

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 in 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.

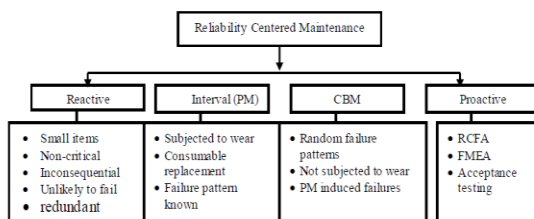


Fig.1.Components of RCM program.

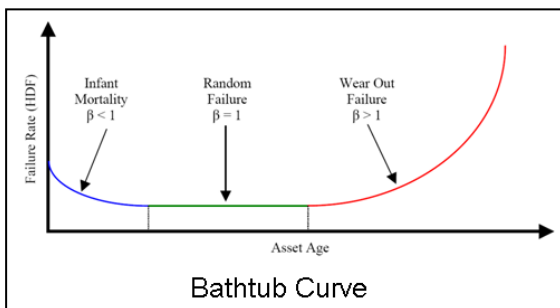


Fig.2.Bathtub Curve & Hazard Rate on Lifecycle of Maintenance.

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.

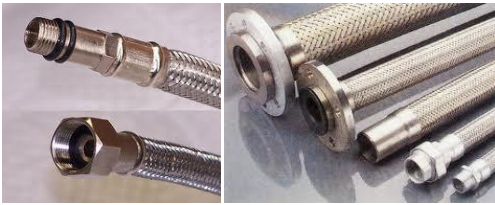


Fig.3.Sample products of High Pressure Hydraulic Hose.



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.

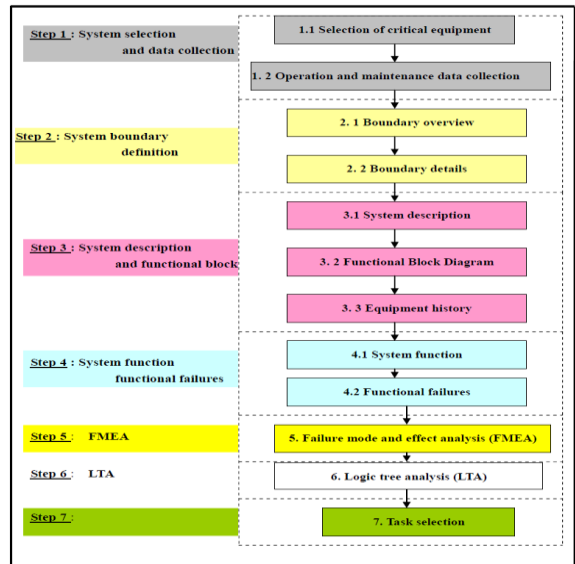


Fig.5. Main steps of the RCM.

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].

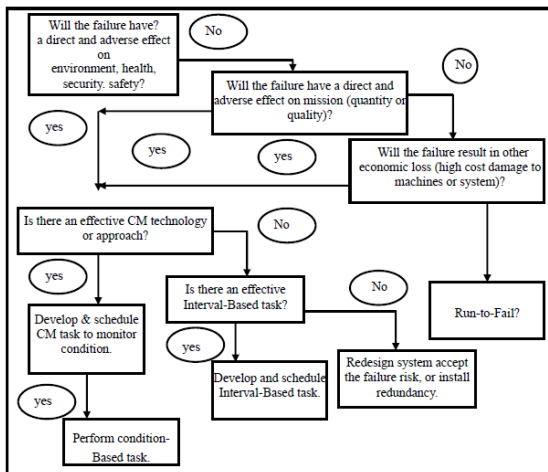


Fig.6. Reliability-centered maintenance (RCM) logic tree.

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.

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

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.	Machine Code	Weight				MC	Criticality Code
		SEI	EM	UR	MCT		
1	HARNES	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	Contact	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).

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

Risk Evaluation such as Small Risk: $\text{RPN} < 60$, Medium Risk: $\text{RPN} < 80$ and High Risk: $\text{RPN} < 100$ and Crisis Risk: $\text{RPN} > 100$, 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't produce efficiently	6	Failure of electrical systems	6	Check with hearing	6	216
		Not working	It can't produce efficiently	6	Using electrical overload	6	Daily monitoring	6	126
2	MOTOR	Having unusual noise	It can't produce efficiently	6	Failure of bearings and gear	6	Check with hearing	6	216
		Motor stopped unexpectedly (burnt)	It stop production	6	Using electrical overload	3	Daily monitoring	3	64
3	PUMP	Loose	Vibration and noise	6	Friction problem and corrosion caused by chemicals	6	Visual inspection and Check with hearing	4	120
		Motor stopped unexpectedly (burnt)	It stop production	6	Using electrical overload	3	Daily monitoring	3	64
4	LOGIC CARD	Not working	It can't produce efficiently	6	Using electrical overload	6	Daily monitoring	6	126
		Not working	It can't produce efficiently	6	Using electrical overload	6	Daily monitoring	6	126
6	Chain	Loose	Vibration and noise	6	Friction problem, overload and corrosion caused by chemicals	6	Visual inspection and Check with hearing	4	120
		Loose	Vibration and noise	6	Friction problem, overload and corrosion caused by chemicals	6	Visual inspection and Check with hearing	4	120
7	CABLE	Loose	Vibration and noise	6	Friction problem, overload and corrosion caused by chemicals	6	Visual inspection and Check with hearing	4	120
		Not working	It can't produce efficiently	6	Using electrical overload	6	Daily monitoring	6	126

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	Contacttor	12,656	18,616	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 CTK1300 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

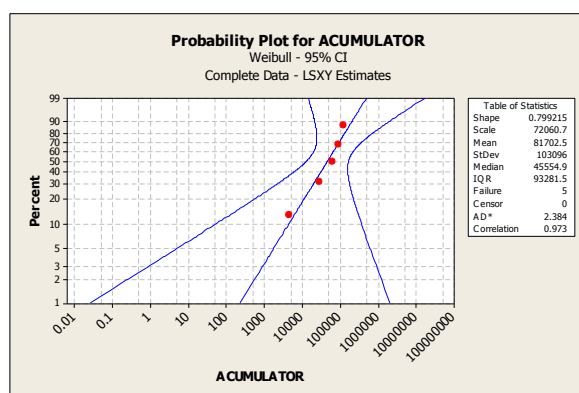


Fig.7. Sample of Probability Plotting with Statistical Software (Source: Minitab Inc., Minitab 17 trial version [Online], accessed 30 August 2014. Available from <http://www.minitab.com>).

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:

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

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

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

$$d_\alpha = \text{Critical Values of Komogorov-Smirnov Tests (in Table 5)} \quad (6)$$

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

Table4. Median Rank [13].

λ	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	50	209	289	20	630	15	910	12	945	10	908	9	830	7	742	6	697	6	107	5
2	70	711	50	500	38	573	31	381	26	445	22	116	28	146	13	116	10	10	7	5
3	79	370	81	427	101	141	36	142	102	152	65	257	123	58	102	147	142	102	142	142
4	84	690	68	619	57	859	50	684	44	515	39	360	35	10	280	75	528	26	208	10
5	87	855	73	555	58	538	48	555	40	458	37	353	30	275	30	452	35	358	348	35
6	90	890	77	517	540	50	507	44	501	36	347	30	246	24	36	347	342	342	342	342
7	90	50	772	787	787	787	787	787	787	787	787	787	787	787	787	787	787	787	787	787
8	91	700	82	784	784	784	784	784	784	784	784	784	784	784	784	784	784	784	784	784
9	92	587	83	774	774	774	774	774	774	774	774	774	774	774	774	774	774	774	774	774
10	93	803	85	704	781	781	781	781	781	781	781	781	781	781	781	781	781	781	781	781
11	93	883	86	707	785	785	785	785	785	785	785	785	785	785	785	785	785	785	785	785
12	94	84	837	87	783	783	783	783	783	783	783	783	783	783	783	783	783	783	783	783
13	94	84	808	88	782	782	782	782	782	782	782	782	782	782	782	782	782	782	782	782
14	95	169	169	80	835	78	821	74	829	70	829	67	829	64	829	61	829	58	829	55
15	95	169	169	80	835	78	821	74	829	70	829	67	829	64	829	61	829	58	829	55
16	95	169	169	80	835	78	821	74	829	70	829	67	829	64	829	61	829	58	829	55
17	95	169	169	80	835	78	821	74	829	70	829	67	829	64	829	61	829	58	829	55
18	95	169	169	80	835	78	821	74	829	70	829	67	829	64	829	61	829	58	829	55
19	95	169	169	80	835	78	821	74	829	70	829	67	829	64	829	61	829	58	829	55
20	95	169	169	80	835	78	821	74	829	70	829	67	829	64	829	61	829	58	829	55

(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 (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	0.326	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	0.362
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).

[illegible]

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

No.	Machine Code	Parameters		K-S Test ($\alpha = 0.05, n$)			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	Contactors	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 C1X1300 Serial No.42715	1.47372	86687.3	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.

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

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

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

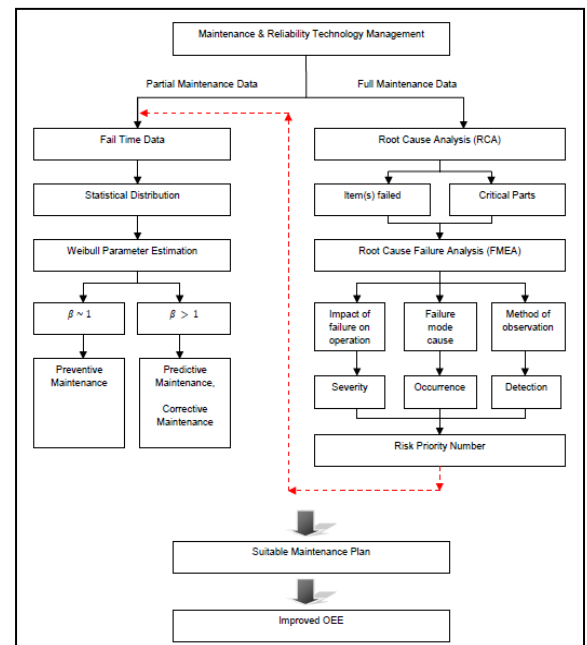


Fig.8. Logic in a combination of the principle of maintenance and reliability.

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

	A	B	C	D	E
1			1. A of ACUMULATOR		
2	t_i	η	$2M = 2\eta \cdot (1/\beta - 1)$	$t_i/2M$	$A = 1 - (t_i/2M)$
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															
2	t_i	$\beta \cdot 10$	η	β/η	t_i/η	$\beta \cdot t_i$	$(\eta/\beta)^2$	$M(t_i)$	$T_i \cdot 10$	$T_i \cdot 10$	$M(t_i) \cdot T_i$	$M(t_i) \cdot T_i$	$S_i \cdot T_i$	$D(t_i)$	ERR
3	10000	28.223	144370	0.000195	0.000069	27.223	0.000000	0.000000	8500	8500	4.8501E-32	8.5001E-32	1.0000E-02	0.963901	0.004222
4	20000	28.223	144370	0.000195	0.000138	54.446	0.000000	0.000000	17000	17000	7.0606E-24	7.0606E-24	2.0000E-02	0.932500	
5	30000	28.223	144370	0.000195	0.000207	81.669	0.000000	0.000000	25500	25500	4.4134E-19	4.4134E-19	3.0000E-02	0.901900	
6	40000	28.223	144370	0.000195	0.000276	108.892	0.000000	0.000000	34000	34000	1.1113E-13	1.1113E-13	4.0000E-02	0.872622	
7	50000	28.223	144370	0.000195	0.000345	136.115	0.000000	0.000000	42500	42500	8.8324E-13	8.8324E-13	5.0000E-02	0.845262	
8	60000	28.223	144370	0.000195	0.000414	163.338	0.000000	0.000000	51000	51000	5.1138E-11	5.1138E-11	6.0000E-02	0.819791	
9	70000	28.223	144370	0.000195	0.000483	190.561	0.000000	0.000000	59500	59500	2.5942E-09	2.5942E-09	7.0000E-02	0.795950	
10	80000	28.223	144370	0.000195	0.000552	217.784	0.000000	0.000000	68000	68000	1.4116E-07	1.4116E-07	8.0000E-02	0.773471	
11	90000	28.223	144370	0.000195	0.000621	245.007	0.000000	0.000000	76500	76500	7.2999E-06	7.2999E-06	9.0000E-02	0.752141	
12	100000	28.223	144370	0.000195	0.000690	272.230	0.000000	0.000000	85000	85000	3.7415E-05	3.7415E-05	1.0000E-01	0.731842	
13	110000	28.223	144370	0.000195	0.000759	299.453	0.000000	0.000000	93500	93500	1.8138E-03	1.8138E-03	1.1000E-01	0.712442	
14	120000	28.223	144370	0.000195	0.000828	326.676	0.000000	0.000000	102000	102000	8.8814E-03	8.8814E-03	1.2000E-01	0.693842	
15	130000	28.223	144370	0.000195	0.000897	353.899	0.000000	0.000000	110500	110500	4.3718E-02	4.3718E-02	1.3000E-01	0.675942	
16	140000	28.223	144370	0.000195	0.000966	381.122	0.000000	0.000000	119000	119000	2.1222E-01	2.1222E-01	1.4000E-01	0.658642	
17	150000	28.223	144370	0.000195	0.001035	408.345	0.000000	0.000000	127500	127500	1.0511E-01	1.0511E-01	1.5000E-01	0.641842	
18	160000	28.223	144370	0.000195	0.001104	435.568	0.000000	0.000000	136000	136000	5.2614E-01	5.2614E-01	1.6000E-01	0.625542	
19	170000	28.223	144370	0.000195	0.001173	462.791	0.000000	0.000000	144500	144500	2.6818E-01	2.6818E-01	1.7000E-01	0.609642	
20	180000	28.223	144370	0.000195	0.001242	489.994	0.000000	0.000000	153000	153000	1.3421E-01	1.3421E-01	1.8000E-01	0.594142	
21	190000	28.223	144370	0.000195	0.001311	517.197	0.000000	0.000000	161500	161500	6.7222E-02	6.7222E-02	1.9000E-01	0.579042	
22	200000	28.223	144370	0.000195	0.001380	544.400	0.000000	0.000000	170000	170000	3.3611E-02	3.3611E-02	2.0000E-01	0.564242	

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	Contactlor	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.

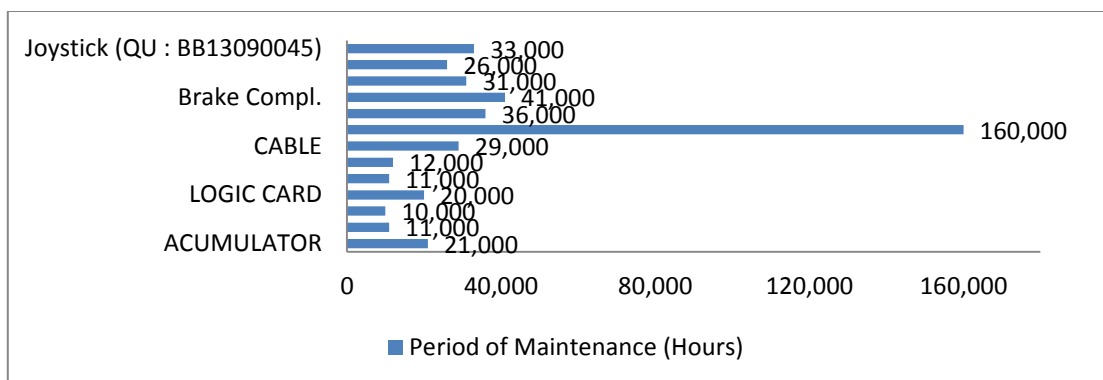


Fig.9. Sample of maintenance planning for Logistics Equipment (Criticality Code: A).

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.

Performance after the improved maintenance plan				
Month	Year	A: Times for workload (hours)	B: Less time in operating (hours)	C: A: Loss Rate (%)
November	2013	480	105.02	21.88
December	2013	530	114.16	21.54
January	2014	540	107.19	19.85
February	2014	510	98.43	19.30
March	2014	480	92.59	19.29
April	2014	530	61.55	18.59
May	2014	480	85.78	17.87
June	2014	490	87.22	17.80
July	2014	550	100.16	18.21
August	2014	510	99.81	19.57
September	2014	480	84.86	17.68
October	2014	480	83.47	17.19
Average availability		488.33	93.25	18.98
The summary of performance before and after the improved maintenance plan				
Department		Performance index	Before	After
Logistics Equipment	Less time in operating (hours)		129.24	93.25
	Loss Rate (%)		27.05	19.06
	Availability Rate (%)		72.95	80.94

3.2 Statistical 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 month) based on the hypothesis testing procedure for the population means on 2 groups by Test Statistics in the equation (10) and (11).

Statistical Hypothesis:

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

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

by

μ_1 = Average of population 1: Average of loss time (before)

μ_2 = Average of population 2: Average of loss time (after)

d_0 = Difference between average of two populations

$$\text{Test Statistics: } T = \frac{(\bar{X}_1 - \bar{X}_2) - d_0}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

$$; \text{ in case } n < 30 \quad (10)$$

$$v = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{\left(\frac{s_1^2}{n_1}\right)^2}{n_1 - 1} + \frac{\left(\frac{s_2^2}{n_2}\right)^2}{n_2 - 1}} \quad (11)$$

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

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

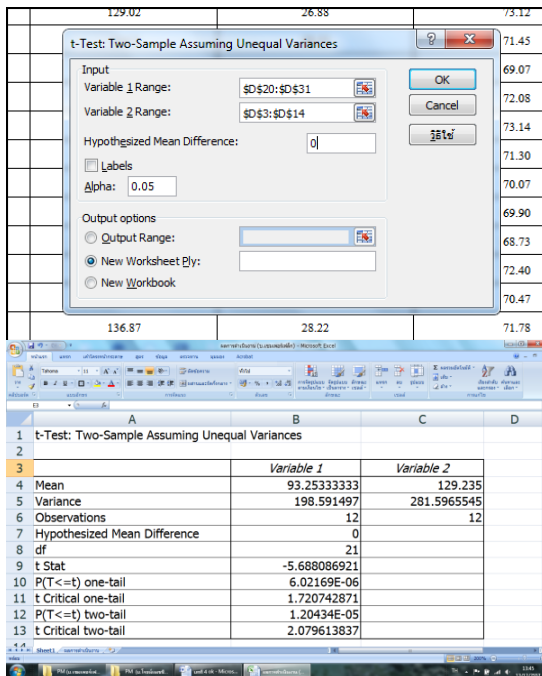


Fig.10. Excel for Statistical analysis on the hypothesis testing.

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 ($P\text{-Value} < \alpha$)

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.

5. Acknowledgements

We wish to express our thanks to the staff members of King Mongkut's University of Technology North Bangkok and Sempreflex Asia Corporation Limited (Thailand), for their support during carrying out this research.

6. References

- [1] Dixey, M., Putting Reliability at the Center of Maintenance, Professional Engineering, Vol. 6, No. 6, pp. 23-25, 1993.
- [2] Abdulrohim, S. A., Salih, O. D. and Raouf, A., RCM Concepts and Application: A Case Study, International Journal of Industrial Engineering, Vol. 7, No. 2, pp. 123-132, 2000.
- [3] Wang, J. and Chu, J., Selection of Optimum Maintenance Strategies Based on a Fuzzy Analytic Hierarchy Process, International Journal of Production Economics, Vol. 107, No. 1, pp. 151-163, 2007.
- [4] Sharma, R. K., Kumar, D. and Kumar, P., FLM to Select Suitable Maintenance Strategy in Process Industries Using MISO Model, Journal of Quality in Maintenance Engineering, Vol. 11, No. 4, pp. 359-374, 2005.

- [5] The National Aeronautics and Space Administration, Reliability-Centered Maintenance Guide for Facilities and Collateral Equipment, NASA, Washington D.C., February, 2000.
- [6] Smith, A. M., Reliability-Centered Maintenance, McGraw-Hill, New York, 1993.
- [7] Shayeri J., Development of Computer-Aided Maintenance Resources Planning (CAMRP): A Case of Multiple CNC Machining Centers, Robotics and Computer-Integrated Manufacturing, Vol. 23, No. 6, pp. 614-623, 2007.
- [8] Rausand, M., Reliability-Centered Maintenance, Reliability Engineering and System Safety, Vol. 60, No. 2, pp. 121-132, 1998.
- [9] Gomaa, A. H., Maintenance Planning and Management, A Literature Study, American University in Cairo, Cairo, 2003.
- [10] Savino, M.M., Brun, A. and Riccio, C., Integrated System for Maintenance and Safety Management through FMECA Principles and Fuzzy Inference Engine, European Journal of Industrial Engineering, Vol.5, No.2, pp. 132-169, 2011.
- [11] Öner, K. B., Kiesmüller, G. P., and Houtum, G. J., Optimization of Component Reliability in the Design Phase of Capital Goods, European Journal of Operational Research, vol. 205, no. 3, pp. 615-624, 2010.
- [12] Wand, L. Z., Xu, Y. G., and Zhang, J. D., Preventive Maintenance Economic Optimization Model Based on Equipment Availability and Reliability, Chinese Journal of Mechanical Engineering, Vol. 46, No. 4, pp. 163-168, 2010.
- [13] Albert H. C. and Tsang K. S., Maintenance Replacement and Reliability Theory and Application, Taylor & Francis Group, 2013.
- [14] Ebeling C. E., An Introduction to Reliability and Maintainability Engineering, Illinois: Waveland Press, 2005.
- [15] Huang, H. Z., Liu, Z. J., and Murthy, D. N., Optimal Reliability, Warranty and Price for New Products, IIE Transactions, Vol. 39, No. 8, pp. 819-827, 2007.
- [16] Anthony, M. S. and Glenn, R. H., RCM-Gateway to World Class Maintenance, Elsevier Butterworth Heinemann, 2004.