ANALYSIS OF PREVENTIVE MAINTENANCE FOR PROCESSING PLANT (GASSIFICATION PROCESS UNIT)

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Laporan ini dikemukakan sebagai
memenuhi sebahagian daripada syarat penganugerahan
Ijazah Sarjana Muda Kejuruteraan Mekanikal (Loji & Penyenggaraan)

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DECLARATION

"I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged."

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Author : ....

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SUPERVISOR DECLARATION

"I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Plant & Maintenance)"

Signature	: ....
Supervisor	:....................................
Date	: ....

DEDICATION

I dedicate this research to all lecturers, my family and friends

ABSTRACT

Preventive maintenance defined as a philosophy, a skill of management series in how to manage the plant operation to be more efficient in terms of cost and times. The purposes of this research is to find the value of preventive maintenance performance that consists of a several activities, according to standard operation of a particular components. The method that will be use is Weibull method, which by this method, the shape parameter and characteristic life can be evaluate to find the failure and reliability distribution in a period of specific time and economic analysis.

The scope of this research are only for terms in preventive maintenance; types of preventive activities, number of labors, inventory / spare parts, failures and any related terms for preventive maintenance. The terms of cost in labors and inventory for economic analysis will have two parameters as to be comparison, the first one is maintenance cost without optimization and the other one is maintenance cost with maintenance optimization. The result of these two parameters are depends on the characteristic life factors (η) and mean time between failure (MTBF).

The result of this research will shows all the evaluation for beta shape parameter, ß and eta characteristic life, η for each of the components in the particular plant. Then both of the parameters will determine the factors needed in terms to find the optimized time line for preventive maintenance and leads to economic analysis after the optimization. Lastly, the conclusion will discuss the overall results and the relationship between all of the comparison, the shape factors, characteristic life and optimized maintenance cost.

ABSTRAK

‘Preventive maintenance’ ataupun penyelenggaraan pencegahan, adalah boleh dikatakan sebagai falsafah yang berkaitan dengan teknik dan pentadbiran operasi loji, unruk menjadikannya lebih efektif daripada segi masa dan kos. Penyelenggaraan ini terdiri daripada beberapa aktiviti yang merujuk kepada satu piawaian yang telah ditetapkan. Loji pemprosesan bergantung kepada kebolehupayaan sesuatu mesin untuk berfungsi dengan baik, dimana jika pengeluaran diberhentikan, ianya akan mempengaruhi keseluruhan loji tersebut. Daripada tesis ini, *process flow diagram* akan memberi gambaran secara keseluruhan aktiviti ini, dimana unit yang digunakan ialah unit-1000, iaitu unit klasifikasi gas. Komponen mesin pada proses loji ini adalah ssangat penting dimana setiap komponen diklasifikasikan sebagai kategori kritikal ataupun sebaliknya. FMEA digunakan untuk memberi garis panduan dalam penyelenggaraan yang akan dilakukan. Data yang diperoleh akan dianalisis dengan menggunakan teknik-teknik tertentu dimana dengan menganalisa data tersebut, setiap komponen yang terlibat dapat dikaitkan dengan parameter tertentu contohnya seperti denggunakan OEE, MTBF dan CMMS, kecekapan sesuatu mesin itu boleh ditentukan dan dianalisa dengan lebih cekap.

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APPENDICES D – RELIABILITY PLOTTED GRAPH

ABBREVIATION

PM	Preventive maintenance
MTBF	Mean time between failure
FMEA	Failure mode effect analysis
MTTR	Mean time to repair
MTTF	Mean time to failure
MTBM	Mean time between maintenance
η	Characteristic life
β	Shape factor
R (t)	Reliability function
F (t)	Failure distribution function
H (t)	Hazard function
TPM	Total productivity maintenance
RCM	Reliability centered maintenance
TPM	Total productive maintenance
TQM	Total quality management
OEE	Overall equipment effectiveness
Qtty.	Quantity

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Since decades ago, the history of preventive maintenance already begun, whereabouts the revolution of industry in Europe and America. Preventive maintenance is an activity that need to secure the reliability of a components or a machine in a period of time. Maintenance can be divided into a few types of major activity ; predictive maintenance (PDM), root cause analysis (RCA), preventive maintenance (PM) and condition based maintenance (CBM). Today's maintenance challenges consists of many factors; the more of the technologies developed each days, the more complicated the machines it can be. Hence, the maintenance activities could be need more advance tools or devices, in order to ease the maintenance work that need to be done, and of course, value of money is the first priority that will be considered. Initially, the keys of maintenance works are the combination of a particular skills in terms of process management, material handling, technical skills and specific knowledge about the machines. However, the maintenance activity must be executed in a manner way; as to comply with the safety of the public and the machines, welfare and health to the society and environment. The goal of the maintenance in process plant is to develop a new technique or a concept so that we can adapt the maintenance activity without interfering any of the process, even the whole equipment changed over times, the subsequence of the maintenance activity are still the same. Therefore, this research is about to on how can we reduce the cost at all manners in terms of all the preventive maintenance activities and to manage the cost effectiveness. The evaluation in this research is based on gasification unit-1000, a raw syngas production processing plants. The process flow diagram of gasification unit-1000 can be refer to the appendices. The equipment consists of different unit which it continuously supply the product to another unit.

1.2 OBJECTIVES

There are a few main objectives of this research by the title; analysis of preventive maintenance planning for process plant. The objectives are to analysis the preventive maintenance plan and schedule of a process plant (gasification process unit), to study the effectiveness of a preventive maintenance planning and scheduling of a process plant in terms of it's failure rate, availability, reliability and maintenance cost. As an add on, the performance parameters can be relate to labor work and inventory (spare parts) cost optimization as well. Also, the other objectives are to estimate the total costs and economic losses incurred within the maintenance planning time horizon, by studying the graphs of the investment of the maintenance cost, tracking and predicting matters related in terms of the graph's fluctuation.

1.3 PROBLEM STATEMENTS

Problem statement in this project may vary but generally the problems arose subjectively due to cost planning and controlling. Preventive maintenance activities consumed a lot of financial related base. These included the skill labor cost, advance calibration equipment, special tools, production downtime, future expand and any other related consequences.

To maintain / reduce the loss of productivity, a time based scheduling and proper planning maintenance time consumption management were the preliminary challenges to build up an effective strategize maintenance management planning. By using a right preventive maintenance planning methods, the failure mode of each the equipment failure can been predicted before it happened and also to control the unnecessary inventory / spare parts / labor cost from flowing out.

1.4 SCOPE

- Total outflow cost are bounded only the PM cost (labor cost and inventory cost).
- To analysis the effect of preventive maintenance performance analysis been done by normal PM methods by using weibull analysis method method.
- The performance of preventive maintenance measured from the availability, reliability and failure distribution.
- Economic losses by the process plant estimated due to the equipment failures.

1.5 SUMMARY

As a conclusion, the impact of the preventive maintenance activities for process plant specifically plays an important role for the whole process and productivity. In either way, the maintenance programs and activities will influenced the fluctuation of the company's welfare. Operational and capital expenditure were the bases of the plant's total cost control. Hence, to achieved the cost planning and management scheduled, it needs to have a proper maintenance activities and Moreover, preventive maintenance planning were the essentials of the equipment in terms to reduce the failure rate being happened and to maintain the cash being flows out. Cost is the ultimate priority in any types of plants.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In preventive maintenance analysis, there are a lot of factors that may influence particular tasks, process or cost. In plant process industry, the high rate of production machine breakdown is one of the disturbance of the production floor. It will effect the profit of the company either in short or long terms. Most of the maintenance research are covering to improving the system. Preventive maintenance prior main objectives is to maintain the system in a good condition, reliable and fulfill the standard of requirement of a full production capacity. Preventive maintenance is one of the most effective in cost controlling and failures. The goal of PM is to reducing cost, minimizing machine downtime, increasing productivity, and improving quality (Usher. et al. [2]). Implementing a well planned of preventive maintenance analysis model can help to reduce the other maintenance effort and any other cost related types matters (Chouhan .R [1]). In this research, an analysis will be performed about the critical components identification, cost optimizing, preventive maintenance performance, failure rate optimization and prediction, equipment management planning and scheduling maintenance, and preventive maintenance improvisation.

2.2 IDENTIFICATION OF CRITICAL COMPONENTS

2.2.1 Introduction

Plant process industries are subjected to deterioration and wear with usage and age. The system will result more breakdown due to time consumption. Employing preventive maintenance method by not considering the critical components may produce more complication in cost and productivity [3]. In addition, if the process plant has higher production rate everyday, it may affect the safety of the plant and can bring harm to the employees. Hence, in order to determine the critical component, an analysis need to be made to achieves the maximum of main PM objectives [4].

2.2.2 Analysis of critical components

[4] has been made a research about implementing ABC analysis in how to prior the critical components level. All of the factors discussed above will be assign in terms of scores in such a way so that the higher of the value, the greater of the criticality. Range of the number of failures can be determine as shown in table 2.0, either the result can be in terms of critical (high, H), semi critical (medium, M) and non critical (low / very low).

Table 2.0 Range limit and critically score [4]

Lower range limit for number of failures	Upper range limit for number of failures	Type of range	Score (S)
0	3	Very Low (VL)	0
3	6	Low (L)	0.25
6	12	Medium (M)	0.50
12	24	High (H)	0.75

The data in table 2.1 shows a list of equipment with the total number of failures, total downtime in min and total downtime within unit time. The arrangement of level of criticality will be determine by this raw data on table 2.2 and table 2.3. Table 2.2 shows the categorization and classification of maintenance at a unit level of the equipment. The scores in the table consist of the production loss, mean cost of repair, and has been found that in the research, the highest cost of all the equipments is felt roll and water pump, while the lowest is rope pulley. Meanwhile in table 2.3, the cumulative of each components is showed. It is been found that five equipment are the most critical equipment as in figure 2.0. Thus, by this findings, we can build a new preventive maintenance schedule while we can save times for scheduling and decrease the maintenance downtime.

Table 2.1 Data of equipment list in 3 years [4]

Sl. No.	Name of equipment/component	Total No. of failures/Unit time	Total downtime within unit time in Min.	Total downtime within unit time in Hrs.
1.	Granite roll doctor blade.	28	968	16.10
2.	Driver part	23	1005	16.75
3.	Calender (top & bottom) doctor blade	22	710	11.83
4.	Hose	19	995	16.58
5.	Rope pulley	14	314	5.23
6.	White water Pump (811-19)	13	1480	24.67
7.	Felt roll	11	2000	33.33
8.	Belts of paper roll No.1	8	885	14.75
9.	Oscillator shower	8	1105	18.42
10.	White water pump (811-24)	4	225	3.75
11.	Vacuum flume to cooling tower pump	3	110	1.75
12.	Fan bearing	3	255	4.25
13.	Swimming roll	2	30	0.50
14.	Refined C.P. stock pump	2	90	1.50
15.	Breast roll	2	755	12.58
16.	Thermo compressor (2 &3)	1	40	0.67
17.	Vaccum pump	1	75	1.25
18.	Nip guard at 3rd roll calender	1	20	0.33
19.	Granite roll bearing	1	1860	31.00
20.	White water pump (811-15)	2	200	0.33

Table 2.2 Categorization of equipment list by total score [4]

Sl. No.	Name of equipment/component	Prob. of failure (p)	Score (S)	Production loss (P_l)	Mean time to repair (T_m)	Mean cost of repairs (R_c)	Total score ($S x P_l x T_m x R_c$)
1.	Granite roll doctor blade	H	0.75	1	0.60	0.1	0.0450
2.	Dryer part	H	0.75	1	0.73	0.2	0.1095
3.	Calender (top & bottom) doctor blade	H	0.75	1	0.74	0.1	0.0405
4.	Hose	H	0.75	1	0.87	0.5	0.3263
5.	Rope pulley	H	0.75	1	0.37	0.1	0.0278
6.	White water pump	H	0.75	1	2.114	0.75	1.1925
7.	Felt roll	M	0.50	1	3.03	1.0	1.5150
8.	Belts of paper roll No.1	M	0.50	1	1.844	0.75	0.6920
9.	Oscillator shower	M	0.50	1	2.3	0.75	0.8625
10.	White water pump (811-24)	L	0.25	1	0.938	1.0	0.2345
11.	Vac. Flume to cooling tower pump	L	0.25	1	0.611	0.5	0.0764
12.	Fan bearing	L	0.25	1	1.42	1.0	0.3550
13.	Swimming roll	VL	0	0	0	0	0
14.	Refined CP stock pump	VL	0	0	0	0	0
15.	Breast roll	VL	0	0	0	0	0
16.	Thermo compressor (2&3)	VL	0	0	0	0	0
17.	Vacuum pumps	VL	0	0	0	0	0
18.	Nip guard at 3rd roll calender	VL	0	0	0	0	0
19.	Granite roll bearing	VL	0	0	0	0	0
20	White water pump.811-15	VL	0	0	0	0	0

Table 2.3 Cumulative scores of ABC analysis [4]

Sl. No.	Name of equipment/component	h	H	Cumulative score %	Cumulative No. of equipment	Critically
1.	Felt Roll	1.515	1.5150	27.97	5.0	
2.	White water pump (811-19)	1.1925	2.7075	49.98	10	Critical
3.	Oscillator shower	0.8625	3.500	64.61	15.0	Do
4.	Belts of paper roll no.1	0.6920	4.6920	78.68	20.0	Do
5.	Fan Bearing	0.3550	4.6170	85.23	25.0	Do
6.	Hose	0.2662	4.8832	90.14	30.0	Semi-critical
7.	White water pump (811-24)	0.2345	5.1177	94.48	35.0	Do
8.	Dryer part	0.1095	5.2272	96.50	40.0	Non-critical
9.	Vacuum flume to cooling tower pump	0.0764	5.3036	97.90	45.0	Do
10.	Granite roll doctor blade	0.0450	5.3486	98.74	50.0	Do
11.	Cal. (top and bot) doctor blade	0.0405	5.3891	99.49	55.0	Do
12.	Rope pulley	0.0278	5.4169	100	60.0	Do
13.	Swimming roll	0.0	5.4169	100	65.0	Do
14.	Refined CP stock pump	0.0	5.4169	100	70.0	Do
15.	Breast roll	0.0	5.4169	100	75.0	Do
16.	Thermo compressor (2 & 3)	0.0	5.4169	100	80.0	Do
17.	Vacuum pump	0.0	5.4169	100	85.0	Do
18.	Nip guard at 3rd roll calender	0.0	5.4169	100	90.0	Do
19.	Granite roll bearing	0.0	5.4169	100	95.0	Do
20	White water pump (811-15)	0.0	5.4169	100	100.0	Do

h = Total score of criticality H = Cumulative score of criticality

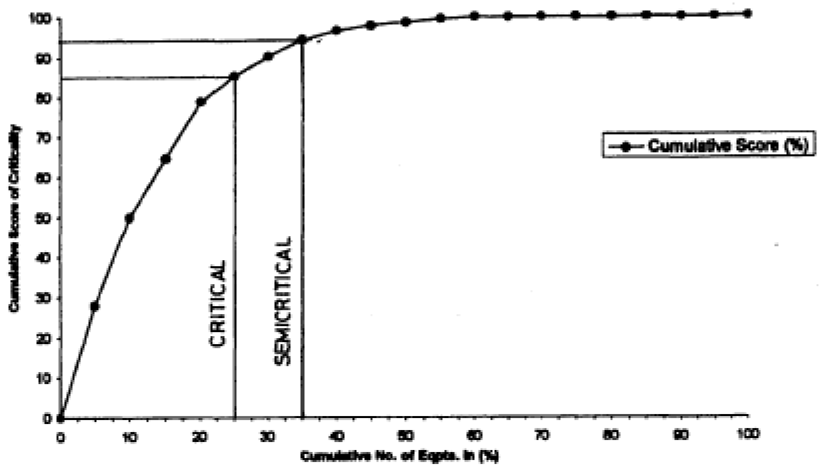


Figure 2.0 ABC analysis [4]

2.2.4 Summary and conclusion

As a summary, by analysis the equipment in terms of critical ranges, it is easy rearrange the process plant gasification unit equipment in in terms of critical severity to do PM maintenance as in what types of level of priority there are. In addition, we can implement the PM activities in such an effective way according to the criticality of the equipment or machines when a task of PM need to be done.

2.3 PREVENTIVE MAINTENANCE PERFORMANCE

The optimization of variables PM planning such as PM frequencies and spare parts and inventories, can be determine by building a model of PM planning by gathering data and simplified the assumptions, which allow a mathematical programming technique to solve (Wang [6]). More complex maintenance planning model that consider simultaneously many decision variables such as preventive maintenance interval, labor work force size, resources allocation, are usually solved by genetic algorithm (GA) iteration (Sum and Gong [7]).

2.3.1 Weibull analysis

Weibull analysis is one of the approaches to determine the maintenance performance in a plotted graph ; preventive or predictive ; by getting the information on the system, and implement the data trough by plotting in a weibull log plot. The parameters by using the weibull plot is the shape factor (beta, ß) and characteristics life (eta, ɳ). These two parameters will be use in function failure distribution and reliability.

Several weibull distribution function are being used in most plant and operation, especially in oil and gas process plant. Adamidis and Loukas [18] introduced the model lifetime data with two parameters exponential geometric distribution parallel with the failure rate decreased. In another life time modeling by Kus [32], he introduced the a poisson distribution modeling, also with decreasing failure rate based experiment.

Weibull distribution in practice is more likely to be one of the industry process implementation to find the distribution of modeling lifetime data. Beta shape factors is useful to present the bath-tub curve; the range of beta shape factor (0 < ß < 4).

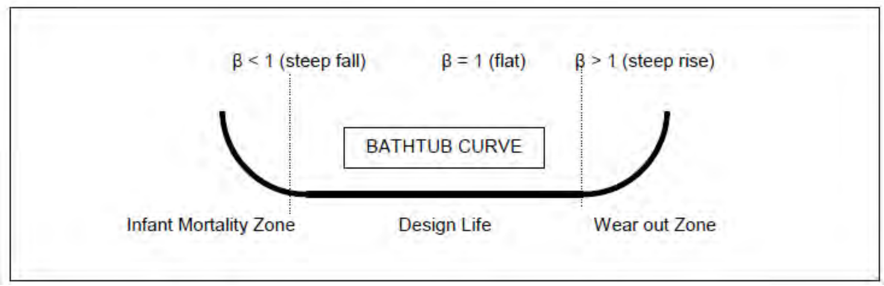
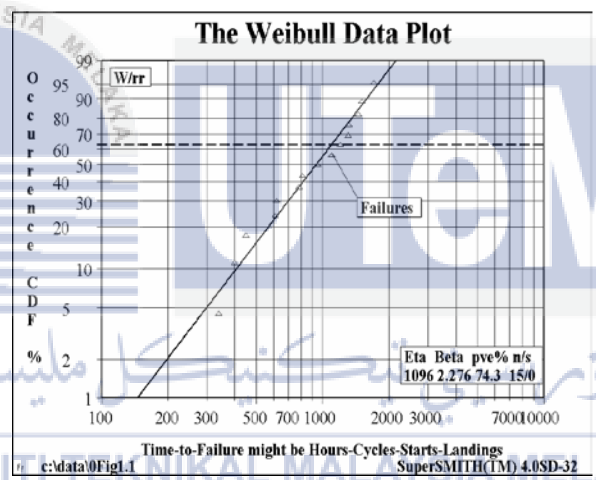


Figure 2.1 Bath tub curve

The beta shape factor determine the conditions of the machines whether in infant mortality, constant failure or in wear out failures as shown in figure 2.1.



Graph 2.0 Weibull data plot graph [17]

W.B Souza, A.L de Morais and G. M Cordeiro [22] has solving the condition-age related by using weibull (Graph 2.0 and Figure 2.2) at ß= 3.5, η = 600 hours and t_o = 900 hours. The shape parameters indicates the worn out failure is occur for the system and the characteristic life at 63% of failure indicates the optimize life for the component is only ≤600 hours, which the after 600 hours the failure will be more severe.

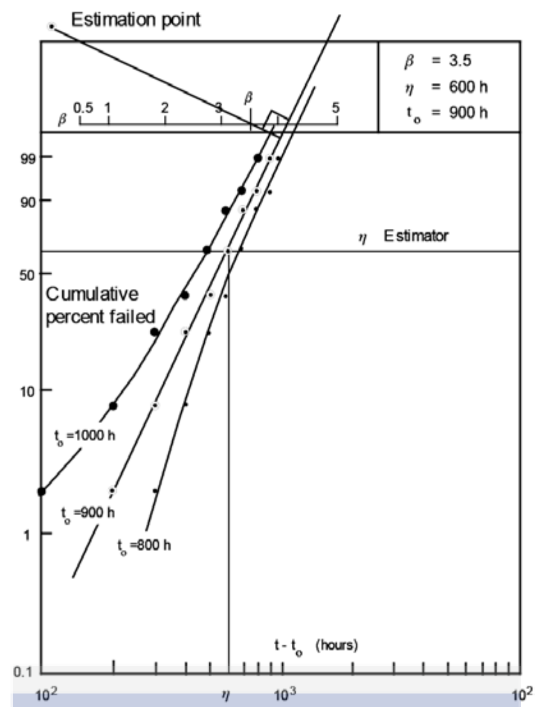


Figure 2.2 Weibull-estimation data plotted-manual [18]

2.3.2 Failure distribution

Failure function is one of maintenance performance indexes which to analyze the performance of preventive maintenance activities. This particular parameters from the distribution weibull density, that will show the relation between the cost, times parameter and maintenance density works. The output of failure function can determine the value of; estimation; how many failures that we can predict, and at the same time to estimate future failures and cost consumption (inventory / spare parts). Also, by the failure distribution, we can arrange the preventive maintenance activities based on the failure function so that at the same time, we can improvise the system in to be more efficient and productive.

Figure 2.3 showed below is the distribution of shape parameters of a different failures system and components by studying the bath tub curve shows. The age related parameters for A is the common for a component or a system that usually happened for a constant age related. The others of the graph (B to F) is the other pattern for age related sense that was been found. The y-axes is the failures frequency and x-axes represent the age of the components

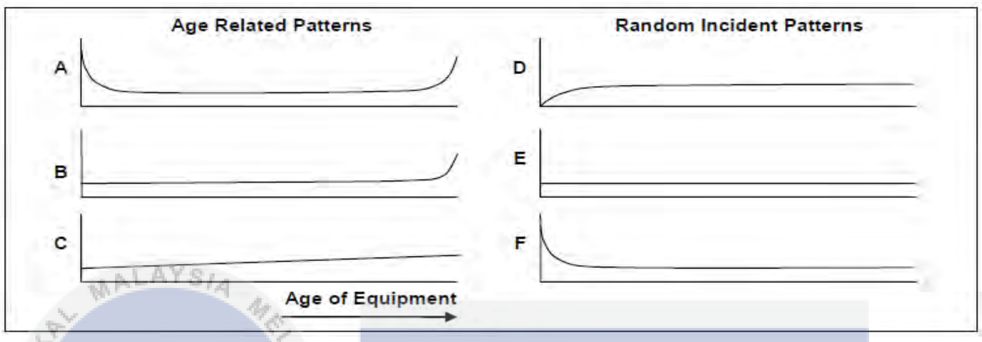


Figure 2.3 Six different failure patterns

Figure 2.4 shows the distribution of shape parameters of a different system and components in terms of the failures frequencies (cumulative) in parallel with operation time or life cycle. As the beta value increase (more than 0), the pattern of failure distribution is different on each stages.

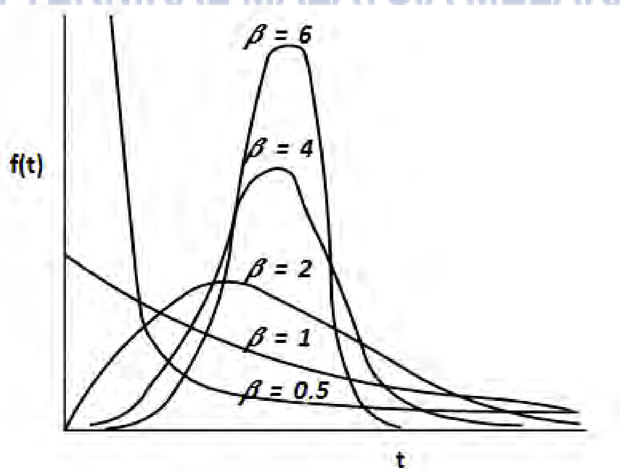


Figure 2.4 Different of beta shape parameters

$$f(t) = 2k^2\lambda e^{-2k\lambda t} + 2\lambda(1-k)^2 e^{-2(1-k)\lambda t} \text{, where } 0 < k \leq 0.5 \quad ....(2.0)$$

$$f(t) = \lambda e^{-\lambda t} \qquad Z(t) = \lambda \quad ......(2.1)$$

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(t-\mu)^2}{2\sigma^2}} \quad .....(2.2)$$

For the equation (1) ,

Running-in failure : $0 \leq$ Beta < 1

For the equation (2) ,

Random / constant failure : $1 \leq$ Beta

For the equation (2) ,

Wear out failure : Beta ≥ 1

As for failure distribution function, the patterns on the growth of cumulative failure as figure 2.5 indicates the relationship between shape parameters, characteristics life, operation time and failures. The optimization of a life time components such as shown, when t_0 until the next of time, which the characteristics life located. In weibull plot distribution graph shows the η is parallel with the $t-t_0$ when,

$$t-t_0 = \eta$$

Assuming if It's constant failure, ß = 1,

$$\text{Hence, } \left(\frac{t-t_0}{\eta}\right) = 1$$

$$\text{At } F(t) = 1 - e^{-1}$$

$$= 0.63 \text{ / } 63 \text{ \% of cumulative}$$

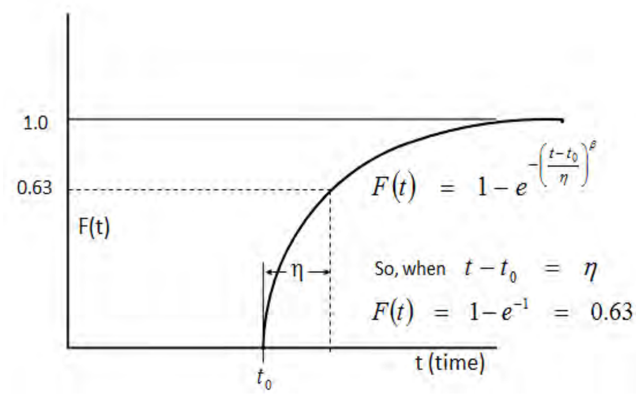


Figure 2.5 Failure distribution of cumulative percentage - time

Wagner B.S , Alice L.M, Gauza M.C [22] shows the differences between shape parameters in a cumulative failure distribution in graph 2.6 (a) and 2.6 (b). The failure on (a) shows the non-worn out cumulative function and the other one is the worn-out cumulative failure function.

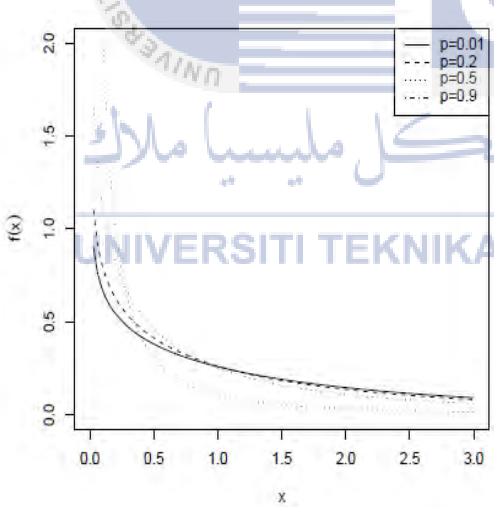


Figure 2.6 (a) Non-worn out failure [22]

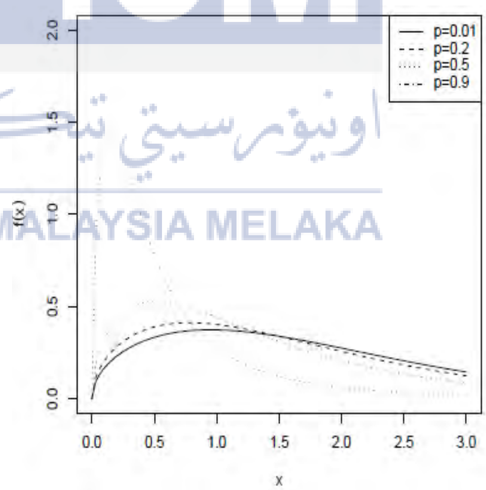


Figure 2.6 (b) Worn-out failure [22]

2.3.3 Reliability of PM

Reliability is an indicator for the capabilities of a system that can survived over a period of time. It emphasizes of the system or a components dependability in a cycle life for a stated conditions; to be the probability of success of a system out of failures. Reliability also one of the cost effectiveness in terms of inventory and spare parts. In reliability time horizon, it can be detect to estimate how much the system or components will survives, in percentages, to show the audiences what is the best practices management maintenance for the particular equipment.

Blanchard, Benjamin S. [24] stated that reliability is an 'asset' to manage the data qualitatively and quantitatively. Risk (failures) in a plant process, especially to the critical equipment is the number one priority to the key performance index especially to overall equipment effectiveness (OEE). Reliability also as an indicator for the failure mode effect analysis, risk based inspection, PARETO analysis and reliability centered maintenance (RCM).

In failure distribution, Ebeling, Charles E. [25] stated that reliability is the fraction ofn failure distribution function, which it can be stated as :

$$\mathbf{R(t) = 1 - F(t)} \ldots\ldots \ (2.4)$$

While Ebeling, Charles E. [25] interpreted the reliability of failure function in a cumulative time horizon (cycles) in figure 2.7 by showing the a hundred percent of reliability goes to zero percent of reliability cumulative. Product A and product B are put into tested which shows in the graph which the product B obviously more reliable 'state' over product A which the reliability density is more higher in order to the time cycle.

In a simply definition, the reliability is for determine the failure's severity, cost planning of maintenance program for the component, which also includes the cost of spare parts, damage, secondary damages, safety of the system and production loss.

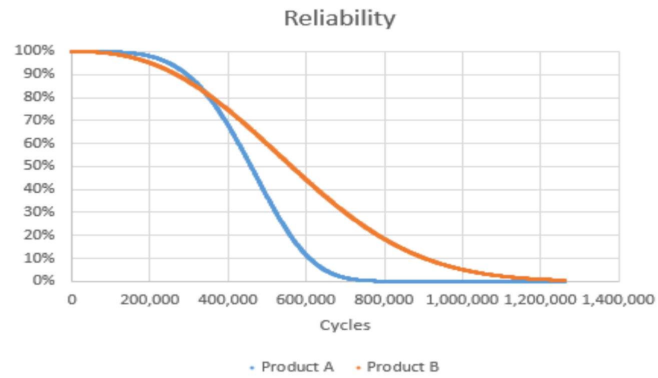


Figure 2.7 Reliability of two parameters function [25]

2.3.5 Availability of a system

Availability of a system is determine by the mean time between failures and mean time to repairs which the parameters are the conceptual to shows the average of failures or, to determine the frequencies of maintenance activities based on the failures. By using the availability process flow (reliability diagram), it will shows the how much the system can perform it's function under a period of time. Availability in a plant is very important indicator because it will determine the mean time between failures (MTBF) and mean time to repairs (MTTR).

The relationship between MTBF and MTTR has been explained by Gleser L.J [20] in figure 2.8, which the availability is higher if the MTTR is so small ; as if it can be neglected, it will nearest to 1 ; a hundred percent of availability achievement.

Availability, A = MTBF / (MTBF + MTTR)……(2.6)

Below is the availability block diagrams from component A to C in series. The overall availability of the system is in series motion, hence :

Availability = A * B * C …..(2.7)

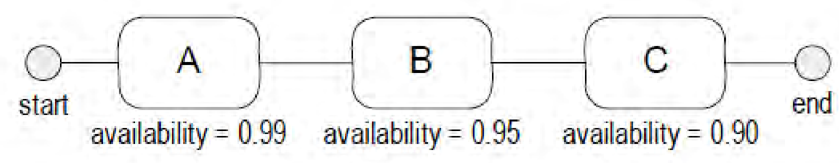


Figure 2.8 System component in series [26]

But if the system is in parallel, hence :

Availability parallel system, $A_{parallel}$ = A * B * C …..(2.8)

The relationship between MTTR and MTBF are concluded in figure 2.9 which the the MTTR and MTBF are depends on the business focused and technology adapted [26].

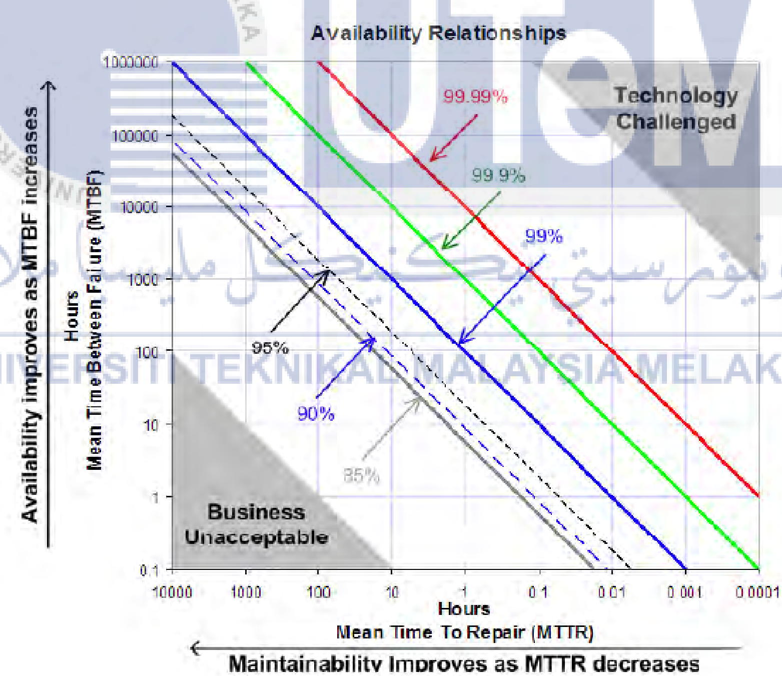


Figure 2.9 Relationship between availability, MTBF and MTTR [26]

2.3.6 Summary and conclusion

The result and analysis that been made by both of the analysis is different according to the data generated. Weibull analysis is the best approaches to see whether the failures from the preventive maintenance data will determine the ‘future’ maintenance activities of a system. Plant, operation and maintenance environment usually get high chances of failures due to internal and external factors. Temperatures, pressures, workload, manufacturers faulty many more. The cumulative data from failures can be reliable to be analyze in such approaches and functions, in terms of the data failures distribution, reliability and hazard function. While availability is the overall effectiveness of the process by each stage of component, in percentages, to sorted out the availability, as the maintenance performance indexes.

2.4 TOTAL MAINTENANCE COST AND ECONOMIC LOSSES

The maintenance budget generally as an indicator to control the flow out unnecessary cash from economic losses. The total spare cost is much more higher than the total labor cost. Some of the reasons because the spare part prices are depended with climate condition of world economic. The shares fluctuation of raw materials prices, petroleum price per barrel, will influence most of the process occurred. It cannot be avoid, which that is a fact; but we can predict and reducing whereas particular factors.

2.4.1 Life cycle cost (LCC) analysis

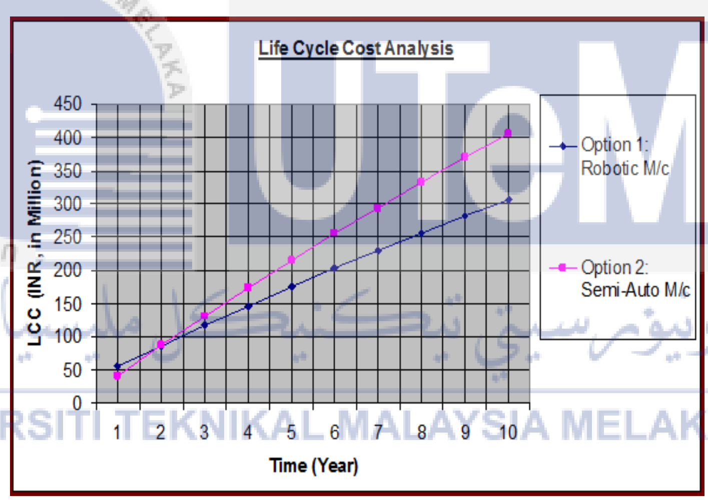
A research about life cycle costing by Nijhar Chakravorti [8], about a case study in a robot operated core making machine plant. Due to increase of demand for its casting, the company wants to install one new core making machine but at the same time, the operation and maintenance cost will be not interfere much. For new machine, there are two options : Similar sophisticated robotic machine or Semi-automated machine which the overall life cost are shown in table 2.4 and table 2.5.

Table 2.4 Computation of LCC option 1 [8]

Operation & Maintenance cost (OC)							
Time Period	Discounting factor	Inflation factor	Future OC at n^{th} year	PV of any year	Total PV incurred	Initial Cost (IC)	Total LCC
n^{th} year	$1/(1+8/100)^n$	$(1+5/100)^{n-1}$	Million INR	Million INR	Million INR	Million INR	Million INR
A	B	C	D	E=DXBXC	F=E+ last year's F	G	H=G+F
1	-	-	-	-	-	55.50	55.50
2	0.86	1.05	34.60	31.15	31.15	55.50	86.65
3	0.79	1.10	34.60	30.28	61.43	55.50	116.93
4	0.74	1.16	34.60	29.44	90.87	55.50	146.37
5	0.68	1.22	34.60	28.62	119.49	55.50	174.99
6	0.63	1.28	34.60	27.83	147.32	55.50	202.82
7	0.58	1.34	34.60	27.05	174.38	55.50	229.88
8	0.54	1.41	34.60	26.30	200.68	55.50	256.18
9	0.50	1.48	34.60	25.57	226.25	55.50	281.75
10	0.46	1.55	34.60	24.86	251.11	55.50	306.61

Table 2.5 Computation of LCC option 2 [8]

Operation & Maintenance cost (OC)							
Time Period	Discounting factor	Inflation factor	Future OC at n^{th} year	PV of any year	Total PV incurred	Initial Cost (IC)	Total LCC
n^{th} year	$1/(1+8/100)^n$	$(1+5/100)^{n-1}$	Million INR	Million INR	Million INR	Million INR	Million INR
A	B	C	D	E=DXBXC	F=E+ last year's F	G	H=G+F
1	-	-	-	-	-	42.00	42.00
2	0.86	1.05	50.00	45.01	45.01	42.00	87.01
3	0.79	1.10	50.00	43.76	88.77	42.00	130.77
4	0.74	1.16	50.00	42.54	131.31	42.00	173.31
5	0.68	1.22	50.00	41.36	172.68	42.00	214.68
6	0.63	1.28	50.00	40.21	212.89	42.00	254.89
7	0.58	1.34	50.00	39.10	251.99	42.00	293.99
8	0.54	1.41	50.00	38.01	290.00	42.00	332.00
9	0.50	1.48	50.00	36.95	326.95	42.00	368.95
10	0.46	1.55	50.00	35.93	362.88	42.00	404.88



Graph 2.1 Life cycle cost analysis option 1 and option 2 [8]

The analysis in graph 2.1 shows to us the initial cost of semi-automated machine is lower. However, the long term LCC is much lower for robotic machine. Considering LCCA, the robotic machine is preferred compared to the semi-automated machine, for this particular application. Also, by this method, we can conduct a research about multiple behavior/ parameters in a particular plant to compute the decision making in terms of cost cycle analysis.

2.4.2 Preventive maintenance cost

M.A.J Smith and Dekker R. [15] made an analysis research to find the optimization cost by relating the uptime, downtime and cost by applying the preventive maintenance 1 out of *n* system. In table 1 there are 3 different cases which in the first to the last row is the total number of machines represented by *n*, and *R* represented the times of PM and CM. For each of the cases, Smith and Dekker formed a function that depending on time T_{pm} and minimize the cost. The function is given by,

$$F(t) = 1 - e^{1/3\, t^{\wedge}1.75}$$

and the iteration of n is by using a GA computer software and generate the following table 2.7 and table 2.8, :

Table 2.6 Table of uptime, downtime and costs [15]

		up time			down time			costs			
	T_{pm}	sim	approx	expon	sim	approx	expon	sim	approx	expon	decomp
$n = 2$	1.25	4.228	4.243	2.172	0.375	0.347	0.500	63.317	61.140	102.013	71.25
$R = 1$	1.55	4.885	4.888	2.711	0.375	0.346	0.500	61.538	59.557	92.220	66.236
	1.85	4.885	4.888	2.711	0.375	0.346	0.500	61.538	59.557	92.220	66.236
	2.15	5.792	5.827	3.545	0.375	0.347	0.500	61.235	59.508	83.818	62.988
	2.45	6.078	6.132	3.830	0.375	0.348	0.500	61.696	60.019	82.194	62.722
	2.75	6.281	6.338	4.039	0.375	0.349	0.500	62.208	60.578	81.346	62.772
	3.05	6.419	6.466	4.186	0.375	0.348	0.500	62.695	61.084	80.933	62.952
	3.35	6.511	6.542	4.286	0.375	0.348	0.500	63.092	61.491	80.756	63.159
	3.65	6.570	6.588	4.351	0.375	0.347	0.500	63.398	61.790	80.698	63.348
	3.95	6.606	6.624	4.392	0.375	0.375	0.500	63.625	61.991	80.696	63.500
$n = 3$	1.25	5.965	6.184	3.100	0.254	0.302	0.583	48.493	50.472	91.456	49.917
$R = 1.75$	1.55	10.971	10.816	4.112	0.354	0.385	0.583	46.937	47.980	80.745	47.781
	1.85	13.711	13.696	5.040	0.396	0.421	0.583	47.658	48.259	75.061	47.410
	2.15	14.705	14.684	5.827	0.396	0.420	0.583	48.728	49.260	72.050	47.736
	2.45	15.433	15.422	6.453	0.396	0.421	0.583	49.760	50.241	70.491	48.370
	2.75	15.948	15.961	6.924	0.396	0.421	0.583	50.657	51.104	69.725	49.008
	3.05	16.302	16.330	7.260	0.396	0.422	0.583	51.388	51.815	69.385	49.576
	3.35	16.538	16.561	7.492	0.396	0.422	0.583	51.943	52.367	69.263	50.038
	3.65	16.690	16.696	7.644	0.396	0.422	0.583	52.341	52.773	69.244	50.391
	3.95	16.786	16.778	7.741	0.396	0.421	0.583	52.624	53.053	69.268	50.645
$n = 4$	1.25	11.892	11.250	4.004	0.279	0.364	0.625	41.803	44.879	82.906	40.408
$R = 2.5$	1.55	20.997	19.409	5.609	0.332	0.388	0.625	41.192	42.605	72.007	40.251
	1.85	29.081	27.255	7.175	0.382	0.434	0.625	42.228	43.130	66.502	41.087
	2.15	33.325	31.647	8.567	0.404	0.453	0.625	43.631	44.315	63.750	42.201
	2.45	35.227	33.498	9.712	0.406	0.456	0.625	44.895	45.524	62.429	43.295
	2.75	36.403	34.627	10.593	0.406	0.456	0.625	45.947	46.549	61.849	44.248
	3.05	37.212	35.410	11.235	0.406	0.456	0.625	46.790	47.361	61.644	45.021
	3.35	37.750	35.928	11.680	0.406	0.456	0.625	47.414	47.978	61.616	45.614
	3.65	38.098	36.252	11.976	0.406	0.456	0.625	47.865	48.426	61.660	46.050
	3.95	38.317	36.450	12.166	0.406	0.455	0.625	48.170	48.757	61.725	46.356

Table 2.7 Uptime, downtime and cost by n-system [15]

T_{pm}	$n = 2$			$n = 3$			$n = 4$		
	up time	down time	costs	up time	down time	costs	up tim	down time	costs
1.25	3.73	0.39	68.02	4.83	0.31	55.21	8.95	0.37	48.03
1.55	4.29	0.39	65.60	8.90	0.39	50.91	16.08	0.39	44.12
1.85	4.75	0.39	64.70	11.40	0.43	51.60	26.60	0.46	45.33
2.15	5.12	0.39	64.61	12.23	0.43	51.60	26.60	0.46	45.33
2.45	5.40	0.39	64.89	12.84	0.43	52.46	28.16	0.46	46.49
2.75	5.59	0.39	65.32	13.29	0.43	53.25	29.11	0.46	47.48
3.05	5.70	0.39	65.75	13.60	0.44	53.91	29.76	0.46	48.27
3.35	5.77	0.39	66.10	13.79	0.44	54.44	30.20	0.46	48.87
3.65	5.80	0.39	66.36	13.90	0.44	54.82	30.47	0.46	49.31
3.95	5.83	0.39	66.52	13.97	0.44	55.09	30.64	0.46	49.62

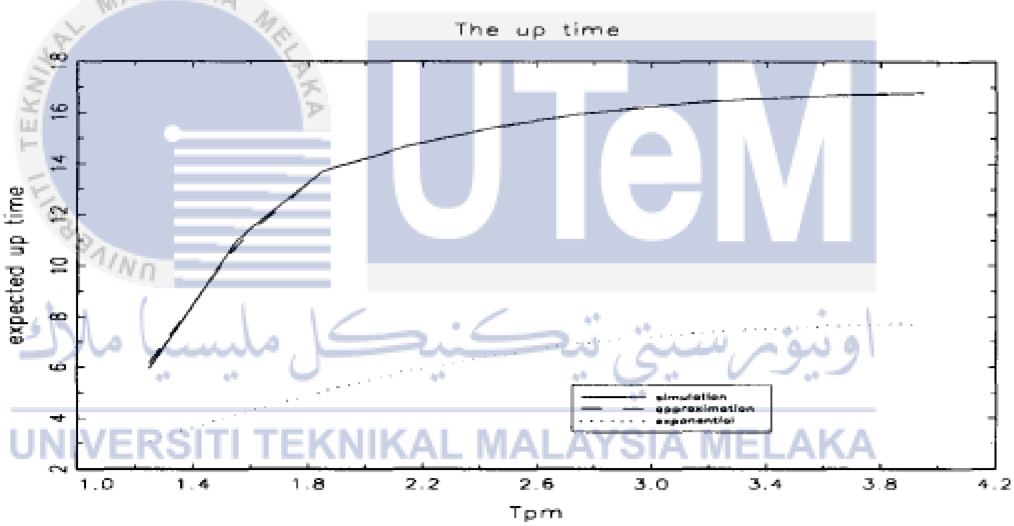


Figure 3.0 T_{pm} vs uptime [15]

Figure 3.0, figure 3.1 and figure 3.2 is connected by expected uptime, expected downtime and expected cost respectively versus total preventive maintenance (T_{pm}) the horizontal axis. The expectations are concluded in figure 3.1 which in the graph the, the example of n=3, the expected total cost at it's minimum value is when T_{pm} is about 1.5.

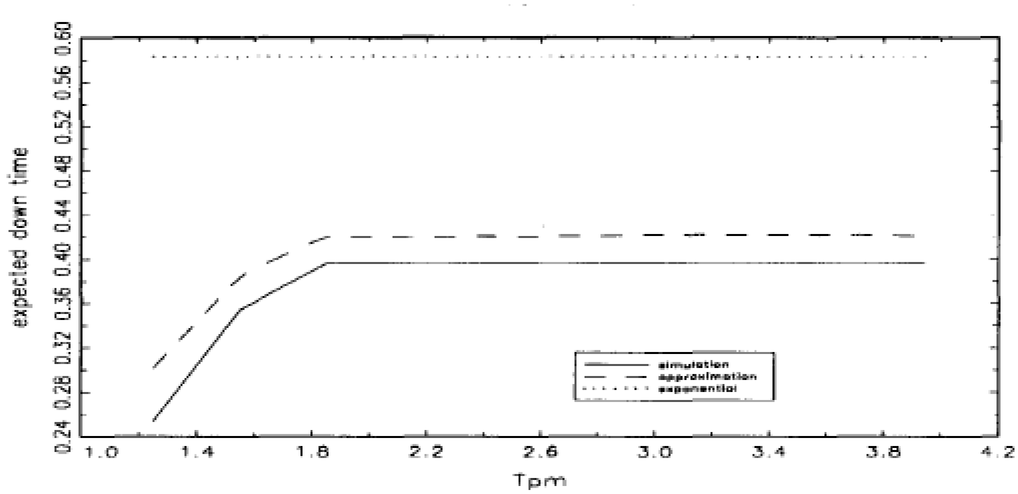


Figure 3.1 T_{pm} vs downtime [15]

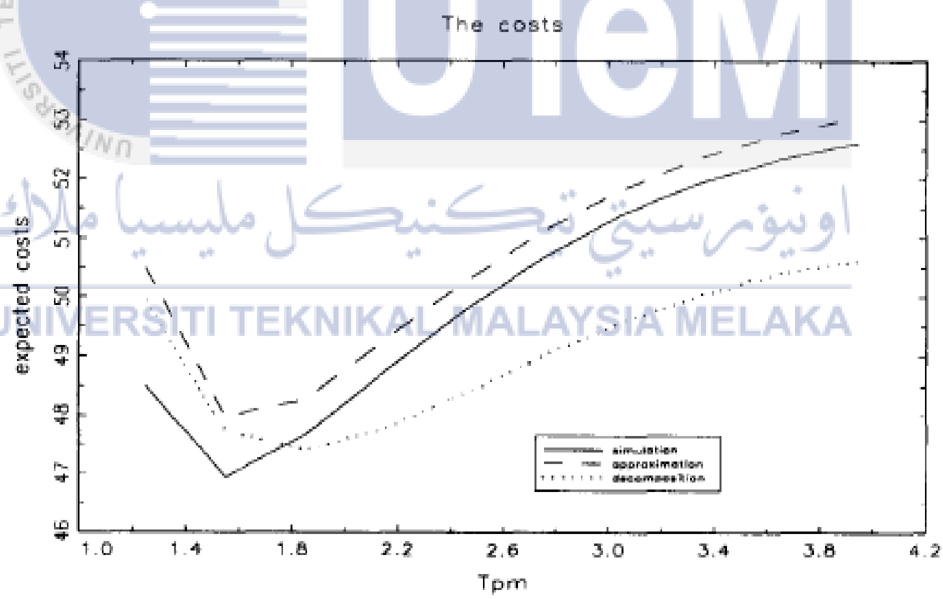


Figure 3.2 T_{pm} vs expected cost (n=3)   [15]

2.4.3 Economic losses

Economic losses is the estimation of all cost in terms of the productivity, efficiency and saving of the money value in any salvage values. The economic losses will be one of the key performance index in a particular plant to show the loss of the cost where about. The economic loss objective value are the inventory / spare parts, labors, unavailability, overtime, utilities and so on.

2.4.4 Summary and conclusion

By comparing the previous research analysis by the two, the method of approaches that they used is more to depends on the plant process activity. In option 1, the cost analysis is more focusing to long terms operational plants, which include all of cost factors while comparing available options about a cost problems. In option 2, they are more focusing of *n*, which it represents the standby equipment; only for uptime and downtime cost based.

2.5 PREVENTIVE MAINTENANCE DATA EVALUATION

Performance and efficiency evaluation are the keys to a successful of a particular plant. A maintenance itself basically can't be measured easily due to complicated parameters that need to include all such as labor works, time consumption, material handling, jobs availability and more variable condition that related. To make it easy, an effective maintenance, or the higher of the performances bring higher chances for a process plant to gain more profitability.

2.5.1 Maintenance evaluation - Total productive maintenance (TPM)

Khairul Hafiz and Muhammad Zameri [16], in their research analysis of implementing the total productive maintenance (TPM) method in fertilizer process plant, there are 12 list of parameters in determine and to achieves their objectives of TPM in their research. They focused on the bucket conveyor (EL102) component and the parameters are as in table 2.9 :

Table 2.8 EL102 –Bucket conveyor failure classification [16]

Parts	Types of Failure	MTBF(estimate)	Cost of Parts	Quantity
Conveyor Belt	Age-related	3-4 years	RM 548,892	1 unit
Gearbox	Age-related	3-4 years	RM 9000	1 set
Coupling	Age-related	3-4 years	RM 6850	1 set
Head Pulley	Age-related	5 years	RM 10,500	1 unit
Tail Pulley	Age-related	5 years	RM 10,500	1 unit
Disc Roller	Random	3 years	RM 5500	2 pcs
Bend Roller	Random	1 year	RM 1480	6 pcs
Guide Roller	Random	1-3 months	RM 255	12 pcs
Carry Roller	Random	1-3 months	RM 1180	44 pcs
Return Roller	Random	1-3 months	RM 1075	76 pcs
Impact Roller	Random	1-3 months	RM 1180	4 pcs

Table 2.9 EL102 spare parts availability [16]

Parts	Status	Remarks
Conveyor Belt	Have 11m portion c/w side wall	Just store in case of conveyor tear off.
Gearbox	No spare parts	Need to order 1set
Coupling	Yes	Have complete 1set. Need to do boring.
Head Pulley	No	Make-to-Order if they are plan to replace
Tail Pulley	No	
Disc Roller	No	
Bend Roller	Spare parts ready	Need to spare at least 6 pcs
Guide Roller	Spare parts ready	Need to spare at least 6 pcs
Carry Roller	Spare parts ready	Need to spare at least 20 pcs
Return Roller	Spare parts ready	Need to spare at least 30 pcs
Impact Roller	Spare parts ready	Need to spare at least 4 pcs

* Data taken until 31 March 2011

Table 2.9 shows the parts of the roller machine as reference by stating the status of the equipment and remarks of the status. This is a part of inventory / spare parts management to show the availability of each spares from time to time. In figure 3.3, the calculation of life cycle cost of the roller machines are based on table 2.9; the focused life time is 3 years, discount rate is 5 % and the equipment value final year is assume as zero.

i. Equipment + installation cost = RM 548 892 (average 3times replacement)
ii. Estimate maintenance cost per year = RM 241 460 (gearbox, roller, pulley, etc.)
iii. Estimate energy cost per year = RM 5 058 (High Voltage Industrial Tariff - E3s)
   - 15kW/day X 24hrs X 30days X RM28.10 X 12mth = RM 5 058
iv. Net discount rate = 5% (estimated)
v. Equipment lifetime = 3years
vi. Equipment value final year = RM 0
   - The value is RM 0 because the rubber is synthetic rubber. So, scrap will classify EL102 conveyor belt as a junk.

Figure 3.3 Data required to analyze the life cycle cost [16]

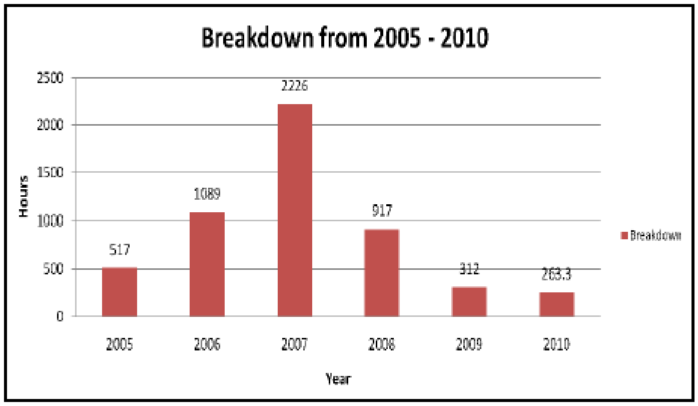


Figure 3.4 Mechanical downtime form 2005 – 2010 plant [16]

The objectives of the analysis at first is to reduce the downtime to 50% for the bucket conveyor from 62.5 hours in 2010 to 31.25 hours in 2011 in terms of three months. Figure 3.4 shows us the summary of downtime data, which the production loss shows that the value exceeding 2.2 million from 2005 to 2011. If the downtime target is achieved, the value will be decrease slightly which saves from cash flowing out. One of the reliability proposal made by them is to providing redundancy to the bucket conveyor.

MONTH	DATE	DOWNTIME	FAILURE DESCRIPTION
January	10/1/2011	12.5 hrs	Repair torn of bucket elevator
February	NO BREAKDOWN		
March	NO BREAKDOWN		
EL102 Total Breakdown	12.5 hrs		

Figure 3.5 Summary of downtime for EL102 in 2011 [16]

Meanwhile, figure 3.5 and table 3.0 shows the region of total time breakdown and total losses by the total breakdown time respectively. The total time (in hours) of breakdown is 2.5 hours and the production loss from year 2005 – 2011 is RM 2 172 090 (6 years).

Table 3.0 Production cost of losses from 2005 until 2011 [16]

Year	Unit Cost	Production Rate	Downtime for EL102
2005	RM 240 / ton	20 ton/hr	196 hrs
2006		21 ton/hr	-
2007		19 ton/hr	7 hrs
2008		19 ton/hr	97 hrs
2009		27 ton/hr	10 hrs
2010	RM 355 / ton	25 ton/hr	62.5 hrs
3/2011		25 ton/hr	15.5 hrs
TOTAL RM Losses			RM 2 172 090

2.5.2 Maintenance evaluation – 7QC tools

Mirko, Jelena, Zdravko and Aleksander [17], in their research about approaching the process data evaluation by using 7QC tools. The evaluation of data by using 7QC tools are in terms of flow chart, Pareto diagram, check sheet, control chart, histogram, scatter plot and cause effect analysis. Any of the maintenance parameters may also use the 7QC tools to evaluate the maintenance performances. Generally, in their research, the approaches is more to how to plan to evaluate the data by using the tools stated previously; graphical data evaluation. As in figure 3.6 and 3.7, they developed a method to improve the data identification and acquisition by splitting the tools to be more effective.

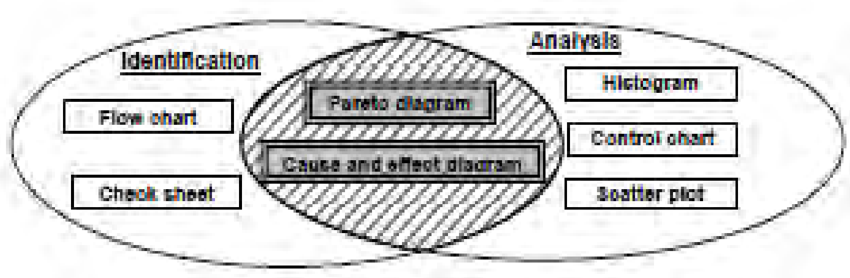


Figure 3.6 Use of 7QC tools in process of data identification [17]

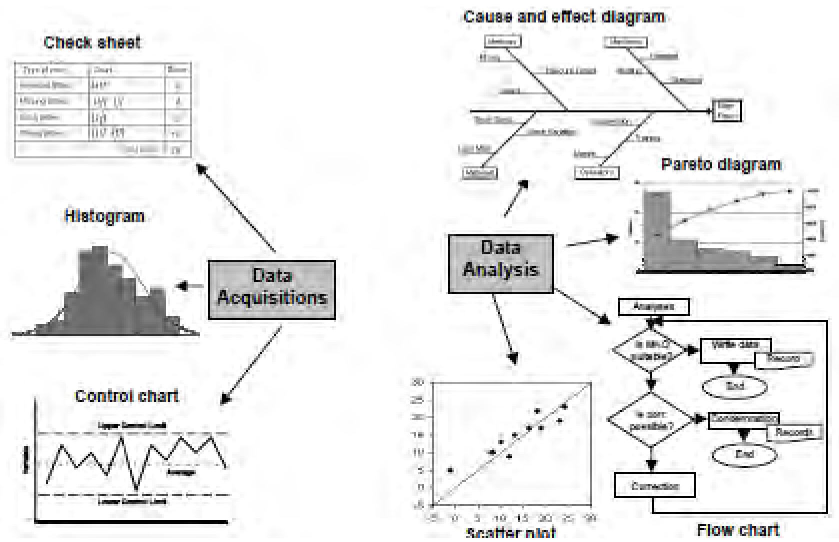


Figure 3.7 Approaches by using seven basic (7QC) tools [17]

Figure 3.8 represents PDCA cycles of a method that in terms of how to manage a data evaluation and their approaches**.** The purposes of using the PDCA cycles is to improve the process of management data while in figure 3.9 is the result of the plan development in their analysis research, to ease to identify each of the problems by using the correlation methods.

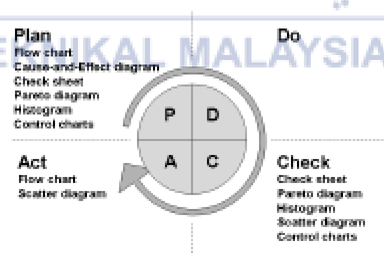


Figure 3.8 PDCA cycles [17]

Seven basic quality tools (7QC tools)	Steps of PDCA-cycle				
	Plan	Do	Plan, Check	Plan, Act	Check
	Problem identification	Implement solutions	Process analysis	Solutions development	Result evaluation
Flow chart	✓			✓	
Cause-and-effect diagram	✓		✓		
Check sheet	✓		✓		✓
Pareto diagram	✓		✓		✓
Histogram	✓				✓
Scatter plot			✓	✓	✓
Control charts	✓		✓		✓

Figure 3.9 Seven basic quality tools in correlation with PDCA cycles [17]

2.5.3 Conclusion and summary

Others of implementation of TPM is by overall equipment effectiveness (OEE) and maintenance performance indicators (MPI). Maintenance evaluation techniques will helps to manage all the data and equipment in a particular plant, to maintain its reliability and availability, in addition, to keep the productivity at its maximum yet decreases wages consumption. In option 2, the implementation of 7QC tools is more to data distribution and how we can relate the the data or information from other process to any other process. The evaluation of ‘hidden’ data can be analyze while making decision process. In this research, i will use both of the data as my main priority to evaluate the PM data.

2.6 SUMMARY OF LITERATUE REVIEW

As a conclusion, there are 3 major aspects that need to be considered heavily in terms of plant process operation. The three major aspects in preventive maintenance engineering were cost, quality and performance. These parameters is tightly related to each other. Beginning from the process plant operation, which will give a basic picture of process plant; what is the process occurred, machines that been used, types of breakdown and so on. There are so many types of processing plant in this world, so many approaches with so many kind of technique to build a stable organization to fulfill their objectives. As to conclude, data and information in each of any kind of work is important. When a machine is breakdown, the data that we can get while inspection, any types of measure and variables, which it will be use to be analyze in terms of cost and maintenance management as to indicate the performance and effectiveness.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The preventive maintenance is a scheduled planned maintenance actions aimed at the prevention of breakdowns and failures. Preventive maintenance included inspection, partial or complete overhaul, oil changes, lubrication and so on. The PM policy is an important policy of maintenance planning. Below is the gantt chart for PSM 1 and gantt chart for PSM II is in appendix A.

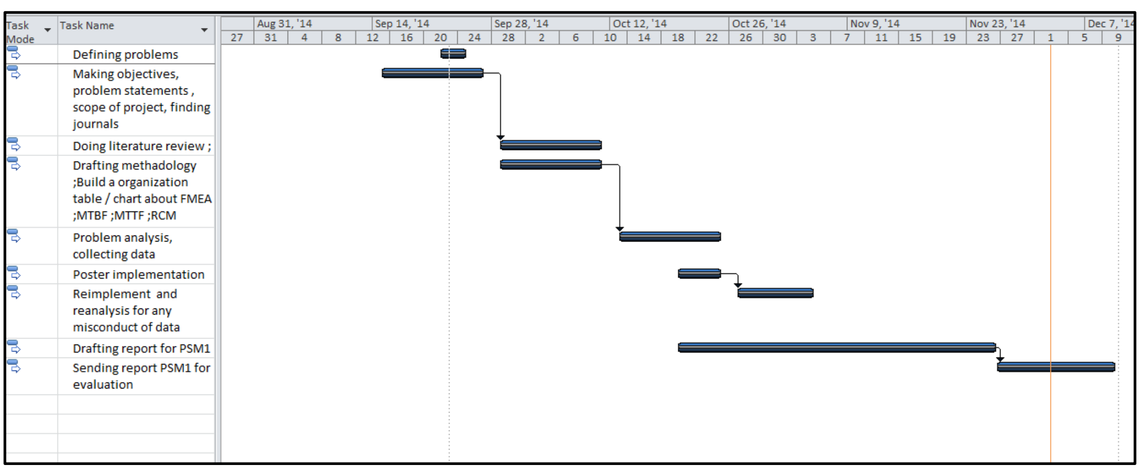


Figure 4.0 Gantt chart of PSM I

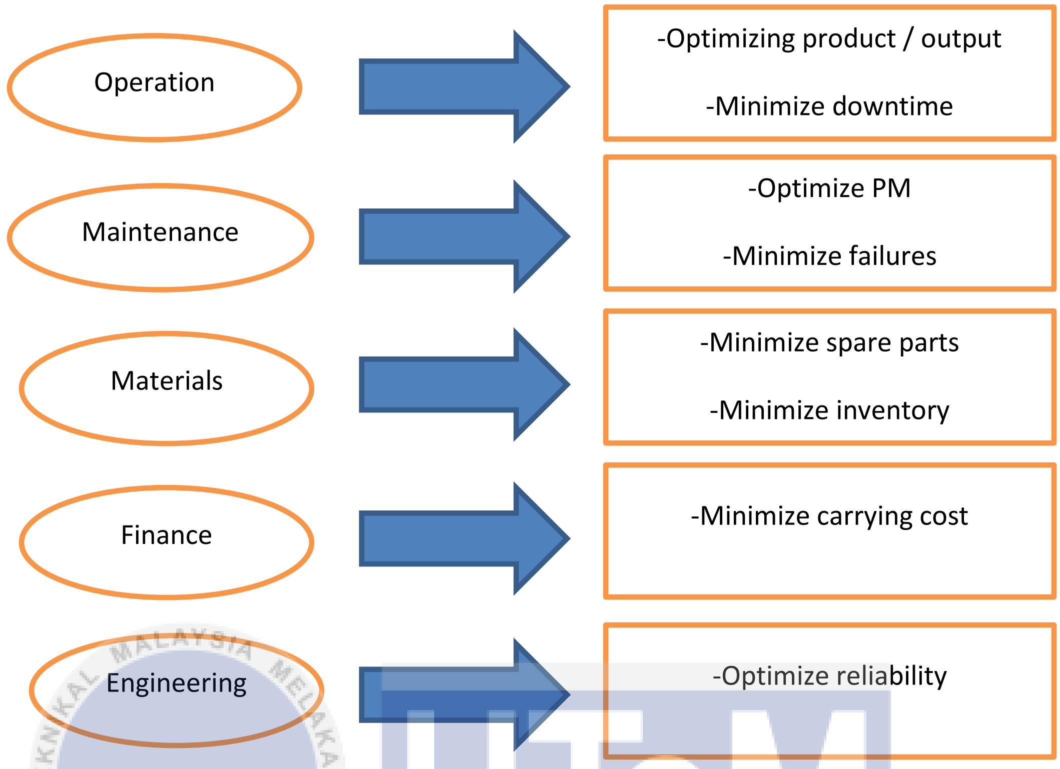


Figure 4.1 Preventive maintenance main objectives

In figure 4.1, the PM activities performance can be classified into several terms, whether the performance are in terms of financial, operation, materials, engineering or maintenance; which each of the terms has their own objectives to analysis, for example, in terms of financing, the PM performance would be seen as to minimize the carrying cost and optimizing reliability would be the main focus for engineering terms as shown in figure 4.1. In figure 4.2, the process flows of methodology is significantly started by collecting the data for the system, such as the failures occur, mean time to repair, mean time between failure and so on. Then, followed by determine the equipment criticality, evaluating FMEA, finding the reliability parameters by using Weibull method, analyze the maintenance cost (economic optimization) and leads to conclusion at the end.

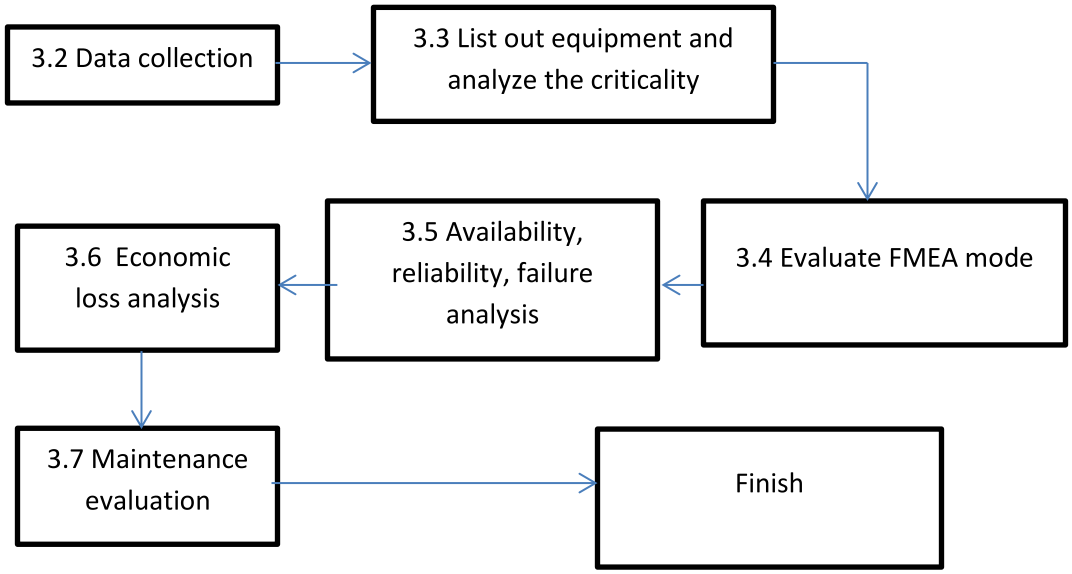


Figure 4.2 Steps of methodology

3.2 EQUIPMENT CRITICALITY

The equipment list are shown in table 3.1 includes the quantity in each of the components. Number of failures, MTBF and ,TTR also included in the table. The list of the equipment in the table are true by the courtesy of Shell MDS Sdn Bhd for gasification unit (unit 1000).

Table 3.1 Maintenance list equipment data

No.	List of equipment	Quantity	Failures (hours)	MTBF	MTTR
01.	Pump	**20**			
02.	Compressor	**10**			
03.	Pressure vessel	**4**			
04.	Heat exchanger	**18**			
05.	Reaction chamber	**10**			
06.	Scrubber	**15**			
07.	Reducer	**16**			
08.	Strainer	**25**			
09.	Valves	**44**			

i) Probability of failure equipment is determine by the following equation :

S = Failures of an equipment / Total failures …. (2.9)

Critically score will determined based on the score provided to see the value of range as shown in table 3.2 by dividing the score from 0-3, 3-6, 6-12, and 12-24. The Lower range and upper range are in terms of the failures occurrence for each of the equipment.

Table 3.2 Range limits and critically range

Lower range	Upper range	Types of range
0	3	Very low
3	6	Low
6	12	Medium
12	24	High

ii) Production loss in fraction, P_{loss}

Production loss can be defined as the process / production affected much from the failures. If a particular components causes 100% to production loss, then that equipment is the most critical. Hence if the score is approaches to unity, then the priority to be a critical component is high.

iii) Mean time to repair, MTTR

$$\textbf{MTTR = Total down time / Total number of failures} \quad ....(3.0)$$

iv) Mean cost of repairs

If the cost of repair increases, the equipment need more attention; hence, it is more critical. This factor is also to be given score as to the actual expenses incurred on an average, for repairs, in monetary terms. In table 3.3, then total score are the multiplies of scores, S, production loss (assume 1), MTTR and MCOR.

Table 3.3 Categorization and level of equipment criticality

Equipment	Prob. of failure, P	Score, S	Production loss, P_{loss}	MTTR	MCOR	Total score S x P_{loss} x MTTR x MCOR
A	H/M/L	X	XX	X	X	XX

3.3 FAILURE ANALYSIS - Failure mode effect analysis (FMEA)

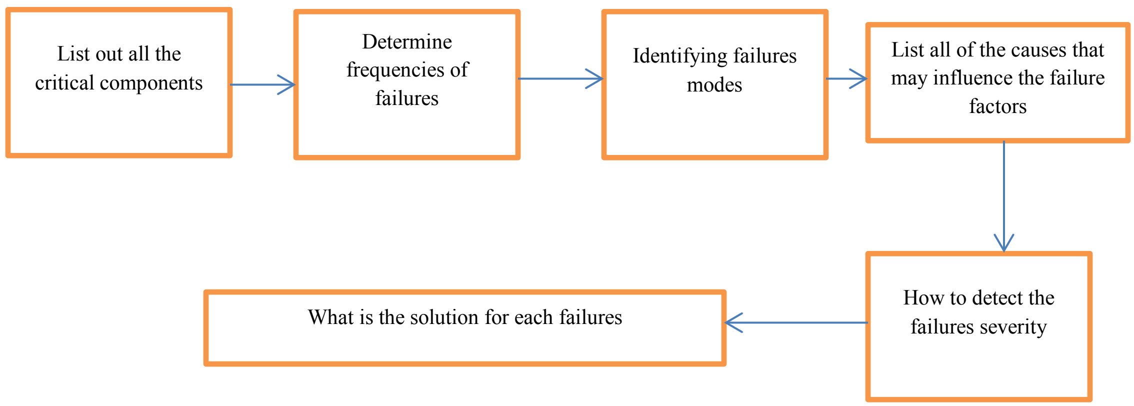


Figure 4.3 Flow process of building FMEA program

Table 3.4 Example of FMEA sheet

<table>
<tr><td colspan="5">Components name :
Date :</td><td colspan="5">P-Probability
S-Severity
R-PxS</td></tr>
<tr><td colspan="10">Range scale : *Ex. 1-3 :Low 4-8 : Moderate 9-10 : High 10> : Catastrophic</td></tr>
<tr><td rowspan="2">Equipment</td><td rowspan="2">Function</td><td rowspan="2">Failure mode</td><td rowspan="2">Causes of failure</td><td rowspan="2">Effect of failure</td><td colspan="3">Risk priority</td><td rowspan="2">Action</td><td rowspan="2">Action taken</td></tr>
<tr><td>P</td><td>S</td><td>R</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Evaluating the FMEA is to find what is the causes and root of failures. This is a very significant in finding the best option for maintenance activities. Figure 4.3 is the modeling process of FMEA, which to conclude all of the possibilities of failures on each components, causes / roots, effect of the failures, and action that need to be taken to prevent the failures will not occurring in the future. The table 3.4 shows the format of FMEA method of a system and the risk priority number is for added value which it is just an option for a better reflection.

3.4 WEIBULL ANALYSIS

In Weibull analysis, the first step is to find the shape parameters and characteristic life of an equipment. Hence the equation 3.1 is to find the MTBF as follows :

MTBF = Times / Failures occurred…… (3.1)

The cumulative of failures in hours is gathered for the quantity as in the table 3.5 :

Table 3.5 Table of cumulative failures (percentage)

No.	Item	Quantity	Failures (Hours)	Failures cumulative
01.	Pump			
02.	Compressor			
03.	Pressure vessel			
04.	Heat exchanger			
05.	Reaction chamber			
06.	Scrubber			
07.	Reducer			
08.	Strainer			
09.	Valve			

Mean time between failure are calculated and mean time to repair value in a table 3.6 for nine main components for unit 1000 as shown below.

Table 3.6 Table of MTBF and MTTR

No.	Item	Mean time between failure (MTBF)	Mean time to repair (MTTR)
01.	Pump		
02.	Compressor		
03.	Pressure vessel		
04.	Heat exchanger		
05.	Reaction chamber		

06.	Scrubber		
07.	Reducer		
08.	Strainer		
09.	Valve		

By determining the most important parameters, shape factor and characteristic life parameters in the graph, beta and eta, the values of the parameters will be use in determine the failures function, reliability function and hazard function. Also, the beta shape factor parameter present the class of failure of the system / component. Mean while, the characteristic life (eta) is indicating the optimum life of an equipment (prediction) before the failure occurred after it begin to enter the worn-out failure conditions. The factors are cumulated in a table as shown (table 3.7)

Table 3.7 Table of shape factor and characteristic life of each component

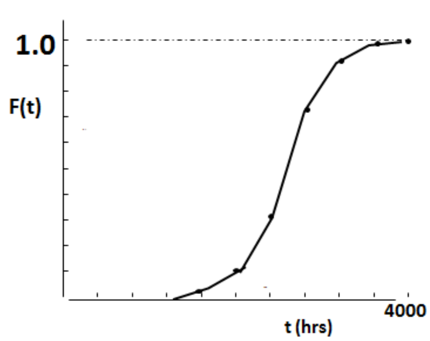
No.	Item	Beta shape factor, ß	Eta shape factor, η
01.	Pump		
02.	Compressor		
03.	Pressure vessel		
04.	Heat exchanger		
05.	Reaction chamber		
06.	Scrubber		
07.	Reducer		
08.	Strainer		
09.	Valve		

3.4.1 Failure distribution, F(t)

In failure distribution we will fixed the operation hours for 0-4000 hours only (5.5 months). The distribution of failures may be differ for more than 4000 hours but the information to be analysis in the particular range only. The class intervals, failures frequency and fraction failing in one table to build the failures cumulative graph and probabilities density function. All failure and reliability probabilities is based on steady state condition of the components, which the machine is under a constant workload, temperature and pressure and so on.

Table 3.8 Table of failure cumulative

Class interval (Hours)	Freq. failures	Failure cumulative	Cumulative failures (%)



Graph 2.2 Failures cumulative distribution function

Failures, F in orders with time, t, by a formulae are as follows :

$$F(t) = 1 - e^{-\left(\frac{t-t_0}{\eta}\right)^{\beta}} \quad \ldots\ldots(3.2)$$

Failures fraction by hours,

$$f(t) = \frac{\beta(t-t_0)^{\beta-1}}{\eta^{\beta}} . e^{-\left(\frac{t-t_0}{\eta}\right)^{\beta}} \quad \ldots\ldots(3.3)$$

Failures occur in a given time,

$$F_x = F(t) * \text{population} \quad \ldots\ldots(3.4)$$

Probabilities of an item occur between t_x and t_y,

$$P_t = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}} \quad \ldots\ldots(3.5)$$

Hence,

$$\mathbf{q = P_{ty} - P_{tx}} \quad \ldots\ldots(3.6)$$

3.4.2 Reliability distribution

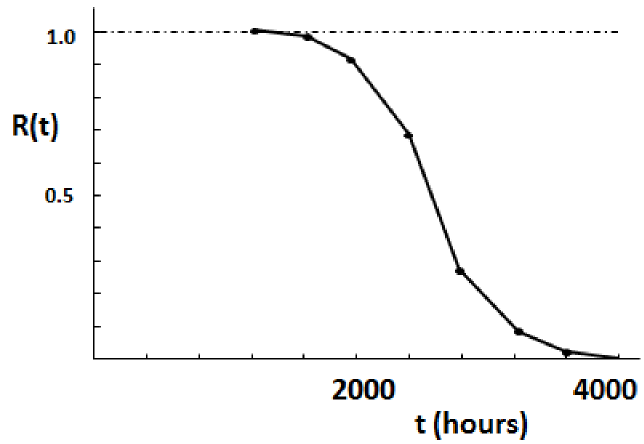
General formulae for find the reliability is,

$$\mathbf{R(t) = 1 - F(t)} \quad \ldots\ldots(3.7)$$

$$\mathbf{R(t) = e^{-\left(\frac{t-t_0}{\eta}\right)^{\beta}}} \quad \ldots\ldots(3.7)$$

The value of beta and eta will be found on the graph, and t_0 id the time optimization. To estimate the number of equipment that will survive at time t, the flows of equation has almost as same as failures, hence the reliability of equipment is :

$$\mathbf{Y = R(t) * population} \quad \ldots\ldots(3.8)$$



Graph 2.3 Reliability cumulative distribution function

3.5 AVAILABILITY

Identifying whether the process flow of the unit is in series or parallel. Below are the block diagram for the system process flow that consists all of the equipment as previously stated. The figure of the availability block diagram are according to the process flow diagram / schematic of process gasification unit in appendices (page 80 – 90).

Availability of a component is a measurement to advocating the performance of a preventive maintenance that been done. In order to achieve the availability target, the rating of the machine or a components need to be high. The availability of each sub unit represent the A1 – A15 as the process flow chart above. The formulae of calculation for the availability and reliability of each sub unit and main system unit are as follows.

From Eq. 2.6, 2.7, 2.8 :

Availability = Operating time/Planned production time

= MTBF / (MTBF + MTTR)

If the block diagram are in series, then,

$$\mathbf{A_T = A_1 * A_2 * A_3 * .... A_n}$$

If the block diagram are in parallel, then,

$$\mathbf{A_T = 1 - [(1\text{-}A_1) \text{ x } (1\text{-}A_2) \text{ x } (1\text{-}A_3) \text{ x}....(1\text{-}A_n)] \quad ....(4.0)}$$

For 1,

$$\mathbf{A_t = 1 - [(1\text{-}A_1)\text{x}(1\text{-}A_2.A_5)\text{x}(1\text{-}A_3)\text{x}(1\text{-}A_4) \quad ....(4.1)}$$

For 2,

$$\mathbf{A_t = [1\text{-}[(1\text{-}A_6)\text{x}(1\text{-}A_7)\text{x}(1\text{-}A_8)\text{x}(1\text{-}A_9)\text{x}(1\text{-}A_{10})\text{x}(1\text{-}A_{11})]] \text{ X } [1\text{-}[(1\text{-}A_{12})\text{x}(1\text{-}A_{13})]] \quad ....(4.2)}$$

For 3,

$$\mathbf{A_t = A_{14} \text{ x } A_{15} \quad ....(4.3)}$$

For the total availability of the unit is,

$$\mathbf{A_T = A_{t\,(1)} \text{ x } A_{t\,(2)} \text{ x } A_{t\,(3)} \quad ....(4.4)}$$

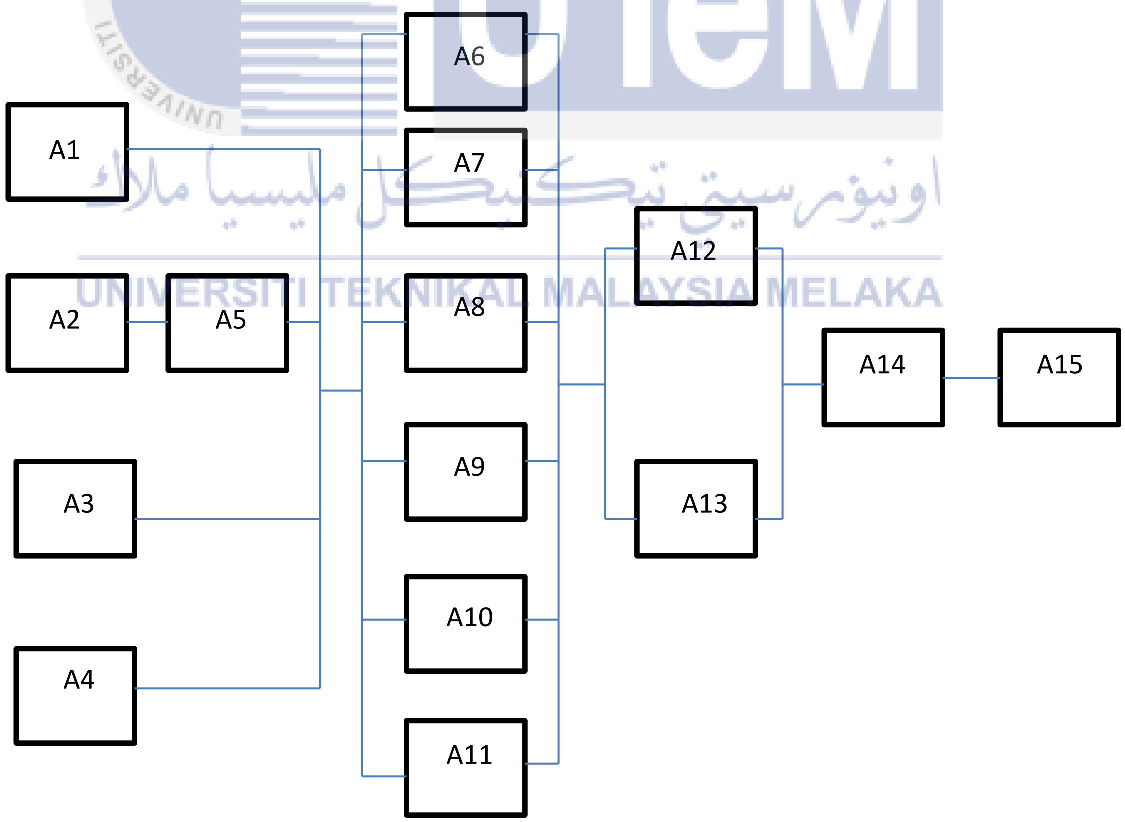


Figure 4.4 Process flow diagram of availability (gasification unit)

Figure 4.4 is the availability block diagram for unit 1000 as indicates in the appendix C which includes all the sub unit inside. Each of the unit labeled as A and numbering to ease the identification for each sub unit. Each of the unit are consists of components that stated earlier, but not each of it are inside. The continuation of the system are only have two types of design; series, parallel, or combination of both. The block diagram will determine the whole system availability.

3.6 ECONOMIC LOSSES

The estimation of total maintenance cost and economic analysis are the critical part in terms of planning the maintenance activities and for the production control. In this research, components that will be analyse consist of five (5) components, which the components being chooses because of the level of criticality in the ABC analysis. The components are :

i) Pressure vessel

ii) Heat exchanger

iii) Reaction chamber

iv) Scrubber

v) Reducer

3.6.1 Estimation of preventive maintenance total cost

There will be two parameters that we need to find, total preventive maintenance and the economic losses estimation. For the total maintenance cost estimation, the total of cost are including of the labour cost, inventory cost only. Hence eq. 4.5 concludes the total cost of maintenance as follow,

$$C_{\text{maintenance, total}} = \underbrace{\textbf{Labor cost + Inventory cost}}_{\textbf{Preventive activities}} \quad .....(4.5)$$

To estimate the labour size of maintenance activities for a system / components, Islam H.A [23] build a systematic estimation by the formulae as shows.

Labour force size $= L_{pm}$

$L_{pm} = md_{annual} / LOC \quad ......(4.6)$

$md_{annual} = f_{annual} * T_{du} * L_{number}$

LOC = Workers operating conditions (days)

md_{annual} = Total preventive maintenance – man – day

$f_{annually}$ = Annually frequencies per preventive maintenance type

T_{du} = Duration time (Operation)

L_{number} = Number of workers per preventive maintenance type (refer to FMEA table)

To optimize the cumulative of maintenance cost, hence we need to use mean time between failure (MTBF) and divided the optimized life cycle time for the component, characteristic life, η, to get the cost optimization being more accurate. Hence in eq. 4.7,

$$\mathbf{PM_{opt.} = \eta / MTBF} \quad .....(4.7)$$

Table 3.9 Total preventive maintenance cost estimation table

No.	Item	A. Labour * Cost (Total, RM)	B. Spares / Inventory cost (RM)	Total maintenance cost (A + B, RM)
01.	Pressure vessel			
02.	Reaction chamber			
03.	Heat exchanger			
04.	Scrubber			
05.	Reducer			

Assumption is made to the values as follow as to fixed the parameters equally in each of the equipment in table 3.9 and some of the values are from Shell MDS Sdn Bhd courtesy:

01. Inventory / spares value of money are according to fixed price.

02. The estimation of PM cost are only for the particular five critical priority components.

04. The failures description and frequencies of failures are only for the data in terms of 0 – 4000 hours of operation's data.

Table 4.0 Analysis of optimization maintenance cost table

No.	Item	A.Maintenance cost – Before opt. (RM)	B.Frequencies of failures	C.Average PM cost (A/D)	D.PM $_{opt}$	Maintenance cost After opt. (RM) (C*D)
01.	Pressure vessel					
02.	Reaction chamber					
03.	Heat exchanger					
04.	Scrubber					
05.	Reducer					

Table 4.0 shows the two main parameters; total maintenance cost without PM optimization and total cost after PM optimization adapted. These two parameters is compared to analyse the percentage of losses that can be save in terms of monetary. Assumption is been made for the table as follow :

01. The economic losses is predicted from the preventive maintenance frequencies for the η time only.

02. The man power ratio for PM is 1 failure = 1 man power

CHAPTER 4

RESULTS AND ANALYSIS

4.1 MAINTENANCE DATA

Before the analysis of the maintenance activities can be done, it is quite important to prepare the data from the system to implementation. The data of the maintenance approaches are currently true by the time and have the permission of the company's credentials. The tables that have shown as followed list out all of the data and information for unit 1000 generally.

The data that have been taken includes the equipment list, the preventive maintenance rate per year, average of preventive maintenance cost, corrective maintenance cost for downtime, the frequencies of failure in a time range, mean time between failure (MTBF) and mean time to failure (MTTF). The option of the MTBF and MTTF is regarding of the reliability of the system.

The difference between MTBF, MTTR and MTTF is the 'function' of each of the words. Mean time between failure is the average time that will be taken, 'expected' will occur the next failure after a failure. Mean time to repair is average time taken to repair, or to fix the repairable items in average. Meanwhile, mean time to failure only means to non-repairable items that highly cost for maintenance activities.

For mean time between failure (MTBF) for each component in order of 0 - 4000 hours of operation time. From Eq. 3.1 as shown below, the value of mean time between failures (MTBF) cab be calculated for each of the components as shown in table 3.4.

MTBF = Hours of operation / Failure occurences

Table 4.1 Mean time between failure for main components

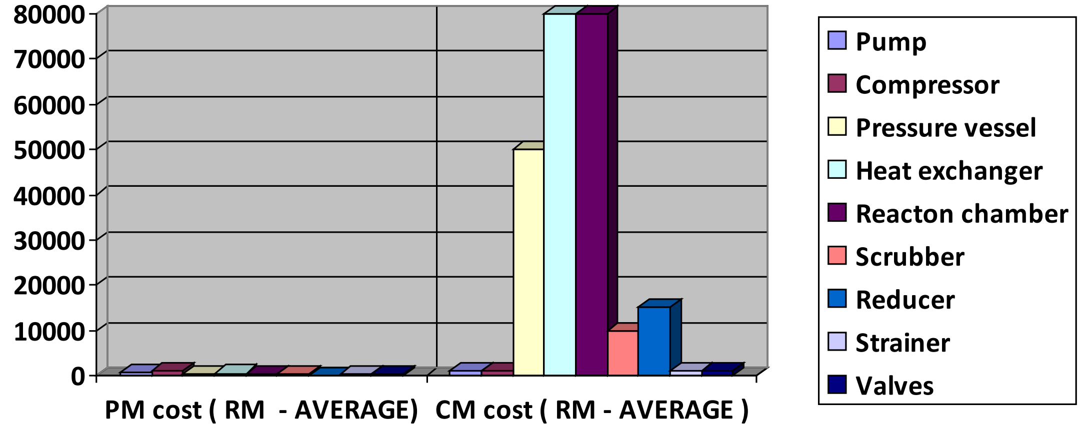
ITEM	MTBF (Hours)
PUMP	43.95
COMPRESSOR	59.7
PRESSURE VESSEL	800
HEAT EXCHANGER	1000
REACTION CHAMBER	1000
SCRUBBER	444.44
REDUCER	400
STRAINER	285.71
VALVE	78.43

The value of MTTR is confidential which the value is already in the table 4.1. The table 4.2 is the combination of table 3.1, table 3.5 and table 3.6. Also the data has an added value for PM and CM cost for each component. The frequencies of failures are in fraction of 1000 hours, thus, it was divided into 4 main class interval. The maintenance data for on table 4.1 is based on information from Shell plant MDS Sdn Bhd, authorized for educational purposes only and copyright.

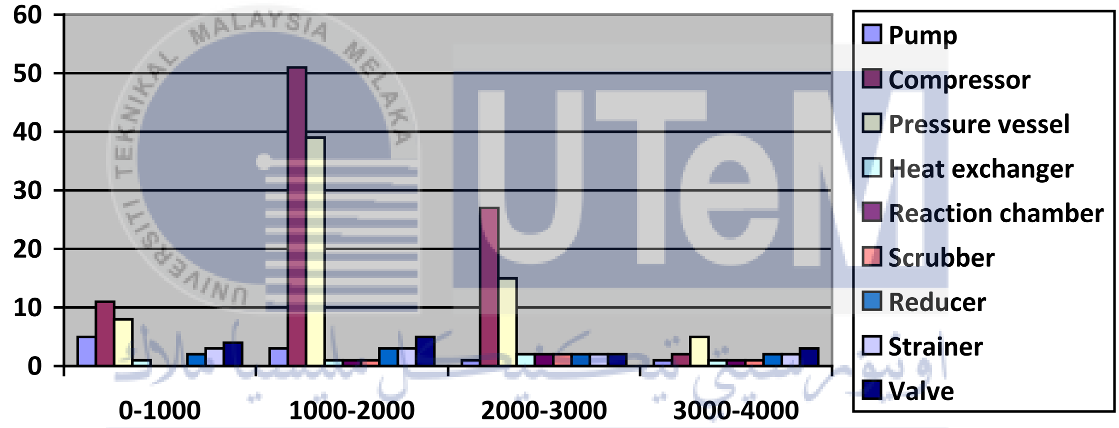
Item	Qtty.	PM rate (per year)	PM cost (Average)	CM cost (Average)	Failure (Hours)				MTBF (Hours)	MTTR (minute)
					0-1000	1000-2000	2000-3000	3000-4000		
Pump	20	40	800	1200	11	51	27	2	43.95	20
Compressor	10	40	1000	1200	8	39	15	5	59.7	20
Pressure vessel	4	5	450	50000	1	1	2	1	800	800
Heat exchanger	18	7	500	80000	0	1	2	1	1000	800
Reaction chamber	10	6	350	80000	0	1	2	1	1000	800
Scrubber	15	9	200	10000	2	3	2	2	444.44	30
Reducer	16	9	100	15000	3	3	2	2	400	30
Strainer	25	10	320	1000	4	5	2	3	285.71	10
Valves	44	10	400	1000	5	13	27	6	78.43	10

Table 4.2 Maintenance data

***All cost are in Ringgit Malaysia (RM) *PM cost average is per PM done *CM cost average is CM cost per failure**



Graph 2.4 PM cost and average cost



Graph 2.5 Frequencies of failure vs time respond

Both of the graph shows the implementation off data by the table 4.1. It can be agreed that the cost of then pressure vessel, heat exchanger and reaction chamber are more higher than the other equipment in the plant as seen in graph 3.6. However, graph 3.7 shows the frequencies of failures vs time respond, in hours which show us that the distribution of failures are more similar to bath tub curve graph. Even the distribution is not smooth as the data provided, but the theory of bath tub curve is proven for each of component as PM activities been done. In bath tub curve there will be a Weibull hazard constant, which represent ß, beta. If $0 < ß < 1$, hence the condition is in infant mortality. If ß=1, the condition is in constant failure rate. But if ß > 1, the condition id is worn out terms.

4.2 EQUIPMENT CRITICALITY

Table 4.0 shows the list of equipment in terms of it's level of criticality and severity. The table also shows the mean time between failure and mean time to failures for each of the component. In table 4.2, the information shows the failure mode effect critical analysis (FMECA) which the core of the main event for preventive maintenance activities.

The probabilities of failures and, scores, production loss, mean time to repair and mean cost of repair are according as follows. The total failures is 255 which based on maintenance data table (table 4.4), by added all the failures overall for all equipments. For score, based on :

S = Failures of an equipment / Total failures

By using the table 4. as the reference, we can get the probability score for each equipment. The value of score is concluded in table 4.5 below.

Table 4.5 Score of 'S'

ITEM	Probability of S
PUMP	0.35
COMPRESSOR	0.26
PRESSURE VESSEL	0.02
HEAT EXCHANGER	0.02
REACTION CHAMBER	0.06
SCRUBBER	0.035
REDUCER	0.039
STRAINER	0.055
VALVE	0.2

Table 4.4 Critical equipment assessment

No.	Equipment	Prob. of failure,P	Score, S	Production loss, P_{loss}	MTTR minute	MCOR	Total score
01.	Pump	M	0.35	1	20	1200	8400
02.	Compressor	M	0.26	1	20	1200	6240
03.	Pressure vessel	L	0.02	1	800	50000	800000
04.	Heat exchanger	L	0.02	1	800	80000	1 280 000
05.	Reaction chamber	L	0.06	1	800	80000	1 280 000
06.	Scrubber	L	0.035	1	30	10000	10 588
07.	Reducer	L	0.039	1	30	15000	17 647
08.	Strainer	H	0.055	1	10	1000	549
09.	Valves	H	0.2	1	10	1200	2400

In table 4.4 above, we can see that the highest score are been dominating by using the ABC analysis (criticality equipment assessment), the data from each of the equipment can be rearrange, which the maintenance activities priorities focusing more on the criticality of the equipment as the maintenance current policies. The probabilities of failures of are depends on the range showed as follow in table 4.5.

Table 4.5 Critically range limit

Lower range	Upper range	Types of range
0	3	Very low
3	6	Low
6	12	Medium
12	24	High

Hence, from the ABC criticality analysis (table 4.4), there are 5 critical components identified ; pressure vessel, heat exchanger, reaction chamber, reducer and scrubber. The failure mode effect analysis as shown in table 4.5, is to show the continuity of effect mode until the process of configuration on how to prevent the matter. FMEA table is very important in preventive maintenance activities as the references, to put what is the main priorities of the maintenance activities on each machine by selecting the types of failure and the maintenance scheduled that need to be done. The MTBF shows the average of time of failures to another in each of components as well it will be use for Weibull method.

Table 4.6 Failure mode effect critical analysis

No.	Item	Types	Critical component	Failure mode	Failure cause	Failure effect	Maintenance activities
01.	Pump	Service & replacement	-Electrical wiring -Vanes -Bearing -Seal	-Trip -Broken -Scaling -Erosion -Crack -Worn out	-Manufacturing -Improper filtration -Overload -Bubble -Dust	-Operation stop -Component Damage -Imbalance -Excessive vibration	-General cleaning -General Troubleshooting -Lubrication -Re-fabrication
02.	Compressor	Service and replacement	***Same as pump**				
03.	Pressure vessel	Service & replacement	-Safety valve -Pressure gauge	-Opened -Closed -False indication	-Broken spring -Corrosion -Manufacturer fault -Worn out	-Over pressure -Burst -Leakage -Secondary damage	-Cleaning the carrion part -Daily general inspection -Valve troubleshooting -Replace new component

04.	Heat exchanger	Service & replacement	-Pipes / Tubes -Temperature / pressure / flow indicators	-Temperature shock -Crack -Corrosion -False indication	-Improper installation -Sudden change in temperature and pressure -Less inspection	-Overheat -Component main/secondary damage -Improper installation	-Daily general inspection -Replace new indicator -General cleaning -Proper operation management
05.	Reaction chamber	Service & replacement	-Heater -O-rings -Thermocouple -Electrical board	-Leakage -Corrosion -Crack	-Worn out -Component damage -Dust -Work overload	-Over flow -Endangered the environment -Secondary damage	-Daily cleaning & general inspection -Replacing heater -Replacing o-ring and thermocouple
06.	Scrubber	Service & replacement	-Gasket -Bolt & nut -Inlet & outlet pipe -manifold and filter	-Vane damage -Corrosion -Scaling -Crack	-Worn out -Improper inspection -Faulty manufacturer -Improper operational	-Secondary damage -Excessive vibration -Clogging	-Daily general inspection -Tighten any bolt and nut -General cleaning inner and outer part

07.	Reducer	Service & replacement	-Shaft -Bolt & nut -Gears -Electrical system	-Looseness -Bearing defect -Excessive friction -Pitting	-Less lubrication -Improper maintenance -External factors -Improper operational condition	-Excessive vibration -Consume more power -Component damage	-Proper lubrication scheduling -Daily inspection -General cleaning -Overhaul
08.	Strainer	Service & replacement	-Filter -Bolt & nut	-Improper flow/pressure -Pressure loss -Corrosion -Clogged	-Improper operational -Worn out -Less maintenance	-Clogging -'Hammering' -Component damage	-Overhaul -Replace filter -General inspection and cleaning
09.	Valve	Service & replacement	-Spring -Screw thread -Stem -Diaphragm	-Corrosion -Component stuck each other -Crack	-Improper operational -Worn out -Less maintenance	-Leakage -Crack / damage	-Replace main component -Overhaul -General inspection and cleaning

4.3 WEIBULL RELIABILITY ANALYSIS

4.3.1 Equipment failure data

Table 4.7 Table of failures F(t) and f(t)

*F (t) = Fraction failing per class interval *f(t) = Fraction failing per hour

No.	Item	Class interval (hours)	No. of failures	Fractions failing	Fraction failing (per hour)
01.	Pump	0-500	2	0.02	0.00040
		501-1000	9	0.10	0.00020
		1001-1500	21	0.23	0.00046
		1501-2000	30	0.33	0.00066
		2001-2500	19	0.21	0.00042
		2501-3000	8	0.09	0.00018
		3001-3500	1	0.01	0.00002
		3501-4000	1	0.01	0.00002
02.	Compressor	0-500	1	0.015	0.00003
		501-1000	7	0.10	0.0002
		1001-1500	19	0.28	0.00056
		1501-2000	20	0.30	0.0006
		2001-2500	8	0.12	0.00024
		2501-3000	7	0.10	0.0002
		3001-3500	4	0.06	0.00012
		3501-4000	1	0.015	0.00003
03.	P. Vessel	0-500	0	0	0.00003
		501-1000	1	0.20	0.0002
		1001-1500	1	0.20	0.00056
		1501-2000	0	0	0.0006
		2001-2500	0	0	0.00024
		2501-3000	2	0.4	0.0002
		3001-3500	1	0.2	0.00012

		3501-4000	0	0	0.00003

No.	Item	Class interval (Hours)	No. of failures	Fractions failing	Fraction failing (per hour)
04.	H.Exchanger	0-500	0	0	0
		501-1000	0	0	0
		1001-1500	1	0.25	0.0005
		1501-2000	0	0	0
		2001-2500	2	0.50	0.0010
		2501-3000	0	0	0
		3001-3500	1	0.25	0.0005
		3501-4000	0	0	0
05.	R.Chamber	0-500	0	0.015	0
		501-1000	0	0.10	0
		1001-1500	1	0.28	0.0005
		1501-2000	0	0.30	0
		2001-2500	0	0.12	0
		2501-3000	2	0.10	0.0010
		3001-3500	1	0.06	0.0005
		3501-4000	0	0.015	0
06.	Scrubber	0-500	1	0.11	0.00022
		501-1000	1	0.11	0.00022
		1001-1500	1	0.11	0.00022
		1501-2000	2	0.11	0.00044
		2001-2500	1	0.22	0.00022
		2501-3000	1	0.11	0.00022
		3001-3500	1	0.11	0.00022
		3501-4000	0	0.11	0.00022

No.	Item	Class interval (Hours)	No. of failures	Fractions failing	Fraction failing (per hour)
07.	Reducer	0-500	0	0	0
		501-1000	3	0.33	0.00066
		1001-1500	2	0.22	0.00044
		1501-2000	1	0.11	0.00022
		2001-2500	1	0.11	0.00022
		2501-3000	1	0.11	0.00022
		3001-3500	1	0.11	0.00022
		3501-4000	1	0.11	0.00022
08.	Strainer	0-500	1	0.07	0.00014
		501-1000	3	0.21	0.00042
		1001-1500	4	0.28	0.00056
		1501-2000	1	0.07	0.00014
		2001-2500	1	0.07	0.00014
		2501-3000	1	0.07	0.00014
		3001-3500	2	0.14	0.00014
		3501-4000	1	0.07	0.00003
09.	Valve	0-500	2	0.04	0.00008
		501-1000	3	0.06	0.00012
		1001-1500	6	0.12	0.00024
		1501-2000	7	0.14	0.00028
		2001-2500	10	0.20	0.00040
		2501-3000	17	0.33	0.00066
		3001-3500	5	0.10	0.00020
		3501-4000	1	0.02	0.00004

The value of fraction failing, F(t) and fraction failing per hour, f(t) from table 4.7 above, are based on table 4.2, which F(t) is the failure for each class interval divided by total failures, and f(t) is the F(t) divided by fractional hours (500 hours).

4.3.2 Equipment reliability analysis

Table of class interval and cumulative failure in appendices D is refer to table 4.7, which the failure frequencies of each components converted to cumulative percentage as in row 3^{rd} and 4^{th}. The percentage of cumulative is to show the increment of failures for each level of class interval (hours). The highest failure frequencies is from pump, compressor and valves. This also can be refer to table 4.2 (maintenance data). The cumulate failure is used in Weibull probability graph as shown in appendices D (1 – 9); Weibull probability plot (95.0% bounds). The graph includes all the parameters needed; beta and eta factors.

In reliability analysis, failures distribution is the most important before going any deeper. In each equipment , the failures frequencies, cumulative failures and cumulative percentage failure is summarized in table 4.9 (pump), table 5.3 (compressor), table 5.7 (pressure vessel), table 6.1 (heat exchanger), table 6.5 (reaction chamber), table 6.9 (scrubber), table 7.3 (reducer), table 7.7 (strainer) and table 8.1 (valve) as indicated in appendices D. The failure function of F(t) is on the Y-axis and time hours (class interval) will be on the x-axis.

The failure frequencies were from table 4.7 which in terms of class interval in hours, from 250 hours – 4000 hours with 500 hours interval. Table 4.7 also includes the data from table 4.2, which the F(t) is the failures occur in terms of class interval while f(t) represent the failure probabilities per hour. The fraction of failures will be the prior data to find shape factor and characteristic life.

The plotted graph is by automatic-online method which is more accurate compare manually which the plotting is by **http://reliabilityanalyticstoolkit.appspot.com/** which is automatically plotted on the graph. The weibull probability graph can be seen in appendices D (1 – 9), which the dotted line is the point where the percentage of F(t) located in parallel (y-axis) with the time fraction (class interval in hours – log) lied in the x-axis. The cumulative failure table as shown is used to build the Weibull probability plot by percentage of the cumulative failures.

Table 4.8 Equipment Weibull shape factor and characteristic life

Item	ß	ɳ	Mean to fail (Hours)	Variance
Pump	2.89	1630	1729.07	424 019.94
Compressor	2.57	1713	1766.21	545 879.95
P. Vessel	1.51	2953.16	2662.77	3 208 681.17
H. Exchanger	1.36	2870	2624.92	3 831 876.16
Reaction chamber	1.26	3154	2929.46	5 430 272.87
Scrubber	1.10	2717.34	2622.86	5 710 648.42
Reducer	2.54	2219	1969.87	691 535.61
Strainer	1.3	1804.40	1666.84	1 674 998.49
Valve	2.93	2275	2559.46	896 579.30

As refer to table 4.7 above, from the boundaries of the pump Weibull probability graph in appendices D-1, the value of failures on 63 % drop to 1630 hours for it's characteristic failure, ɳ. While the beta shape factor is more than 1, hence. it is indicate that the component (pump) is in wear out condition, which the value of the beta is 2.86. Also, the mean hours (in class interval) for pump is 1729.07 hours while the variance is 424 019.94 hours.

Followed by compressor on appendices D-2, the value of failures on 63 % drop to 1713 hours for it's characteristic failure, ɳ. While the beta shape factor is more than 1, hence. it is indicate that the component (compressors) is also in wear out condition, which the value of the beta is 2.57. Also, the mean hours for compressor is 1766.21 and the variance is 545 879.95 hours. As for the pressure vessel, the value of characteristic life is to 1713 hours, while the beta shape factor is more than 1, hence. it is indicate that the component (pressure vessels) is in wear out condition, which the value of the beta is 2.57.

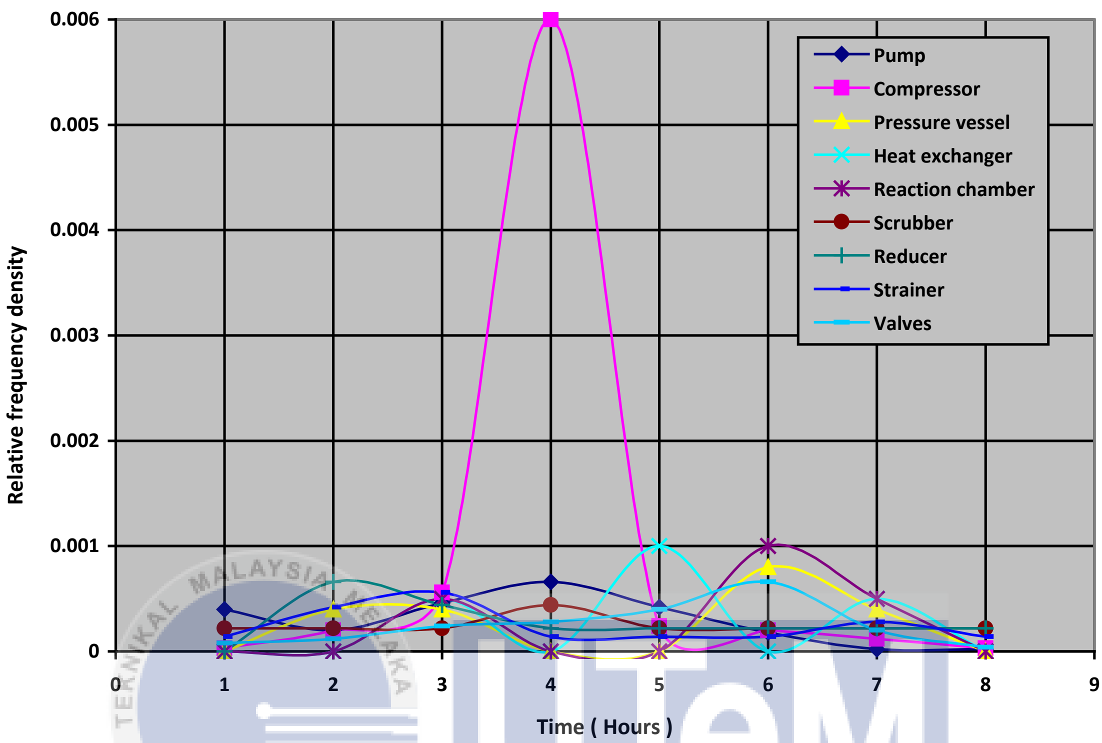
All of the beta value indicates that the components is in wear out condition, which is more than 1. The highest of characteristic life is reaction chamber which is 3254 hours compare to the lowest, pump. In the information of eta value, we can conclude that the availability of reaction chamber is more than the others; the life of 'allowed' failure is more higher. Meanwhile, all of the components has the same range of beta shape factor, which indicates all of the components were in wear out failure range.

The third column in table 4.7 is the mean time to failure (optimized) as shown, which the information can be get from appendices D in appendices section. Mean time to failure means a component that functional before the first failure occur; which simply to say, as for example, a pump that has 1729.07 hours of mean time to failure before a failure occur after maintenance or overhaul implied. In time horizon of maintenance planning, it was the time $0 - t_0$, and $t_0 - t$ is the failure start to happened.

There are 3 graph related in Weibull method; reliability density function, failure density function and hazard rate. In appendices D, the all of the Weibull graph are based on the characteristic life as the limit point at x-axis. For each of reliability density function graph, the point limit is at 36.8 % of probabilities; opposite to failure probabilities at 63.2 %. This is because at any point of time given, the probabilities of failure at 63.2 %, the other rest of percentage; 36.8 %; is not having fail. The same reason goes for the rest of the particular graphs.

The value for table reliability function and failure function at time, t, as seen in appendices D (1-9), is randomly chosen as from equation 3.7, 3.8, 3.2 and 3.3, and as well the beta and eta factors as the implementation. The value of both reliability and failure table are to shows the probabilities of particular value in terms to find the parameters related, whether how much components is survived; no failures; can refer to reliability table, and how much the components is expected to fail can be refer to failure table.

4.3.3 Cumulative of relative frequency failure



Graph 2.6 Relative frequency F(t) per component vs time (Hours)

In graph 2.6, compressor has the highest peak among of the components at 4 – 5 time cycle operations. This means the workload on the compressor are higher at the particular time point which it can relate that compressor might be use to support any of the system in terms of power generation. Others are not higher than 0.001 or 0.1 %. The condition of failures seems to be fluctuated and 'not stable' along of the operation hours. This is seems that most of the failures are likely to entering the worn out conditions.

4.4 UNIT / SYSTEM AVAILABILITY

Availability of a system also one of the maintenance performance index to see what are the capabilities of a component can perform in a period of time. Availability of a system can be measure in percentages, which the international target standard for globally is 0.95 or 95%. The system in unit 1000 can be refer in appendices C, which consist of 15 sub unit. All of the unit are represented in process flow diagram in the particular appendices.

As shown in figure 4.5, the process flow chart represented in block flow diagrams and the name of each sub unit as well. All of the unit are continue from A1 until A15. The continuation process divided into 3 major system, which the system is still not being simplified yet. The simplified for the availability system can be seen in figure 4.6 to be exact. The simplification are also based on to PFD diagram as in appendices C, which in the simplification, there are only nine main components that be focused on; pump, compressor, pressure vessel, heat exchanger, reaction chamber, scrubber, strainer, reducer and valve.

The simplification in figure 4.6 consists of three main majors, parallel system for number 1, combination of series and parallel for number 2 and series for number 3. The value of each component's availability can be seen in table 4.9, which includes the calculation of each. The value of MTBF and MTTR can be found in table 4.2 and it is simply the data to find the availability is only use the MTBF and MTTR in the particular table 4.4.

Availability = Operating time / Planned production time = MTBF / (MTBF + MTTR)

*MTBF = Mean time between failure

*MTTR = Mean time to repair

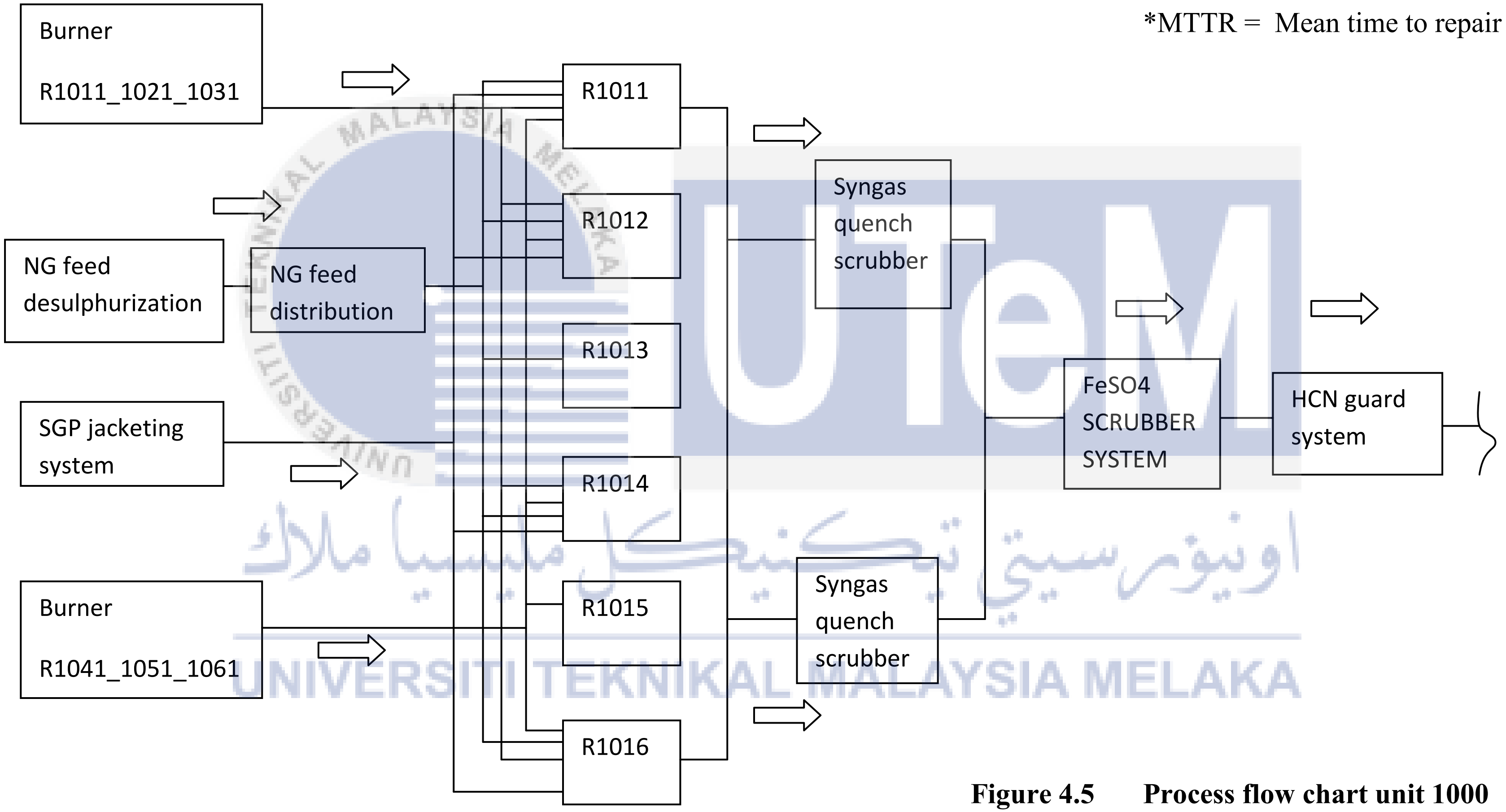


Figure 4.5 Process flow chart unit 1000

*Reliability block diagram for gasification unit

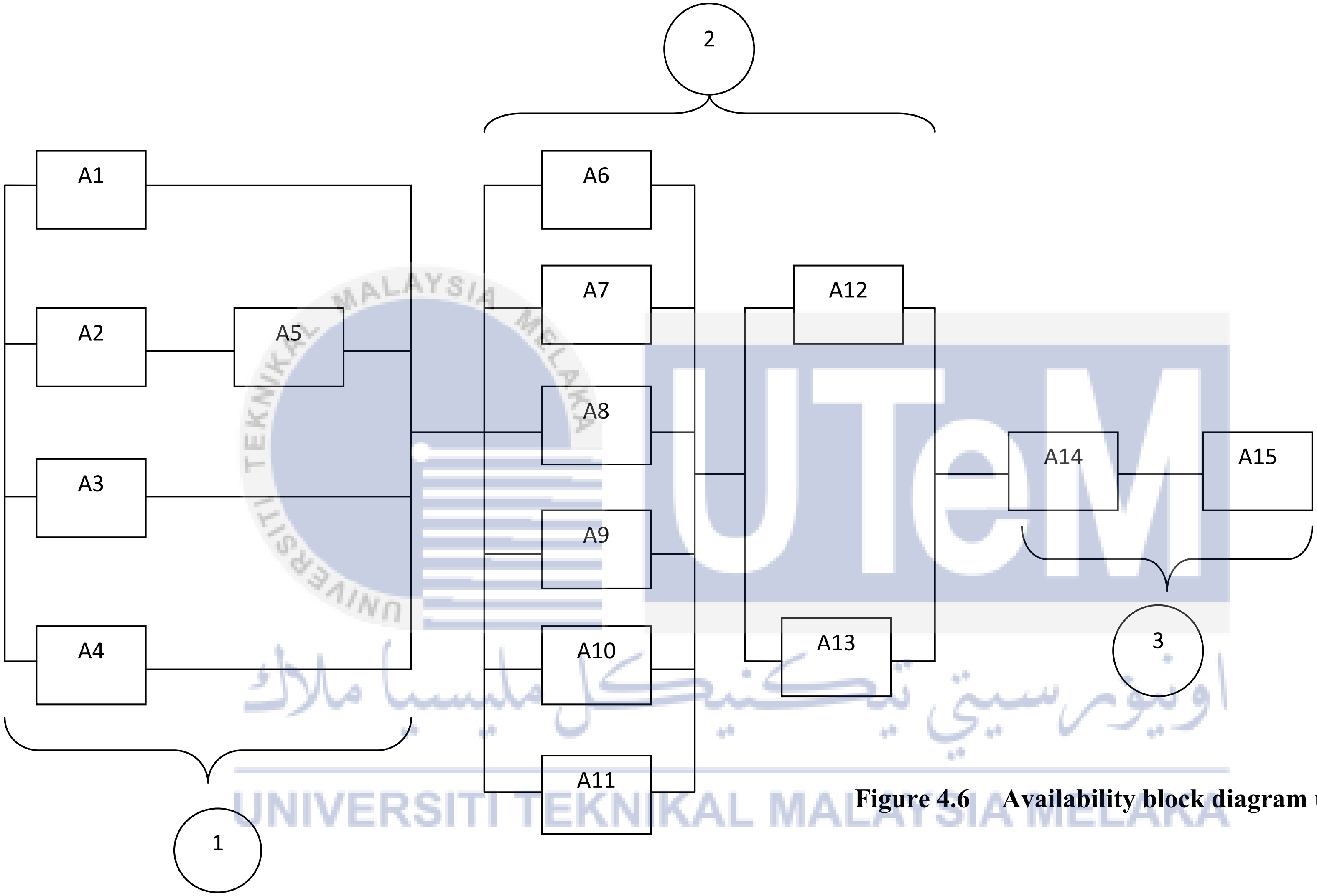


Figure 4.6 Availability block diagram unit 1000

From the equation of availability, A= MTBF / (MTBF + MTTR)

Table 4.9 Availability values

Item	Availability (A)
Pump	0.99
Compressor	0.99
Pressure vessel	0.98
Heat exchanger	0.99
Reaction chamber	0.99
Scrubber	0.99
Reducer	0.99
Strainer	0.99
Valve	0.99

For block A_1 ,

= 0.98*[1-(1-0.99)*(1-0.99)]

= 0.98*0.98

= **0.97**

For block A_2 ,

= 0.99*[1-(1-0.99)*(1-0.99)]

= **0.97**

For block A_3 ,

= [1-(1-0.99)*(1-0.99)]

= **0.98**

For block A_4 ,

= 0.98*[1-(1-0.99)*(1-0.99)]

= **0.97**

For block A_5 ,

= **0.99**

For block $A_6 – A_{11}$,

= [1-[1-(1-0.99)*(1-0.99)]*(1-0.97)*(10.97)]]
(0.93)(0.99*0.99 *0.99*0.99)

= **0.89**

For block A_{12} ,

= 0.99*0.98*0.99*0.99*0.99

= **0.94**

For block A_{13} ,

= **0.94**

For block A_{14} ,

= **0.99**

For block A_{15} ,

= 0.98*[1-(1-0.99)*(1-0.99)] = **0.97**

(1) $$A_{t,1} = 1-[(1-0.97)*(1-0.97.0.99)*(1-0.98)*(1-0.97)]$$

$$= \underline{\mathbf{0.99}}$$

(2) $$A_{t,2} = [1-[(1-0.89)*(1-0.89)*(1-0.89)*(1-0.89)*(1-0.89)*(1-0.89)] *[1-(1-0.94)*(1-0.94)]$$

$$= \underline{\mathbf{0.98}}$$

(3) $$A_{t,3} = 0.99*0.97$$

$$= \underline{\mathbf{0.96}}$$

Total of availability of the whole system,

$$A_T = 0.99 * 0.98 * 0.96$$

$$= \underline{\mathbf{0.93\ @\ 93\ \%\ OF\ AVAILABILITY}}$$

In terms of plant efficiency, the mean of availability, is how much (time) the system or a component can perform it's function. The international standard for availability for a plant overall equipment effectiveness is 0.95, or 95%. Hence the value for the account of availability in the parameters is lower than expected. One of the reason why the system is low in terms of availability was the designation of process flow equipment. Most of the system that has the series is much low of availability compare to the parallel system. As the system is mostly in parallel, hence, the availability is still above of the 90 percent (90%) but still not achieved the target value for 99% availability. The series system is intend to gain more secondary failure because the system is continuous motion.

4.5 MAINTENANCE COST

4.5.1 Estimation of preventive maintenance total cost

The total of maintenance cost is based on equation 4.5 by only need two parameters such as follows. The labour cost and inventory are the two parameters to get the estimation of maintenance cost. The labour cost can be find trough $\mathbf{L_{pm}}$ which the size of labour**s** multiplied with fixed wages according to the salary guide based on the 'Hays recruiting experts oil and gas : The oil and gas salary guide 2013'. For $\mathbf{md_{time}}$, indicated the total of preventive maintenance of man in day (man – day) by divide by 24 (hours). The total preventive maintenance activities are based on FMEA table; in table 4.7; which we assume to have one failures for one PM activities. We are assumed the maintenance cost is for 0-4000 hours time horizon and not annually.

$$\mathbf{C_{maintenance,\ total} = Labour\ cost + Inventory\ cost \ldots (4.5)}$$

$$\mathbf{L_{pm} = md_{time} / LOC}$$

$$\mathbf{md_{timel} = f_{time} * T_{du} * L_{number}}$$

For **LOC**, the value is fixed which represents the working hours condition annually and for $\mathbf{f_{annual}}$, the value of frequencies of failures also based on table 4.7 (FMEA table) and table 4.4 to see the failures frequencies for each components. $\mathbf{T_{du}}$ and $\mathbf{L_{number}}$ are the duration operational hours and number of labour per PM @ CM types. These two are fixed according to the FMEA table for assumption.

LOC = Workers operating conditions (day / year)

LOC value is assumed that each of labours has 12 hours shift work, 6 days per week which in this case is fixed in days, LOC = [(12 hours * 6) * 4] * 12

= 3456 / 24 hours

= 144 days / year (assuming LOC is fixed for 144 days)

The value of maintenance cost in terms of labour and inventory cost are concluded in table 5.0 as follows :

Table 5.0 Table of size of labours, Lpm

ITEM	f_{time}	T_{du} (Hours)	$L_{num.}$ (Fixed)	md_{time} $[(f_{time} * T_{du} * L_{number})/24]$	LOC (Fixed)	L_{pm}, (md_{time}/LOC)
Pressure vessel	5	8640	1	1800	144	12.5
Reaction chamber	7	8640		2520		17.5
Heat exchanger	6	8640		2160		15
Scrubber	9	8640		3240		22.5
Reducer	9	8640		3240		22.5

Total = 12.5 person + 17.5 person + 15 person + 22.5 person + 22.5 person

= <u>90 person</u>

The total number estimated for the plant is 90 person (roughly) which due to total hours of operation hours and working days. The highest labour size are for scrubber and reducer, 22.5 person for each in 24 hours operation shift. The size of labour are includes the technician, supervisor, engineers and so on. The number of labour size used as the benchmark for total maintenance cost in table 5.2 and 5.3.

To optimize the cumulative of maintenance cost, hence we need to use mean time between failure (MTBF) and divided the optimized life cycle time foe the component, characteristic life, η, to get the cost optimization being more accurate. In preventive maintenance interval, i am using characteristic life and MTBF. Each of the failure element will present one types of preventive maintenance. Hence, determining the preventive maintenance interval optimization by using the values of MTBF and characteristic life, η in equation 4.7, to the nearest integer, we get :

$$\mathbf{PM_{opt.} = \eta \, / \, MTBF}$$

The eta (characteristic life) can be refer to table 3.7 and MTBF in table 4.2. The value of PM optimized is the time value that needed for cost optimization in maintenance time horizon interval. The value for each PM optimization are concluded in table 5.1 below :

Table 5.1 Value of freq. of PM optimization based on eta (η) and MTBF

Item	**η (hours)**	**MTBF (hours)**	**PM $_{opt.}$ = η / MTBF (Freq.)**
Pressure vessel	2953.16	800	**3.69**
Heat exchanger	2869.81	1000	**2.87**
Reaction chamber	3154.13	1000	**3.15**
Scrubber	2717.34	444.44	**6.11**
Reducer	2218.69	400	**5.55**

Table 5.1 shows the PM optimization for each component, which scrubber has the highest number of failures freq.in terms of its characteristic life at 2717.34 hours and the lowest is from heat exchanger, which 2.87 times at 2869.81 hours. Table 5.1 indicates the frequencies of failures 'allowed' in characteristic life time, before preventive maintenance need to be done. In characteristic life, the failure will still happened, so preventive maintenance is unnecessary while just doing the corrective maintenance only.

In table 5.2 and 5.3 shows the total of maintenance cost before PM optimization and with optimization respectively.

Assumption :

01. Salary (wages) guide is based on the 'Hays recruiting experts oil and gas : The oil and gas salary guide 2013'. The wages on the table 8.4 indicates wages per person per year in Ringgit Malaysia.

02. Spares price is fixed based on :

i) http://www.alibaba.com/showroom/oil-and-gas-spare-parts.html

ii) http://www.weiroilandgas.com/products/oil__gas_services

iii) http://deltahuiles.com/index.html

iv) Duy Quang N. , Miguel B. [12]

Table 5.2 Total preventive maintenance cost estimation table

No.	Item	A. Labour * wages (Total, RM)	B. Spares / Inventory cost (RM)	Total maintenance cost (A + B, RM)
01.	Pressure vessel	12.5*47 100 = 588 750	15000	603 750
02.	Reaction chamber	17.5*47 100 =824 250	28000	852 250
03.	Heat exchanger	15*47 100 =706 500	25000	731 500
04.	Scrubber	22.5*47 100 =1 059 750	15000	1 074 750
05.	Reducer	22.5*47 100 =1 059 750	12000	1 071 750

TOTAL : RM 4 334 000

Table 5.2 and table 5.3 shows the total of maintenance cost before and after optimization respectively. In table 5.2, the total number of labour in section A plus the fixed cost of inventory form each component and leads up the value of maintenance cost is RM 4 334 000 for the five main critical components. The value of total maintenance cost as shows is for a year, as we fixed the wages and inventory cost for a year. Hence the total up of maintenance cost is not accurate because the price of parts and wages may differ from each company and depend on the global economic values for oil crude barrel. The highest value of maintenance cost if for scrubber and reducer and the lowest is the pressure vessel. The total maintenance cost is not based on the quantity of the components which the value cost in table 5.2 is the overall value. In table 4.2 (maintenance data), there are quantity of each of the component as reference.

Table 5.3 is the conclusion of the maintenance total cost before and after optimization. The second row is the maintenance cost from table 5.2, frequencies of failures, which can be refer to table 4.2, average PM cost; maintenance cost divided by the frequencies of failures for each component. Last of the row is the optimized maintenance cost which the value of average in row fourth multiple by the frequencies of optimization, PM_{opt}, the final value in the last row indicates the estimated of maintenance value for each system. The highest rank is from heat exchanger and followed by the lowest, scrubber and reducer. Even in the table 5.3 showed the highest of maintenance cost is from scrubber and reducer but in table 5.3, they are the lowest. This is due to factor of failures occurrence as an input factors to determine the precision costing in the plan time horizon. The final value of the optimized maintenance cost is RM 1 671 968.41 which the difference is about 60 % by comparing the value of maintenance cost before optimization in just 5.5 months (0 – 4000 hours) operation.

Table 5.3 Analysis of optimization economic losses table

No.	Item	A.Maintenance cost – Before opt. (RM)	B.Frequencies of failures	C.Average PM cost (A/D)	D.PM $_{opt}$	Maintenance cost After opt. (RM) (C*D)
01.	Pressure vessel	603 750	5	120 750	3.69	445 567.5
02.	Reaction chamber	852 250	4	213 062.50	2.87	611 489.38
03.	Heat exchanger	731 500	4	182 875	3.15	576 056.25
04.	Scrubber	1 074 750	9	119 416.70	6.11	19 544.47
05.	Reducer	1 071 750	10	107 175.00	5.55	19 310.81

Total PM cost = <u>RM 4 334 000</u> **Total PM optimization = <u>RM 1 671 968.41</u>**

Total percentage save = [(4 334 000 -1 671 968.41) / 4 334 000] x 100%

= **61.4%**

CHAPTER 5

DISCUSSION

5.1 Weibull analysis

The result of Weibull method is concluded in appendices D (1-9), and also in chapter 4. The value of failure function in equation 3.3 and 3.3 indicates the table of failures in appendices D, as well in the Weibull probability plot graph. The value of beta shape actor and eta characteristic life are the key to maintenance performance indicator and as well for reliability, failure and hazard function. The beta and eta factor for each components is in table 5.0. To look more better for the usage of reliability function, the value of reliability probabilities for a component, can be seen in table 7.7 as an example, for strainer. The value of reliability in range of 1588.0 hours until 1845.5 hours indicates 'how much' of the components at those time 'survive' without any fail. By take the middle point of estimation, Hence, from the table :

$$1588.0 = 0.4286 \quad \text{and} \quad 1845.5=0.3571$$

Probabilities of components that 'survive' without failure is,

$$= 0.4286 - 0.3572 = 0.0714$$

And then, the value of 0.0714 multiplied by the population of the components, by refer to table 4.4, the population for strainer is 25, then we get :

= 0.0714 * 25

= 1.785 = 2 (to the nearest)

In the information given, there will be 2 components that have no failures inside the range of time between 1588.0 hours to 1845.5 hours. In reliability function, the purposes is to find how many item that can survived at a given point (hours). This will be useful in terms of purchasing new component planning. Same goes to other component which by using beta and eta value to determine or predict the components 'survived' at a specific time. One more for example, in table 7.0 for scrubber, the components that will 'survived' that has no failures at the point t=6216.3 and t=4160.3 can be predict as follow by using the same method.

= 0.2024 – 0.0833

= 0.1191

By multiplying 0.1191 with the population (refer to table 4.4),

= 0.1191 * 15

= 1.7865 = 2 (to the nearest)

Hence, as conclusion, the component that will not failure on the time horizon is two. By using equation 3.7 and 3.8 below, we can specified the expectation of components at any points of time.

$$R(t) = e^{-\left(\frac{t-t_0}{\eta}\right)^{\beta}} \quad .....(3.7)$$

$$Y = R(t) * \text{population} \quad ...... (3.8)$$

In terms of failure distribution function, there are two parameters of failures function, F(t) and f(t). These two are the same but not the same value. To be more understanding of the failure function in Weibull method, the figure 2.5 below shows the relationship of beta and eta factors to the failure distribution of a component in a time horizon. Lets take an example to put thing to be more understandable, by refer to the failure function table for heat exchanger in appendices D-4. The method is same as reliability, but differ in terms of the 'meaning'. At 696.1 hours and 2192.2 hours, the probabilities of failure is 0.1354 and 0.5 respectively. Hence,

$$0.5 - 0.1354 = 0.3646$$

By multiplying with the population (refer to table 4.4),

$$0.3646 * 18 = 6.56 \text{ (7 as to the nearest)}$$

There are 7 failures occur in terms between 696.1 hours until 2192.2 hours. The failure distribution for each components is so much important especially in planning the maintenance activities and inventory preparation by minimizing the cash wasted. The failure distribution also very useful to predict failures frequencies for the next time of period. By using the same method and equation 3.2, the prediction can be made as follow.

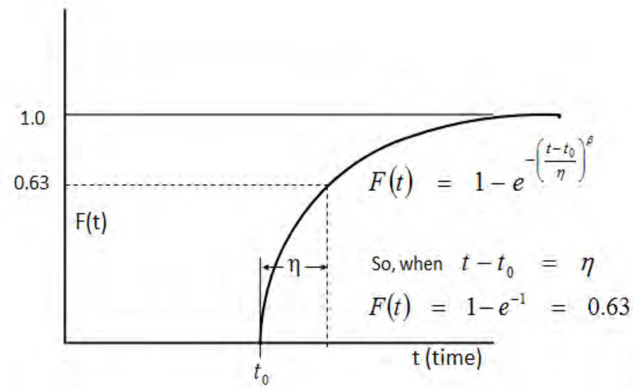
Lets say for an example for pressure vessel, the total failure in this research, for operating hours 0 – 4000 hours (5.5 months), beta factor is1.51 and eta factor is 2953.16 and the prediction is the total failure for the whole year. Thus, there are 8760 hours in a year, hence :

$$F(t) = F(8760) - F(4000)$$

$$F(t) = \left[1 - e^{-\left(\frac{8760}{2953.16}\right)^{1.51}} \right] - 1 - e^{-\left(\frac{4000}{2953.16}\right)^{1.51}}$$

$$= 0.99 - 0.79 = 0.2$$

Multiplying by the population, 0.2 * 4 = 0.8 (1 to the nearest), and we get the value of total expected failures in that year is 6 times.



As shown in the figure 2.5, the time at 0 to t_0 is where the 'safe' time for the components, which theoretically, there are no failures at all. This theory is based on best maintenance practices, which after maintenance being implied to the component, the component is assume to be 'new' again. So that's why the there are no failures assume to occur. The time for 0 to t_0 was the mean (hours) in table 5.0. The characteristic life is where the failure start to occur until at point, which at 0.63 percent of the failure is allowed. If two of the time values added, it will shows the exact time value of interval for the preventive maintenance. As in the characteristic life, doing preventive maintenance is not suitable yet corrective maintenance is more good to implied. This is because by doing PM at the eta time horizon, the failures will continue to occur yet waste the inventory values. It is simply to conclude that if an equipment, let's say an example is for reaction chamber, the eta value is 3154 and the mean life is 2929.46. By added this two value,

$$3154 + 2929.46 = 6083.46 \text{ hours}$$

It means the interval time for preventive maintenance that need to be done is every 6083.46 hours. However the corrective maintenance lies on the characteristic life. Mean while, the hazard function is an indicator about the 'severity' of the failures by the fraction of f (t) and R (t). By the following equation 3.9 below,

$$\mathrm{H(t)} = \frac{f(t)}{R(T)} = \frac{\beta}{\eta^{ß}}(t - t_0)^{\beta-1} \quad \ldots\ldots.(\ 3.9\ )$$

Hazard function is not too significant in terms of maintenance performance but however it can be implied at any of point to show the severity of failure occurrences.

5.5 Availability

The availability of a machines indicates the machines capabilities to operational. If the value of availability from equation 3.0 and 3.1 is 0.99 per equipment, hence it means that the 'available' percentage at the operating hours as given is in 0.99 percent ready and functional. In order to set up either series or parallel, the design of continuity of components can be arrange and analyze, which the parallel system is more 'available' rather than series. All the value of each single components is more than 0.95 of probabilities.

The value correspondence to then value of A is the MTBF and MTTR which as can be seem in table 8.3, the highest availability blocks are for the block A14 which indicates 0.99 availability. The availability value is to show 'which' among of the system needs more attention. The lowest availability is on the block A6 – A11. As we can see in process flow diagram in appendices C, the blocks in A6 – A11 is the main heart for the whole process unit. This is where the main process begin and that may explain why it is important to find the availability of each process so that the identification to know which system is more available is better. Also, availability can helps to plan the inventory plan based on the percentages; if the percentage of availability is lower, hence the more of spare parts is needed.

As for the conclusion, If the MTTR value is higher than MTBF, hence the availability is lower, but if the MTTR is lower than MTBF, then it is said that the availability is higher. As a conclusion, the value of MTTR need to be more emphasize in order to achieved the availability range target which it will be use in plant performance efficiency , overall equipment effectiveness (OEE) as the plant's key performance indicator or any available approaches that might be think is more suitable.

5.6 Maintenance cost

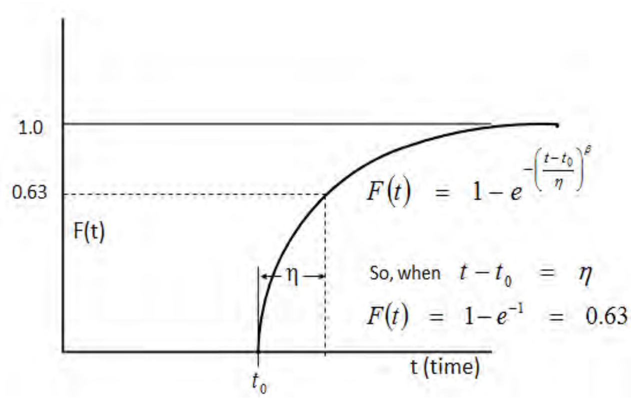
In economic analysis, the preventive maintenance cost is only based on labor cost and inventory cost.. The characteristics life, η indicates the optimized failures ‘authorized’ at a given time, which to indicates the optimization of maintenance activities at the particular hours. The characteristics life information can be found in appendices D (1 – 9), which the characteristics life is the key to optimization. The total maintenance cost as in table 8.4 is the total of maintenance cost before the optimization, which for 0-4000 hours of operation is RM 4 334 000.

This value are not include any mischiefs related maintenance cost but only in terms of preventive maintenance and corrective maintenance only. The information of the cost includes the PM cost and CM cost for the failures. The highest cost of maintenance is by scrubber and the lowest cost is by pressure vessel. This is because of the value of maintenance cost by scrubber are due to the quantity that much more than other components and as well for pressure vessel which has less of quantity. However, in terms of singularity, pressure vessel has the most high of maintenance cost per equipment.

In table 8.5, the frequencies of failures are according to table 4.4, which the failures are only occur at time range 0-4000 hours. In PM optimization from the equation 4.7 as follow,

$$\mathbf{PM_{opt.} = \eta / MTBF \quad .....(4.7)}$$

and from figure 2.5,



The significant of relationship between the equation 4.7 and the figure 2.5 is the time horizon. The failures between time t=0 and t_0 is when the 'safe' time which the assumption there are no failures occur. Characteristic life indicates failures start to occur from t_0 to t_n (where the characteristic life time horizon) , and at one point, the characteristic life (eta, η) is defined. Eta is mentioned as 'how much failures can be allowed' before the time goes to maximize of failures. MTBF is the benchmark for the failures which MTBF indicates the time of failures to another failure in a time horizon.

As per example, the pressure vessel as indicated in table 8.5, which the total amount of maintenance cost is RM 603 750. It is been reminded that the cost is including the CM cost, as in table 8.4. PM optimization for pressure vessel is 3.69, which there are 4 times of failure will occur in the optimized failure occurrence based on eta factor and figure 2.5. In this particular time, CM activities need to be done 4 times before PM, which at this point (characteristic life), we are only doing the corrective maintenance (run-to-failure), and the components is set (assume) to be as 'new' again after PM is implied after the characteristic life.

In such particular cases, the eta factor can optimized the maintenance cost which not included PM activities in characteristic life, so the redundancy of unnecessary maintenance activities in terms of maintenance planning. As in table 8.5, the optimized maintenance cost for 5 critical main component is reduced to RM 1 671 968.41 which the effectiveness of the total differences by comparing with the total maintenance cost before optimization, is 61.4%. The highest cost optimized is from reaction chamber, followed by heat exchanger, pressure vessel, scrubber and reducer. The value is too obvious that this is the effective approached to defined the maintenance effective cost by using Weibull method.

5.7 Data constraint

There are few of constraints that can't be override in terms of the data organization and management. The constraints here is the unpredictable or hidden factors that can influence the data to be inaccurate. The constraints are listed as follows :

i - Operation hours – The operation hours by using this method is only for 0-4000 hours range, which the range of hours is regarding about the after the maintenance being done, it get to be 0 hours back (assume after maintenance being done, the state of machine is ('new'). Hence, the failure expectation forwards is assuming if the condition state of the machines is constant as same for the historic failure data presented.

ii – Failures and equipment – The failures and analysis is based on preventive maintenance only and not includes corrective maintenance. Also, the failures state is based upon the quantities and not the specific which component. This is due to failure that occur is randomly falls in terms of the quantity.

iii – Labor size – The labor size also not included but to find most accurate of preventive activities, the labor works is assume as operational standard 12 hours shift. Also, the wages of labor's wages is not fixed which it depends on the company's policies.

iv – Inventory / spare parts – Spare parts and inventory also being assumed as the price and value for spare parts is differ in terms of the model, manufacturer, power consumption, global financial economic disorder and many more.

CHAPTER 6

RECOMMENDATION AND CONCLUSION

6.1 RECOMMENDATION

In order to achieve performance target in any types of process plant, asset integrity is one of the factors that need to be taken care of. Preventive maintenance is one out of few maintenance types beside corrective maintenance, predictive maintenance and pro-active maintenance. One of the disadvantages of preventive maintenance is the failure is still happening even though at the mean time, the prevention activities is done already. The sudden failures in preventive maintenance is the reason why the other types of maintenance task is developed.

Reliability centered maintenance (RCM) is one of recommendation which is highly regardless of the equipment. The function of reliability centered maintenance is to manage the types of failures, types of causes specifically, options of maintenance task that fit the most suitable for the failure, planning optimization and cost effective. Reliability centered maintenance is well known for all plant's maintenance policy, to save waste cost on no exact prediction, yet the cost is outflows. In RCM , maintenance fraction between all types of maintenance can be combine to build; CDM and PM, PdM and PRO-M and so on. This method can lead to a very successful maintenance plan regardless by stay focus on one types of preventive maintenance only.

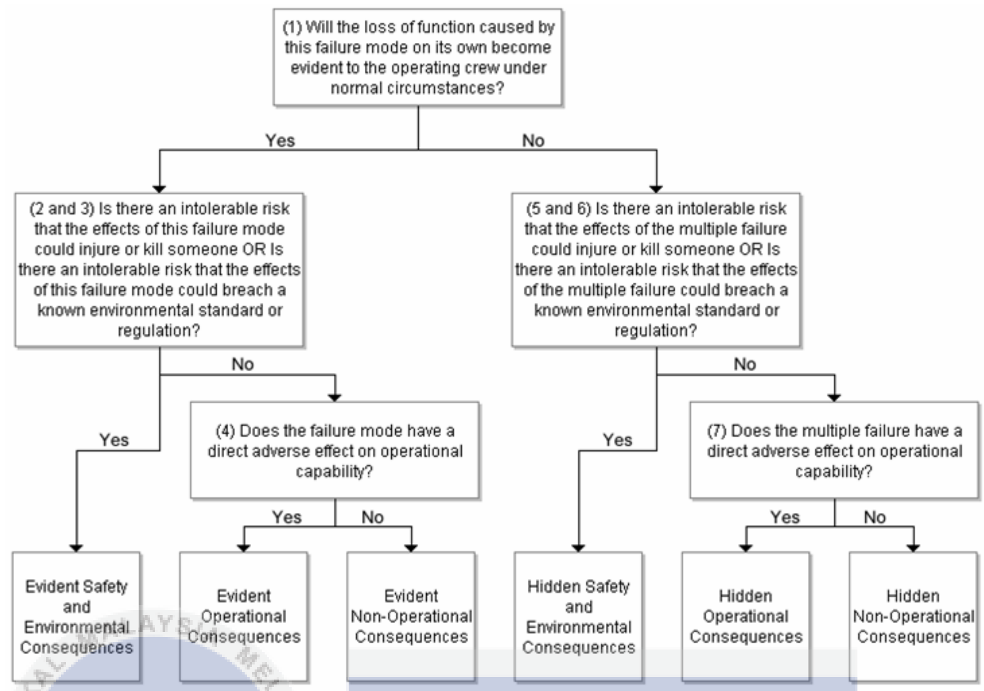


Figure 3.8 RCM logic process diagram

(Source : HotWire issue 73, hot topics, SAE J1012 RCM logic diagram)

6.2 CONCLUSION

In conclusion, the Weibull method to use as to find the performance of maintenance in terms of it's availability, reliability and hazard is a very effective way. While there are so much maintenance modeling approaches out there such as Markov, but one of the Weibull advantages is that the data is fixed and the parameters, can be evaluate for the three sub-performance indicator; failures, reliability and hazard. The objectives are to analyze the performance of preventive maintenance performance in terms of reliability by using Weibull method is successfully achieved.

The main findings in this research is all about beta and eta factors. These two parameters are the root of all equation and graph in Weibull method. As we can see in each of the components, the value of these two is differ from each others. The beta for pump, for example, 2.89 and for compressor is 2.57. In terms of bath tub curve, the value of these two components are exceeding 1, which it was in worn-out range. However, this is not the real findings, because in each components, there are many sub multi-components inside. Hence, the beta value is only an 'indicator' that the system is most probability to worn-out. It needs more deeper research and by any methods such as reliability centered maintenance to understand more of the failures and what types of maintenance plan that is more suitable for the components.

Eta factors is about 'how much failure can be considered' in terms of the components life cycle. In this research, for example, the characteristic life of pump, from the Weibull graph, the 'life of failures' that can be considerate is 1630 hours. By all means, in the particular time being, the components is said to be have optimized of life time 1630 hours before it needs preventive maintenance on it. The beta and eta factors are important especially in determine the planning and scheduling for PM in the future. Also, the Weibull method is very effective in terms to find the optimized maintenance cost, which in every company is emphasized on this particular matter. Cost and maintenance are two main parameters in a process plant, where it related to OEE of a plant in terms of a long time period or short term period. Hence, it is a main matters to understand the 'life' of a system in terms to enhance the productivity of a plant and Welbull method is one of it.

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