Enhancing Maintenance Management System Using Reliability Centered Maintenance (RCM) Case Study Curing Tire Section in Leading Tire Manufacturer

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Abstract*—PT MTI is a company that produces motorcycle tires. The company has the problem of not achieving the average production target, which is only 93.65%. The most significant cause is the downtime of the curing machine, especially the M Closing Force Problem. The annual total loss due to downtime curing machine reaches IDR 37,211,400,000. Companies must improve maintenance programs by using the RCM concept, combining the FMEA and Seven tools, and finding the BEP by using the financial analysis. Based on the maintenance data, the reliability value can be obtained from the MTBF and MTTR. Obtained the most outstanding MTBF value is 1057 hours, and the MTTR value of 4.62, and the value of reliability is 0.36803. The action in predictive maintenance is replacing the machine's spare parts, such as the upper body, lower body, crank gear, arm, and dial gauge. The preventive maintenance action is to replace the crank gear bushing every 3.5 months. The BEP improvement is in 9.65 months, and the cost reduction is IDR 2,332,349,008.65 in the first year and IDR 8,518,599,008.65 in the second year.

***Keywords*—reliability, downtime, maintenance strategy, tire manufacturing, BEP.**

I. INTRODUCTION

In the current global competition era, companies must increase their companies' productivity in order to remain competitive with other companies [1]. In the structure of a company engaged in manufacturing or production, it will have a maintenance section whose job is to do all work related to engine and component maintenance problems supporters [2]. PT MTI is a company that produces motorcycle tires. In general, making motorcycle tires is divided into three sub-processes: section material, building, and curing. The last section is curing or transforming a greentire into a tire. Each section in PT MTI has a Key Performance Indicator (KPI). Section curing has three main KPIs, as follows:

1. Production target of 95% of the Schedule given by Production Planning Control (PPC)
2. The maximum defect target is 0.37% of the total production
3. The target of achieving a minimum Original Equipment Manufacturer (OEM) of 95% of production.

The production data in PT MTI from 2013 until 2019 have an average production achievement of 95.34%. The analysis of lost production from the machine consistently increased every year. The production results in 2020 from January to June 2020 have an average production percentage of 93.65%. The enormous lost time came from the downtime machine, with 66% of all lost time. It is necessary to create a maintenance program effectively and economically to prevent fatal and very detrimental damage. Skilled employees must support the maintenance program to make observations on the production machine's systems [2]. This research will analyze the problem of breakdown curing machine BOM's type that occurs at the company by using Reliability Centered Maintenance (RCM) and perform the validation by calculating the engineering economic factor. In summary, RCM is a systematic approach to evaluating a facility and resources to produce high reliability and cost-effectiveness [3]. This research uses RCM to accommodate excellent and efficient system maintenance, maintain system functions, identify the mode of damage, prioritize the importance of the damage mode, and choose effective and applicable preventive maintenance measures [3].

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II. LITERARTURE REVIEW

A. Failure Mode Effect Analysis (FMEA)

Failure Mode Effect Analysis (FMEA) is a methodology used to evaluate occurred failures in a system, design, process, or service. FMEA is a technique widely used to make a qualitative assessment of reliability system [3]. Failure Mode and Effect Analysis (FMEA) is the process for identifying the failures of a component that can cause the system failure [4]. FMEA is a quality improvement and control program that can prevent failure in a product or process [5]. FMEA is a method used to identify or analyze a failure starting from the cause of the failure, the failure's effect, and the level of criticality of the failure effect [6]. Failure modes can be used to determine consequences and decide what to do to anticipate, prevent, detect, and remedy [7]. There are three assessment variables in FMEA, namely Severity, Occurrence, and Detection [8]. Failure analysis focuses on qualitative analysis and identification of the impact of failure modes and means of detection of these modes of failure. Equation 1 shows the formula for calculating RPN, while Table 1 shows the criteria of maintenance strategy based on RPN calculation [9].

$$RPN = (S \ x \ O \ x \ D) \quad (1)$$

Where:
RPN = Risk Priority Number
S = Severity
O = Occurence
D = Detection

TABLE I
CRITERIA OF MAINTENANCE STRATEGY BASED ON RPN

Rank	Maintenance Strategy	Criteria
1	Predictive Maintenance	RPN > 300
2	Preventive Maintenance	200 < RPN < 300
3	Corrective Maintenance	RPN < 200

B. Maintenance Strategy

The types of maintenance strategies that will be used are as follows [10]:

- Corrective Maintenance (CM): Maintenance performed when the machine has a problem. No action was taken until the engine failed.
- Preventive Maintenance (PM): Maintenance in terms of reliability by checking and periodic repairs to determine a machine's condition and whether the machine can still be used or replaced. In preventive maintenance, periodic repairs are essential, so the equipment remains at its best performance when used.
- Condition Based Maintenance (CBM): similar to preventive maintenance, but in CBM, periodic data is used to determine whether or not a machine is feasible to continue to be used, in this case determining the system age of a machine. The system age of a machine can be seen by carrying out periodic maintenance. If there is a decrease in performance, then repairs or engine replacement are taken.
- Predictive Maintenance (PdM): Maintenance requires periodic data. Unlike CBM, the PdM data is used to analyze risks that occur to determine future machine failures.

C. Reliability Centered Maintenance (RCM)

Reliability Centered Maintenance (RCM) is a process used to determine the most effective approach to maintenance. RCM uses identification to measures when the performance is reduced by the likelihood of failure and most cost-effective. This maintenance strategy is not applied independently but is integrated to achieve the benefits of its respective strengths to optimize facility and equipment operating capabilities and efficiency while lowering life cycle costs [1]. The RCM approach's advantage is that maintenance activities are more effective due to reduced downtime and optimal machine usage time [11]. RCM is a systematic approach to evaluating a facility and resources to produce high reliability and cost-effectiveness [3]. Reliability Centered Maintenance (RCM) is a process used to determine any physical asset's maintenance needs in the context of its operation [4]. RCM is a technology-oriented approach that aims to identify maintenance requirements and determine the type of maintenance policy suitable for a system or equipment based on the level of reliability and its consequences for operation failure [12]. Reliability Centered Maintenance (RCM) is a maintenance method utilizing information related to facility reliability to obtain an effective, efficient, and easy-to-perform facility maintenance strategy [9]. RCM recognizes that maintenance cannot do more than ensure that assets continue to achieve their inherent reliability [13]. RCM is a systematic method used to strike a balance between preventive and corrective maintenance [14]. RCM is used to obtain maintenance activities so that a physical asset continues to work and perform its function according to the context of its operation [15]. RCM is an integrated method of quantitative and qualitative analysis in determining engine maintenance planning. RCM has the advantage of determining a maintenance plan that is focused on critical machines and avoids unnecessary maintenance activities [16].

D. Reliability, Availability, Maintainability

- Reliability

Reliability is the probability that a system will work correctly in a certain period and under certain conditions. Equation 2 shows the formula to calculate the Reliability value [17].

$$R(t) = 1 - F(t) \quad (2)$$

Where:
$R\ (t) = Reliability$
$F\ (t) = Cumulative\ distribution\ function\ (CDF)$

- Availability

Availability is the probability that a machine can operate well under certain conditions. Availability only pays attention to operation time and downtime. The availability value can be calculated with the formula as seen in Equation 3 [17].

$$A\ (tp) = 1 - D(tp) \tag{3}$$

Where:
$A\ (tp) = Availability\ in\ period\ t$
$D\ (tp) = Downtime\ in\ period\ t$

- Maintainability

Maintainability is the probability that the damaged system can be operated again effectively within a given period. The maintainability value can be calculated with the formula as seen in Equation 4 [17].

$$\boldsymbol{M(tp)} = \frac{\boldsymbol{MTTF}}{\boldsymbol{F(tp)}} \tag{4}$$

Where:
$M\ (t) = Maintainability\ in\ period\ t$
$MTTF\ = Mean\ Time\ To\ Failure\ (hour)$
$F\ (t) = Cumulative\ Distribution\ Function\ (CDF)$

E. Financial Feasibility Analysis

- Break Even Point (BEP)

BEP is a balance point in the production or sales amount that must be made, so the costs incurred can be covered, or the value where the profit received is zero. In other words, the point where the amount of income will be equal to the total amount of expenditure. The formulation of the BEP can be described as follows: [18]

$$BEP\ at\ unit\ \frac{FC}{P-VC} \tag{5}$$

$$BEP\ at\ IDR\ \frac{FC}{1-\frac{VC}{P}} \tag{6}$$

Where:
$FC = Fixed\ Costs$
$P = Selling\ price\ per\ unit$
$VC = Variable\ cost\ per\ unit$

F. Exponential Distribution Function

This distribution is used to describe the reliability over machine failure time when the failure rate (λ) is constant. Other functions in the exponential distribution can be described as follows [17].

- Probability Density Function (PDF)
  The PDF can be obtained by:

$$\boldsymbol{f(t)} = \boldsymbol{\lambda e^{(-\lambda.t)}} \tag{7}$$

Where:
$\boldsymbol{\lambda} = Rate\ Parameter$
$e = natural\ logarithm$
$t = time$

- Cumulative Distribution function (CDF)
  The CDF can be derived by:

$$\boldsymbol{F(t)} = \boldsymbol{1 - e^{(-\lambda.t)}} \tag{8}$$

- Reliability Function
  The Reliability can be calculated by:

$$\boldsymbol{R(t)} = \boldsymbol{e^{(-\lambda.t)}} \tag{9}$$

- Mean Time to Failure in Exponential Distribution
  The MTTF can be acquired by:

$$\boldsymbol{MTTF} = \frac{\boldsymbol{1}}{\boldsymbol{\lambda}} \tag{10}$$

III. RESEARCH METHODOLOGY

Fig.1 is showhing, the curing machine's maintenance system will be evaluated by looking for the MTTF value and reliability of the curing machine components that are often damaged. Then, proceed with making predictive and preventive maintenance due to downtime problem by analyzing the result of the RPN values in the FMEA. The research began firstly by determining the background and research problems. The main problem is the underachievement of the production below the KPI due to the curing machine's severe damage. This study aimed to determine the causes of damage to the curing machine and reduce unscheduled downtime.

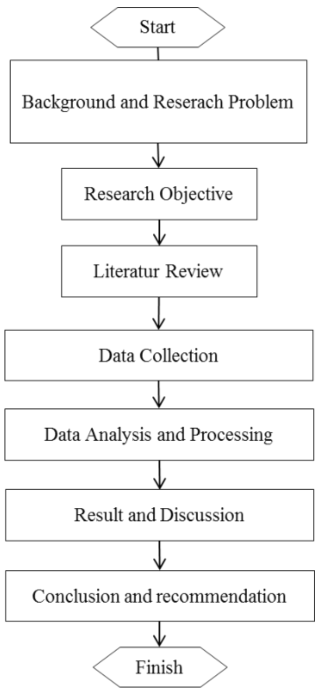

Fig. 1 Research flow

The data collection process requires production achievement data to be analyzed by using Fishbone and Pareto. Furthermore, the reliability value can be obtained by calculating the MTBF dan MTTR based on the downtime data. Then, the financial analysis is carried out in order to strengthen the decision on the maintenance strategy. The collected data from the internal company is the downtime curing machine from January to June 2020. The downtime data is downloaded from Enterprise Asset Management (EAM), consisting of collecting input of historical downtime on each curing machine. The variable data is downtime data of the BOM Curing Machine caused by Adjuster and Crank Gear.

IV. Result and Discussion

A. Downtime Data

TABLE II
DOWNTIME DATA

No	Problem	Sum of Occurrence	%
1	M. Closing Force Problem	354	32%
2	E. Auto Problem	95	9%
3	M. Top Ring Problem	83	8%
4	E. Open Problem	63	6%
5	M. Open Problem	56	5%
6	M. Internal Steam Problem	55	5%

Table 2 describes the downtime data of the curing machine that occurred at PT MTI. The data was taken from January to June 2020. The biggest problem came from the M Closing Force problem with a percentage of 32%.

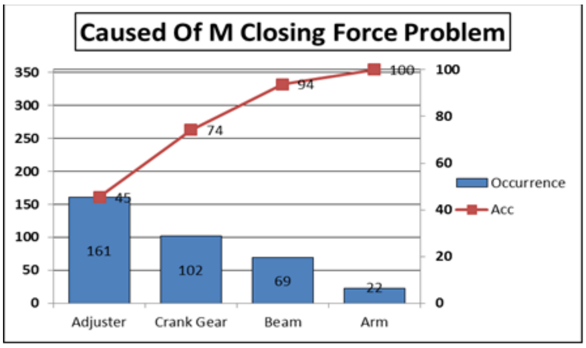

Fig. 2 Caused of M closing force problem

Fig. 2 explains the Pareto chart cause of the M Closing force problem. The two biggest problems are Adjuster and Crank gear.

B. MTBF and MTTR Data

The calculation of MTBF and MTTR values uses downtime data from January to June 2020. The focus problem is the M Closing Force Problem with the cause due to the Adjuster and Crank Gear.

From the adjuster data, the value of MTBF is 14.89 hours, and the value of MTTR is 0.75 hours. While, from the crank gear data, the value of MTBF is 16.96 hours, and the value of MTTR is 4.62 hours. After improvement, the value of MTBF becomes 51 hours and MTTR 1 hour.

C. Reliability Value

TABLE III
RELIABILITY, MAINTAINABILITY, AVAILABILITY OF ADJUSTER

t (hour)	F(t)	R(t)	M(t)	D(t)	A(t)
100	0.12808	0.87192	5696.44	0.00037	0.99963
150	0.18583	0.81417	3926.17	0.00027	0.99973
200	0.23976	0.76024	3043.1	0.00021	0.99979
250	0.29011	0.70989	2514.92	0.00017	0.99983
300	0.33713	0.66287	2164.17	0.00015	0.99985
350	0.38104	0.61896	1914.81	0.00013	0.99987
400	0.42203	0.57797	1728.8	0.00011	0.99989
450	0.46031	0.53969	1585.03	0.0001	0.9999
500	0.49606	0.50394	1470.81	9.2E-05	0.99991

From Table 3, the reliability value of adjuster with more than 50% to be on a period of 500 hours.

TABLE IV
RELIABILITY OF ADJUSTER AFTER IMPROVEMENT

t (hour)	F(t)	R(t)	M(t)	D(t)	A(t)
1300	0.40585	0.59415	6152.51	3.08E-07	1.000000
1400	0.42918	0.57082	5818.14	2.86E-07	1.000000
1500	0.45158	0.54842	5529.43	2.67E-07	1.000000
1600	0.47311	0.52689	5277.81	2.50E-07	1.000000
1700	0.4938	0.5062	5056.74	2.35E-07	1.000000

After the improvement, the reliability with more than 50% is on a period of 1700 hours, as seen in Table 4.

D. FMEA Analysis

For the Adjuster's FMEA results, the severity value is six because the downtime ranges from 1-4 hours, and the occurrence value is ten because the percentage of occurrence is more than 10%. The detection value is eight, which was obtained from observation since it was difficult to detect each running size's correct setting. Then, the calculated RPN value for the problem caused by the Adjuster is 480. Reducing the occurrence value becomes the suggestion to reduce the calculated RPN value of the Adjuster. The improvement recommendations are to make guidelines for the dial gauge settings for the thickness of each size's molds required for production. The RPN value after taking improvement is 288.

For the crack gear's FMEA results, the severity value is six because the downtime ranges from 1-4 hours, and the occurrence value is ten because the percentage of occurrence is more than 10%. The detection value six, which was obtained from observation since it was difficult to detect. Then, the calculated RPN value for the problem caused by the crank gear is 360. Reducing the occurrence value becomes the suggestion to reduce the RPN value. The improvement recommendations are to make guidelines for the dial gauge settings for the thickness of each size's molds required for production. The RPN value after taking improvement is 216.

E. Improvement Maintenance System

From the maintenance strategy based on the RPN value, the company must begin with the predictive maintenance implementation, then continue with the preventive maintenance. The predictive maintenance with procedures based on the condition of the several parts of the BOM Curing machine as seen in Fig. 3 and Fig. 4, such as:

a) Upper Body
b) Lower Body
c) Crank Gear
d) Bushing Crank Gear
e) Arm
f) Dial Gauge

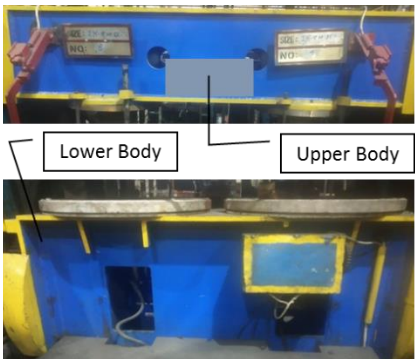

Fig. 3 Part Curing Machine

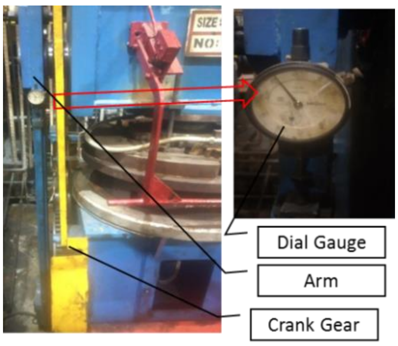

Fig. 4 Part curing machine continue

The activities of preventive maintenance can be described as follows:

1. Crank Gear Bushing Replacement; Routinely replace the crank gear bushing so that the Lower Body and Upper body are not easily damaged.
2. Making guidance dial gauge setting based on the thickness of the mold
3. Check the oil level every day
4. Check crank gear bolts every day
5. Lubrication Gear uses grease every day

F. Improvement Cost

TABLE V

PREDICTIVE MAINTENANCE COST

No	Item	Prize	Amount 49 machine BOM
1	Crank Gear	IDR 33,000,000.00	IDR 1,617,000,000.00
2	Bushing Crank gear	IDR 20,000,000.00	IDR 980,000,000.00
3	Lower Body	IDR 32,000,000.00	IDR 1,568,000,000.00
4	Upper Body	IDR 22,000,000.00	IDR 1,078,000,000.00
5	Dial Gauge	IDR 1,250,000.00	IDR 61,250,000.00
6	Arm	IDR 18,000,000.00	IDR 882,000,000.00
	Total	**IDR 126,250,000.00**	**IDR 6,186,250,000.00**

Table 5 explains the cost of replacing spare parts for the BOM curing machine. The total cost per machine is IDR 126,250,000.00, and the total cost for 49 machines is IDR 6,186,250,000.00.

TABLE VI

PREVENTIVE MAINTENANCE COST

Total of BOM Machine	49
PM Change Bushing Crank gear	Every 3,47 month
Cost per Machine	IDR 20,000,000.00
PM per year (times)	3.5
Cost PM per year (per Machine)	IDR 69,164,265.13
Cost PM per year	IDR 3,389,048,991.35

Table 6 describes the cost of replacing the crank gear bushings every 3.5 months. The total cost of the crank gear bushing replacement for each year is IDR 3,389,048991.35.

If the average lost time per month is 20673 pcs tires, and one tire costs IDR 150,000.00, then the total loss in a month becomes IDR 3,101,010,000.00. The previous data explained that the total downtime due to the M Closing Force problem is 32% of the total downtime, then the total cost wasted due to the M closing Force problem is 0.32 x IDR 3,101,010,000.00, which equals to IDR 992,323,200.00 every month or IDR 11,907,878,400.00 in a year.

BEP = Total Cost / Saving Cost
BEP = IDR 9,575,298,991.35/ IDR 992,323,200.00
= 9.65 months
BEP will be 9.65 months in the first-year investment, assuming the problem due to the M Closing force is resolved.

V. Conclusion And Recommendations

A. Conclusion

From the research that has been done, it can be concluded as follows:

- Predictive maintenance with the condition-based procedure was used for predicting several parts such as upper body, lower body, crank gear, arm, while dial gauge needs to be installed.
- In the preventive maintenance, the crank gear bushings need to be replaced every 3.5 months,
- Root cause analysis from the downtime data shows that the M closing force problem contributed around 32% from the total downtime.
- Increasing reliability of M Closing Force in crank gear from 0.62322 to 0.81853 or a 30% increase.
- The BEP from improvement is around 9 months 20 days.
- Based on improvement analysis, in the 1^{st} year, saving cost = IDR 194,362,417.39/month, while in the 2^{nd} year, saving cost = IDR 709,883,250.72/month.

B. Recommendations

Suggestions in this study are

- Performing EOQ methods analysis on the procurement of spare parts needed by the curing machine.
- Performing analysis of material design on Bushing crank gear to increase the reliability value.

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