Proposed maintenance policy using reliability centered maintenance (RCM) method with FMECA analysis: A case study of automotive industry

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Abstract. PT XYZ is one of the companies engaged in the automotive industry, especially in the motorcycle industry that produces spare parts on motorcycles. One component made by PT XYZ is Guide Comp Level K1AA. The problem in the company is one of the machines to produce the Guide Comp Level K1AA component, which is a Press machine that has a high frequency of failure. The Press machine itself consists of electrical and mechanical systems that each system consists of sequential subsystems as many as 6 subsystems and 10 subsystems. By using risk matrix, obtained two critical subsystems namely brake and trigger. Then the analysis of failure mode, effects and criticality analysis (FMECA) was carried out with output in the form of risk priority number (RPN), obtained that the selected critical subsystem is the brake. Using the reliability centered maintenance (RCM) method, then obtained the maintenance policy for the brake critical subsystem are 2 scheduled on condition task with interval time is 2.55 months and 2 scheduled restoration task with 5,394 months. The proposed maintenance policy also decreases the total maintenance cost for the critical subsystem brake up to 25% from existing maintenance costs.

Keywords: reliability centered maintenance, failure mode effects and criticality analysis (FMECA), maintenance task, maintenance cost.

1. Introduction
Reliability centered maintenance (RCM) is maintenance strategy to optimize the maintenance program of a company or facility. RCM is implemented to determine the most effective maintenance scheduling that would economically benefit the industry [1]. RCM is widely used in various industrial sectors, quoted from the paper written by Yavuz et al. [2] the RCM method can be applied in the food industry, the results of this study are an actual function of packaging machine in the process and its relationship with the product are understood for teams that use the equipment and the equipment get the sustainability. [3] stated that RCM can be integrated with
other method, namely reliability availability maintainability (RAM) with the object is oil and gas company. The output obtained from this study is to suggest improvements to the more established RCM methodology that applies to industries with high priority levels. Furthermore, there are studies from [4] that use the RCM method on the research object, namely electric feeder system (EFS). The results of this study indicate the feasibility of optimizing the RCM maintenance method. Other study from [5] which used the RCM method which makes the object of a crossroads infrastructure in Nigeria that produces an effective preventive maintenance strategy. This study provides results that the application of the classic RCM method can be applied to the highway industry that can reduce reactive maintenance activities by optimizing preventive maintenance strategies. Another paper from [6] which is the research object is aircraft engine, implements the RCM method to propose the maintenance scenario analysis for critical aircraft subsystem mixed with risk based maintenance (RBM). The paper created by [7] applies the RCM method by developing an analytical network process (ANP) to overcome problems in multi-criteria decision making in component criticality analysis. So the result of this research is to determine the decision of the maintenance planning problem by prioritizing critical components on the research object, namely CNC lathe. Aa Wind Turbine object in Denmark applied the combined method of RCM with FMECA analysis and life cycle cost (LCC) to find out the potential causes of downtime and prevention of malfunction [8]. Other paper created by [9] presents an application of the new Rational Reliability Centered Maintenance (RRCM) model to optimize the maintenance management of electrical power equipment. The output of this study is when implementing effective maintenance optimization with the RRCM approach will increase the reliability and availability of the electrical system, improve the safety of people, property and the environment and reduce overall operation and maintenance costs. Next, RCM is also applied to the printing industry which RCM mixed with reliability centered spares (RCS) method. This paper analyzes and propose the RCM and RCS maintenance system to obtain the optimum maintenance policy in printing machine [10]. Next paper written by [11] which the research object is calcinator unit of travancore titanium products, the result of this paper is RCM combined with AHP for maintenance strategy selection for process plants.

The object of this research is PT XYZ which is one of the companies engaged in the automotive motorcycle industry that produces spare parts for motorcycles. The production of PT XYZ depends on the number of orders received or it can be said the production system is make to order. PT XYZ produces many types of components, one type of component produced is the Guide Comp Level K1AA. As for the Guide Comp Level K1AA production process flow, it requires several machines to carry out the process, namely Shearing machine for shearing process, Press machine for blanking, piercing, bending, flange, embosing, while Turret machine for trimming and Welding to do the welding process. The high production target that must be achieved by the company requires the machine to always be ready to use so as not to lose revenue due to high downtime. Figure 1 below is a graph of the amount of failure to Shearing, Press, Turret, and Welding machines in 2019.
The high amount of failure indicates that the level of reliability is low, that means it can affect the number of company production [12]. The high amount of failure also affects the maintenance costs that must be incurred. Therefore, this research will focus on Press machines for further analysis. A policy is needed for maintenance activities that pay attention to the characteristics of the failure in detail. One method that can be used is RCM. The method considers the consequences of failure factors that include operational, safety, environmental, and hidden failure. Based on these four factors the consequences can be determined maintenance tasks under the type of failure. The main purpose of this method is to make priorities of preventive maintenance activities, obtain important information in increasing the reliability of components, and develop activities related to preventive maintenance to restore the level of safety and reliability of components at the appropriate level [10].

2. Theoretical framework
Maintenance is defined as a combination of all technical, administrative and managerial actions during the life cycle of an item intended to maintain it or return it to a state where the item can perform its function as required [13]. The first stage is to determine the critical system contained in the Press machine using risk matrix. Risk matrix is a matrix used during risk assessment to determine the level of risk by considering the probability category (likelihood) and the likelihood of the consequence severity category, risk matrix that being used is standard from (AS/NZS4360, 2004) [14]. Determination of the level of risk using 2 parameters, namely likelihood and severity. Next step is FMECA, FMECA is widely used and accepted tool to enhance maintenance practices in process industries [15]. FMECA basically is a methodology designed to identify potential failure modes for a product or process that is used to assess the risks associated with these failure modes, then rank them according to the most serious level of criticality and take corrective actions based on the problem. FMECA consists of two separate analyzes, namely failure mode and effects analysis (FMEA) and criticality analysis (CA) [16-18]. Next stage, RCM is used to determine the specific maintenance task. RCM is a series of tasks that are generated based on systematic evaluations that are used to develop or optimize maintenance programs [19]. The output of RCM is the optimal preventive maintenance schedule for critical components of machinery and equipment [20]. There are two types of maintenance that commonly used in RCM, there are corrective maintenance and preventive maintenance. Corrective maintenance is carried out after damage has occurred and new handling is done, it has the intention of returning the equipment to a state where the equipment can perform the necessary functions directly or suspended [13]. Whereas preventive maintenance is a strategy to prevent components before failure [19]. Preventive maintenance takes into account the time interval for each maintenance carried out.
also calculates the cost of preventive maintenance to see how much the costs are incurred by the company if the company does preventive maintenance [21]. RCM generates preventive task, it is divided into three categories, namely scheduled restoration task, scheduled discard task, and scheduled on condition task [22]. At last, to prove that RCM can reduce maintenance costs, then the maintenance costs are calculated. Calculation of maintenance costs is used to find out how much the costs incurred during maintenance, it can be calculated using equation 1 [21].

\[ T_c = (C_M + C_r) \cdot F_m \]  

where:

- \( C_M \) = Costs incurred for maintenance
- \( F_m \) = Maintenance frequency
- \( C_r \) = Cost of component

3. Research methodology

![Research conceptual model](image)

**Figure 2.** Research conceptual model

**Figure 1** shows a conceptual model of research. The study began with input, namely the plant from PT XYZ, which then obtained a failure record system that would produce failure data for each machine that occurred at the company. After looking at historical data, it turns out that the Press
machine has the highest frequency of failure compared to other machines, and therefore the Press machine was chosen for further investigation. Then the critical subsystem selection is performed using the Risk Matrix method, which contains the frequency (likelihood) as well as the severity (severity) and risks posed on a scale of 1-5. After the critical subsystem has been selected, then the qualitative approach is measured using the RCM method which consists of FMECA and logic tree analysis (LTA) which will then be included in RCM II Decision Worksheet, then performed task selection to get the right type of treatment and will get an optimal maintenance time interval.

4. Result and discussion

4.1 Critical system determination
Determination of the critical system can be determined by looking at the amount of historical data of the failure of the Press machine in the 2017 – 2019 period. Failures of the Press machine based on the system can be divided into two, namely electrical and mechanical. The focus of the study is based on the system with the highest amount of failure. As for the amount of failure that can be seen in each system in Table 1.

| System       | Number of Failure |
|--------------|-------------------|
| Electrical   | 17                |
| Mechanical   | 49                |
| Total        | 66                |

4.2 Critical subsystem determination
Risk Matrix is used as a tool in determining critical subsystems. Risk Matrix is obtained through the product of the severity matrix and the predetermined likelihood matrix. If seen based on Table 2, it can be seen that the brake and trigger subsystems are in the red category, namely extreme with a score of 12, so that the two subsystems are said to be critical subsystems selected for further analysis.

| Likelihood       | Severity                     |
|------------------|------------------------------|
| Insignificant    | Minor | Moderate | Major | Catastrophic |
| 1                | 2     | 3        | 4     | 5            |
| Almost Certain   | 5     | 10       | 15    | 20           | 25          |
| Likely           | 4     | 8        | 12    | 16           | 20          |
| Possible         | 3     | 6        | 9     | Brake, Trigger | 15        |
| Unlikely         | 2     | 4        | Crankshaft, Vanbelt | Ram, Spring | 10       |
| Rare             | 1     | Grease pump | 2     | Flywheel     | Clutch, Pedal | 5          |

4.3 Data distribution test for time to failure (TTF) and time to repair (TTR)
At this stage, the distribution test of the TTF and TTR data was carried out to obtain the most representative data distribution. Tests carried out using the Anderson-Darling test on three distributions, namely normal, exponential, and 2-parameter Weibull. The criterion in determining
the distribution that best represents TTF and TTR data are to look at the value of AD and P-Value. Testing is done using Minitab 17 software. The results can be seen in Table 3 and Table 4.

| Subsystem | Distribution | AD Value | P-Value | Chosen Distribution |
|-----------|--------------|----------|---------|---------------------|
| Brake     | Normal       | 0.608    | 0.082   | 2-parameter Weibull |
|           | Exponential  | 3.206    | <0.003  |                     |
|           | 2-parameter Weibull | 0.581 | 0.118  |                     |
| Trigger   | Normal       | 0.352    | 0.398   | 2-parameter Weibull |
|           | Exponential  | 3.661    | <0.003  |                     |
|           | 2-parameter Weibull | 0.342 | >0.250 |                     |

Table 4. Results of distribution test for TTR data

| Subsystem | Distribution | AD Value | P-Value | Chosen Distribution |
|-----------|--------------|----------|---------|---------------------|
| Brake     | Normal       | 1.355    | <0.005  | 2-parameter Weibull |
|           | Exponential  | 1.230    | 0.054   |                     |
|           | 2-parameter Weibull | 0.958 | 0.012  |                     |
| Trigger   | Normal       | 0.741    | 0.039   | 2-parameter Weibull |
|           | Exponential  | 0.470    | 0.503   |                     |
|           | 2-parameter Weibull | 0.429 | >0.250 |                     |

4.4 Mean time to failure (MTTF) and Mean time to repair (MTTR) Determination

In determining the MTTF and MTTR, a representative time distribution is used. The two critical subsystems have the same type of time distribution there is Weibull 2-parameter. Therefore, the MTTF and MTTR calculation can be done using the equation 2. The results of MTTF and MTTR calculations can be seen in the following Table 5 and Table 6.

\[
\text{MTTF for MTTR} = \eta \cdot \Gamma \left(1 + \frac{1}{\beta} \right)
\]

Table 5. Results of MTTF

| Subsystem | Distribution | Parameter | (1+1/β) | Value of Gamma | MTTF (hour) |
|-----------|--------------|-----------|----------|----------------|-------------|
| Brake     | 2-parameter Weibull | η | 2554.16  | 1.18        | 0.9237      | 2359.354    |
|           |              | β | 5.41495  |             |             |             |
| Trigger   | 2-parameter Weibull | η | 2217.17  | 1.16        | 0.9298      | 2061.525    |
|           |              | β | 6.37336  |             |             |             |
Table 6. Results of MTTR

| Subsystem | Distribution | Parameter | (1+1/β) | Value of Gamma | MTTF (hour) |
|-----------|--------------|-----------|---------|----------------|-------------|
| Brake     | 2-parameter Weibull | η | 6.62673 | 1.66 | 0.90167 | 5.975 |
|           |              | β | 1.52336 |         |              |             |
| Trigger   | 2-parameter Weibull | η | 5.30097 | 1.79 | 0.92877 | 4.923 |
|           |              | β | 1.2684  |         |              |             |

4.5 Failure mode, effects, and criticality analysis (FMECA)

FMECA is designed to identify potential failure modes for a product or process used to assess risks associated with these failure modes, then rank according to the most serious level of criticality and take corrective actions based on the problem. The results of FMECA can be seen in Table 7 and Table 8. Based on Table 7 and Table 8, it can be obtained that brake selected as critical subsystem which will be further analyzed because it has the highest RPN value of 16.

Table 7. FMECA for critical subsystem brake

| Item Number | Item/Functional ID | Potential Failure Modes | Single Component | Redundant System |
|-------------|-------------------|-------------------------|------------------|------------------|
| 1.1         | Brake/holding Ram when slides down | Brake pads wear thin | 4 4 16 | Have Need O' S RPN' |
| 1.2         |                   | Brake spring wearout    |                 |                  |
| 1.3         |                   | Broken brake pads plate | 1 1 4 4 16 |                  |
| 1.4         |                   | Brake nuts overtightened |                 |                  |

Table 8. FMECA for critical subsystem trigger

| Item Number | Item/Functional ID | Potential Failure Modes | Single Component | Redundant System |
|-------------|-------------------|-------------------------|------------------|------------------|
| 2.1         | Trigger/hold the rotation of gear wheel | Broken trigger | 4 4 16 | Have Need O' S RPN' |
| 2.2         |                   | Trigger wearout         | 2 1 4 3 12 |                  |

4.6 Maintenance time interval determination

Determination of the maintenance time interval is carried out to determine the interval of maintenance time which the engineer will do later. Maintenance time intervals are determined based on the type of task that has been obtained from each failure mode that has been previously identified. As for determining the time interval based on the type of task obtained can be calculated in the following below:
1. Scheduled On Condition Task
   Interval calculation for scheduled on condition task is \( \frac{1}{2} P-F \) interval with P-F interval using the assumption of MTTF data.

2. Scheduled Restoration and Discard Task
   The calculation of the time interval for both types of tasks using the equation 3 to 5.

\[
TM = \frac{CM}{Cf} \left( \frac{CM}{Cf} \right)^{\frac{1}{\beta}} \quad (3)
\]
\[
CM = (Co + Cw) MTTR + material cost \quad (4)
\]
\[
Cf = Cr + MTTR (Co + Cw) \quad (5)
\]

Where:
- \( Cf \) = cost of repair
- \( CM \) = cost incurred to carry out maintenance
- \( \eta \) = parameter distribution of TTF data
- \( \beta \) = parameter distribution of TTF data
- \( Cr \) = cost of component replacement
- \( Co \) = loss of revenue cost
- \( Cw \) = cost of corrective maintenance engineer

From equation 5, it can be obtained for proposed maintenance time interval.

### Table 9. Comparison of maintenance time interval

| Subsystem | Information Reference | Existing Task | Existing Task Interval (hour) | Proposed Task | Proposed Task Interval (hour) |
|-----------|-----------------------|---------------|-------------------------------|---------------|------------------------------|
| F         | 1.1                   | Time based    | 1848                          | On Condition  | 1179.677                     |
|           | 1.2                   | Time based    | 1848                          | Restoration   | 2491.934                     |
|           | 1.3                   | Time based    | 1848                          | Restoration   | 2491.934                     |
|           | 1.4                   | Time based    | 1848                          | On Condition  | 1179.677                     |

Table 9 shows that the existing maintenance interval is 1848 hours which means it should be done every 1848 hours for each failure modes. The proposed maintenance time interval is different every failure modes, it shows that on condition task should be done every 1179 hours and restoration task every 2491 hours. The existing maintenance task activity tends to do the overall maintenance in one time, so it typically causes longer downtime and interrupts production time. The maintenance activity for proposed task is different from the existing, the form of activity for the on condition task for failure mode number 1.1 is to carry out a visual inspection, while for failure mode number 1.4 is to check bolt tightness. The form of activity for the restoration task for both failure mode number 1.2 and 1.3 is to do repair.

### 4.7 Total of existing and proposed maintenance cost

PT XYZ has established preventive maintenance activities every 3 months carried out by maintenance engineers. So that in a year the maintenance activities were carried out 4 times. The maintenance activities for proposed task carried out every 3 months for on condition task and 6 months for restoration task. The cost for one maintenance activity (CM) is IDR 1,042,728.00. The calculation of existing and proposed maintenance costs use the equation 1. The calculation comparison results can be seen in the Table 10.
Table 10. Comparison between existing and proposed maintenance cost

| Subsystem | Information Reference | Fm | Existing Cost | Proposed Cost |
|-----------|-----------------------|----|---------------|---------------|
| Brake     | FFM                   | 1.1| 4 IDR 4.170.910,00 | 1 IDR 4.170.910,00 |
|           |                       | 1.2| 4 2 IDR 4.170.910,00 | 1 IDR 4.170.910,00 |
|           |                       | 1.3| 4 2 IDR 4.170.910,00 | 1 IDR 4.170.910,00 |
|           |                       | 1.4| 4 4 IDR 4.170.910,00 | 1 IDR 4.170.910,00 |
| Total Cost|                       |    | IDR 16.683.641,00 | IDR 12.512.731,00 |

The calculation of the total proposed maintenance costs are based on maintenance activities determined through the task selection stage for the critical brake subsystem. Based on Table 10 it can be seen that proposed maintenance cost is cheaper than existing maintenance cost.

5. Conclusion
After the reliability centered maintenance (RCM II) method is used to obtain a proposed preventive maintenance policy for the critical brake subsystem, the results are 2 scheduled on condition tasks and 2 scheduled restoration tasks with maintenance time intervals respectively are 2.55 months and 5.394 months. The total cost of existing maintenance activities for the critical brake subsystem is IDR 16,683,641.00, while the proposed maintenance activities for the critical brake subsystem are IDR 12,512,731.00. Therefore, the company can save costs as much as IDR 4,170,910.00.

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