CHAPTER 1
INTRODUCTION

1.1 Background of Study

In Centralised Utility Facilities Kertih (CUFK), there are many of centrifugal pump that use for transfer liquid from one place to another place. There is one pump that has many problems during its operation and due to this problems, the current pump reliability is reduce and not achieve the company target. The pump is the Liquid Oxygen (LOX) Process Pump. The appendix 1 shows the diagram of the LOX Process pump. So, this project will use the LOX Process pump as a Reliability Centered Maintenance (RCM) case study. The LOX Process pump function are for transport the Liquid Oxygen from Low pressure or High pressure Column to liquid oxygen storage. The reliability of the LOX Process pump can be improved by implementing the RCM.

Reliability Centered Maintenance (RCM) is an industrial improvement approach focused on identifying and establishing the operational, maintenance, and capital improvement policies that will manage the risks of equipment failure most effectively. Reliability Centered Maintenance can be used to create a cost-effective maintenance strategy and to address dominant causes of pump failure. It is a systematic approach to defining a routine maintenance program composed of cost-effective tasks that preserve important functions [1].

1.2 Problem Statement

In industry world, the theoretical RCM method are not the same that the method or system that the company used. The similarities and differences of this method have to be identified. For the case study, the LOX Process Pump is one of the most important pumps that operating in CUFK plan. This pump is having many problems during the operation and the maintenance cost for this pump is too high. The critical part of the pump is the MTBF of the pump and the pump equipment criticality. The current pump MTBF is about 1 month per failure and this MTBF value are too low and indicate the reliability of the pump is poor.

For the equipment criticality, there is no revised equipment criticality assessment for 2 year period (2008 – 2009) and some of the equipment part are fall under lower critically rating (rating 1). So, with this project, will revised the Equipment Criticality for the LOX process pump and proposed possible solution for the possible failure cause to improve the pump MTBF value and its reliability.

1.3 Objectives

The objectives of the project are:

a) To compare the RCM implemented at CUF Kertih with the theoretical RCM analysis process to identify the differences similarities between these two analysis.
b) To assess the Equipment Critically for 2008-2009 to identify the criticality of each pump equipment.
c) To perform the Failure Mode and Effect Analysis (FMEA) to identify the failure mode and effect of each failure mode to the pump and its operation.

1.4 Scope of Study

The project is start with the study of the concept and process theoretical RCM and RCM implemented at CUFK. Next step is to perform the Equipment Criticality Analysis to revise the equipment criticality and also to identify the pump component that bring major consequence to the plan. Next are the Failure Mode Effects and Effect Analysis (FMEA). All the failure mode and failure effect will be analysis. This FMEA is to identify the potential causes of the system failure before the failure actually occurs.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 Reliability

Reliability is the probability that an item will operate in given operating period, under specified operating conditions, without failure [13].

2.1.1 Reliability Parameter

a. Failure Rate

The rate at which failures occur in a specified time interval is called the failure rate during that interval. The failure rate (Fr) is expressed as [8]:

$$Fr = \text{No. of failures/Total operating hours} \qquad (2.1)$$
$$= \lambda$$

b. Mean Time Between Failure (MTBF)

Mean Time Between Failure (MTBF) is the average frequency with which a equipment fails, the average time between failure or the length of time a component or equipment is expected to work without failure. It is also an indicator of system reliability that is calculated from known failure rates of various equipment components [12]. MTBF is the reliability parameter of determining the reliability of the equipment; it indicates the failure rate of equipment and its components and is usually given in units of hours. The equipment is more reliable when the MTBF is higher. The MTBF can be computed as:

$$MTBF = 1/\lambda \qquad (2.2)$$

λ = Failure Rate

2.2 Reliability Centered Maintenance (RCM)

RCM is a process used to determine what must be done to ensure that any physical asset continues the desired standard performance in its present operating context. RCM also is a technique for developing a reliability maintenance program [1]. It is based on the assumption that the inherent reliability of the equipment is a function of the design and the build quality. An effective reliability maintenance program will ensure that the inherent reliability is realized. It cannot, however, improve the reliability of the system. This is only possible through redesign or modification.

RCM was designed to improved equipment operating performance, greater maintenance cost effectiveness and also will improve safety and environmental integrity.

An RCM analysis basically provides answers to the following seven questions:

1) What are the functions and associated performance standards of the equipment in its present operating context?
2) In what ways does it fail to fulfill its functions?
3) What is the cause of each functional failure?
4) What happens when each failure occurs?
5) In what way does each failure matter?
6) What can be done to prevent each failure?
7) What should be done if a suitable preventive task cannot be found?

2.3 Reliability Maintenance Methods

The reliability maintenance of today can be divided into two major group, preventive maintenance (PM) and corrective maintenance (CM). Preventive maintenance has also been divided into two categories, condition based and predetermined maintenance. Figure 2.1 show the type of reliability maintenance methods.

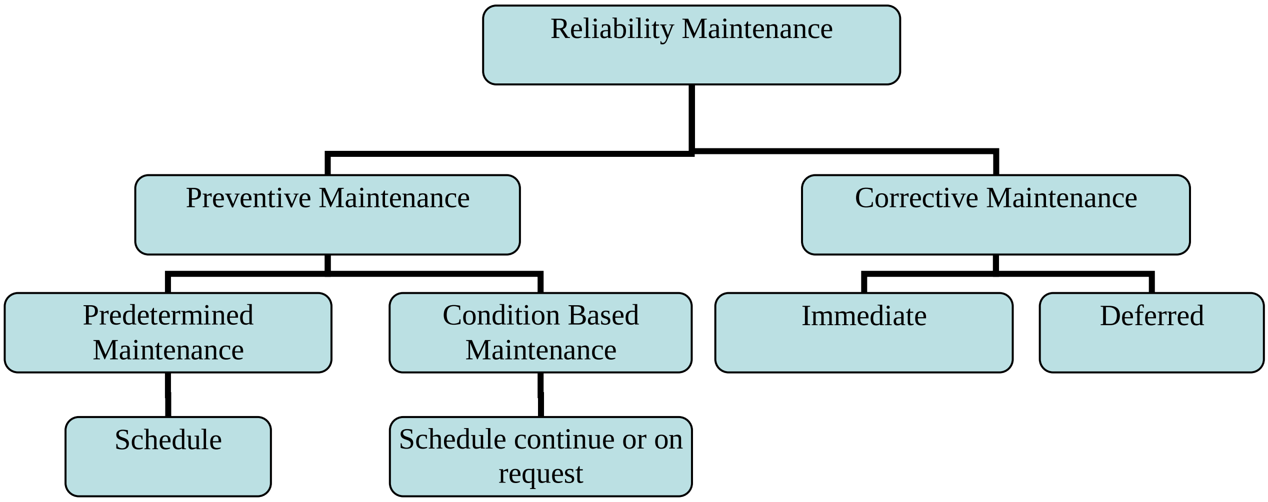

Figure 2.1: Type of reliability maintenance methods. [9]

2.3.1 Corrective Maintenance

Corrective maintenance is performed with the intension to restore a function after a failure has occurred. Corrective maintenance also goes under the name unplanned or unscheduled maintenance

Corrective maintenance has been divided into two subgroups, immediate and deferred, where the deferred maintenance has been chosen and is quite good. The immediate maintenance is the negative maintenance, which goes under the name 'unplanned'.

2.3.2 Preventive Maintenance

Preventive maintenance activity to reduce the probability of failure before the failure has occurred. This is done by either predetermined or condition base maintenance.
Predetermined maintenance is carried out according to maintenance schedules, in time intervals. Predetermined maintenance is done on the equipment regardless of the status of them. The interval must be adapted, so that it doesn't become corrective maintenance. Predetermined maintenance is done on simple items or complex items with a high failure rate.

Condition based maintenance is done through a maintenance schedule, but instead of exchanging the items directly, a check of the items status is done before replacing it. Condition based equipment is also suitable for condition monitoring, due to the fact that all item give some kind of signal before they break.

2.4 Reliability Centered Maintenance Analysis Process

The RCM analysis may be carried out as a sequence of activities or steps. This is the list of RCM process:

1) Study preparation
2) Define the functions of each asset in its operating context, together with the associated desired standards of performance**.**
3) Identification of Functional Failures
4) Identification of Failure Mode
5) Identification of the Failure Effect
6) Identification of Failure Consequence
7) Failure Mode and Effect Analysis (FMEA)
8) Selection of recommendation action

2.4.1 Study preparation

Overall drawings and process diagrams, like technical description of the equipment system (capacity, operating condition, equipment description), piping and instrumentation diagrams, P&ID, pump process flow diagram, historical PM and CBM schedule, operation logbook, maintenance record, past Failure and Effect Analysis and operation efficiency record must be collected and study. All this data are importance in RCM process because this data will be use for further RCM analysis and selection task.

2.4.2 Define the functions of each asset in its operating context, together with the associated desired standards of performance.

The functions of each asset in its operating context can be split into two categories:

1) Primary functions, which summarize why the asset was acquired in the first place. This category of functions covers issues such as speed, output, carrying or storage capacity, product quality, and customer service.
2) Secondary functions, which recognize that every asset is expected to do more than simply fulfill its primary functions. Users also have expectations in areas such as safety, control, containment, comfort, structural integrity, economy, protection, and efficiency of operation, environmental compliance and even the appearance of the asset.

The performance standard can be defined in two ways, as follow:

1) Desired performance (what the user want the asset to do)
2) Built in capability (what it can do)

For any asset to be maintainable, the desired performance of the asset must fall within the envelope of its initial capability. In order to determine this is so, not only the initial capabilities of the asset need to know, the exact minimum performance also need to know. The figure 2.2 will show the differences between the initial capabilities and the desired performance

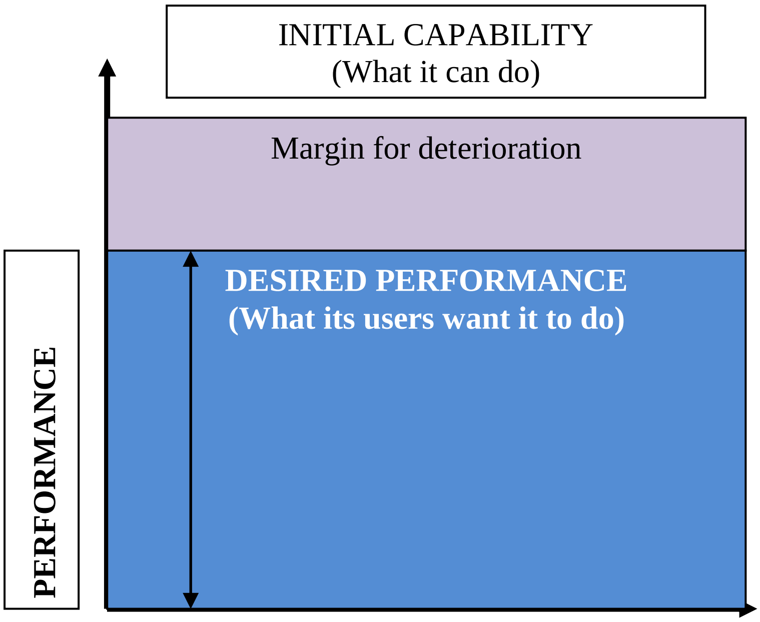

Figure 2.2: Difference between initial capability and desired performance [1]

2.4.3 Identification of Functional Failures

Functional failure will describe the potential system failure modes. In most of the RCM references the system failure modes are denote functional failures. A variety of classifications schemes for failure modes have been published. Some of these schemes may be used to secure that all relevant functional failures are identified. The classification of failures as follows:

1) Sudden failures are failures that could not be forecast by prior testing or examination.
2) Gradual failures are failures that could be forecast by testing or examination. A gradual failure will represent a gradual 'drifting out' of the specified range of performance values. The recognition of gradual failures requires comparison of actual device performance with a performance specification, and may in some cases be a difficult task.

2.4.4 Identification of the Failure Mode

A failure mode could be defined as any event which is likely to cause an asset or system to fail. More precise definition of failure mode is any event which causes a functional failure. The best way to show the connection and the distinction between failed states and the event which could cause them is to list functional failures first, then to record the failure modes which could cause each functional failure.

A list of possible failure mode should be including the following:

1) Failures which have occurred before
2) Failure mode which are already the subject of proactive maintenance routines.
3) Any other failure mode which have not yet occurred but which are considered to be real possibilities.

2.4.5 Identification of the Failure Effect

Failure effect describes what happens when a failure mode occurs. A description of failure effect should include all the information needed to support the evaluation of the consequence of the failure. Specifically, when describing the effect of a failure, the following should be recorded:

1) what evidence (if any) that the failure has occurred
2) In what ways (if any) it poses a threat to safety or the environment
3) In what ways (if any) it affects production or operations.
4) What physical damage (if any) is caused by the failure
5) What must be done to repair the failure?

2.4.6 Identification of Failure Consequence

Failure consequences are classified into three categories in descending order of importance, as follow:

1) **Safety and environmental consequence**: A failure has safety consequence if it could injure or kill someone. It has environmental consequences if it leads to a breach of any corporate, regional or national environmental standard.
2) **Operational consequence**: A failure has operational consequences if it effects production or operations(output, product quality, customer service or operating cost in addition to the direct cost of repair

3) **Non-operational consequence**: Evident failure in this category affect neither safety nor production cost in addition to the direct cost of repair.

2.4.7 Failure Modes and Effects Analysis (FMEA)

FMEA is a design evaluation procedure used to identify potential failure modes and determined the effect of each on the system performance. It a combination of the identification of the equipment function, equipment standard performance, functional failure, failure mode and effect, and the failure consequence [10]. All the identified function, functional failure, and failure effect will be filled in the FMEA worksheet. Example of the FMEA worksheet is shown at APPENDIX 1.

2.4.8 Selection of Maintenance Actions

This step is the most novel compared to other maintenance planning techniques. Decision logic is used to guide the analyst through a question-and-answer process. The input to the RCM decision logic is the dominant failure modes from the FMEA. The main idea is for each dominant failure mode to decide whether a PM task is applicable and effective, or it will be best to let the item deliberately run to failure and afterwards carry out a corrective maintenance task. There are generally three main reasons for doing a PM task. First is to prevent a failure, second is to detect the onset of a failure and lastly to discover a hidden failure.

In selection of maintenance action, the following basic maintenance tasks are considered:

1) Scheduled on-condition task is a task to determine the condition of an item, for example, by condition monitoring. There are three criteria that must be met for an on-condition task to be applicable.

a) It must be possible to detect reduced failure resistance for a specific failure mode.
b) It must be possible to define a potential failure condition that can be detected by an explicit task.
c) There must be a reasonable consistent age interval between the time of potential failure (P) and the time of functional failure (F), as illustrated in Figure 2.3.

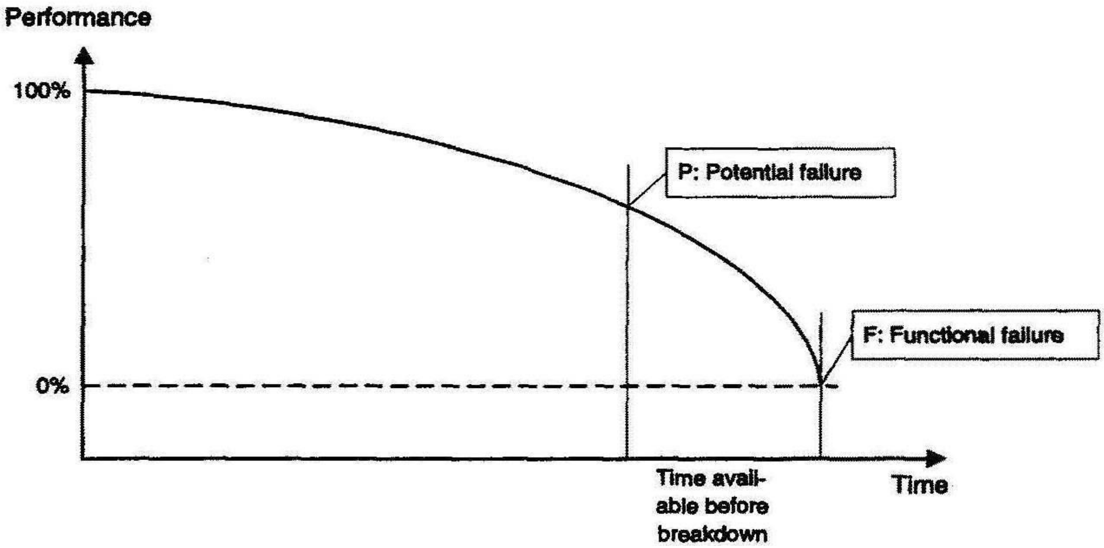

Figure 2.3: Potential Failure – Functional Failure Curve [1]

2) Scheduled overhaul may be performed of an item at or before some specified age limit, and is often called 'hard time maintenance'. An overhaul task is considered applicable to an item only if the following criteria are met.

a) There must be an identifiable age at which there is a rapid increase in the item's failure rate function.
b) A large proportion of the units must survive to that age.
c) It must be possible to restore the original failure resistance of the item by reworking it.

3) Scheduled replacement is replacement of an item (or one of its parts) at or before some specified age limit. A scheduled replacement task is applicable only under the following circumstances.

a) The item must be subject to a critical failure.
b) Test data must show that no failures are expected to occur below the specified life limit.
c) The item must be subject to a failure that has major economic (but not safety) consequences.
d) There must be an identifiable age at which the item shows a rapid increase in the failure rate function.
e) A large proportion of the units must survive to that age.

4) Scheduled function test is a scheduled failure-finding task or inspection of a hidden function to identify any failure. Failure-finding tasks are preventive only in the sense that they prevent surprises by revealing failures of hidden functions. A scheduled function test task is applicable to an item under the following conditions.

a) The item must be subject to a functional failure that is not evident to the operating crew during the performance f normal duties.
b) The item must be one for which no other type of task is applicable and effective.

5) Run to failure is a deliberate decision to run to failure because the other tasks are not possible or the economics are less favorable. PM will not prevent all failures. Consequently, if there is a clear identifiable failure mode that cannot be adequately addressed by an applicable and effective PM task that will reduce the probability of failure to an acceptable level, then there is needed to redesign or modify the item. If the consequences of failure relate to safety or the environment then this redesign recommendation will normally be mandatory. For operational and economic consequences of failure this may be desirable, but a cost-benefit assessment has to be performed.

The criteria given for using the various tasks should only be considered as guidelines for selecting an appropriate task. A task might be found appropriate even if some of the criteria are not fulfilled. A variety of different RCM decision logic diagrams are used in the main RCM references. Some of these are rather complex.

2.5 Equipment Reliability Strategy (ERS)

ERS is a systematic and comprehensive reliability strategy methodology that used to drive specific analysis and step to ensure the plan equipment operates in the standard desired performance. It also used achieve improvements in fields such as the establishment of safe minimum levels of maintenance, minimize the equipment failure consequence and changes to operating procedures and strategies and the establishment of capital maintenance regimes and plans. The activities and analysis that involve in the ERS such as:

1) Equipment failure data gathering
2) Equipment Criticality Analysis
3) Root cause Failure Analysis
4) Asset strategy

The main ERS process flow can be shown at the Figure 2.4.

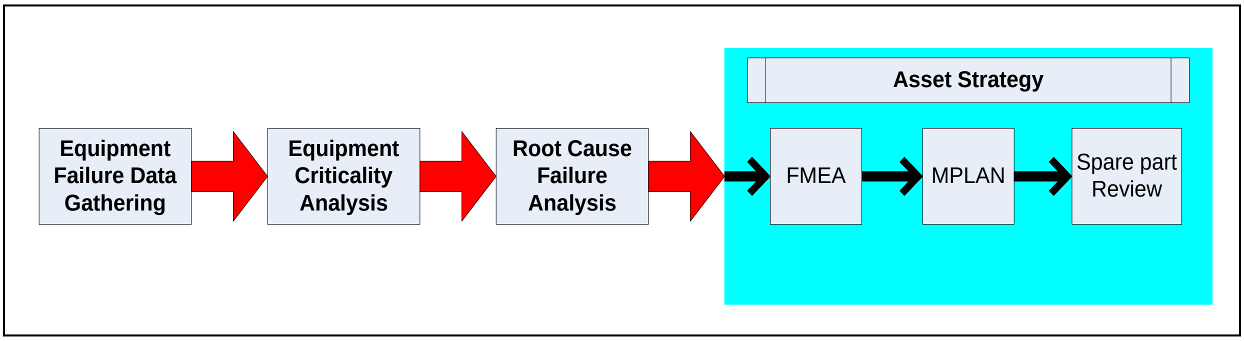

Figure 2.4: Equipment Reliability Strategy process flow [3]

2.5.1 Equipment Failure Data Gathering

After the failure of the equipment occurs, there must be a step that record and collect the data regarding the equipment failure such as the time, location, the operation record, the effect of the failure in term of the economic, health and safety, and environment, and the failure industry data. The failure histories of the equipment also need to be collected in order to do the further analysis. This step is important to provide the evident of the failure and can initiate another process of the ERS.

2.5.2 Equipment Criticality Analysis

ECA is the method of analysis that contains the economic, health and safety, and environment evaluation for each of the equipment failures and assigns the plan equipment criticality based on risk level. This analysis objective is:

1) Record and evaluate the economic losses in term of the production loss and maintenance cost for the equipment failure
2) Record and evaluate the health and safety, and environment issue regarding the failure problem.
3) Identify the equipment criticality based on risk to priorities the strategy effort.

The evaluations of the criticality of the equipment are based on the risk level.

2.5.2.1 Risk Definition

Risks are events or occurrences that prevent asset or equipment from achieving performance objectives of target [4]. The risk level can be expressed as

$$\text{Risk Level} = \text{Probability Ranking x (Consequence)} \qquad (2.3)$$

The probability is in term of MTBF and there are three consequences that the risk level evaluation; economic, health and safety, and environment.

2.5.3 Root Cause Failure Analysis (RCFA)

Root cause analysis is investigation technique that designed to help:

1) Describe what happened during a particular occurrence
2) Determined how it happened
3) Understand why it happened

Root cause Failure Analysis seeks to determine why a particular event or failure took place so as to correct the problem from ever occurring again in that or any other product. In this way, RCFA is a tool that can be used to constantly improve all aspect of equipment development and production.

Basically the step that the CUFK investigation team uses is:

1) Conduct physical evaluation
2) Review documents, and procedure, and check against the standard
3) Interview the witnesses
4) Conduct the sampling testing
5) Coordinate across the supply chain

2.5.4 Asset Strategy

In the asset strategy, there three major procedures that have been apply in the CUFK; FMEA, Maintenance Plan (MPlan), and Spare part review. After the RCFA investigations are done, the causes of the failure are updated in the FMEA. The effect of each failure will be also identifying. In the Mplan, the maintenance types that are involve is preventive maintenance, corrective maintenance, predetermined maintenance, schedule operation and the working procedure. All this Mplan are will be revised and new Mplan will be proposed and upload to the SAE system. For the spare part review process, the spare part requirement will be review based on critical equipment, long lead item, and annual usage.

CHAPTER 3
METHODOLOGY

In this research, the methodology consists of four main parts, which is the data gathering and analysis on the topic, RCM comparison, Equipment Criticality Analysis and Failure Mode and Effect Analysis. Figure 3.1 show the procedure that will follow in order to carry out and implement the project. This project flow will be the guide for the overall project work and will ensure the project will be accomplished within the time given.

3.1 Work Flow

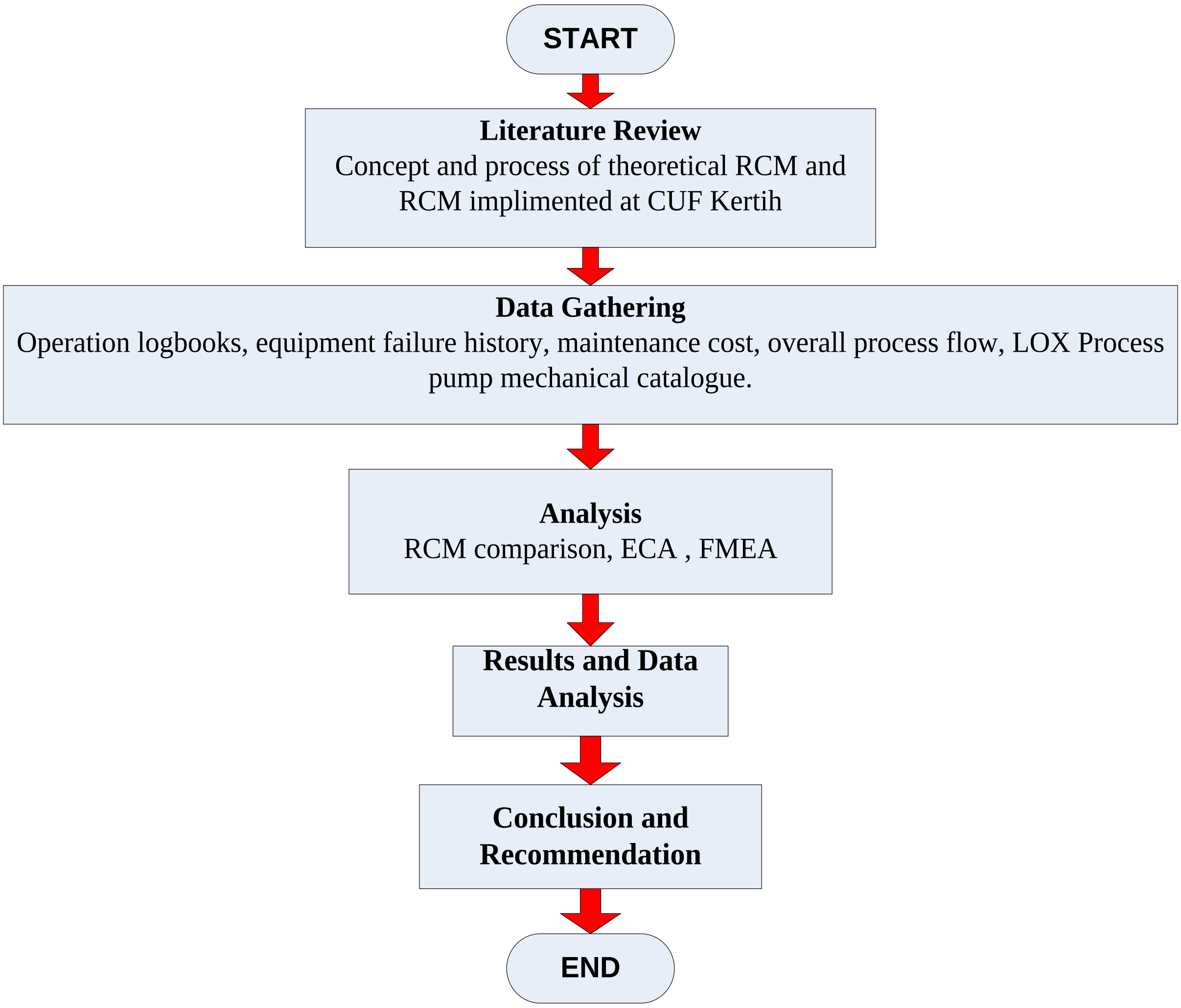

Figure 3.1: Project Flow Schematic Diagram.

3.2 Data Gathering and Analysis

The data that will use for further analysis will be collected from CUFK Maintenance Department and from the SAP system. The collected and gathered data are:

I. operation logbooks
II. equipment failure history
III. maintenance cost
IV. overall ASU 2 process flow
V. Mechanical catalogue.

3.3 Theoretical RCM analysis comparison with the RCM implementation at CUFK

This step is important to identify the First is, theoretical RCM analysis and the RCM implemented at CUFK are studied to understand the RCM process flow. The theoretical RCM source is from the RCM books and from the internet article and for the RCM implemented at CUFK source is from the CUFK Equipment Reliability Strategy handbook.

3.4 Equipment Criticality assessment using the ECA method.

The step of ECA is:

1) Collect and evaluate the data regarding the consequence of the failure in three class; Economic, Health and safety, and environment.
2) Identify the main equipment in each of the functional unit.
3) Identify and grouping all the failure in each main equipment category
4) Review each criticality of the main equipment by assessing the impact of the failures on Health Safety and Environment and also the economic (production loss and maintenance cost) consequence on the Risk Matrix.
5) Calculate the risk level on each failure component
6) Determine the Equipment criticality based on the risk level. All the dominant failure modes will be considered but the biggest consequence will determine the overall risk level for pump equipment.
7) Select the high criticality equipment (Below 2) for further analysis.

3.4.1 Risk Evaluation

The risk evaluation is started with set of the consequence ranking of each EC assessment scope. The EC assessment scope with ranking can be shown in table 3.1, 3.2, 3.3 and 3.4.

Table 3.1: The Evaluation of the Mean Time Between Failure ranking [4]

Mean Time Between Failure		
Probability Class	**Rating**	**Likelihood of Failure**
Almost Certain	**4**	Estimated time between failure (occurrence) is less than 6 months
Likely	**3**	Estimated time between failure (occurrence) is between 0.5 to 4 years
Possible	**2**	Estimated time between failure (occurrence) is between 4 to 20 years
Unlikely/ remote	**1**	Estimated time between failure (occurrence) is more than 20 years

Table 3.2: The Evaluation of the Economic Consequence Ranking [4]

ECONOMIC		
Consequences Class	**Rating**	**Economics impact of Failure (production loss, maintenance, materials)**
Catastrophic	**5**	Stop in production exceeding “100” hours Significant reduced rate of production exceeding “100” hours **Extensive / Massive damage** - exceeding “RM 200k” of total economic impact
Major	**4**	Stop in production between “40” to “100” hours Significant reduced rate of production between “40” to “100” hours **Major damage** – “RM 150k” to “RM 200k” of total economic impact
Moderate	**3**	Stop in production between “8” to “40” hours Reduced rate of production between “8” to “40” hours **Localised / Moderate** damage – exceeding “RM 100k” – “RM 150k” of total economic impact
Minor	**2**	Stop in production lasting less than “8” hours Reduced rate of production lasting less than “8” hours **Minor damage** – less than “RM 50k“ to “RM 100k” of total economic impact
Insignificant	**1**	No effect on production within a defined period of time **Slight damage** – less than “RM 50k” of total economic impact

Table 3.3: The Evaluation of the Health and Safety Consequence ranking [4]

HEALTH AND SAFETY		
Consequences Class	**Rating**	**HSE Impact of Failure (Harm to People)**
Catastrophic	**5**	**Multiple fatalities -** From an accident or occupational illness (poisoning, cancer).
Major	**4**	**Single fatality -** From an accident or occupational illness (poisoning, cancer).
Moderate	**3**	**Major injury or health effects** (including Permanent Partial Disability) - Affecting work performance in the longer term, such as a prolonged absence from work. Irreversible health damage without loss of life, e.g. noise induced hearing loss, chronic back injuries.
Minor	**2**	**Minor injury or health effects** (Lost Time Injury) - Affecting work performance, such as restriction to activities (Restricted Work Case) or a need to take a few days to fully recover (Lost Workday Case). Limited health effects which are reversible, e.g. skin irritation, food poisoning.
Insignificant	**1**	**Slight injury or health effects** (including first aid case and medical treatment case) - Not affecting work performance or causing disability.

Table 3.4: The Evaluation of the Environment Consequence ranking [4]

ENVIRONMENT		
Consequences Class	**Rating**	**Environment Impact of Failure**
Catastrophic	**5**	**Massive effect** - Persistent severe environmental damage or severe nuisance extending over a large area. In terms of commercial or recreational use or nature conservancy, a major economic loss for the company. Constant, high exceedance of statutory or prescribed limits.
Major	**4**	**Major effect** - Severe environmental damage. The company is required to take extensive measures to restore the contaminated environment to its original state. Extended exceedance of statutory or prescribed limits.
Moderate	**3**	**Localised effect** - Limited loss of discharges of known toxicity. Repeated exceedance of statutory or prescribed limit. Affecting neighbourhood.
Minor	**2**	**Minor effect** - Contamination. Damage sufficiently large to attack the environment. Single exceedance of statutory or prescribed criterion. Single complaint. No permanent effect on the environment.
Insignificant	**1**	**Slight effect** - Local environmental damage. Within the fence and within systems. Negligible financial consequences.

Using the equation of risk level, the risk level is calculated with respect to each of the consequence ranking.

Table 3.5: Risk Level value based on probability and the consequence ranking

Probability Rating	**Risk Level**				
4	**4**	**8**	**12**	**16**	**20**
3	**3**	**6**	**9**	**12**	**15**
2	**2**	**4**	**6**	**8**	**10**
1	**1**	**2**	**3**	**4**	**5**
Economic/H&S/ Environment Consequence rating	**1**	**2**	**3**	**4**	**5**

From the risk level value in table, the criticality are decided based on the risk level value interval

Table 3.6: Criticality Based on Risk level interval

Criticality	**Risk Level Interval**
3	1 – 3
2	4 – 9
1	10 – 20

From criticality based on risk level interval and the risk level based on probability table, the Equipment Critically Matrix was developed. Appendix 4 shows the Equipment Critically Matrix.

3.5 Perform the FMEA

A FMEA analysis usually carried out progressively in two steps:

a) Identify the function and the standard performance of the equipment
b) Identifying failure modes and their effects (Failure Mode and Effects Analysis). In this analysis, the function, functional failures, failure mode and failure effect will identify.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 RCM comparison

The comparison can be made by focusing on the two scope; method objective, maintenance method and analysis process.

4.1.1 Method Objective

The both method object are shown in the table below:

Table 4.1: Comparison of the RCM and ERS Objective

No	RCM	ERS
1	Improved equipment operating performance and its reliability.	Improved equipment operating performance and its reliability.
2	Greater maintenance cost effectiveness	Minimize the maintenance cost and the production losses due to the equipment failure
3	Improve safety and environmental integrity	Minimize the health and safety, and environment consequence issue.

4.1.2 Maintenance Method

RCM and ERS use the same maintenance method that will revise and used to prevent or to repair the equipment failure in order to achieve the method objective. The figure 4.1 indicates the type of maintenance that involves in both methods.

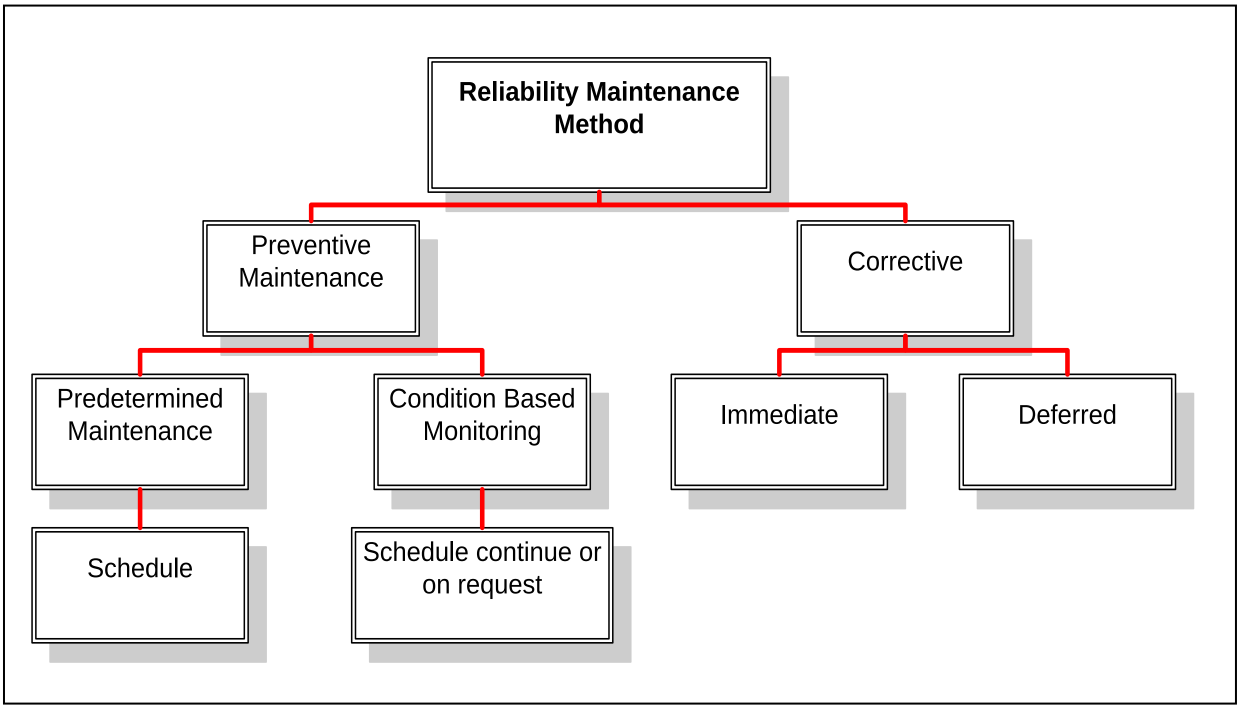

Figure 4.1: Type of maintenance that involves in RCM and ERS.

4.1.3 Analysis Process

The overall process flow of the analysis of RCM and ERS are shown at figure 4.2 and 4.3.

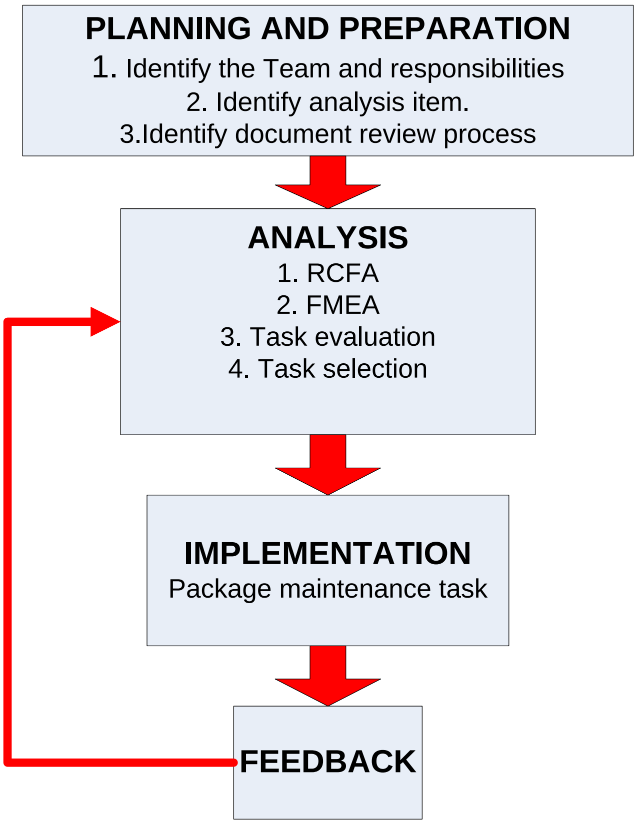

Figure 4.2: RCM process flow

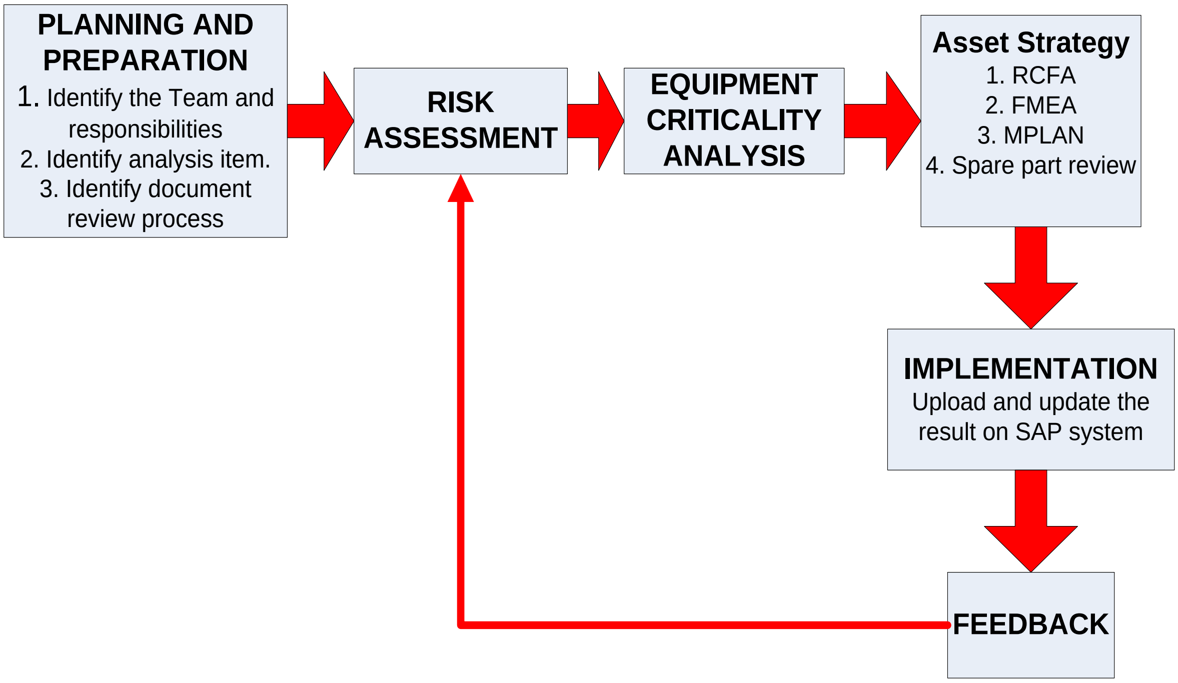

Figure 4.3: ERS process flow

4.1.4 Discussion

After understanding and analyzed the RCM and ERS concept and process, the similarities and differences of these two methods are identified. For the objective of these two methods, the comparison shows that the objectives are the same; to improve the reliability of the equipment and minimize the consequence of the failure. For the maintenance method also show the similarities of these two methods.

The analysis process of the RCM and the ERS has slightly differences. For ERS, after the planning and preparation step, there are Risk Assessment and Equipment Criticality Analysis.

4.2 Equipment Criticality Assessment

4.2.1 Maintenance cost for pump failure

The maintenance cost of each pump failure is collected from the SAP system. The maintenance cost can be categorize in three part; internal manpower, external services and maintenance materials. The maintenance cost for pump equipment is shown in table 4.2 below:

Table 4.2: Maintenance cost for pump failure [5].

NO	SYSTEM / SUBSYSTEM EQUIP DESC	VALUE CATEGORY (RM)			TOTAL (RM)
		INTERNAL MANPOWER	EXTERNAL SERVICE	MAINTENANCE MATERIALS	
1	P1-254A06A-Mechanical seal	500.00		1752.00	2252.00
2	P1-254A06A-Motor (DE) high vibration			57265.00	57265.00
3	P1-254A06A-Mechanical seal leak			21907.00	21907.00
4	P1-254A06A-Mechanical seal leak		23331.00		23331.00
5	P1-254A06A-Motor (DE) high vibration	1008.00			1008.32
6	P1-254A06A-Mechanical seal leak	5937.00			5937.00
7	P1-254A06A-Mechanical seal	1176.00			1176.00
8	P1-254A06A-Bearing (DE) high Temperature	7532.00			7532.00
9	P1-254A06A-Mechanical seal	1120.00			1120.00
10	P1-254A06A-Manual isolating valve			1285.00	1285.00
11	P1-254A06A-recycle valve pass		3217.00		3217.00
12	P1-254A06A-Manual isolating valve		53445.12		53445.12
13	P1-254A06A-Motor (DE) high vibration	2000.00		18000.00	20000.00
14	P1-254A06A-Disc valve leaking	448.00			448.00
15	P1-254A06A-shutdown(overhaul motor)		1383496.00		138496.00
16	P1-254A06A-seal & purge gas sys Switch			5000	5000
17	P1-254A06A-seal&purge g sys Var Area mtr			5000	5000
18	P1-254A06A-START ENABLE,Sw.	4000			4000

	contact				
19	P1-254A06A-STOP,Sw. contact	4000			4000
20	P1-254A06B-seal & purge gas sys Switch			5000	5000
21	P1-254A06B-seal&purge g sys Var Area mtr			5000	5000
22	P1-254A06B-START ENABLE,Sw. contact	4000			4000
23	P1-254A06B-STOP,Sw. contact	4000			4000
24	P1-254A06B-seal &purge gas sys Press Reg			5000	5000
25	P1-254A06B-seal & purge gas sys PG			5000	5000

4.2.2 Calculation of the Failure Rate and MTBF of Equipment Component

Using the equation 2.1 and 2.2, the failure rate and MTBF of the pump equipment component are calculated. This 2 parameter will be use in the evaluation of the equipment criticality. The failure rate and MTBF of each pump equipment component is as below:

Table 4.3: Failure Rate and MTBF value for the pump equipment [5]

No	Pump equipment	Failure Rate (failure/year)	MTBF
1	P1-254A06A MECHANICAL SEAL	3	4 months
2	P1-254A06A MOTOR	2	6 months
3	P1-254A06A BEARING (DE)	0.5	2 years
4	P1-254A06A RECYCLE VALVE PASS	0.5	2 years
5	P1-254A06A MANUAL ISOLATING VALVE	1	1 years
6	P1-254A06A DISC VALVE	0.5	2 years
7	P1-254A06A SEAL & PURGE GAS SYSTEM SWITCH	0.5	2 years
8	P1-254A06B SEAL & PURGE GAS SYSTEM SWITCH	0.5	2 years
9	P1-254A06A SEAL &PURGE G SYS VAR AREA MTR	0.5	2 years
10	P1-254A06B SEAL &PURGE G SYS VAR AREA MTR	0.5	2 years
11	P1-254A06A START ENABLE, SW. CONTACT	0.5	2 years
12	P1-254A06B START ENABLE, SW. CONTACT	0.5	2 years
13	P1-254A06A STOP, SW CONTACT	0.5	2 years
14	P1-254A06B STOP, SW CONTACT	0.5	2 years
15	P1-254A06B SEAL & PURGE GAS SYS PRESS REG	0.5	2 years
16	P1-254A06B SEAL & PURGE GAS SYS PG	0.5	2 years

4.2.3 Consequence of Each Failure

Failure consequence of the pump can be categorized in three class; Health and safety, Environment and the Economic. This consequence classification will be use to evaluate the equipment criticality of the LOX Process Pump equipment. Table 4.4 shows the consequence evaluation for the health and safety, and environment. Table 4.5 shows the consequence evaluation for economic.

Table 4.4: The evaluation of the health and safety, and environment consequence [5].

No	System / Subsystem / Equip Desc	Consequence class	
		Health and safety	Environment
1	P1-254A06A MECHANICAL SEAL	No injury / Near Miss / FAC	No / slight effect
2	P1-254A06A MOTOR	No injury / Near Miss / FAC	No / slight effect
3	P1-254A06A BEARING (DE)	No injury / Near Miss / FAC	No / slight effect
4	P1-254A06A RECYCLE VALVE PASS	No injury / Near Miss / FAC	No / slight effect
5	P1-254A06A MANUAL ISOLATING VALVE	No injury / Near Miss / FAC	No / slight effect
6	P1-254A06A DISC VALVE	No injury / Near Miss / FAC	No / slight effect
7	P1-254A06A SEAL & PURGE GAS SYSTEM SWITCH	No injury / Near Miss / FAC	No / slight effect
8	P1-254A06B SEAL & PURGE GAS SYSTEM SWITCH	No injury / Near Miss / FAC	No / slight effect
9	P1-254A06A SEAL &PURGE G SYS VAR AREA MTR	No injury / Near Miss / FAC	No / slight effect
10	P1-254A06B SEAL &PURGE G SYS VAR AREA MTR	No injury / Near Miss / FAC	No / slight effect
11	P1-254A06A START ENABLE, SW. CONTACT	No injury / Near Miss / FAC	No / slight effect
12	P1-254A06B START ENABLE, SW. CONTACT	No injury / Near Miss / FAC	No / slight effect
13	P1-254A06A STOP, SW CONTACT	No injury / Near Miss / FAC	No / slight effect
14	P1-254A06B STOP, SW CONTACT	No injury / Near Miss / FAC	No / slight effect
15	P1-254A06B SEAL & PURGE GAS SYS PRESS REG	No injury / Near Miss / FAC	No / slight effect
16	P1-254A06B SEAL & PURGE GAS SYS PG	No injury / Near Miss / FAC	No / slight effect

Table 4.5: The evaluation of economic consequence [5].

NO	EQUIPMENT PART	MAINTENANCE COST(RM)						TOTAL COST (RM)
1	P1-254A06A MECHANICAL SEAL	2252.00	21907.00	23331.00	5937.00	1176.00	1120.00	55723.00
2	P1-254A06A MOTOR (DE)	57265.00	1008.00	20000.00	138476.00			216769.00
3	P1-254A06A BEARING (DE)	7532.00						7532.00
4	P1-254A06A RECYCLE VALVE PASS	3217.00						3217.00
5	P1-254A06A MANUAL ISOLATING VALVE	1285.00	53445.12					54730.12
6	P1-254A06A DISC VALVE	448.00						448.00
7	P1-254A06A SEAL & PURGE GAS SYSTEM SWITCH	5000.00						5000.00
8	P1-254A06B SEAL & PURGE GAS SYSTEM SWITCH	5000.00						5000.00
9	P1-254A06A SEAL &PURGE G SYS VAR AREA MTR	5000.00						5000.00
10	P1-254A06B SEAL &PURGE G SYS VAR AREA MTR	5000.00						5000.00
11	P1-254A06A START ENABLE, SW. CONTACT	4000.00						4000.00
12	P1-254A06B START ENABLE, SW. CONTACT	4000.00						4000.00
13	P1-254A06A STOP, SW CONTACT	4000.00						4000.00
14	P1-254A06B STOP, SW CONTACT	4000.00						4000.00
15	P1-254A06B SEAL & PURGE GAS SYS PRESS REG	5000.00						5000.00
16	P1-254A06B SEAL & PURGE GAS SYS PG	5000.00						5000.00

4.2.4 Risk Level Value of each pump equipment failure

The evaluation of risk level of the pump equipment failure are based on the probability, economic, health and safety, environment consequence rating. The risk value can be calculated using the equation 2.3. The value of the risk level of each pump equipment failure can be shown at table 4.6.

Table 4.6: The value of the risk level of each equipment failure

No	System / Subsystem / Equip Desc	Prob. ranking	Risk Level for different consequence			Dominant Risk Level
			Economic	Health and safety	Environment	
1	P1-254A06A MECHANICAL SEAL	4	8	4	4	8
2	P1-254A06A MOTOR	4	20	4	4	20
3	P1-254A06A BEARING (DE)	3	3	3	3	3
4	P1-254A06A RECYCLE VALVE PASS	3	3	3	3	3
5	P1-254A06A MANUAL ISOLATING VALVE	3	3	3	3	3
6	P1-254A06A DISC VALVE	3	3	3	3	3
7	P1-254A06A SEAL & PURGE GAS SYSTEM SWITCH	3	3	3	3	3
8	P1-254A06B SEAL & PURGE GAS SYSTEM SWITCH	3	3	3	3	3
9	P1-254A06A SEAL &PURGE G SYS VAR AREA MTR	3	3	3	3	3
10	P1-254A06B SEAL &PURGE G SYS VAR AREA MTR	3	3	3	3	3
11	P1-254A06A START ENABLE, SW. CONTACT	3	3	3	3	3
12	P1-254A06B START ENABLE, SW. CONTACT	3	3	3	3	3

13	P1-254A06A STOP, SW CONTACT	3	3	3	3	3
14	P1-254A06B STOP, SW CONTACT	3	3	3	3	3
15	P1-254A06B SEAL & PURGE GAS SYS PRESS REG	3	3	3	3	3
16	P1-254A06B SEAL & PURGE GAS SYS PG	3	3	3	3	3

4.2.4 Equipment Criticality Assessment for 2008-2009

Using the information from the pump equipment MTBF calculation, table 4.3, 4.4, the risk level of the equipment failure and the risk matrix, each of the pump equipment criticality are evaluated. The Equipment Criticality Assessment for year 2007 until 2009 is shown in table 4.5.

4.2.5 Discussion

After Equipment Criticality Analysis has been done, the result shows that only the motor pump is fall in criticality of one. The two aspects that contribute to this criticality, first is the pump motor MTBF. The pump MTBF value is 6 months and the ranking is 4. This value is fall in highest ranking for the MTBF evaluation. Second contribution is in the economic consequence. The money losses from this pump motor failure are RM 216769.00. this value of money losses are indicate that the economic consequence ranking for this particular equipment are fall in the ranking 5. So, with the lowest criticality value, the pump motor high vibration failure will be the first priority of problem solving analysis effort that the CUF Kertih should consider.

Table 4.5: Equipment Criticality Assessment for the 2008-2009

No	System / Subsystem / Equip Desc	MnWkCtr	Economics			Consequence Class				PROBABILITY	Equip. Criticallity
			Product losses (RM)	Maint. (RM)	Total (RM)	ECON	H&S	ENV	Consequence		
1	P1-254A06A MECHANICAL SEAL	MROT	0	55723	55723	Minor Damage	No injury / Near Miss / FAC	No / slight effect	MINOR	< 6 month	2
2	P1-254A06A MOTOR	MROT	0	216769	216769	Extensive Damage	No injury / Near Miss / FAC	No / slight effect	CATASTROPHIC	0.5 - 4 years	1
3	P1-254A06A BEARING (DE)	MROT	0	7532	7532	Slight Effect	No injury / Near Miss / FAC	No / slight effect	INSIGNIFICANT	0.5 - 4 years	3
4	P1-254A06A RECYCLE VALVE PASS	MSTAT	0	3217	3217	Slight Effect	No injury / Near Miss / FAC	No / slight effect	INSIGNIFICANT	0.5 - 4 years	3
5	P1-254A06A MANUAL ISOLATING VALVE	MSTAT	0	54730	54730	Minor Damage	No injury / Near Miss / FAC	No / slight effect	MINOR	0.5 - 4 years	2
6	P1-254A06A DISC VALVE	MSTAT	0	448	448	Slight Effect	No injury / Near Miss / FAC	No / slight effect	INSIGNIFICANT	0.5 - 4 years	3
7	P1-254A06A SEAL & PURGE GAS SYSTEM SWITCH	INST	0	5000	5000	Slight Effect	No injury / Near Miss / FAC	No / slight effect	INSIGNIFICANT	0.5 - 4 years	3
8	P1-254A06B SEAL & PURGE GAS SYSTEM SWITCH	INST	0	5000	5000	Slight Effect	No injury / Near Miss / FAC	No / slight effect	INSIGNIFICANT	0.5 - 4 years	3

9	P1-254A06A SEAL &PURGE G SYS VAR AREA MTR	INST	0	5000	5000	Slight Effect	No injury / Near Miss / FAC	No / slight effect	INSIGNIFICANT	0.5 - 4 years	3
10	P1-254A06B SEAL &PURGE G SYS VAR AREA MTR	INST	0	5000	5000	Slight Effect	No injury / Near Miss / FAC	No / slight effect	INSIGNIFICANT	0.5 - 4 years	3
11	P1-254A06A START ENABLE, SW. CONTACT	INST	0	4000	4000	Slight Effect	No injury / Near Miss / FAC	No / slight effect	INSIGNIFICANT	0.5 - 4 years	3
12	P1-254A06B START ENABLE, SW. CONTACT	INST	0	4000	4000	Slight Effect	No injury / Near Miss / FAC	No / slight effect	INSIGNIFICANT	0.5 - 4 years	3
13	P1-254A06A STOP, SW CONTACT	INST	0	4000	4000	Slight Effect	No injury / Near Miss / FAC	No / slight effect	INSIGNIFICANT	0.5 - 4 years	3
14	P1-254A06B STOP, SW CONTACT	INST	0	4000	4000	Slight Effect	No injury / Near Miss / FAC	No / slight effect	INSIGNIFICANT	0.5 - 4 years	3
15	P1-254A06B SEAL & PURGE GAS SYS PRESS REG	INST	0	5000	5000	Slight Effect	No injury / Near Miss / FAC	No / slight effect	INSIGNIFICANT	0.5 - 4 years	3
16	P1-254A06B SEAL & PURGE GAS SYS PG	INST	0	5000	5000	Slight Effect	No injury / Near Miss / FAC	No / slight effect	INSIGNIFICANT	0.5 - 4 years	3

4.3 Failure Mode and Effect Analysis

4.3.1 Function and Standard Performance of LOX process pump motor

For starting the FMEA the function and standard performance of the LOX Process Pump are identify. This standard performance can be the indication of the pump failure. Table 4.6 show the function and standard performance of the LOX Process Pump.

Table 4.6: Function and standard performance of the LOX Process Pump.

NO	FUNCTION	STANDARD PERFORMANCE
1	To rotate the shaft and the impeller.	Rotate with speed of 7100rpm with allowable vibration velocity 3 mm/s and the peak to peak amplitude are not more than 106 μm.

4.3.2 FMEA for Motor High Vibration Problem

From the ECA result, the failure that is to be selected to be analyzed using the FMEA is the pump motor high vibration. The result of the FMEA is shown in table 4.7.

Table 4.7: FMEA for the Pump Motor High Vibration Problem

Functional Failure		Failure Mode Level 1		Failure Mode Level 2	Failure Effect
High Vibration (Value above 2 mil)	1	Bent shaft	1.1	Bearing damaged	High Vibration
			1.2	Shaft Fatigue	Bearing Damage, Motor damage.
	2	Rotor unbalance	2.1	Bearing damaged	Shaft scratches or crack
			2.2	Impeller crack	High Vibration.
			2.3	Bent shaft	Bearing or motor damage
			2.4	Impeller fouling	High vibration.
	3	Bearing damaged	3.1	Insufficient/over lubrication	1. Bearing seize, overheat and shorten life span. 2. Motor damage.
			3.2	Wrong grease spec	1. Bearing seize, overheat and shorten life span. 2. Motor damage.
			3.3	Bearing offspec/material	1. Bearing seize, overheat and shorten life span. 2. Motor damage.
			3.4	Bearing wornout	1. Bearing seize, overheat and shorten life span. 2. Motor damage.
			3.5	Residue grease left in	1. Bearing seize, overheat and shorten life span. 2. Motor damage.
	4	Looseness	4.1	Off spec nut	Motor & pump high vibration.
			4.2	Wrong torque	Motor & pump high vibration.
			4.3	Support damaged	Motor & pump high vibration.
			4.4	Bolt and nut corrosion	Motor & pump high vibration.

4.3.3 Discussion

The Using FMEA method, this method are identified each level of the failure mode of the functional failure of the pump motor. The first level of the failure mode contains 4 failure mode, bent shaft, rotor unbalanced, bearing damaged and looseness. And for the second failure mode level contains 15 failure modes. The second level of the failure mode indicates that the occurrence of the first failure mode can be link into several way of other failure mode.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

From this project, several conclusions could be drawn from the analysis results. There were also some recommendations for future work that could probably be carried out to enhance the Reliability Centered Maintenance implemented for this case study and to further improve the accuracy of results.

5.1 Conclusion

The objectives of this project have been achieved throughout literature reviews, data gathering and analysis. This project has concluded that:

a) From the RCM comparison, the objective of the theoretical RCM and the RCM implemented (ERS) are mostly same. There small differences in the process flow of these two methods. In ERS, there are two additional analyses, Risk Assessment and Equipment Criticality Analysis.

b) From the Equipment Criticality Assessment 2008-2009, the only motor pump component is in the criticality of one. There are two aspect that contribute this criticality; low value of MTBF and also high maintenance cost for that equipment. This indicates that, the priority of the effort that has to be done to pump motor high vibration problem.

c) From the FMEA, this method are identified each level of the failure mode of the functional failure of the pump motor. The first level of the failure mode contains 4 failure mode, bent shaft, rotor unbalanced, bearing damaged and looseness. And for the second failure mode level contains 15 failure modes. The second level of the failure mode indicates that the occurrence of the first failure mode can be link into several way of other failure mode. The analysis shows the relationship between the first level failure mode and the second level of failure mode.

5.2 Recommendation

There are some recommendations for future work that could probably be carried out to enhance the Reliability Centered Maintenance implemented for this case study and to further improve the accuracy of results. The recommendations are:

1) Find the actual failure rate from the pump supplier to calculate the reliability of the LOX process pump for that particular period (2008-2009).
2) To carry out the Root Cause Failure Analysis to identify the major root cause of the pump motor failure.
3) To perform the Mplan analysis to find appropriate maintenance plan in order to overcome the failure.

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