Research Article

Applying Reliability Engineering & Maintenance on Logistics Equipment in Factory of High Pressure Hydraulic Hose

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Abstract

This paper describes the applications of Reliability Engineering in the development of maintenance planning on Logistics Equipment in a Factory of High Pressure Hydraulic Hose. The main objective of Reliability Engineering on maintenance management is the effective maintenance planning of machine components inherent reliability value. Also, this research aims to reduce machine downtime maintenance that stems from machine breakdown, and to select preventive maintenance activities based on the engineering reliability for the machine parts. The first step of the research involves critical parts priority of Logistics Equipment. After that, we analyze the damage and risk level data by using Failure Mode and Effects Analysis (FMEA) in order to calculate the suitable reliability parameter. The final step is to select the preventive maintenance task. As a result of this research, the failure rate of Logistics Equipment can be reduced 7.99% and the machine availability rate of Logistics Equipment is increased to 80.94% accordingly. Within this context, a maintenance program for Logistics Equipment is carried out based on Reliability Engineering concept. Applying the reliability engineering for maintenance planning & application on Logistics Equipment in Factory of High Pressure Hydraulic Hose showed that the main time between failures for this equipment and the probability of sudden equipment failures are decreased.

Keywords: Reliability Engineering; Maintenance Planning; FMEA.

1. Introduction

Reliability Engineering for Maintenance Management (REM) is a corporate level maintenance strategy that is implemented to optimize the maintenance program of a company or facility. The final results of an REM program are the maintenance strategies that should be implemented on each of the assets of the facility. The maintenance strategies are optimized so that the functionality of the plant is maintained using cost-effective maintenance techniques. This work aims to generate a maintenance program that is based on the REM technique for the process-steam plant components. This technique should be able to minimize the downtime and improve the availability of the plant components [1]. The developed Preventive Maintenance (PM) programs minimize equipment failures and provide industrial plants with effective equipment [2]. REM is one of the best

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known and most used devices to preserve the operational efficiency of the steam system. However, it is difficult to select a suitable maintenance strategy for each piece of equipment and each failure mode, for the great quantity of equipment and uncertain factors of maintenance strategy decision [3,4]. REM philosophy employs PM, predictive maintenance (PdM), real-time monitoring, run-to-failure and proactive maintenance techniques is an integrated manner to increase the probability that a machine or component will function in the required manner over its design life cycle with a minimum of maintenance [5,6]. Reliability-centered maintenance (RCM) is the optimum mix of reactive, time or interval-based, condition-based, and proactive maintenance practices [7]. The components of RCM program are shown in Fig. 1. This figure showing that RCM program consists of (reactive maintenance, preventive maintenance, condition based maintenance, and proactive maintenance) and its patterns.

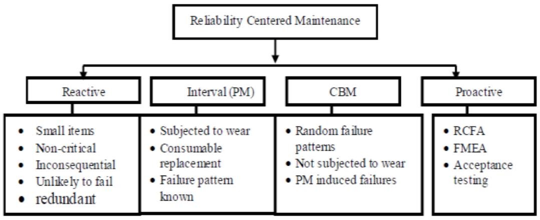


Fig.1. Components of RCM program.

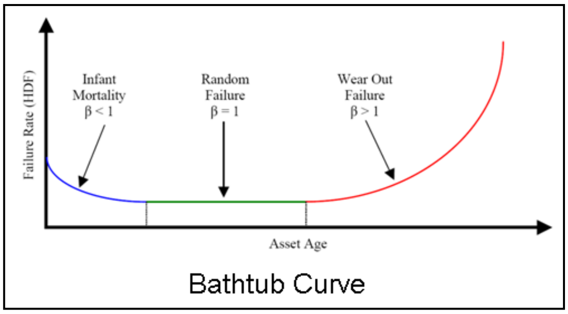


Fig.2. Bathtub Curve & Hazard Rate on Lifecycle of Maintenance.

Hazard Rate is very important for Maintenance Engineering because it is popular to use in order to estimate Time to Failure or Availability of System. It is a function that depends on time. We applied Bathtub Curve in Fig. 2 to be explain Hazard Rate on lifecycle of maintenance.

The bathtub curve was integrated with Weibull distribution. This is one of the most important aspects of the effect of β on Weibull distribution. Applications on Weibull distributions with Reliability theory, we must consider the probability that each part isn't less than the limit time.

Weibull distributions with $\beta < 1$ have a failure rate that decreases with time, also known as infantile or early-life failures. Weibull distributions with β close to or equal to 1 have a fairly constant failure rate, indicative of useful life or random failures. Weibull distributions with $\beta > 1$ have a failure rate that increases with time, also known as wear-out failures. These comprise of three sections of the classic "bathtub curve." A mixed Weibull distribution with one subpopulation with $\beta < 1$, one subpopulation with $\beta = 1$ and one subpopulation with $\beta > 1$ would have a failure rate plot that was identical to the bathtub curve.

2. Materials and Methods

2.1 Our Case Study

Semperflex Asia Corporation Limited (Semperflex) is a joint venture between STA and Semperit Technische Produkte Gesellschaft m.b.H. It was established in 1996 to manufacture and distribute high-pressure hydraulic hoses for industrial use in Fig. 3. Semperflex is Thailand's largest producer of high-pressure hydraulic hoses, with production facilities located in Thailand, Austria, China and the Czech Republic as well as distribution channels in the USA, Singapore, China, India, Brazil and Austria. High-pressure hydraulic hoses produced by Semperflex have gained global recognition thanks to their high quality and wide variety. Semperflex has used Logistics Equipment in Fig. 4 about 20 units in this factory.

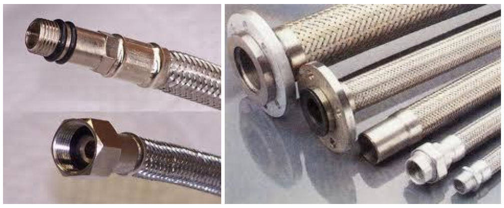


Fig.3. Sample products of High Pressure Hydraulic Hose.

Fig.4. Logistics Equipment in Factory of High Pressure Hydraulic Hose.

2.2 RCM Steps

The RCM steps are presented in Fig. 5. The steps describe the systematic approach used to implement the preserves the system function, identifies failure mode, priorities failure, identifies failure mode, priorities failure modes and performs PM tasks.

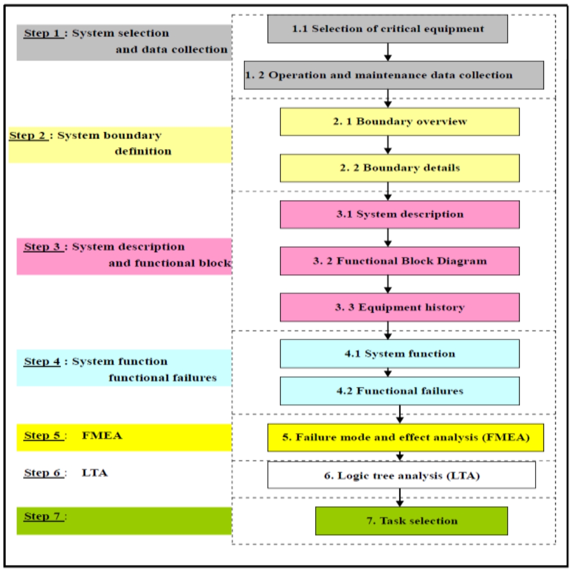


Fig.5. Main steps of the RCM.

2.3 System Selection and Data Collection

Determining the list of the system components is one of the first steps in RCM. The criticality analysis requires different kind of data of each component that build up the system. The effect of failure of the system main components may effect system productivity and maintenance cost. The factors effecting selection of critical system are as follows:

1) Mean-time between failures
2) Total maintenance cost
3) Mean time to repair
4) Availability.

2.4 Logic Tree Analysis (LTA)

The basic (LTA) uses the decision tree structure shown in Fig. 6 from this figure, decision bins: 1) safety-related, 2) outage-related, or 3) economic-related were noticed. Each failure mode is entered into the top box of the tree, where the first question is posed: Does the operator, in the normal course of his or her duties, know that something of an abnormal or detrimental nature has occurred in the plant? It is not necessary that the operator know exactly what is awry for the answer to be yes [6].

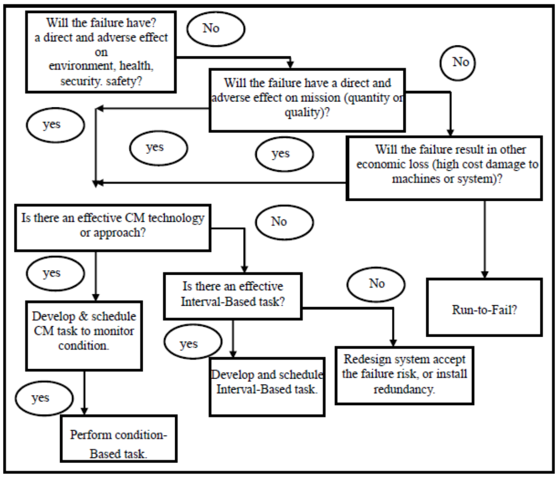


Fig.6. Reliability-centered maintenance (RCM) logic tree.

2.5 Criticality Analysis

Criticality analysis is a tool used to evaluate how equipment failures impact organizational performance in order to systematically rank plant assets for the purpose of work prioritization, material classification, PM/PdM development and reliability improvement initiatives [9]. In general, failure modes, effects and criticality analysis (FMEA/FMECA) required the identification of the following basic information in Table 1. Criticality of each machine (MC) was calculated based on the following four criteria:

1. Effect of the machine downtime on the production process (EM)

2. Utilization rate of the machine (Bottleneck or not) (UR)

3. Safety & environmental incidence of machine failure (SEI)

4. Technical complexity of the machine and need of external maintenance resources (MTC).

Each of the criteria was given a weight showing its importance relative to the criticality indices. The weight of each criterion ranges from zero (no effect) to three (very important effect). Machine criticality was then calculated in Eq. (1) and criticality codes such as A (most critical machine): 20 to 27, B: 12 to 19, C: 0 to 11.

$$MC = 3*EM + 2*UR + 3*SEI + I*MTC \quad (1)$$

2.6 Failure Mode Effects Analysis (FMEA)

Failure modes and effects analysis (FMEA) is a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service.

This is the severity rating, or S. Severity is usually rated on a scale from 1 to 10, where 1 is insignificant and 10 is catastrophic.

Table1. Sample of some values of machine criticality.

Part No.	Weight	3	3	2	1	MC	Criticality Code
	Machine Code	SEI	EM	UR	MCT		
1	HARNESS	1	1	2	1	11	C
2	PAN	1	2	2	3	16	B
3	ACUMULATOR	2	3	3	2	23	A
4	HYDRAULIC OIL HYSPIN A WS 32	1	1	2	1	11	C
5	MOTOR	3	3	2	3	26	A
6	PUMP	2	3	3	2	23	A
7	VALVE	1	2	2	1	14	B
8	LOGIC CARD	2	2	3	2	20	A
9	Contactor	2	2	3	2	20	A
10	Packing set	1	2	2	1	14	B
11	Plate	1	2	2	1	14	B
12	Screw	1	1	2	1	11	C

If a failure mode has more than one effect, write on the FMEA table only the highest severity rating for that failure mode.

For each cause, determine the occurrence rating, or O. This rating estimates the probability of failure occurring for that reason during the lifetime of your scope. Occurrence is usually rated on a scale from 1 to 10, where 1 is extremely unlikely and 10 is inevitable. On the FMEA table, list the occurrence rating for each cause.

For each control, determine the detection rating, or D. This rating estimates how well the controls can detect either the cause or its failure mode after they have happened but before the customer is affected. Detection is usually rated on a scale from 1 to 10, where 1 means the control is absolutely certain to detect the problem and 10 means the control is certain not to detect the problem (or no control exists). On the FMEA table, list the detection rating for each cause.

The risk priority number, or RPN was then calculated in Eq. (2).

$$RPN = (S) \times (O) \times (D) \quad (2)$$

Risk Evaluation such as Small Risk: RPN < 60, Medium Risk: RPN < 80 and High Risk: RPN <100 and Crisis Risk: RPN > 100, then we should consider the RPN of components with the highest value first. Table 2 shows a sample of some values of RPN.

2.7 Maintenance Assessment of Reliability Engineering

We applied a Maintenance Assessment of Reliability Engineering to calculate the probability on the parameters of reliability. First, we collected the data of Time To Fail: TTF to support calculating parameters in Table 3. After that, we adopted Reliability Engineering for the calculation by using graph probability (Probability Plotting) with Statistical Software in Fig. 7 to estimate the parameters

Table2. Sample of some values of RPN (Criticality Code: A).

No.	Machine Code	Features of damage	Severity (SEV)		Occurrence (OCC)		Detection (DET)		RPN
			Information	Scores	Information	Scores	Information	Scores	
1	ACUMULATOR	Having unusual noise	It can not produce efficiently.	6	Failure of electrical systems	6	Check with hearing	6	216
		Not working	It can not produce efficiently.	5	Using electrical overload	5	Daily monitoring	5	125
2	MOTOR	Having unusual noise	It can not produce efficiently.	6	Failure of bearings and gear	6	Check with hearing	6	216
		Motor stopped unexpectedly (burns)	To stop production	6	Using electrical overload	3	Daily monitoring	3	54
3	PUMP	Loose	Vibration and noise	5	Fixing problem and corrosion caused by chemicals	6	Visual inspection and Check with hearing	4	120
		Motor stopped unexpectedly (burns)	To stop production	6	Using electrical overload	3	Daily monitoring	3	54
4	LOGIC CARD	Not working	It can not produce efficiently.	5	Using electrical overload	5	Daily monitoring	5	125
5	Contactor	Not working	It can not produce efficiently.	5	Using electrical overload	5	Daily monitoring	5	125
6	Chain	Loose	Vibration and noise	5	Fixing problem, overload and corrosion caused by chemicals	6	Visual inspection and Check with hearing	4	120
7	CABLE	Loose	Vibration and noise	5	Fixing problem, overload and corrosion caused by chemicals	6	Visual inspection and Check with hearing	4	120
8	Logic box	Not working	It can not produce	5	Using electrical overload	5	Daily monitoring	5	125

Table3. Sample of the data for Time To Fail: TTF (unit: hour).

No.	Machine Code	Time To Failure : TTF				
		1	2	3	4	5
1	ACUMULATOR	4,480	28,000	61,600	92,960	125,440
2	MOTOR	10,080	21,280	33,040	45,360	57,344
3	PUMP	3,360	14,560	28,784	43,364	57,680
4	LOGIC CARD	20,160	38,080	58,240	76,160	95,200
5	Contactor	12,656	18,816	30,016	42,560	54,320
6	Chain	13,440	20,160	33,600	48,160	61,600
7	CABLE	20,160	52,080	83,440	115,360	145,600
8	Logic box	70,560	100,800	134,400	153,440	179,200
9	SRO01 Overhead Charge	36,960	72,800	112,000	134,400	168,000
10	Brake Compl.	42,000	84,000	128,800	159,040	182,560
11	Nut	33,600	67,200	90,720	112,000	151,200
12	BT CTX1300 Serial No.42715	22,400	44,800	68,880	100,800	134,400
13	Joystick (QU : BB13090045)	33,600	63,840	95,200	123,200	168,000

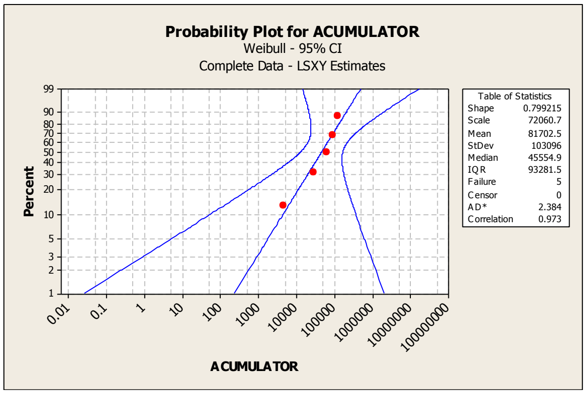


Fig.7. Sample of Probability Plotting with Statistical Software (Source: Minitab Inc., Minitab 17 trial version [Online], accessed 30 August 2014. Available from http://www.minitab.com).

In addition, we tested conditions about Goodness of Fit Test to confirm that a hypothesized distribution fits a data set by Kolmogorov-Smirnov Test for the small population using Eq. (3)-(6). Then we created Excel Simulation to calculate Eq. (3)-(6) in Table 6 and the results on Goodness of Fit are summarized in Table 7.

Statistical Hypothesis:
H_0: TTF Data is Weibull distribution with β (Sharpe) and η (Scale)
H_1: TTF Data isn't Weibull distribution with β (Sharpe) and η (Scale)
Test Statistics by Kolmogorov-Smirnov Test:

$$d = max\left\{\left|F(t_i) - \hat{F}(t_i)\right|, \left|F(t_i) - \hat{F}(t_{i-1})\right|\right\} \quad (3)$$

$$F(t_i) = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}} \quad (4)$$

$\hat{F}(t_i) =$ Opportunity of Breakdown (in Table 4) (5)

d_α = Critical Values of Komogorov-Smirnov Tests (in Table 5) (6)

Decision criteria on Significance level (α): Acceptd H_0 if $d < d_\alpha$

Table4. Median Rank [13].

j \ n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	50.000	29.289	20.630	15.910	12.945	10.910	9.428	8.300	7.412	6.697	6.107	5.613	5.192	4.830	4.516	4.240	3.995	3.778	3.582	3.406
2		70.711	50.000	38.573	31.381	26.445	22.849	20.113	17.962	16.226	14.796	13.598	12.579	11.702	10.940	10.270	9.678	9.151	8.677	8.251
3			79.370	61.427	50.000	42.141	36.412	32.052	28.624	25.857	23.578	21.669	20.045	18.647	17.432	16.365	15.422	14.581	13.827	13.147
4				84.090	68.619	57.859	50.000	44.015	39.308	35.510	32.380	29.758	27.528	25.608	23.939	22.474	21.178	20.024	18.988	18.055
5					87.055	73.555	63.588	55.984	50.000	45.169	41.189	37.853	35.016	32.575	30.452	28.589	26.940	25.471	24.154	22.967
6						89.090	77.151	67.948	60.691	54.831	50.000	45.951	42.508	39.544	36.967	34.705	32.704	30.921	29.322	27.880
7							90.572	79.887	71.376	64.490	58.811	54.049	50.000	46.515	43.483	40.823	38.469	36.371	34.491	32.795
8								91.700	82.038	74.142	67.620	62.147	57.492	53.485	50.000	46.941	44.234	41.823	39.660	37.710
9									92.587	83.774	76.421	70.242	64.984	60.456	56.517	53.059	50.000	47.274	44.830	42.626
10										93.303	85.204	78.331	72.472	67.425	63.033	59.177	55.766	52.726	50.000	47.542
11											93.893	86.402	79.955	74.392	69.548	65.295	61.531	58.177	55.170	52.458
12												94.387	87.421	81.353	76.061	71.411	67.296	63.629	60.340	57.374
13													94.808	88.298	82.568	77.525	73.060	69.079	65.509	62.289
14														95.169	89.060	83.635	78.821	74.529	70.678	67.205
15															95.484	89.730	84.578	79.976	75.846	72.119
16																95.760	90.322	85.419	81.011	77.033
17																	96.005	90.849	86.173	81.945
18																		96.222	91.322	86.853
19																			96.418	91.749
20																				96.590

(Source: Jardaine, Andrew K.S., and Albert H.C. Tsang, Maintenance Replacement and Reliability Theory and Application, Boca Raton Florida : Taylor & Francis Group, 2013)

Table5. Critical Values of Komogorov-Smirnov Tests [13].

Sample Size	Level of Significance (d_α)				
n	0.2	0.1	0.05	0.02	0.01
1	0.900	0.950	0.975	0.990	0.995
2	0.684	0.776	0.842	0.900	0.929
3	0.565	0.636	0.708	0.785	0.829
4	0.493	0.565	0.624	0.689	0.734
5	0.447	0.509	0.563	0.627	0.669
6	0.410	0.468	0.519	0.577	0.617
7	0.381	0.436	0.483	0.538	0.576
8	0.358	0.410	0.454	0.507	0.542
9	0.339	0.387	0.430	0.480	0.513
10	0.323	0.369	0.409	0.457	0.489
11	0.308	0.352	0.391	0.437	0.468
12	0.296	0.338	0.375	0.419	0.449
13	0.285	0.325	0.361	0.404	0.432
14	0.275	0.314	0.349	0.390	0.418
15	0.266	0.304	0.338	0.377	0.404
16	0.258	0.295	0.327	0.366	0.392
17	0.250	0.286	0.318	0.355	0.381
18	0.244	0.279	0.309	0.346	0.371
19	0.237	0.271	0.301	0.337	0.361
20	0.232	0.265	0.294	0.329	0.352
25	0.208	0.238	0.264	0.295	0.317
30	0.190	0.218	0.242	0.270	0.290
35	0.177	0.202	0.224	0.251	0.269
40	0.165	0.189	0.210	0.235	0.252
Over 40	$1.07/\sqrt{n}$	$1.22/\sqrt{n}$	$1.36/\sqrt{n}$	$1.52/\sqrt{n}$	$1.63/\sqrt{n}$

(Source: Jardaine, Andrew K.S., and Albert H.C. Tsang, Maintenance Replacement and Reliability Theory and Application, Boca Raton Florida : Taylor & Francis Group, 2013)

Table6. Excel Simulation to calculate the equation (3)-(6).

	A	B	C	D	E	F	G	H	I	J	K	L	M
2	t_i	η	t/η	β (Shape)	$(t/η)^β$	e = 2.7182	$e^{(t/η)^β}$	$1/e^{(t/η)^β}$	$F(t_i) = 1 - (1/e^{(t/η)^β})$	$\hat{F}(t_i)$ by Median Rank Table	$\|F(t_i) - \hat{F}(t_i)\|$	$\|F(t_i) - \hat{F}(t_{i-1})\|$	d
3	4,480	72060.7	0.0622	0.799215	0.1086	2.7182	1.11471	0.8971	0.1029	0.12945	0.0265		0.0265
4	28,000	72060.7	0.3886	0.799215	0.4698	2.7182	1.59962	0.6251	0.3749	0.31381	0.0610	0.2454	0.2454
5	61,600	72060.7	0.8548	0.799215	0.8822	2.7182	2.41612	0.4139	0.5861	0.50000	0.0861	0.2723	0.2723
6	92,960	72060.7	1.2900	0.799215	1.2257	2.7182	3.40652	0.2936	0.7064	0.68619	0.0203	0.2064	0.2064
7	125,440	72060.7	1.7408	0.799215	1.5574	2.7182	4.74631	0.2107	0.7893	0.87055	0.0812	0.1031	0.1031
8												max d =	0.2723

Table7. Sample of the summarized results on Goodness of Fit (Criticality Code: A).

No.	Machine Code	Parameters		K-S Test (α = 0.05, n)			Hypothesis Test:
		β	η	max d	d_α	n	
1	ACUMULATOR	0.799215	72060.7	0.2723	0.563	5	accepted H_0
2	MOTOR	1.51643	39238.5	0.2234	0.563	5	accepted H_0
3	PUMP	0.933295	34497.5	0.2564	0.563	5	accepted H_0
4	LOGIC CARD	1.69412	67296.9	0.2291	0.563	5	accepted H_0
5	Contactor	1.76227	36694.6	0.2271	0.563	5	accepted H_0
6	Chain	1.67860	41049.1	0.2295	0.563	5	accepted H_0
7	CABLE	1.34070	98302.3	0.2381	0.563	5	accepted H_0
8	Logic box	2.82230	144370	0.2445	0.563	5	accepted H_0
9	SRO01 Overhead Charge	1.75237	122522	0.2606	0.563	5	accepted H_0
10	Brake Compl.	1.77698	139330	0.2671	0.563	5	accepted H_0
11	Nut	1.81834	105994	0.2243	0.563	5	accepted H_0
12	BT CTX1300 Serial No.42715	1.47372	86887.3	0.2120	0.563	5	accepted H_0
13	Joystick (QU : BB13090045)	1.66486	113045	0.2144	0.563	5	accepted H_0

3.8 Maintenance & Reliability Technology Management

We define the task of preventive maintenance in accordance with the results of estimating Reliability to each component by choosing a category and preventative maintenance based on the statistical properties of Failure Mode. We used logic to select a combination of the principle of maintenance and reliability as shown in Fig. 8. We are able to analyze the data further that

1. Selecting the maintenance task for Weibull Parameter Estimation : $\beta \sim 1$ is Preventive Maintenance (PM).

2. Selecting the maintenance task for Weibull Parameter Estimation : $\beta > 1$ is Predictive Maintenance (PdM) and Corrective Maintenance.

2.9 Maintenance Period Analysis

If $\beta \sim 1$: Constant Failure Mode regarded as Exponential Distribution. We applied the technique of Failure Finding by calculating the inspection interval in Eq. (7) [13]. Also, we created Excel Simulation to calculate Eq. (7) in Table 8.

$$A = 1 - \frac{FFI}{2M} \quad (7)$$

by A = Availability of the protective device

FFI = The inspection interval (t_i)

M = MTTF

If $\beta > 1$ considered Increase Failure Mode. We applied the technique of Determination of Optimal Preventive Replacement Interval to determine the optimal replacement interval (t_p) between preventive replacements to minimize total downtime per unit time by calculating in Eq. (8) and (9) [13]. So, we created Excel Simulation to calculate Eq. (8) and (9) in Table 9.

$$D(t_p) = \frac{H(t_p)\,T_f + T_p}{t_p + T_p} \quad (8)$$

$$\mathrm{H}(t) = \frac{\beta}{\eta} \times \left[\frac{t}{\eta}\right]^{\beta-1} \quad (9)$$

By

$D(t_p)$ = The total Downtime per unit time

$H(t_p)$ = The number of failures in interval (0, t_p)

T_p = The mean downtime required to make a failure replacement

T_f = The mean downtime required to make a preventive replacement

t_p = Preventive replacement at time

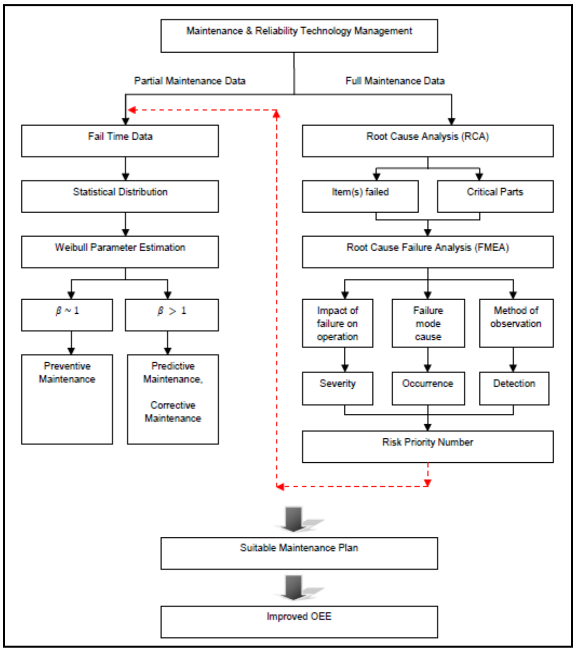


Fig.8. Logic in a combination of the principle of maintenance and reliability.

Table8. Excel Simulation to calculate Eq.(7).

	A	B	C	D	E
1			1. A of ACUMULATOR		
2	t_i	η	2M = 2η ; (if β~1)	t_i / 2M	A = 1 - (t_i / 2M)
3	1000	72060.7	144121.4	0.006939	0.993061
4	2000	72060.7	144121.4	0.013877	0.986123
5	3000	72060.7	144121.4	0.020816	0.979184
6	4000	72060.7	144121.4	0.027754	0.972246
7	5000	72060.7	144121.4	0.034693	0.965307
8	6000	72060.7	144121.4	0.041632	0.958368
9	7000	72060.7	144121.4	0.048570	0.951430
10	8000	72060.7	144121.4	0.055509	0.944491
11	9000	72060.7	144121.4	0.062447	0.937553
12	10000	72060.7	144121.4	0.069386	0.930614
13	11000	72060.7	144121.4	0.076325	0.923675
14	12000	72060.7	144121.4	0.083263	0.916737
15	13000	72060.7	144121.4	0.090202	0.909798
16	14000	72060.7	144121.4	0.097140	0.902860
17	15000	72060.7	144121.4	0.104079	0.895921
18	16000	72060.7	144121.4	0.111018	0.888982
19	17000	72060.7	144121.4	0.117956	0.882044
20	18000	72060.7	144121.4	0.124895	0.875105
21	19000	72060.7	144121.4	0.131833	0.868167
22	20000	72060.7	144121.4	0.138772	0.861228
23	21000	72060.7	144121.4	0.145710	0.854290
24	22000	72060.7	144121.4	0.152649	0.847351
25	23000	72060.7	144121.4	0.159588	0.840412
26	24000	72060.7	144121.4	0.166526	0.833474

Table9. Excel Simulation to calculate Eq. (8) and (9).

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1								1. D (t_p) of Logic box							
2	t_p	β*10	η	β / η	t / η	β-1	$(t/η)^{β-1}$	H(t_p)	T_f *10	T_p *10	H(t_p) T_f	H(t_p) T_f + T_p	t_p + T_p	D (t_p)	MIN
3	10000	28.223	144370	0.000195	0.069266	27.223	0.000000	0.000000	8500	672	4.5301E-32	6.7200E+02	10672	0.062969	0.004352
4	20000	28.223	144370	0.000195	0.138533	27.223	0.000000	0.000000	8500	672	7.0965E-24	6.7200E+02	20672	0.032508	
5	30000	28.223	144370	0.000195	0.207799	27.223	0.000000	0.000000	8500	672	4.4134E-19	6.7200E+02	30672	0.021909	
6	40000	28.223	144370	0.000195	0.277066	27.223	0.000000	0.000000	8500	672	1.1117E-15	6.7200E+02	40672	0.016522	
7	50000	28.223	144370	0.000195	0.346332	27.223	0.000000	0.000000	8500	672	4.8324E-13	6.7200E+02	50672	0.013262	
8	60000	28.223	144370	0.000195	0.415599	27.223	0.000000	0.000000	8500	672	6.9138E-11	6.7200E+02	60672	0.011076	
9	70000	28.223	144370	0.000195	0.484865	27.223	0.000000	0.000000	8500	672	4.5942E-09	6.7200E+02	70672	0.009509	
10	80000	28.223	144370	0.000195	0.554132	27.223	0.000000	0.000000	8500	672	1.7415E-07	6.7200E+02	80672	0.008330	
11	90000	28.223	144370	0.000195	0.623398	27.223	0.000003	0.000000	8500	672	4.2998E-06	6.7200E+02	90672	0.007411	
12	100000	28.223	144370	0.000195	0.692665	27.223	0.000046	0.000000	8500	672	7.5701E-05	6.7200E+02	100672	0.006675	
13	110000	28.223	144370	0.000195	0.761931	27.223	0.000610	0.000000	8500	672	1.0138E-03	6.7200E+02	110672	0.006072	
14	120000	28.223	144370	0.000195	0.831198	27.223	0.006518	0.000001	8500	672	1.0831E-02	6.7201E+02	120672	0.005569	
15	130000	28.223	144370	0.000195	0.900464	27.223	0.057602	0.000011	8500	672	9.5716E-02	6.7210E+02	130672	0.005143	
16	140000	28.223	144370	0.000195	0.969731	27.223	0.433114	0.000085	8500	672	7.1969E-01	6.7272E+02	140672	0.004782	
17	150000	28.223	144370	0.000195	1.038997	27.223	2.833291	0.000554	8500	672	4.7080E+00	6.7671E+02	150672	0.004491	
18	160000	28.223	144370	0.000195	1.108263	27.223	16.417881	0.003210	8500	672	2.7281E+01	6.9928E+02	160672	0.004352	
19	170000	28.223	144370	0.000195	1.177530	27.223	85.520415	0.016718	8500	672	1.4211E+02	8.1411E+02	170672	0.004770	
20	180000	28.223	144370	0.000195	1.246796	27.223	405.361241	0.079244	8500	672	6.7358E+02	1.3456E+03	180672	0.007448	
21	190000	28.223	144370	0.000195	1.316063	27.223	1766.314738	0.345298	8500	672	2.9350E+03	3.6070E+03	190672	0.018917	
22	200000	28.223	144370	0.000195	1.385329	27.223	7136.715526	1.395162	8500	672	1.1859E+04	1.2531E+04	200672	0.062445	

Table10. Sample of Assessment Guidelines in Maintenance & Reliability Engineering (Criticality Code: A).

No.	Machine Code	Parameters		Type of maintenance	Period of Maintenance (Hours)
		β	η		
1	ACUMULATOR	0.799215	72060.7	PM	21,000
2	MOTOR	1.51643	39238.5	PM	11,000
3	PUMP	0.933295	34497.5	PM	10,000
4	LOGIC CARD	1.69412	67296.9	PM	20,000
5	Contactor	1.76227	36694.6	PM	11,000
6	Chain	1.67860	41049.1	PM	12,000
7	CABLE	1.34070	98302.3	PM	29,000
8	Logic box	2.82230	144370	PdM	160,000
9	SRO01 Overhead Charge	1.75237	122522	PM	36,000
10	Brake Compl.	1.77698	139330	PM	41,000
11	Nut	1.81834	105994	PM	31,000
12	BT CTX1300 Serial No.42715	1.47372	86887.3	PM	26,000
13	Joystick (QU : BB13090045)	1.66486	113045	PM	33,000

and the results on Assessment Guidelines for the maintenance of Reliability Engineering are summarized in Table 10. In addition, we are able to develop the maintenance planning for the plant of Hard Chrome Plating in Fig.9. by applying reliability-centered maintenance of the plant components inherent reliability value.

Our case study of Logic box which has the period of maintenance: 160,000 hours. We selected the way to replace this Logic box. In addition, our period of maintenance of Logic box is used to support annual planning of maintenance cost to prepare ordering the new item of Logic box.

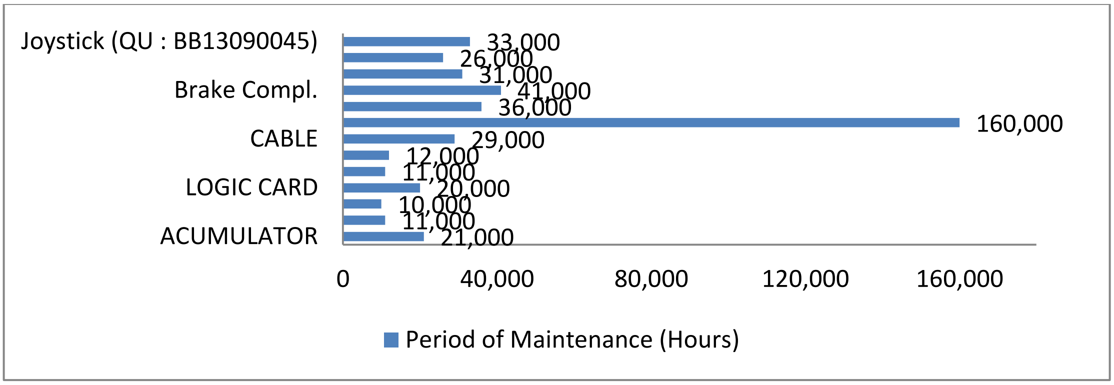


Fig.9. Sample of maintenance planning for Logistics Equipment (Criticality Code: A).

3. Results and Discussion

3.1 Case Study Result

The measurements on this research was divided into 2 parts: (1) Before the improved maintenance plan: November 2012 to October 2013, and (2) After the improved maintenance plan: November 2013 to October 2014.

We then created an Excel Simulation to calculate a performance summary before and after the improved maintenance plan in Table 11. As a result of this research, the failure rate of the plant can be reduced 7.99% and the machine availability rate of the plant is increased to 80.94% accordingly.

Table11. Excel Simulation to calculate performance summary of maintenance plan.

16	Performance after the improved maintenance plan					
17	Month	Year	A: Times for workload (hours)	B: Loss time in operating (hours)	B / A: Loss Ratio (%)	1-(B / A): Availability Rate (%)
18	November	2013	480	105.02	21.88	78.12
19	December	2013	530	114.16	21.54	78.46
20	January	2014	540	107.19	19.85	80.15
21	February	2014	510	98.43	19.30	80.70
22	March	2014	480	92.59	19.29	80.71
23	April	2014	330	61.35	18.59	81.41
24	May	2014	480	85.78	17.87	82.13
25	June	2014	490	87.22	17.80	82.20
26	July	2014	550	100.16	18.21	81.79
27	August	2014	510	99.81	19.57	80.43
28	September	2014	480	84.86	17.68	82.32
29	October	2014	480	82.47	17.18	82.82
30	Average monthly		488.33	93.25	19.06	80.94
31						

32	The summary of performance before - after the improved maintenance plan				
33	Department	Performance index	Before	After	Different
34	Logistics Equipment	Loss time in operating (hours)	129.24	93.25	35.98
35		Loss Ratio (%)	27.05	19.06	7.99
36		Availability Rate (%)	72.95	80.94	-7.99

3.2Statistical analysis of the results

To confirm our results of this research, we used statistical analysis for the effect of Loss time in operating (hours) which is reduced with significant or not. We applied the statistical comparison of loss time in operating (hours) before and after the improved maintenance plan (each mouth) based on the hypothesis testing procedure for the population means on 2 groups by Test Statistics in the equation (10) and (11).

Statistical Hypothesis:

$$H_0 : \mu_1 - \mu_2 \geq d_0 \qquad (d_0 = 0)$$

$$H_1 : \mu_1 - \mu_2 < d_0$$

by

$\mu_1 =$ Average of population 1: Average of loss time (before)

$\mu_2 =$ Average of population 2: Average of loss time (after)

$d_0 =$ Difference between average of two populations

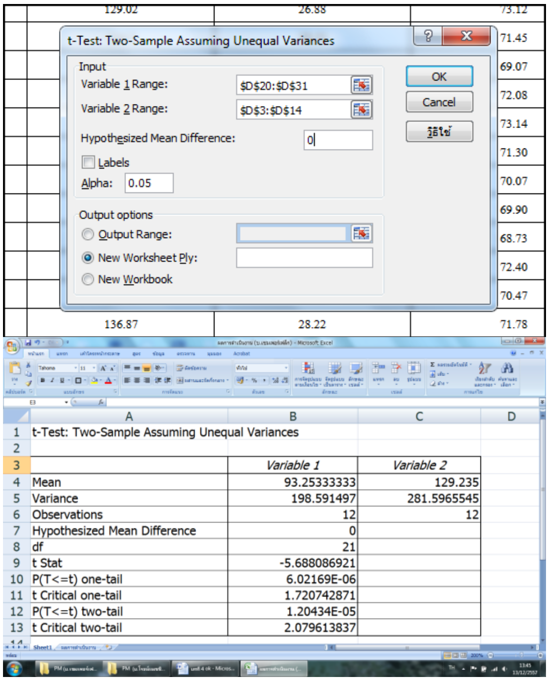
Test Statistics: $$T = \frac{(\overline{X_1} - \overline{X_2}) - d_0}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$

; in case n < 30 (10)

$$v = \frac{\left(\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}\right)^2}{\frac{\left(\frac{S_1^2}{n_1}\right)^2}{n_1 - 1} + \frac{\left(\frac{S_2^2}{n_2}\right)^2}{n_2 - 1}} \qquad (11)$$

Decision criteria on Significance level (α) : Reject H_0 if $T \leq -t_\alpha$ or P-Value < α

Consequently, we applied Excel for Statistical analysis on the hypothesis testing procedure for the population means on 2 groups in Fig. 10.



	A	B	C
1	t-Test: Two-Sample Assuming Unequal Variances		
2			
3		*Variable 1*	*Variable 2*
4	Mean	93.25333333	129.235
5	Variance	198.591497	281.5965545
6	Observations	12	12
7	Hypothesized Mean Difference	0	
8	df	21	
9	t Stat	-5.688086921	
10	P(T<=t) one-tail	6.02169E-06	
11	t Critical one-tail	1.720742871	
12	P(T<=t) two-tail	1.20434E-05	
13	t Critical two-tail	2.079613837	

Fig.10. Excel for Statistical analysis on the hypothesis testing.

It can be said that Excel for Statistical analysis on the hypothesis testing gave us Reject H_0. So, The statistical test was selected to review and analyze the result of this research that it reaches to significant level at 0.05 which P-Value less than the significant level (P-Value < α)

4. Conclusion

Within this context, a maintenance program for the plant is carried out based on this reliability-centered maintenance concept. Applying of the reliability-centered maintenance methodology showed that the main time between failures for the plant equipment and the probability of sudden equipment failures are decreased.

We should follow up on the data of damage system after established preventive maintenance based on reliability engineering used constantly to improve the maintenance plan to suit the current conditions. Workers should be trained to know how to find the real cause of the damage in the machine and the manufacturing process including loss of data collection in order to be properly diagnosed and resolved the following points. In fact, the previous data history of the components and the previous maintenance plans together with a probabilistic study are considered in the model to improve accuracy.

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