Proposed optimal maintenance intervals for milling machine using risk based maintenance and analytical hierarchy process at manufacturing plant

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Abstract. PT IIS is an outsourcing company that offers manufacturing spare parts and dies forging. In producing dies forging product PT IIS uses Milling machines, lathes, and CNC 20-L Liquy Hising machines. Based on machine failure data, milling machines suffered a total of 27 times failure during the 2018-2019 period, the frequency of failure will affect the production process and resulted in large maintenance costs. Thus, it takes more observation regarding the maintenance of the Milling machine. The method used for research is Risk-based maintenance (RBM) which aims to estimate and minimize risks arising from failure. The results of collection and processing using RBM revealed that Milling machines with 2880 hours maintenance intervals had a total risk of Rp6,395,124.84 with the percentage of 0.67% exceeding the company's risk tolerance limit of 0.50%. Using the approach to minimizing risks, the proposed maintenance interval is 1100 hours and is at the company's risk acceptance criteria of 0.50%. This study also uses the Analytical Hierarchy Process (AHP) method which decides the maintenance policies that are tailored to the company's conditions, for Spindel components and rags using condition-based maintenance, and coolant hose components using time-based maintenance.

1. Introduction

PT Indo Integral Sekawan is a company that offers manufacturing spare parts and forging Dies. PT IIS produces Forging Dies through 3 machine use processes, namely Milling machine, lathe, and Liquy Hising CNC20-L. The three machines have experienced failure, the following is a data of engine failure in 2018-2019.

The machine that experiences the most amount of failure is a Milling machine, from the large frequency of failure it will affect the production process and result in a large maintenance cost. So, more observation is needed regarding the maintenance of the Milling machine.

PT IIS has implemented treatments for safety and reliability by conducting corrective maintenance, and maintenance intervals for 2880 hours. The implementation of the maintenance system was still higher than the company's risk acceptance criteria, so a new maintenance system with maintenance intervals optimization was needed according to the company conditions.
Risk-based maintenance (RBM) strategy is a quantitative approach that integrates reliability analysis and risk assessment to develop cost-effective maintenance policies to reduce overall risk in operating facilities, and see how much risk and cost resulting from machine failure [1]. Minimizing maintenance costs and risks is calculated to optimize maintenance interval, to reduce the cost of corrective maintenance [2]. Besides, this study used the Analytical Hierarchy Process (AHP) method. AHP is a multi-criteria decision-making tool implemented in almost all applications related to decision making [3]. In this study, AHP aims to make decisions in determining preventive maintenance actions that are relevant to the results of Risk based maintenance calculations and company conditions.

2. Basic Theory and Methodology

2.1. Definition of maintenance

Maintenance is to ensure that all equipment in the company repaired, replaced, adjusted and modified in accordance with the requirements of production [4]. According to [5], maintenance is defined as the combination of all technical measures, and managerial during the life cycle of an item, to maintain or restore it to a state where an item can perform a required function. Based on previous literacy maintenance can be said to be technical and managerial activities to maintain or restore the condition of a company's equipment by repairing, replacing, modifying according to company conditions.

2.2. Risk Based Maintenance (RBM)

The RBM strategy is a quantitative approach that integrates reliability analysis and risk assessment to develop cost-effective maintenance policies [1]. RBM method consists of three interrelated phases, namely: risk estimation, risk evaluation, and maintenance planning. The results obtained from the combined calculation of the RBM stage can develop the overall maintenance plan for the system.

2.3. Analytical Hierarchy Process (AHP)

The AHP method is a structured technique for organizing and analyzing complex decisions based on mathematics and psychology [6]. Using AHP as a method of determining maintenance policies provides two advantages for research. First, AHP makes it easy for researchers to compare and describe qualitative judgments into quantitative values. Second, pairwise comparisons enable AHP to help researchers reach decisions on complex decisions making problems by considering several factors in the same time period, by producing a comprehensive and practical assessment [7].

Figure 1. Machine data failure
2.4. Conceptual Model

The conceptual model is an explanation of the flow of research in solving problems in the form of a framework of thought in the form of information flow and linkages in the analysis process. The following figure shows the conceptual model in this study.

![Conceptual Model Diagram](image)

Based on Figure 2, seen from the highest failure frequency, the Milling machine selected as the object of research. The breakdown structure of the Milling machine aims to see the possible causes of machine failure from the machine components. Next, determination of critical machine components by using FMEA from the calculation of risk priority number (RPN), where the ranking is based on the multiplication severity criteria (S), occurrence (O), and Detection (D) [1]. From the failure data history from the 2018-2019 review, it showed that the distribution of TTF, TTR, and DT critical components that best represent aided by the Minitab software17 in the testing process. Avsim+ software helps the parameter determination form of the critical component, in order to get the value of MTTF, MTTR, and MDT components critical Milling machine. The next step is to calculate using the RBM method to determine the total risk due to failure with additional information on cost factors such as: lost revenue, engineer wages, material prices, and component prices. Then, determine treatment intervals using minimizing maintenance costs and risks. The final stage, determining the maintenance policy using the AHP method approach.

3. Study Case

3.1. Data collection

The data collection in this study was taken based on field observations at PT IIS, at the plant maintenance department by discussing with the maintenance crew or the company's CEO. This study takes the object of the Milling machine in the process of making Dies forging and retrieves information about the failure of the machine in the period 2018-2019.
3.2. Determination of critical components

According to [1] FMEA is a method recommended by international standards such as AIAG. FMEA considers three parameters are usually evaluated, each has a range assessment score (min. 1 to max. 10), namely the severity (S), Occurrence (O), and Detection (D). Followed by the calculation of the RPN obtained from interviews with relevant experts, such as: operator, maintenance crew, and CEO. From the results of table 1, the critical components of the Milling machine are cutter, coolant hose, and vise.

| No | Component      | RPN | Rank |
|----|----------------|-----|------|
| 1  | Handle         | 10  | 7    |
| 2  | Coolant hose   | 126 | 2    |
| 3  | Engine motor   | 50  | 4    |
| 4  | Chuck          | 48  | 5    |
| 5  | Spindel        | 84  | 3    |
| 6  | Vise           | 210 | 1    |
| 7  | Belt           | 45  | 6    |

3.3. Determination of MTTF, MTTR, and MDT data

The determination of MTTF, MTTR, and MDT is calculated based on the selected distribution parameters for each critical component using Avsim + 9.0 software. The calculation of engine maintenance intervals for reference to preventive maintenance can be determined based on the results of these calculations. The MTTF, MTTR, and DT values for each critical component can be seen in table 2, table 3, and table 4.

| Component | Distribution | Parameter | MTTF (Hours) |
|-----------|--------------|-----------|--------------|
| Spindel   | Normal       | \( \mu \) 1488.08 | 1488.08 |
|           |              | \( \sigma \) 1016.06 |       |
| Coolant hose | Normal | \( \mu \) 1532.31 | 1532.31 |
|           |              | \( \sigma \) 1203.88 |       |
| Vise      | Normal       | \( \mu \) 2249.98 | 2249.98 |
|           |              | \( \sigma \) 955.65 |       |

| Component | Distribution | Parameter | MTTR (Hours) |
|-----------|--------------|-----------|--------------|
| Spindel   | Normal       | \( \eta \) 1.65667 | 1.66 |
|           |              | \( \beta \) 0.123458 |       |
| Coolant hose | Normal | \( \mu \) 2.02 | 2.02 |
|           |              | \( \sigma \) 0.385586 |       |
| Vise      | Normal       | \( \mu \) 0.2275 | 0.23 |
|           |              | \( \sigma \) 0.105587 |       |
Table 4. Calculation of MDT

| Component   | Distribution | Parameter | MDT (Hours) |
|-------------|--------------|-----------|-------------|
| Spindel     | Normal       | $\eta$ 1.99 | 1.99        |
|             |              | $\beta$ 0.173613 |            |
| Coolant hose| Normal       | $\mu$ 3.206 | 3.21        |
|             |              | $\sigma$ 1.12768 |            |
| Vise        | Normal       | $\mu$ 0.375 | 0.38        |
|             |              | $\sigma$ 0.163575 |            |

3.4. Risk Assessment

3.4.1. Compilation of failure scenarios. Based on interviews with those who are considered experts that maintenance staff in the company regarding the malfunction of a critical component when damaged. Here is a critical component failure scenario Milling machine.

Table 5. Failure scenarios

| System       | Component     | Possible failure | Consequence                                               |
|--------------|---------------|------------------|----------------------------------------------------------|
| Milling      | Spindel       | Spindel stops    | There is no cutting process on the workpiece             |
| machine      | Loose position|                  | Defects can occur on the workpiece                       |
|              | Coolant hose  | Jammed hose      | Overheating can occur so that several other components fail |
|              | Leaked hose   |                  | The cutting process is not optimal                        |
|              | Vise          | Jammed Threaded  | Unable to function properly to pinch the workpiece causing movement |
|              | Wear on the threaded rod retaining part | | Product defects can occur due to loosen grip |

3.4.2. Quantification of consequences. Perform quantitative consequences due to functional failure of the Milling machine which results in maintenance costs and losses due to failure, determine the normalization value with the parameters stated by [8] as follows.

Table 6. Normalizing the consequences

| Component    | Failure scenarios | normalizing the consequences |
|--------------|-------------------|------------------------------|
| Spindel      | Spindel stops, there is no cutting process on the workpiece | 10 |
|              | Loose position, the workpiece has a defect | 10 |
| Coolant hose | Jammed hose, overheating in other components | 8 |
|              | Leaked hose, the cutting process is not optimal | 7 |
| Vise         | Jammed Threaded, cannot clamp the workpiece to the maximum | 5 |
|              | Wear on the threaded rod retaining part, product defects due to sliding of the workpiece | 7 |

3.5. Risk Estimation

3.5.1. Probability of failure calculation. Milling machine failure probability is calculated from the probability of failure for each critical component during 2880 operating hours, with previously known MTTF distribution parameters. Can be known the chance of failure is obtained from the following substitution reliability equation [6].
\[ R(T) = 1 - \phi\left(\frac{T - \mu}{\sigma}\right) \]  

The following table shows probability of failure,

| Component   | Distribution Parameter | T(Hours) | R(T)  | Q(T)  |
|-------------|------------------------|----------|-------|-------|
| Spindel     | 1488.08, 1016.06       | 2880     | 0.0869| 0.9131|
| Coolant hose| 1532.31, 1203.88       |          | 0.1335| 0.8665|
| Vise        | 2249.98, 955.65        |          | 0.2578| 0.7422|

3.5.2. Consequence of failure. In this study, the failure that occurs in the Milling machine only gives consequences to the system performance loss (SPL). SPL calculation that involves the sum of losses incurred and the calculation of risk is the product of the SPL and the probability of failure, by the following equation:

\[ \text{SPL} = (\text{Loss of Revenue x DT}) + (\text{MTTR x engineer cost}) + \text{material cost} + \text{component cost} \]

\[ \text{Risk} = \text{SPL x Q(T)} \]

Based on the SPL and Risk equation, consequence of failure are as follows:

| Component   | MDT  | MTTR | SPL          | Q(T)  | Risk           |
|-------------|------|------|--------------|-------|----------------|
| Spindel     | 1.99 | 1.66 | Rp 1,788,655.18 | 0.9131| Rp 1,633,221.04|
| Coolant hose| 3.206| 2.02 | Rp 2,046,022.92 | 0.8665| Rp 1,772,878.86|
| Vise        | 0.375| 0.2275| Rp 4,027,249.99 | 0.7422| Rp 2,989,024.94|
| Total       |      |      | Rp 6,395,124.84 |       |                |

3.6. Risk Evaluation

Determination of acceptance criteria is done through discussion with the company's CEO and it was decide that the company's risk acceptance criteria at 0.50% of the machine's production capacity. Machine production capacity was obtained based on operating hours and hourly rate. The following table shows a calculation of the percentage of risk incurred during 2880 operating hours.

| Existing period (hour) | Hourly rate | production Machine's capacity | Risk total | Percentage | Acceptance criteria |
|------------------------|-------------|--------------------------------|------------|------------|---------------------|
| 2880                   | Rp333,333   | Rp 960,000,000                 | Rp 6,395,125| 0.67%      | 0.50%               |

According to table 9, the risk incurred still exceeded the company's risk acceptance criteria of 0.67%, so it needed more evaluation in the company's maintenance system.

3.7. Determination of optimal maintenance intervals

Determination of optimal maintenance intervals is a step in reducing the level of risk so that it is within the company's risk acceptance criteria. The method used in this study is the minimization of maintenance costs and risks [10], with trial and error trials seeing the value of the reliability of the machine. The following is a recapitulation of the comparison of existing and proposed maintenance time intervals.

Table 10 shows that the proposed risk posed is smaller than the existing risk, supported by the percentage of acceptance criteria for proposed maintenance intervals of 0.50% of production capacity, and greater reliability value then the 1100 hours maintenance intervals can be proposed to be the optimal maintenance of the Milling machine.
Table 10. Maintenance intervals comparation

| Component/Intervals | Existing (2880 hours) | Proposal (1100 hours) |
|---------------------|------------------------|-----------------------|
|                     | Risk                   |                       |
| Spindel             | Rp 1,633,221           | Rp 629,607            |
| Coolant hose        | Rp 1,772,879           | Rp 743,116            |
| Vise                | Rp 2,989,025           | Rp 463,536            |
| Total               | Rp 6,395,125           | Rp 1,836,259          |
|                     | Realibility            |                       |
| Spindel             | 0.0708                 | 0.648                 |
| Coolant hose        | 0.1335                 | 0.6368                |
| Vise                | 0.2578                 | 0.8849                |

3.8. Determination of preventive maintenance policy activities

AHP was used in this study to determine the maintenance policy that is suitable for critical components according to company conditions. The data obtained by giving questionnaires to 4 experts (CEO, 2 maintenance crew, and operators) to determine maintenance priorities. The following are the result of processing from AHP.

Figure 3. Hierarchy structure

Table 11. Global score

| Component     | TBM    | SD      | CBM     |
|---------------|--------|---------|---------|
| Spindel       | 0.356932 | 0.262062 | 0.381006 |
| Coolant hose  | 0.52319  | 0.288738 | 0.188072 |
| Vise          | 0.271841  | 0.236732 | 0.491427 |

From table 11, it is known that the cutter and vise components had a Condition based maintenance policy, and for coolant hoses had a Time based maintenance policy.
4. Conclusion
This study took Milling machine objects based on the frequency of engine failure and used the Risk Priority number to obtain critical components, namely Spindel, coolant hose, and vise. The use of Risk based maintenance methods and Analytical hierarchy processes in this study is to determine the amount of risk (system performance loss) that was generated by system failures and determine maintenance policies that are appropriate to company conditions. The result of the RBM method showed an intensive maintenance recommendation of 1100 hours for the three critical components of the Milling machine with a total risk of Rp1,836,259 and the percentage of risk is at an acceptable risk of damage of 0.50%.

Based on the AHP method, the maintenance policy for Spindel and vise components was to use Condition based maintenance and Coolant hose using Time based maintenance.

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