0,34	0,003405108	3,03885E-07	2,1272E-06	4,25439E-06	9,24314E-06	1,84862E-05	2,77292E-05	5,54576E-05	0,000110912	0,000221812
107	Spurious Stop	UST	0,75	Interstage seals	0,34	0,003405108	3,03885E-07	2,1272E-06	4,25439E-06	9,24314E-06	1,84862E-05	2,77292E-05	5,54576E-05	0,000110912	0,000221812
46	Low Output	LOO	0,75	Lube oil	0,69	0,006910366	3,01389E-07	2,10972E-06	4,21943E-06	9,1672E-06	1,83343E-05	2,75013E-05	5,50019E-05	0,000110001	0,00021999
12	Abnormal Instrument Reading	AIR	0,75	Monitoring	0,69	0,006910366	1,36153E-06	9,5307E-06	1,90613E-05	4,14125E-05	8,28233E-05	0,000124232	0,000248449	0,000496837	0,000993427
62	Other	OTH	0,75	Monitoring	0,34	0,003405108	1,42749E-07	9,99242E-07	1,99848E-06	4,34194E-06	8,68386E-06	1,30258E-05	2,60513E-05	5,2102E-05	0,000104201
85	Minor In-Service Problems	SER	0,25	Monitoring	0,34	0,003405108	1,04687E-07	7,32806E-07	1,46561E-06	3,18421E-06	6,36842E-06	9,55261E-06	1,91051E-05	3,82099E-05	7,64183E-05

63	Other	OTH	0,75	Oil	0,34	0,003405108	1,42749E-07	9,99242E-07	1,99848E-06	4,34194E-06	8,68386E-06	1,30258E-05	2,60513E-05	5,2102E-05	0,000104201
86	Minor In-Service Problems	SER	0,25	Oil	0,34	0,003405108	1,04687E-07	7,32806E-07	1,46561E-06	3,18421E-06	6,36842E-06	9,55261E-06	1,91051E-05	3,82099E-05	7,64183E-05
17	External Leakage - Process Medium	ELP	1	Other	0,34	0,003405108	1,02317E-07	7,16216E-07	1,43243E-06	3,11213E-06	6,22425E-06	9,33635E-06	1,86726E-05	3,73449E-05	7,46884E-05
27	External Leakage - Utility Medium	ELU	1	Other	0,34	0,003405108	5,34956E-07	3,74469E-06	7,48936E-06	1,62714E-05	3,25426E-05	4,88135E-05	9,76247E-05	0,00019524	0,000390442
47	Low Output	LOO	0,75	Other	0,34	0,003405108	1,4851E-07	1,03957E-06	2,07914E-06	4,51718E-06	9,03434E-06	1,35515E-05	2,71028E-05	5,42048E-05	0,000108407
64	Other	OTH	0,75	Other	0,69	0,006910366	2,89696E-07	2,02787E-06	4,05574E-06	8,81156E-06	1,7623E-05	2,64344E-05	5,28682E-05	0,000105734	0,000211456
87	Minor In-Service Problems	SER	0,25	Other	1,37	0,013720581	4,21825E-07	2,95277E-06	5,90554E-06	1,28304E-05	2,56607E-05	3,84908E-05	7,69802E-05	0,000153954	0,000307885
96	Structural Deficiency	STD	0,75	Other	0,34	0,003405108	4,0514E-08	2,83598E-07	5,67195E-07	1,2323E-06	2,4646E-06	3,69689E-06	7,39377E-06	1,47875E-05	2,95748E-05
98	Unknown	UNK	0,25	Other	0,69	0,006910366	3,98866E-08	2,79206E-07	5,58413E-07	1,21322E-06	2,42643E-06	3,63965E-06	7,27928E-06	1,45585E-05	2,91168E-05
28	External Leakage - Utility Medium	ELU	1	Piping	3,26	0,032648973	5,12927E-06	3,59043E-05	7,18074E-05	0,000156004	0,000311983	0,000467938	0,000935656	0,001870437	0,003737376
88	Minor In-Service Problems	SER	0,25	Piping	0,52	0,005207812	1,60109E-07	1,12076E-06	2,24152E-06	4,86997E-06	9,73991E-06	1,46098E-05	2,92195E-05	5,84381E-05	0,000116873
108	Spurious Stop	UST	0,75	Piping	0,11	0,001101652	9,83159E-08	6,88211E-07	1,37642E-06	2,99044E-06	5,98086E-06	8,97128E-06	1,79425E-05	3,58847E-05	7,1768E-05
54	Overheating	OHE	1	Piping, pipe support + bellows	0,17	0,001702554	3,62031E-08	2,53422E-07	5,06843E-07	1,10118E-06	2,20235E-06	3,30353E-06	6,60704E-06	1,3214E-05	2,64279E-05
55	Overheating	OHE	1	Pump w/ motor	0,86	0,008612919	1,83145E-07	1,28202E-06	2,56403E-06	5,57065E-06	1,11413E-05	1,67119E-05	3,34234E-05	6,68457E-05	0,000133687
74	Parameter Deviation	PDE	0,75	Pump w/ motor	1,72	0,017225839	2,12115E-06	1,4848E-05	2,96957E-05	6,45164E-05	0,000129029	0,000193537	0,000387036	0,000773922	0,001547245
89	Minor In-Service Problems	SER	0,25	Pump w/ motor	0,34	0,003405108	1,04687E-07	7,32806E-07	1,46561E-06	3,18421E-06	6,36842E-06	9,55261E-06	1,91051E-05	3,82099E-05	7,64183E-05
99	Unknown	UNK	0,25	Pump w/ motor	0,34	0,003405108	1,96543E-08	1,3758E-07	2,7516E-07	5,97818E-07	1,19563E-06	1,79345E-06	3,5869E-06	7,17379E-06	1,43475E-05
29	External Leakage - Utility Medium	ELU	1	Purge air	0,34	0,003405108	5,34956E-07	3,74469E-06	7,48936E-06	1,62714E-05	3,25426E-05	4,88135E-05	9,76247E-05	0,00019524	0,000390442
41	Fail to Start on Demand	FTS	0,25	Purge air	0,34	0,003405108	3,9615E-08	2,77305E-07	5,5461E-07	1,20496E-06	2,40991E-06	3,61486E-06	7,22972E-06	1,44594E-05	2,89185E-05
75	Parameter Deviation	PDE	0,75	Purge air	2,06	0,020630946	2,54045E-06	1,7783E-05	3,55657E-05	7,72691E-05	0,000154532	0,00023179	0,000463525	0,000926836	0,001852812
90	Minor In-Service Problems	SER	0,25	Purge air	1,03	0,010315473	3,17139E-07	2,21997E-06	4,43993E-06	9,64626E-06	1,92924E-05	2,89385E-05	5,78762E-05	0,000115749	0,000231485
109	Spurious Stop	UST	0,75	Radial bearing	0,34	0,003405108	3,03885E-07	2,1272E-06	4,25439E-06	9,24314E-06	1,84862E-05	2,77292E-05	5,54576E-05	0,000110912	0,000221812
13	Abnormal Instrument Reading	AIR	0,75	Reservoir w/ heating system	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
50	Noise	NOI	0,25	Rotor w/ impellers	0,34	0,003405108	4,65819E-09	3,26073E-08	6,52146E-08	1,41687E-07	2,83373E-07	4,25059E-07	8,50119E-07	1,70024E-06	3,40047E-06
110	Spurious Stop	UST	0,75	Rotor w/ impellers	0,69	0,006910366	6,16708E-07	4,31695E-06	8,63388E-06	1,8758E-05	3,75157E-05	5,62731E-05	0,000112543	0,000225073	0,000450096
30	External Leakage - Utility Medium	ELU	1	Seals	0,34	0,003405108	5,34956E-07	3,74469E-06	7,48936E-06	1,62714E-05	3,25426E-05	4,88135E-05	9,76247E-05	0,00019524	0,000390442
18	External Leakage - Process Medium	ELP	1	Shaft seals	0,34	0,003405108	1,02317E-07	7,16216E-07	1,43243E-06	3,11213E-06	6,22425E-06	9,33635E-06	1,86726E-05	3,73449E-05	7,46884E-05
31	External Leakage - Utility Medium	ELU	1	Shaft seals	3,44	0,034451678	5,41248E-06	3,78868E-05	7,57721E-05	0,000164617	0,000329206	0,000493768	0,000987293	0,001973611	0,003943327
111	Spurious Stop	UST	0,75	Shaft seals	0,34	0,003405108	3,03885E-07	2,1272E-06	4,25439E-06	9,24314E-06	1,84862E-05	2,77292E-05	5,54576E-05	0,000110912	0,000221812
14	Abnormal Instrument Reading	AIR	0,75	Subunit	0,69	0,006910366	1,36153E-06	9,5307E-06	1,90613E-05	4,14125E-05	8,28233E-05	0,000124232	0,000248449	0,000496837	0,000993427
19	External Leakage - Process Medium	ELP	1	Subunit	0,34	0,003405108	1,02317E-07	7,16216E-07	1,43243E-06	3,11213E-06	6,22425E-06	9,33635E-06	1,86726E-05	3,73449E-05	7,46884E-05
32	External Leakage - Utility Medium	ELU	1	Subunit	0,69	0,006910366	1,08565E-06	7,59949E-06	1,51989E-05	3,30212E-05	6,60413E-05	9,90603E-05	0,000198111	0,000396182	0,000792208
44	Internal Leakage	INL	0,75	Subunit	0,34	0,003405108	6,98728E-09	4,8911E-08	9,78219E-08	2,1253E-07	4,25059E-07	6,37589E-07	1,27518E-06	2,55035E-06	5,1007E-06
48	Low Output	LOO	0,75	Subunit	1,03	0,010315473	4,49899E-07	3,14929E-06	6,29857E-06	1,36843E-05	2,73685E-05	4,10524E-05	8,21032E-05	0,0001642	0,000328372
51	Noise	NOI	0,25	Subunit	0,34	0,003405108	4,65819E-09	3,26073E-08	6,52146E-08	1,41687E-07	2,83373E-07	4,25059E-07	8,50119E-07	1,70024E-06	3,40047E-06
56	Overheating	OHE	1	Subunit	0,34	0,003405108	7,24062E-08	5,06843E-07	1,01369E-06	2,20235E-06	4,4047E-06	6,60704E-06	1,3214E-05	2,64279E-05	5,28551E-05
65	Other	OTH	0,75	Subunit	1,03	0,010315473	4,32445E-07	3,02711E-06	6,05422E-06	1,31535E-05	2,63067E-05	3,94599E-05	7,89181E-05	0,00015783	0,000315635
91	Minor In-Service Problems	SER	0,25	Subunit	0,34	0,003405108	1,04687E-07	7,32806E-07	1,46561E-06	3,18421E-06	6,36842E-06	9,55261E-06	1,91051E-05	3,82099E-05	7,64183E-05
112	Spurious Stop	UST	0,75	Subunit	1,37	0,013720581	1,22448E-06	8,57132E-06	1,71426E-05	3,72439E-05	7,44864E-05	0,000111728	0,000223443	0,000446835	0,000893471
20	External Leakage - Process Medium	ELP	1	Unknown	0,34	0,003405108	1,02317E-07	7,16216E-07	1,43243E-06	3,11213E-06	6,22425E-06	9,33635E-06	1,86726E-05	3,73449E-05	7,46884E-05
33	External Leakage - Utility Medium	ELU	1	Unknown	0,69	0,006910366	1,08565E-06	7,59949E-06	1,51989E-05	3,30212E-05	6,60413E-05	9,90603E-05	0,000198111	0,000396182	0,000792208
42	Fail to Start on Demand	FTS	0,25	Unknown	0,69	0,006910366	8,03952E-08	5,62766E-07	1,12553E-06	2,44535E-06	4,8907E-06	7,33603E-06	1,4672E-05	2,93438E-05	5,86868E-05
66	Other	OTH	0,75	Unknown	1,03	0,010315473	4,32445E-07	3,02711E-06	6,05422E-06	1,31535E-05	2,63067E-05	3,94599E-05	7,89181E-05	0,00015783	0,000315635
76	Parameter Deviation	PDE	0,75	Unknown	0,34	0,003405108	4,19298E-07	2,93508E-06	5,87016E-06	1,27536E-05	2,5507E-05	3,82602E-05	7,6519E-05	0,000153032	0,000306041
100	Unknown	UNK	0,25	Unknown	0,34	0,003405108	1,96543E-08	1,3758E-07	2,7516E-07	5,97818E-07	1,19563E-06	1,79345E-06	3,5869E-06	7,17379E-06	1,43475E-05
113	Spurious Stop	UST	0,75	Unknown	2,06	0,020630946	1,84119E-06	1,28882E-05	2,57763E-05	5,60012E-05	0,000111999	0,000167994	0,00033596	0,000671808	0,001343165
15	Abnormal Instrument Reading	AIR	0,75	Valves	0,69	0,006910366	1,36153E-06	9,5307E-06	1,90613E-05	4,14125E-05	8,28233E-05	0,000124232	0,000248449	0,000496837	0,000993427
21	External Leakage - Process Medium	ELP	1	Valves	1,03	0,010315473	3,09959E-07	2,16971E-06	4,33942E-06	9,42789E-06	1,88557E-05	2,82834E-05	5,6566E-05	0,000113129	0,000226245
34	External Leakage - Utility Medium	ELU	1	Valves	0,69	0,006910366	1,08565E-06	7,59949E-06	1,51989E-05	3,30212E-05	6,60413E-05	9,90603E-05	0,000198111	0,000396182	0,000792208
36	Erratic Output	ERO	0,75	Valves	2,41	0,024136204	6,87302E-07	4,81111E-06	9,62219E-06	2,09052E-05	4,181E-05	6,27144E-05	0,000125425	0,000250834	0,000501605
43	Fail to Start on Demand	FTS	0,25	Valves	1,03	0,010315473	1,2001E-07	8,40071E-07	1,68014E-06	3,6503E-06	7,30059E-06	1,09509E-05	2,19016E-05	4,38028E-05	8,76036E-05
49	Low Output	LOO	0,75	Valves	3,09	0,03094642	1,3497E-06	9,44784E-06	1,88956E-05	4,10524E-05	8,21032E-05	0,000123152	0,000246289	0,000492518	0,000984794
57	Overheating	OHE	1	Valves	0,34	0,003405108	7,24062E-08	5,06843E-07	1,01369E-06	2,20235E-06	4,4047E-06	6,60704E-06	1,3214E-05	2,64279E-05	5,28551E-05
67	Other	OTH	0,75	Valves	0,34	0,003405108	1,42749E-07	9,99242E-07	1,99848E-06	4,34194E-06	8,68386E-06	1,30258E-05	2,60513E-05	5,2102E-05	0,000104201
77	Parameter Deviation	PDE	0,75	Valves	4,81	0,048172258	5,93182E-06	4,1522E-05	8,30422E-05	0,00018041	0,000360788	0,000541134	0,001081974	0,002162778	0,004320878
92	Minor In-Service Problems	SER	0,25	Valves	2,58	0,025838758	7,94386E-07	5,56069E-06	1,11214E-05	2,41623E-05	4,8324E-05	7,24852E-05	0,000144965	0,000289909	0,000579734
97	Structural Deficiency	STD	0,75	Valves	0,34	0,003405108	4,0514E-08	2,83598E-07	5,67195E-07	1,2323E-06	2,4646E-06	3,69689E-06	7,39377E-06	1,47875E-05	2,95748E-05
114	Spurious Stop	UST	0,75	Valves	0,69	0,006910366	6,16708E-07	4,31695E-06	8,63388E-06	1,8758E-05	3,75157E-05	5,62731E-05	0,000112543	0,000225073	0,000450096

Appendix H

Presentation for Quality Norway Smart Verdibasert Vedlikehold – Moderne Vedlikehold

Optimum Maintenance Strategy Recommendation of Compressor Based on OREDA Failure Rate

Abram Dionisius Antory

7.-8. Juni, 2023

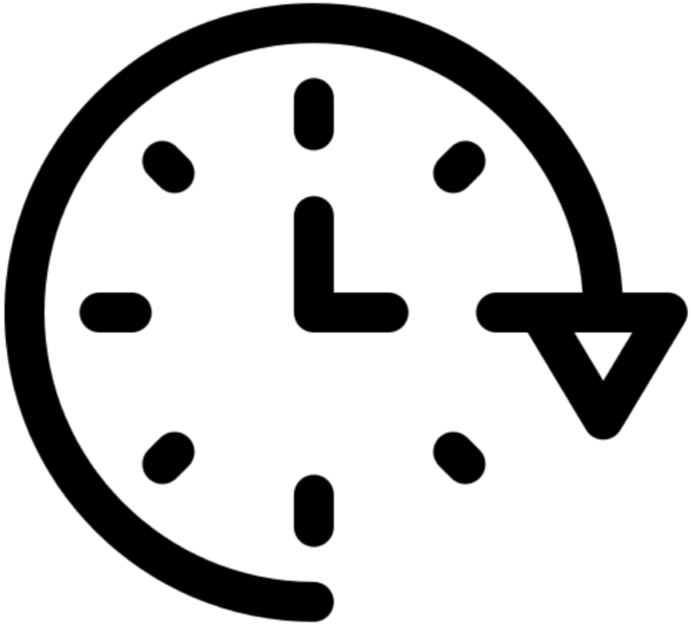
Lillestrøm

NTNU

Norwegian University of Science and Technology

Agenda

- Introduction
- Objectives
- Methodology
- Result



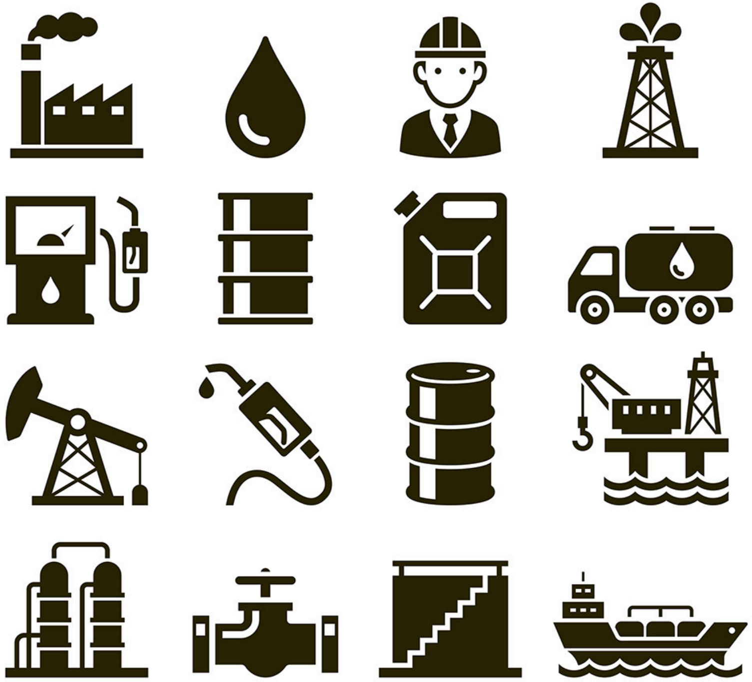
Statements

- OREDA has been the document to look up to in oil and gas industry.

- Formulating basic and optimum maintenance strategy might be unfamiliar for some graduate engineers.

Objectives

- Basic formulation of maintenance strategy.
- Using OREDA as the base of maintenance analysis.
- Oil and gas project document writing.



Methodology

- Equipment choice:
  - **Electric-driven screw compressor**
- Why?
  - Wanted to move away from gas turbine compressor (axial, centrifugal, or engine)
  - Might be overlooked?

	SERVICE CONDITION		
1	SERVICE : AIR		
2	DUTY : 2 x 100% (RUN/STAND BY & LEAD/LAG)		
3	TYPE : SCREW COMPRESSORS		
4	NUMBER OF STAGES : (*)		
5	CORROSIVE DUE TO : SALT LADEN ATMOSPHERIC		
	OPERATING CONDITIONS		
6	ACTUAL CAPACITY PER COMPRESSOR	Sm³/h	(*)
7	SKID CAPACITY RATED (NOTE 19, 20)	Sm³/h	266.1 Sm³/hr @ 14.7 psia & 60°F (2 SETS)
8	**SUCTION CONDITIONS**		
9	RATIO OF SPECIFIC HEAT (Cp/Cv)		1.407
10	COMPRESSIBILITY, Z		0.9993
11	OPERATING TEMPERATURE (MIN/MAX)	°C	AMB (23 / 31)
12	OPERATING PRESSURE	barg	ATM
13	MASS FLOW	kg/h	325.2 (*)
14	ACTUAL INLET VOLUME	ACFM	(*)
15	**DISCHARGE CONDITIONS**		
16	RATIO OF SPECIFIC HEAT (Cp/Cv)		1.423 (*)
17	COMPRESSIBILITY, Z		0.997 (*)
18	OPERATING TEMPERATURE	°C	40 - 50 (*)
19	DISCHARGE PRESSURE	barg	10.6 barg (154 psig) (**)
20	TOTAL PRESSURE RATIO		(*)
21	POWER PER STAGE	kW	(*)
22	POWER DRIVER COUPLING	kW	(*)
23	DRIVER RATING	kW	(*)
24	DRIVER SPEED	rpm	(*)
25	DESIGN TEMPERATURE	°C	70 / 0
26	DESIGN PRESSURE **(Note 28)**	barg	12 barg (175 psig) (**)
	ONDITION		
27	LOCATION	□ INDOOR	■ OUTDOOR
		□ HEATED	■ UNHEATED
28	TROPICALISATION REQUIRED :	■ YES	□ NO
29	AMBIENT TEMPERATURE	°C	= 36 ; MIN = 18
30	RELATIVE HUMIDITY	%	59 - 86
31	ELEVATION	m	22 (MEZZANINE DECK)
32	AREA CLASSIFICATION : UNCLASSIFIED		
33	NOISE LIMITATION : 85 dB (A) @ 1 m (as per PTS 12.01.02)		
34	WIND VELOCITY	m/s	14 (1 hour mean@ 2 years)
35	SEISMIC CONDITION : ELE : X= 0.085g; Y= 0.088g; Z= 0.220g		
35	ALE : X= 0.165g; Y= 0.163g; Z= 0.314g		
	COMPRESSOR SKID CONNECTIONS		

	PACKAGE SCOPE OF SUPPLY		
48	**COMPRESSOR TAG NO** : K-5410 A/B		
49	**COMPRESSOR TYPE** : SCREW, OIL FREE TYPE		
50	**DRIVER TYPE** : ELECTRIC MOTOR		
51	**COUPLING GUARD** :	■ YES	□ NO
52	**BASEPLATE :** □ SEPARATE	■ COMBINED	■ SKID
53	**LIFTING FRAMES** :	■ YES	□ NO
54	**INTAKE FILTER/SILENCER** :	■ YES	□ NO
55	**AIRCOOLER(S)** :	■ YES	□ NO
56	**PREFILTER** : YES	**AFTER FILTER** : YES	
57	**OIL COOLER** :	■ YES	□ NO
58	**AUTO-CONDENSATE TRAP** :	■ YES (AUTOMATIC)	□ NO
59	**AIR DRYER** :	■ YES	□ NO
60	DESICCANT CAGE :	■ YES	□ NO
61	BLOW OFF SILENCER :	■ YES	□ NO
62	VIBRATION MONITOR (ACCELEROMETER) :	□ YES	■ NO
63	**INSTRUMENT SYSTEM OF PACKAGE :**	■ YES	□ NO
64	WIRING CONTROLS & INSTRUMENTS :	■ YES	□ NO
65	CONTROL PANEL :	■ YES	□ NO
66	CONTROL PANEL TYPE :	■ LOCAL	□ REMOTE
67	SPEC. REQUIRED : ISO 10440-2, BTP2B-EPCIC-BTJTB-M-SPC-0013		
68	PTS 12.11.35, PTS 14.10.02		
69	**ELECTRIC SYSTEM OF PACKAGE :**	■ YES	□ NO
70	ELECTRIC MOTOR & ACCESSORIES	■ YES	□ NO
71	ELECTRIC MOTOR POWER :	kW	(*)
72	VOLTS : 400	PHASE : 3	Hz : 50
73	SPEC. REQUIRED : BTP2B-EPCIC-BTJTB-E-SPC-0001		
75	BTP2B-EPCIC-BTJTB-E-SPC-0011		
76	**INTERCONNECTING PIPEWORK AND VALVES :**	■ YES	□ NO
77	MATERIALS : (*) BTP2B-EPCIC-BTJTB-P-SPC-0001		
78	PSV :	■ YES	□ NO
79	**ENCLOSURE** : (*)	■ YES	□ NO
80	ENCLOSURE TYPE : (*)	■ ACOUSTIC	■ WEATHERPROOF
81	AIR COOLING SYSTEM	■ YES	□ NO
82	**PAINTING & COATING :**	■ YES	□ NO
83	SPEC. REQUIRED : PTS 15.20.03, PROTECTIVE COATINGS AND LINING		
84	FOUNDATION BOLTS :	■ YES	□ NO
85	COOLING WATER SUPPLY :	□ YES	■ NO
86	LUBRICATION SYSTEM :	■ YES	□ NO
	CASING		
87	MODEL		(*)
88	MATERIAL AND GRADE		(*)

Methodology

- OREDA data for equipment choice:
  - There are several categories (critical, degraded, etc.)
  - Same failure modes will be added

Taxonomy no	Item		
1.1.3.2	Machinery Compressors Screw Electric driven		
Population	**Installations**	**Aggregated time in service (10^6 hours)**	**No of demands**
		Calendar time * / **Operational time** †	
33	16	1.0800 / 0.5894	38694

Failure mode	No of failures	Failure rate (per 10^6 hours) Lower	Mean	Upper	SD	n/τ	Active rep.hrs	Repair (manhours) Min	Mean	Max
Critical	**79***	**0.00**	**119.07**	**623.23**	**280.02**	**73.15**	**14.7**	**1.0**	**23.2**	**163.0**
	79†	**0.00**	**140.31**	**771.01**	**373.65**	**134.04**				
Erratic output	4*	0.00	7.43	41.04	20.71	3.70	6.8	7.0	9.8	15.0
	4†	0.00	9.79	53.91	26.83	6.79				
External leakage - Process medium	2*	0.43	2.02	4.58	1.33	1.85	17.5	12.0	29.0	46.0
	2†	0.00	3.55	15.81	6.24	3.39				
External leakage - Utility medium	7*	0.00	12.91	71.93	37.34	6.48	14.1	13.0	38.9	96.0
	7†	0.00	16.30	92.72	49.64	11.88				
Fail to start on demand	12*	0.01	19.39	85.34	33.45	11.11	5.9	1.0	8.7	32.0
	12†	0.03	27.31	112.65	42.77	20.36				
Low output	11*	0.00	18.32	100.68	48.26	10.19	16.2	2.0	26.7	163.0
	11†	0.00	22.95	126.63	63.80	18.66				
Noise	1*	0.00	1.14	6.30	3.17	0.93	73.0	76.0	76.0	76.0
	1†	0.00	1.64	7.89	3.25	1.70				
Other	1*	0.00	1.14	6.30	3.17	0.93	7.0	7.0	7.0	7.0
	1†	0.00	1.64	7.89	3.25	1.70				
Overheating	4*	0.00	5.69	25.77	10.24	3.70	20.1	2.0	20.5	70.0
	4†	0.05	7.60	26.23	9.67	6.79				
Parameter deviation	2*	0.01	2.90	11.70	4.40	1.85	10.8	11.0	21.5	32.0
	2†	0.00	4.42	21.89	9.28	3.39				
Spurious stop	34*	0.00	49.58	255.89	111.67	31.48	15.8	2.0	23.6	148.0
	34†	0.00	60.15	320.06	146.70	57.69				
Structural deficiency	1*	0.00	1.64	8.64	3.90	0.93	21.5	43.0	43.0	43.0
	1†	0.01	1.96	7.64	2.83	1.70				
Degraded	**92***	**0.00**	**145.57**	**800.25**	**391.94**	**85.19**	**9.2**	**1.0**	**15.2**	**111.0**
	92†	**0.00**	**163.88**	**929.89**	**529.52**	**156.10**				
Abnormal instrument reading	1*	0.00	1.14	6.30	3.17	0.93	5.0	5.0	5.0	5.0
	1†	0.00	1.64	7.89	3.25	1.70				
Erratic output	5*	0.00	8.39	44.63	20.45	4.63	6.9	2.0	10.6	35.0
	5†	0.00	11.16	58.06	25.82	8.48				

Methodology

- Maintainable item versus failure mode:
  - Rows downwards are maintainable items
  - Columns to the right are the failure mode

- Calculate alpha values from this table. *(x / total)*

- Hence, each maintainable item has each failure mode alpha value.

Maintainable item versus failure mode, to be continued
Item: Compressors

	AIR	BRD	ELP	ELU	ERO	FTS	HIO	INL	LOO	NOI
Actuating device	0.04	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
Antisurge system	0.22	0.00	0.04	0.13	0.35	0.18	0.04	0.18	0.00	0.00
Base frame	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bearing	0.00	0.00	0.00	0.18	0.00	0.04	0.00	0.00	0.00	0.00
Buffer gas system	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Cabling & junction boxes	0.22	0.00	0.00	0.04	0.00	0.09	0.00	0.00	0.00	0.00
Casing	0.00	0.02	0.04	0.18	0.00	0.00	0.00	0.00	0.00	0.00
Check valves	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Control unit	0.84	0.00	0.00	0.04	0.22	0.53	0.00	0.00	0.00	0.00
Control-, isolating & check valves	0.04	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00
Cooler(s)	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00
Coupling to driven unit	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00
Coupling to driver	0.00	0.00	0.00	0.11	0.18	0.00	0.00	0.00	0.00	0.00
Cylinder liner	0.13	0.00	1.94	0.62	0.00	0.04	0.00	0.04	5.78	0.00
Dry gas seal	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.04	0.00	0.00
Filter(s)	0.02	0.00	0.04	0.18	0.00	0.00	0.09	0.04	0.31	0.00
Gearbox/var.drive	0.09	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.09
Instrument, flow	0.57	0.00	0.00	0.09	0.00	0.04	0.00	0.00	0.00	0.00
Instrument, general	0.84	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.04	0.00
Instrument, level	2.07	0.00	0.00	0.22	0.00	0.04	0.00	0.04	0.00	0.00
Instrument, pressure	4.07	0.00	0.00	0.31	0.09	0.31	0.04	0.00	0.04	0.00
Instrument, speed	0.26	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00
Instrument, temperature	4.65	0.00	0.04	0.11	0.09	0.13	0.00	0.00	0.04	0.00
Instrument, vibration	1.08	0.00	0.00	0.11	0.04	0.00	0.00	0.00	0.00	0.00
Internal piping	0.02	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Internal power supply	0.22	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00
Interstage seals	0.00	0.00	0.09	0.11	0.00	0.00	0.00	0.04	0.04	0.00

Methodology

- Beta value*:
  - Impact of the failure mode to the system or to the equipment itself.

FM Severity	Description	Beta
NEGLIGIBLE	No effect to the equipment.	0,1
LESSIMPACT	Prolonged effect. No direct effect to performance.	0,25
IMPACTFUL	Effect to performance. Reduced.	0,75
FAILED	Failed equipment.	1

<u>* This might be limited to the experience of the person, therefore experienced maintenance engineer may give better and closer value to real-life situation</u>

Methodology

- Three main equations that would be used are:
  - Failure rate (λ_i)
  - Criticality (C)
  - Probability of Failure (PoF)
- λ_0 is the failure rate per failure mode acquired from OREDA.
- t is the maintenance time interval, decided by users.

$$\lambda_i = \lambda_0 . \alpha . \beta$$

$$C = \lambda_i . t$$

$$PoF = 1 - e^{-C}$$

Methodology

Failure Mode	FM	Alpha	Failure Rate per 10^6 Hours	Lambda (per hour)	FM Severity	Beta	Lambda.A.B
AIR	22,670	0,227	109,46	0,0000109460	IMPACTFUL	0,75	1,86389E-06
BRD	0,000	0,000	0,00	0,0000000000	NEGLIGIBLE	0,1	0
ELP	2,730	0,027	12,52	0,0000012520	FAILED	1	3,42309E-08
ELU	13,740	0,138	65,46	0,0000065460	FAILED	1	9,00772E-07
ERO	3,100	0,031	15,82	0,0000015820	IMPACTFUL	0,75	3,68368E-08
FTS	4,110	0,041	19,39	0,0000019390	LESSIMPACT	0,25	1,99532E-08
HIO	0,000	0,000	0,00	0,0000000000	NEGLIGIBLE	0,1	0

- FM is the number in the maintainable item versus failure mode page
- Failure rate is the total of the failure mode in different categories
- FM severity would decide the beta value, hence λ_i (*Lambda.A.B*) is found

Result

CRITICALITY

Maintenance Interval	Time	AIR	BRD	ELP	ELU	ERO	FTS	HIO
Daily	24	4,47333E-05	0	8,21543E-07	2,16185E-05	8,84082E-07	4,78876E-07	0
Weekly	168	0,000313133	0	5,7508E-06	0,00015133	6,18857E-06	3,35213E-06	0
Bi-weekly	336	0,000626267	0	1,15016E-05	0,000302659	1,23771E-05	6,70426E-06	0
Monthy	730	0,001360639	0	2,49886E-05	0,000657563	2,68908E-05	1,45658E-05	0
2-monthly	1460	0,002721279	0	4,99772E-05	0,001315126	5,37817E-05	2,91316E-05	0
3-monthly	2190	0,004081918	0	7,49658E-05	0,00197269	8,06725E-05	4,36974E-05	0
6-monthly	4380	0,008163836	0	0,000149932	0,003945379	0,000161345	8,73948E-05	0
Yearly	8760	0,016327672	0	0,000299863	0,007890759	0,00032269	0,00017479	0
2-yearly	17520	0,032655344	0	0,000599726	0,015781518	0,00064538	0,000349579	0

- C is calculated per time interval that is decided by the user
- This example, daily until 2-yearly time interval were used

Result

PROBABILITY

Maintenance Interval	Time	AIR	BRD	ELP	ELU	ERO	FTS	HIO
Daily	**24**	4,47323E-05	0	8,21542E-07	2,16183E-05	8,84082E-07	4,78876E-07	0
Weekly	**168**	0,000313084	0	5,75078E-06	0,000151318	6,18856E-06	3,35212E-06	0
Bi-weekly	**336**	0,000626071	0	1,15015E-05	0,000302613	1,23771E-05	6,70424E-06	0
Monthy	**730**	0,001359714	0	2,49883E-05	0,000657347	2,68905E-05	1,45657E-05	0
2-monthly	**1460**	0,002717579	0	4,99759E-05	0,001314262	5,37802E-05	2,91312E-05	0
3-monthly	**2190**	0,004073598	0	7,4963E-05	0,001970745	8,06692E-05	4,36965E-05	0
6-monthly	**4380**	0,008130602	0	0,00014992	0,003937607	0,000161332	8,7391E-05	0
Yearly	**8760**	0,016195098	0	0,000299818	0,007859709	0,000322638	0,000174774	0
2-yearly	**17520**	0,032127915	0	0,000599546	0,015657642	0,000645172	0,000349518	0

- PoF is calculated per criticality from previous table

$$PoF = 1 - e^{-C}$$

Result

PROBABILITY

Maintenance Interval	Time	AIR	BRD	ELP	ELU	ERO	FTS	HIO
Daily	24	4,47323E-05	0	8,21542E-07	2,16183E-05	8,84082E-07	4,78876E-07	0
Weekly	168	0,000313084	0	5,75078E-06	0,000151318	6,18856E-06	3,35212E-06	0
Bi-weekly	336	0,000626071	0	1,15015E-05	0,000302613	1,23771E-05	6,70424E-06	0
Monthy	730	0,001359714	0	2,49883E-05	0,000657347	2,68905E-05	1,45657E-05	0
2-monthly	1460	0,002717579	0	4,99759E-05	0,001314262	5,37802E-05	2,91312E-05	0
3-monthly	2190	0,004073598	0	7,4963E-05	0,001970745	8,06692E-05	4,36965E-05	0
6-monthly	4380	0,008130602	0	0,00014992	0,003937607	0,000161332	8,7391E-05	0
Yearly	8760	0,016195098	0	0,000299818	0,007859709	0,000322638	0,000174774	0
2-yearly	17520	0,032127915	0	0,000599546	0,015657642	0,000645172	0,000349518	0

Probability of Failue		Quantitative Range
At least once every < 6 months	Frequent	> 2.28E-04
At least once every 6 months to 2 years	Probable	2.28E-04 to 5.70776E-05
At least once every 2 to 4 years	Rare	5.70776E-05 to 2.85388E-05
At least once very 4 to 20 years	Remote	2.85388E-05 to 5.70776E-06
At least once every > 20 years	Improbable	5.70776E-06 >

Result

No.	Failure Mode	Failure Mode Code	Beta	Maintainable Item (Failure Cause)	Probability	Alpha	Maintenance Interval Time								
							Daily	Weekly	Bi-Weekly	Monthly	2-monthly	3-monthly	6-monthly	Yearly	2-yearly
1	Abnormal Instrument Reading	AIR	0,75	Cabling & junction boxes	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
		AIR	0,75	Filter(s)	0,17	0,001702554	3,35451E-07	2,34815E-06	4,6963E-06	1,02032E-05	2,04064E-05	3,06094E-05	6,12179E-05	0,000122432	0,000244849
		AIR	0,75	Instrument, flow	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
		AIR	0,75	Instrument, general	1,72	0,017225839	3,39397E-06	2,37575E-05	4,75145E-05	0,000103228	0,000206445	0,000309652	0,000619208	0,001238033	0,002474533
		AIR	0,75	Instrument, level	0,69	0,006910366	1,36153E-06	9,5307E-06	1,90613E-05	4,14125E-05	8,28233E-05	0,000124232	0,000248449	0,000496837	0,000993427
		AIR	0,75	Instrument, pressure	6,53	0,065398097	1,28852E-05	9,01927E-05	0,000180377	0,00039185	0,000783546	0,001175089	0,002348797	0,004692076	0,009362137
		AIR	0,75	Instrument, speed	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
		AIR	0,75	Instrument, temperature	9,28	0,092939409	1,83115E-05	0,000128173	0,00025633	0,000556825	0,001113339	0,001669544	0,003336301	0,006661471	0,013278568
		AIR	0,75	Instrument, vibration	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
		AIR	0,75	Internal piping	0,17	0,001702554	3,35451E-07	2,34815E-06	4,6963E-06	1,02032E-05	2,04064E-05	3,06094E-05	6,12179E-05	0,000122432	0,000244849
		AIR	0,75	Internal power supply	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
		AIR	0,75	Monitoring	0,69	0,006910366	1,36153E-06	9,5307E-06	1,90613E-05	4,14125E-05	8,28233E-05	0,000124232	0,000248449	0,000496837	0,000993427
		AIR	0,75	Reservoir w/ heating system	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
		AIR	0,75	Subunit	0,69	0,006910366	1,36153E-06	9,5307E-06	1,90613E-05	4,14125E-05	8,28233E-05	0,000124232	0,000248449	0,000496837	0,000993427
		AIR	0,75	Valves	0,69	0,006910366	1,36153E-06	9,5307E-06	1,90613E-05	4,14125E-05	8,28233E-05	0,000124232	0,000248449	0,000496837	0,000993427

Probability of Failue		Quantitative Range
At least once every < 6 months	**Frequent**	> 2.28E-04
At least once every 6 months to 2 years	**Probable**	2.28E-04 to 5.70776E-05
At least once every 2 to 4 years	**Rare**	5.70776E-05 to 2.85388E-05
At least once very 4 to 20 years	**Remote**	2.85388E-05 to 5.70776E-06
At least once every > 20 years	**Improbable**	5.70776E-06 >

Result

No.	Failure Mode	Failure Mode Code	Beta	Maintainable Item (Failure Cause)	Probability	Alpha	Maintenance Interval Time								
							Daily	Weekly	Bi-Weekly	Monthly	2-monthly	3-monthly	6-monthly	Yearly	2-yearly
93	Structural Deficiency	STD	0,75	Base frame	0,34	0,003405108	4,0514E-08	2,83598E-07	5,67195E-07	1,2323E-06	2,4646E-06	3,69689E-06	7,39377E-06	1,47875E-05	2,95748E-05
22	External Leakage - Utility Medium	ELU	1	Bearing	1,37	0,013720581	2,15556E-06	1,50888E-05	3,01774E-05	6,55627E-05	0,000131121	0,000196675	0,000393312	0,000786469	0,00157232
94	Structural Deficiency	STD	0,75	Bearing	0,34	0,003405108	4,0514E-08	2,83598E-07	5,67195E-07	1,2323E-06	2,4646E-06	3,69689E-06	7,39377E-06	1,47875E-05	2,95748E-05
1	Abnormal Instrument Reading	AIR	0,75	Cabling & junction boxes	0,34	0,003405108	6,70901E-07	4,6963E-06	9,39258E-06	2,04064E-05	4,08123E-05	6,12179E-05	0,000122432	0,000244849	0,000489638
58	Other	OTH	0,75	Cabling & junction boxes	0,69	0,006910366	2,89696E-07	2,02787E-06	4,05574E-06	8,81156E-06	1,7623E-05	2,64344E-05	5,28682E-05	0,000105734	0,000211456
78	Minor In-Service Problems	SER	0,25	Casing	0,69	0,006910366	2,12452E-07	1,48716E-06	2,97433E-06	6,46207E-06	1,29241E-05	1,93861E-05	3,87718E-05	7,75421E-05	0,000155078
35	**Erratic Output**	**ERO**	**0,75**	**Control unit**	**0,69**	**0,006910366**	1,9678E-07	1,37746E-06	2,75491E-06	5,98536E-06	1,19707E-05	1,7956E-05	3,59116E-05	7,1822E-05	0,000143639
37	**Fail to Start on Demand**	**FTS**	**0,25**	**Control unit**	**0,34**	**0,003405108**	3,9615E-08	2,77305E-07	5,5461E-07	1,20496E-06	2,40991E-06	3,61486E-06	7,22972E-06	1,44594E-05	2,89185E-05
59	**Other**	**OTH**	**0,75**	**Control unit**	**0,34**	**0,003405108**	1,42749E-07	9,99242E-07	1,99848E-06	4,34194E-06	8,68386E-06	1,30258E-05	2,60513E-05	5,2102E-05	0,000104201
68	**Parameter Deviation**	**PDE**	**0,75**	**Control unit**	**0,34**	**0,003405108**	4,19298E-07	2,93508E-06	5,87016E-06	1,27536E-05	2,5507E-05	3,82602E-05	7,6519E-05	0,000153032	0,000306041
101	**Spurious Stop**	**UST**	**0,75**	**Control unit**	**0,69**	**0,006910366**	6,16708E-07	4,31695E-06	8,63388E-06	1,8758E-05	3,75157E-05	5,62731E-05	0,000112543	0,000225073	0,000450096
23	External Leakage - Utility Medium	ELU	1	Cooler(s)	0,86	0,008612919	1,35312E-06	9,47182E-06	1,89436E-05	4,11567E-05	8,23117E-05	0,000123465	0,000246915	0,000493768	0,000987293
52	Overheating	OHE	1	Cooler(s)	0,34	0,003405108	7,24062E-08	5,06843E-07	1,01369E-06	2,20235E-06	4,4047E-06	6,60704E-06	1,3214E-05	2,64279E-05	5,28551E-05
60	Other	OTH	0,75	Cooler(s)	0,34	0,003405108	1,42749E-07	9,99242E-07	1,99848E-06	4,34194E-06	8,68386E-06	1,30258E-05	2,60513E-05	5,2102E-05	0,000104201
69	Parameter Deviation	PDE	0,75	Cooler(s)	0,34	0,003405108	4,19298E-07	2,93508E-06	5,87016E-06	1,27536E-05	2,5507E-05	3,82602E-05	7,6519E-05	0,000153032	0,000306041
102	Spurious Stop	UST	0,75	Cooler(s)	0,46	0,00460691	4,11139E-07	2,87797E-06	5,75593E-06	1,25054E-05	2,50106E-05	3,75157E-05	7,50301E-05	0,000150055	0,000300087

Probability of Failue		Quantitative Range
At least once every < 6 months	**Frequent**	> 2.28E-04
At least once every 6 months to 2 years	**Probable**	2.28E-04 to 5.70776E-05
At least once every 2 to 4 years	**Rare**	5.70776E-05 to 2.85388E-05
At least once very 4 to 20 years	**Remote**	2.85388E-05 to 5.70776E-06
At least once every > 20 years	**Improbable**	5.70776E-06 >

Result

- Pressure and Temperature Instrument would be maintained daily or weekly for their longest interval.

- Control Unit would be maintained bi-weekly or 3-monthly for its longest interval.

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Takk for i dag!

Spørsmaler?

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