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COMBINING RELIABILITY-CENTERED MAINTENANCE WITH PLANNING METHODOLOGY AND APPLICATIONS IN HARD CHROME PLATING PLANTS

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ABSTRACT

This article explains the application of the Reliability-Centered Maintenance (RCM) approach to developing maintenance planning in Hard Chrome Plating plants. The key to the RCM purpose is an effectual maintenance planning of plant components inherent in their 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 setting a priority for critical parts of the Hard Chrome Plating machine. After that, we analyze the damage and risk level data by using Failure Mode and Effects Analysis (FMEA) for calculating a suitable reliability parameter. The final step is to select the preventive maintenance task. As a result of this research, the failure rate of the plant can be reduced 9.22% and the machine availability rate of the plant is increased to 80.34% accordingly. Following this theme, a maintenance plan for the plant is conducted with respect to this RCM concept. Application of the RCM approach revealed that the key time between plant equipment failures and the likelihood of abrupt equipment failures are reduced.

Keywords: FMEA; Maintenance Planning; RCM

1. INTRODUCTION

Nowadays, medium to large industries have adopted various technologies or machineries used in manufacturing systems. So, they are able to use those machines to achieve maximum efficiency. Moreover, it is crucial to have the machines stop work to minimize further damage. A proper maintenance schedule which is capable of maintaining performance of the machinery is necessary. RCM with Planning is a means to reduce machine breakdown. (Albert, 2013). If our machines are managed by RCM planning, we will find that machinery breakdown will be reduced. Besides, RCM planning can reduce defective equipment before their scheduled time and enhance planned maintenance time at a higher level of accuracy. It is important to determine how to maintain each model to fit the machines with different applications such as Preventive Maintenance, Predictive Maintenance, or Condition-Based Monitoring (Anthony & Glenn, 2007).

Equipment reliabilities and availabilities, reached by reducing the feasibility of system failure are the targets of RCM. These maintenance strategies are a function of the equipment

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characteristics, which is firstly determined and then possible failure modes and their aftermath are analyzed and predicted. The most effective technique implemented to enhance the reliability of the facility for all.RCM is a systematic methodology to consider the needs for plant equipment and maintenance schedule within the plant operations (Dixey, 1993) It has been adopted to enhance the strategies of Preventive Maintenance (PM). Explicit PM plans reduce equipment failure and ensure industrial plants are outfitted with capable equipment (Abdulrohim, 2000). RCM is one of the most well-known and the most implemented methodology to guarantee operational efficiency for a boiler system. It is hard to select an adequate maintenance strategy for each equipment component and each failure mode, considering the high incidence of equipment maintenace requirements and imprecise factors related to maintenance strategy (Wang, 2007; Sharma, 2005). RCM philosophy employs PM, real-time monitoring, predictive maintenance, run-and-failure monitoring and techniques of pro-active maintenance which are a combined feature to enhance the feasibility of individual machine or component operation. The approach applies to the design life cycle of the machine with a minimum amount of maintenance (Smith, 1993). RCM is an optimal combination of reactive, time or interval-based, condition-based, and pro-active maintenance practices. Those key maintenance strategies, more than being used freely, are joined to gain the optimal performance for their respective strengths by maximizing the reliability of equipment, while reducing life-cycle costs. Overall productive maintenance, overall maintenance assurance, PM, RCM, and a number of other innovative procedures to solve the maintenance problems all aim at reinforcing the effectiveness of the machines to enhance productivity (Shayeri, 2007).

2. METHODOLOGY

2.1. Our Case Study

With more than 30 years of expertise, Rojekolakarn & Machinery Co., Ltd. has been providing industrial plants for Hard Chrome Plating, Surface Hardening, Grinding, and also Turning. These activities suit a broad range of customers' needs, including mold and die makers, hydraulic systems rebuilders, plastic injection machine owners, and all types of machinery manufacturers shown in Figure 1.

Figure 1 Hard Chrome Plating machine

2.2. RCM Steps

These steps explain the systematic procedures implemented to adopt conservation of system functions, to identify failure modes, to prioritize incidents of failure and to operate PM works. The RCM steps are as follows: (Rausand, 1998): 1st Step: Data collection and system selection, 2nd Step: System boundary definition, 3rd Step: Functional block and system description, 4th Step: System function failures, 5th Step: Analysis of failure mode effect, 6th Step: Logic tree diagram and 7th Step: Task selection.

2.3. Criticality Analysis

Criticality Analysis is a gearing mechanism implemented to analyze how equipment failures influence firm efficiency for the systematic ranking of plant properties with the objective of work prioritization, material classification, reliability improvement initiatives and PM/PdM development (Gomaa, 2003). Generally, failure modes of criticality analysis and failure modes of effects (FMECA/FMEA) are needed to identify the basic information in Table 1. Machine Criticality (MC) was evaluated in respect to these criteria:

1. Effect of Machine downtime on the manufacturing process (EM)
2. Utilization Rate of the machines (Blockage or not) (UR)
3. Safety and Environmental Incidence of machine failures (SEI)
4. Machine Technical Complexity and the need of external maintenance resources (MTC)

Each criterion was provided a weighting related to its significance in the criticality indices. The weight of each criterion runs from 0 (No effect) to 3 (Highly significant effect). Then machine criticalities are enumerated in Equation (1) and Criticality Codes range from 'A' (the most critical machine): 20 to 27, to B: 12 to 19, to C: 0 to 11.

$$MC = 3*EM + 2*UR + 3*SEI + I*MTC \tag{1}$$

Table 1 Sample of some values of machine criticality

Part No.	Weight Machine Code	3	3	2	1	MC	Criticality Code
		SEI	EM	UR	MCT		
1	Carrier Body	3	3	2	3	26	A
2	Motor 1	2	3	3	2	23	A
3	Spur Gear 1	1	1	2	1	11	C

2.4. Failure Mode Effects Analysis (FMEA)

Failure Mode Effects Analysis (FMEA) is a piecemeal procedure to identify all feasible failures in design, manufacturing, assembling processes, products or service. This is called the Severity rating (SEV). Severity is always scored on a point basis from 1 to 10, where 1 is 'Non-significant' and 10 is 'Catastrophic'. If a failure mode contains more than one effect, then the result is recorded for only the top severity rating for that failure mode in the FMEA table. For each cause, the Occurence rating (OCC) must be considered. This rating approximates a likelihood of failure appearing for that same reason within the scope of the machine's lifetime. Occurrence is always scored on a point basis from 1 to 10, where 1 is 'Highly Unlikely' and 10 is 'Inevitable.' On the FMEA table, (OCC) is listed for each cause. Within each control level, the Detection rating (DET) is considered.This rating approximates how finely the controls are able to detect errors, either as the cause or as the failure mode, depending on when they have occurred, but prior to the customer being affected. Detection is always scored on a point from 1 to 10, where 1 means the control is definitely certain to detect the issue and 10 means the control is certain not to detect the issue (none of the control mechanisms exist). On the FMEA table, the Detection rating for each cause is to be listed.

The Risk Priorty Number (RPN) is then calculated in the Equation 2.

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

Risk Evaluation is assessed as Small Risk: RPN < 60, Medium Risk: RPN < 80 and High Risk: RPN <100 and Crisis Risk: RPN > 100. Then the RPN of components with the highest value first is designated. Table 2 shows samples of some RPN values.

Table 2 Samples of some RPN values

No	Machine Code	Features of damage	Severity (SEV)		Occurrence (OCC)		Detection (DET)		RPN
			Information	Scores	Information	Scores	Information	Scores	
1	Carrier Body	Leaking	It can not produce efficiently.	7	Deterioration of seals	8	Visual inspection	7	336
		Seepage	Skin corrosion of Carrier Body	4	Residues of chemicals	5	Visual inspection	5	100
2	Motor 1	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

2.5. Maintenance Assessment of Reliability Engineering

We applied the 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 the calculation of parameters in Table 3.

Table 3 Sample of the data of Time To Fail: TTF (unit: week)

No.	Machine Code	Time To Failure : TTF (unit: week)									
		1	2	3	4	5	6	7	8	9	10
1	Carrier Body	16	40	47	64	78	140	162	-	-	-
2	Motor 1	8	26	62	74	77	86	90	132	150	-

After that, we adopted Reliability Engineering for the calculation by using graph probability (Probability Plotting) with Minitab Statistical Software in Figure 2 to estimate the parameters.

In addition, we tested conditions about the 'Goodness of Fit Test' to confirm that a hypothesized distribution fits a data set from the Kolmogorov-Smirnov Test (Albert, 2013) for a small population using Equations 3–6. Then an Excel Simulation was created to calculate Equations 3–6 in Table 4 and the results on the 'Goodness of Fit Test' are summarized in Table 5.

Statistical Hypothesis:

H_0: TTF Data are a Weibull distribution with β (Sharpe) and η (Scale)

H_1: TTF Data are not a Weibull distribution with β (Sharpe) and η (Scale)

Test Statistics from the Kolmogorov-Smirnov Test:

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

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

$$\hat{F}(t_i) = \text{ Opportunity of Breakdown} \tag{5}$$

$$d_{\alpha} = \text{Critical Values of Komogorov-Smirnov Tests} \tag{6}$$

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

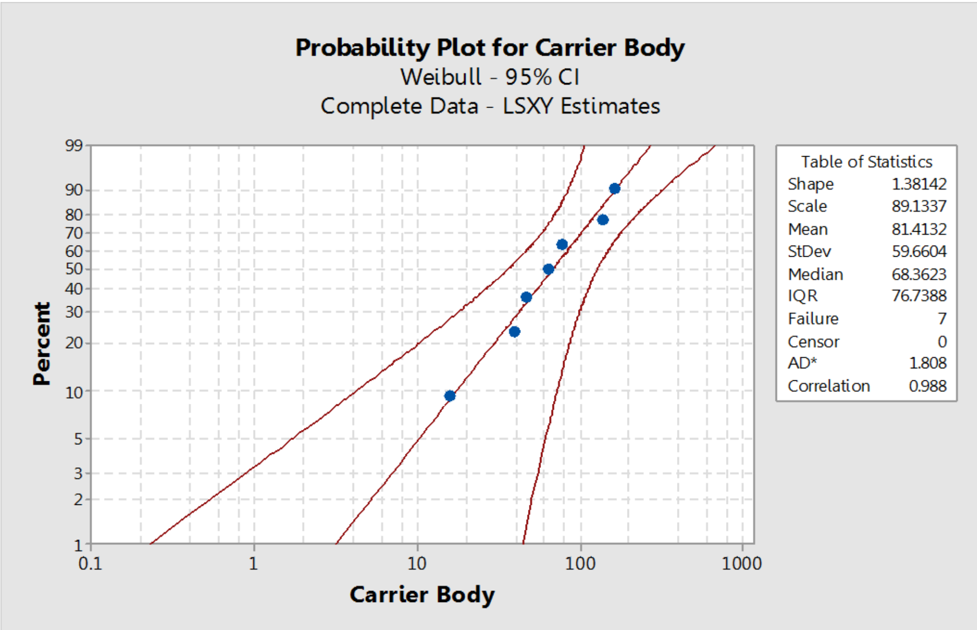

Figure 2 Sample of Probability Plotting with Minitab Statistical Software

Table 4 Excel Simulation Sample to calculate the Equation 3–6

	A	B	C	D	E	F	G	H	I	J	K	L	M
2	t_i	η (Scale)	t/η	β (Sharpe)	$(t/\eta)^{\beta}$	e = 2.7182	$e^{(t/\eta)^{\beta}}$	$1/e^{(t/\eta)^{\beta}}$	$F(t_i) = 1 - (1/e^{(t/\eta)^{\beta}})$	$F'(t_i)$ by Median Rank Table	$\lvert F(t_i) - F'(t_i)\rvert$	$\lvert F(t_i) - F'(t_{i-1})\rvert$	d
3	16	89.1337	0.1795	1.38142	0.0932	2.7182	1.09771	0.9110	0.0890	0.09428	0.0053		0.0053
4	40	89.1337	0.4488	1.38142	0.3306	2.7182	1.39178	0.7185	0.2815	0.22849	0.0530	0.1872	0.1872
5	47	89.1337	0.5273	1.38142	0.4131	2.7182	1.51146	0.6616	0.3384	0.36412	0.0257	0.1099	0.1099
6	64	89.1337	0.7180	1.38142	0.6328	2.7182	1.88285	0.5311	0.4689	0.50000	0.0311	0.1048	0.1048
7	78	89.1337	0.8751	1.38142	0.8317	2.7182	2.29710	0.4353	0.5647	0.63588	0.0712	0.0647	0.0712
8	140	89.1337	1.5707	1.38142	1.8659	2.7182	6.46116	0.1548	0.8452	0.77151	0.0737	0.2093	0.2093
9	162	89.1337	1.8175	1.38142	2.2827	2.7182	9.80220	0.1020	0.8980	0.95720	0.0592	0.1265	0.1265
10												max d =	0.2093

Table 5 Sample of the summarized results in the 'Goodness of Fit Test'

No.	Machine Code	Parameters		K-S Test (α = 0.05, n)			Hypothesis Test:
		β	η	max d	d_α	n	
1	Carrier Body	1.38142	89.1337	0.2093	0.483	7	accepted H_0
2	Motor 1	1.27584	91.2374	0.2775	0.430	9	accepted H_0

2.6. Maintenance & Reliability Technology Management

We are able to analyze the data further by (1) Selecting the maintenance task for the Weibull Parameter Estimation: β ~ 1 is PM: Preventive Maintenance. (2) Selecting the maintenance task for the Weibull Parameter Estimation: β > 1 is PdM: Predictive Maintenance and Corrective Maintenance.

2.7. Maintenance Period Analysis

If β ~ 1: Constant Failure Mode is regarded as Exponential Distribution. The technique of Failure Finding is applied by calculating the inspection interval in Equation 7 (Albert, 2013). Also, an Excel Simulation was created to calculate Equation 7 for the sample output shown in Table 6.

$$A = 1 - \frac{FFI}{2M} \tag{7}$$

where *A* is the Availability of the protective device, *FFI* is the inspection interval (t_i), *M* is the MTTF.

Table 6 Sample output from the calculation of the Equation 7

No.	Machine Code	Parameters		t_i (Week)	A (%)
		β	η (M)		
1	Carrier Body	1.38142	89.1337	17	90.46
2	Motor 1	1.27584	91.2374	18	90.14

If β > 1 is considered as the Increase Failure Mode, then the technique of the Determination of the Optimal Preventive Replacement Interval is applied to consider the optimum replacement interval (t_p) between preventive replacements to keep at a minimum the total downtime per unit time by calculating Equations 8 and 9 (Albert, 2013). An Excel Simulation was created to calculate Equations 8 and 9 in Table 7.

Table 7 Sample output from the calculation of Equations 8 and 9

No.	Machine Code	Parameters		T_f	T_p	MIN: D (t_p)
		β	η (M)			
1	Y-Bearing 1	2.75330	30.2882	0.075	0.005	0.000390
2	Y-Bearing 2	3.36729	31.4344	0.071	0.005	0.000375

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

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

where $D(t_p)$ is the total downtime per unit time, $H(t_p)$ is the number of failures in interval (0, t_p), T_p is the mean downtime desired to provide a failure replacement, T_f is the mean downtime desired to provide a preventive replacement, t_p is the preventive replacement at time.

The results of the Assessment Guidelines for the maintenance of Reliability Engineering are summarized in Table 8. The maintenance planning for the Hard Chrome Plating plant can be developed by applying reliability-centered maintenance for the plant components' inherent reliability value.

Table 8 Sample of Assessment Guidelines in Maintenance & Reliability Engineering

No.	Machine Code	Parameters		Type of maintenance	Period of Maintenance (Week)
		β	η		
1	Carrier Body	1.38142	89.1337	PM	17
2	Motor 1	1.27584	91.2374	PM	18
3	Y-Bearing 1	2.75330	30.2882	PdM	29
4	Y-Bearing 2	3.36729	31.4344	PdM	23

3. RESULTS

The measurements in this research were divided into 2 parts:

1. Before the improved maintenance plan: November 2012 to October 2013
2. After the improved maintenance plan: November 2013 to October 2014

Then, an Excel Simulation was created to calculate the before and after performance summary for the improvement of maintenance plan on the output in Tables 9 and 10. As a result of this research, the failure rate of the plant can be decreased 9.22% and the machine availability rate of the plant is increased to 80.34% accordingly.

Table 9 Performance after the improved maintenance plan

Month	Year	Performance after the improved maintenance plan			
		A: Times for workload (hours)	B: Loss time in manufacturing (hours)	B/A: Loss Ratio (%)	1- (B/A): Availability Rate (%)
November	2013	455	112.48	24.72	75.28
December	2013	467	99.70	21.35	78.65
January	2014	460	97.47	21.19	78.81
February	2014	450	90.41	20.09	79.91
March	2014	480	95.18	19.83	80.17
April	2014	330	64.94	19.68	80.32
May	2014	470	82.34	17.52	82.48
June	2014	466	83.32	17.88	82.12
July	2014	435	84.96	19.53	80.47
August	2014	465	86.21	18.54	81.46
September	2014	480	83.86	17.47	82.53
October	2014	470	85.02	18.09	81.91
Average monthly		452.33	88.82	19.66	80.34

Table 10 Performance after the improved maintenance plan

The summary of performance before - after the improved maintenance plan				
Department	Performance index	Before	After	Different
Coating Machine	Loss time in manufacturing (hours)	129.52	88.82	40.69
	Loss Ratio (%)	28.87	19.66	9.22
	Availability Rate (%)	71.13	80.34	-9.22

4. DISCUSSION

To confirm the results of this research, statistical analysis was used to determine the effect of Loss Time in manufacturing (hours) which is reduced, whether it is significant or not. The statistical comparison of loss time in manufacturing (hours) before and after the improved maintenance plan (each mouth) was applied based on the hypothesis of testing the procedure for the population means on 2 groups by Test Statistics in Equations 10 and 11.

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

$H_1 : \mu_1 - \mu_2 < d_0$

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

Test Statistics:

$$T = \frac{(\bar{X}_1 - \bar{X}_2) - d_0}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}, \quad \text{in case } n < 30 \tag{10}$$

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

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

Consequently, an Excel Simulation for Statistical analysis was applied on the hypothesis testing procedure for the population means in 2 groups shown in Figure 3.

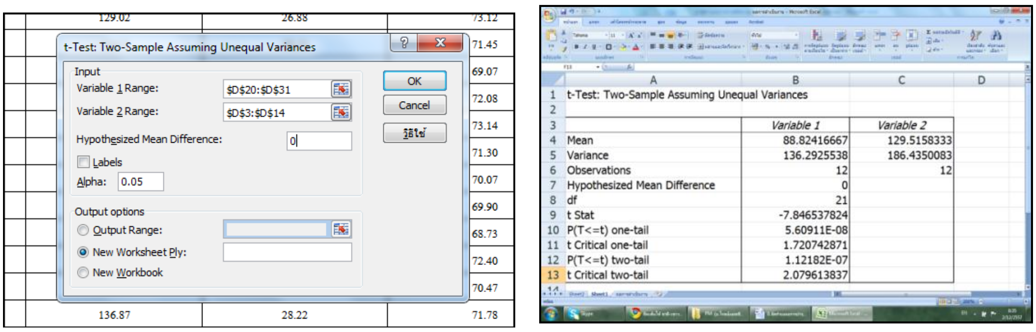

Figure 3 Excel for statistical analysis on the hypothesis testing

It can be said that an Excel simulation for Statistical analysis on the hypothesis of testing resulted in the determination to Reject H_0. So, the statistical test was selected to review and analyze the results of this research and to note that it reaches a significant level at 0.05 in which P-Value is less than the significant level (P-Value < α). As an advantage, our RCM and Planning analyses are able to reduce the breakdown of machines. In addition, we can reduce defective equipment before their scheduled time in order to support planned maintenance times to a greater degree of accuracy. However, the weakness of our methodology is that we need a long-term history and a higher degree of accuracy in recording damaged machines

5. CONCLUSION

It is currently believed that the former data history of the components and the former maintenance programs along with a probabilistic study are determined in the RCM model in order to improve the model to a higher degree of accuracy. Along the lines of this theme, a maintenance plan for the plant is conducted and respected to respond to this RCM concept. Adopting the RCM procedure revealed that the key time between failures for the plant equipment and the likelihood of abrupt equipment failures are reduced. We should follow up on the data of the damaged system, after having established preventive maintenance based on reliability engineering that is used constantly to improve the maintenance plan to suit the current conditions.

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