Production Machine Maintenance System Design Using Reliability Centered Maintenance

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Abstract. One of the indicators in increasing productivity is the level of reliability of production machines. The reliability level of a production machine is determined by the effective and efficient maintenance process of the company. A case study was conducted in a manufacturing company. In the period January until June 2019, the percentage of machine downtime is more than 3.0% (ideal benchmarking downtime for the manufacturing industry). Research carried out using Reliability Centered Maintenance (RCM). It starts with determining critical objects, then identifies each function of the assets, carries out FMEA analysis and calculates the highest risk of each failure mode, calculates proper maintenance intervals for the five highest failure modes, then ends with making a maintenance strategy by considering risk based inspection. This study aims to develop a maintenance strategy model that is better than what is currently used. By applying Reliability Centered Maintenance, machine reliability can be increased by an average increase of 39.34% and the right maintenance strategy can be found. Furthermore, it will get a new framework to become a new maintenance policy for the company.

1. Introduction

In producing products in one production line, the aspect of productivity must be highly considered. One of the indicators in increasing productivity is the level of reliability of production machines. The level of effectiveness and efficiency of the maintenance process determines the reliability level of the production machine [1]. Maintenance activities aim to ensure that the assets function according to what the user wants [2]. Maintenance is related to procedures, tasks, instructions, qualifications of personnel, equipment, and resources needed to maintain the system or return it to a better condition [3]. Proper maintenance operations can increase long-term productivity, maintain product functional level, and reduce unscheduled downtime [4]. Downtime is the total time that a machine cannot operate due to a failure. Downtime may not be a severe problem if the machine or process can be reset and can be started again with a relatively fast time. However, downtime can be a serious problem if it results in process interruptions, such as rework, and takes a long time to set the machine or process to start again [5], and this is the main actual problem on our research object. Therefore, it is very important to identify the level of machine reliability during production time to increase the long-term system's availability and meet short-term system requirements [4]. Study of [39] shows by identifying the level of machine reliability during production time, the downtime rate decreased by 34.91%.

A case study was conducted in the engine production shop of “Company XYZ” in Indonesia. As an automotive car company with the highest market share in Indonesia [6], a world-class maintenance
policy is needed so that the reliability of the production machine is optimal. The production machine breakdown data showed that during January 2019 to June 2019, the percentage of machine downtime in the cylinder block production line was 6.56%, while the cylinder head production line was 9.14%, and 6.3% for the crankshaft production line, 6.09% for the camshaft production line and 1.32% for the assembly line. Of these percentages, the cylinder head production line has the highest downtime, while the ideal benchmarking downtime for the manufacturing industry is less than 3.0% [7]. In addition to increasing the cost of downtime, high downtime can disrupt productivity because products that should be able to finish quickly must stop first (line stop) if the machine breaks down and reproduces if the machine has been repaired. Company XYZ implemented corrective maintenance and preventive maintenance actions as primary maintenance actions [8]. However, maintenance policy does not consider the level of machine reliability during production time and the level of risk of any machine failure, therefore the machine still experiences a breakdown during the production process. As a result, the average shortage of cylinder head production is 11 products/day in the period January 2019 until June 2019 (1 day = 2 shifts, with 1 shift = 8 working hours). This shows that the frequency of products produced (actual) does not match the frequency of products that have been planned (plan). As for the cost of downtime, the cylinder head production line has a capacity of 26 products/hour with a profit of Rp281,000/part. With an average length of downtime per day for 1.45 hours, the average downtime cost is around Rp10,593,700/day. From the exposure to the problem, we will develop the maintenance strategy model so that it can optimize both downtime minimization and maximize productivity in Company XYZ.

In this research, we use reliability-centered maintenance (RCM) to develop a maintenance strategy model that is better than what is currently used. This study aims to fulfill the objective function of increasing reliability (at least 80%) and estimating costs for maintenance. RCM has been successfully applied in various industries [9] and has the opportunity to maintain and potentially increase reliability and optimize source maintenance power allocation [10]. Several studies use RCM and confirm that RCM can help the company achieve optimal maintenance policies and strategies [11]–[17]. There are two contributions from this research. We give RCM framework to clearly understand the specific relationship of the RCM framework [18] for the maintenance of the production machine, especially in the cylinder head production line which is the advantage of this research. We also provide the results of the level of machine reliability, maintenance time interval, maintenance cost, percentage increase in reliability to compare the actual conditions with proposed results, and maintenance strategies for Company XYZ.

This paper consists of four sections. The second section contains the research design used in research, as for the third shows the result of applying reliability centered maintenance. The fourth section contains the conclusions drawn in this study.

2. Research Design

2.1. Research Methodology

The study was conducted from January 2019 to June 2019. This research has an objective that is to develop a maintenance strategy model for the cylinder head production line. The research object is the engine production shop of Company XYZ, which is located in Jakarta, Indonesia. This research requires data, such as interviews, field observations, the number of daily productions, and machine breakdown data in cylinder head production lines at the engine production shop. Starting with determining the critical object, that is cylinder head production line. The next step is to identify each machine function in the cylinder head production line. We conducted an FMEA analysis to identify the effects of failures that occurred. Next we calculate the highest risk from each failure mode. Then calculate the proper maintenance intervals for the five highest failure modes by finding the optimal distribution using Weibull ++ software, and then ending by creating a maintenance strategy taking into account risk-based inspections.
2.2. Reliability Centered Maintenance

RCM is a maintenance perspective that understands company needs and then develops maintenance strategies to optimize maintenance results [19]. RCM is the most successful method for developing failure management policies to maintain the functional performance of physical assets owned [20]. The term RCM is derived from the title of the work of Stanley Nowlan and Howard Heap entitled "Reliability Centered Maintenance," published by United Airlines together with the US Defense Department in 1978. The basis of this book is a decision diagram designed for the selection of maintenance strategies because reliability has been seen a bathtub curve, which then the US Defense Department decided to require that all major systems on an aircraft be evaluated with RCM.

According to [21], there are seven key elements of RCM, which are as follows: (a) Operational context and function; function is the standard level of performance or usability of assets expected/desired by the user. If every asset is to be maintained, then the asset's performance must be within its initial ability. The user should know the initial capabilities of an asset and the minimum performance that is prepared to be accepted in the context in which the asset is used. (b) Functional failure; failures are the inability of an asset to perform its function. Functional failure is the inability of assets to meet functions to performance standards that are acceptable to users [2]. Usually, preventive maintenance strategies are designed to prevent functional failure by assigning preventive maintenance tasks that target the cause of functional failure to prevent functional failure [22]. (c) Failure mode; failure modes are the cause of functional failures [2]. The failure mode must be defined in detail in order to choose the appropriate failure management policy. (d) Failure effects; a failure effect is a description of the condition when a failure mode occurs [2]. Failure effects are usually identified carried out at three levels, namely assembly - local, system, and plant. By describing effects in this way, the increase in effects can be seen clearly [5]. The local level is the effect of the failure mode on the function of a particular item. The next level is the system's effect of the failure mode on the function of items at a higher level (in a unitary production system). The last level is plant level which is the effect of the failure mode on the function of the item at the highest level (regarding the factory as a whole). (e) Failure consequences; failure consequences aim to answer the question, "What is the problem?". In RCM, the consequences can be classified into four parts. The first is hidden failure consequences. This category occurs where the failure cannot be proven immediately after the failure took place. A unique technique is needed to overcome the effects of this type of failure. The second part is safety and environmental consequences. This category occurs when a failure of an item has consequences for workers' safety or other humans. The environmental consequences occur when the failure of an item's function has an impact on environmental sustainability. The third one is the operational consequences. This category occurs when it results in production or operations (product quality, customer service, or operational costs for component improvement). The last one is non-operational consequences. The category is not classified as a safety or production consequence, but this failure only results in component repair costs. (f) Proactive tasks and task intervals; according to [2], proactive tasks are tasks performed before the failure occurs as a precaution. There are two prevention options available in this situation: scheduled restoration tasks and scheduled discard tasks. Scheduled restoration tasks involve rebuilding a single component or overhauling an entire unit before the specified age limit, regardless of conditions at the time. Scheduled discard tasks include disposing of items or components before the specified age limit, regardless of the condition. If it is possible to take strategies to prevent or avoid the consequences of functional failure, tasks designed to detect potential failures are known as on-conditions tasks. On-condition tasks include checking for possible failures, so strategies can be taken to prevent functional failure or to avoid the consequences of functional failure. (g) Default actions; several conditions require default actions, namely: if a proactive task that reduces the risk of multiple failures cannot be found, the default decision is failure-finding tasks; if a proactive task reduces the risk of failure and increases safety or the environment cannot be found, then the default decision is that the item must be redesigned or the process must be changed; if
a proactive task with a lower cost is not found during a certain period of time with a failure that has operational consequences, then the default decision is no scheduled maintenance; and if a proactive task with a lower cost is not found during a certain period with a failure that has non-operational consequences, then the default decision is no scheduled maintenance.

2.3. Failure Mode and Effect Analysis

Failure Modes and Effect Analysis (FMEA) is one of the popular methods used to evaluate designs in the early stages of reliability [23], [24]. The FMEA methodology is one of the risk analysis techniques recommended by many international standards organizations, such as the Society of Automotive Engineers, the US Military of Defense, and the Automotive Industry Action Group. FMEA is an effective tool for identifying and assessing how potential failures can affect the performance of a process [25]. FMEA makes it possible to identify and analyze all system errors, evaluate their importance in system reliability, and focus on maintenance practices and their effects on system reliability. FMEA prioritizes potential sources that differ from variability, failure, error, or defects in a product or process relative through three criteria, namely occurrence, severity, and detection [26]. Three scores for each criterion, namely occurrence, detection, and severity, are multiplied to get a risk priority number (RPN). The source of variability or failure with the highest RPN is the focus for further process improvement.

\[ RPN = S \times O \times D \] (1)

2.4. Mathematical Model of Statistical Distribution and Maintenance

According to [20], reliability is the ability of an item to perform the functions for a certain period. Reliability is related to reducing the frequency of failures during time intervals and measuring the probability of avoiding failures during certain time intervals [27].

| Information | Formula |
|-------------|---------|
| Reliability | \( R(t) = 1 - F(t) = 1 - \int_0^t f(t) dt \) |
| Mean Time to Failure | \( MTTF = \int_0^\infty R(t) dt \) |
| Mean Time to Repair | \( MTTR = \sum_k k = 1 \cdot CMT \) |
| Reliability of Exponential Distribution | \( R(t) = e^{-\lambda t} \) |
| Reliability of Normal Distribution | \( R(t) = \frac{1}{\sqrt{2\pi}\sigma} \int_t^\infty e^{-\frac{(t-\mu)^2}{2\sigma^2}} dt \) |
| Reliability of Lognormal Distribution | \( R(t) = \frac{1}{\sqrt{2\pi}\sigma} \int_t^\infty e^{-\frac{(ln(t)-\mu)^2}{2\sigma^2}} dt \) |
| Reliability of Weibull Distribution | \( R(t) = e^{-\left(\frac{t-\gamma}{\alpha}\right)^\beta} \) |

Maintenance costs are costs associated with any corrective (CF) or preventive (CM) action. Corrective maintenance costs are the total costs of maintenance resources needed to repair or replace a failed item. Whereas, the cost of preventive maintenance is the total cost of maintenance resources needed to inspect items before a failure occurs and to replace items that are rejected. Thus, the total maintenance cost over the system/product's life is the sum of corrective and preventive maintenance costs [28]. To calculate the optimal maintenance costs required component costs, costs of production losses due to turnover, and technicians' costs. The equation for treatment costs is shown by the equation below [29].
\[ CF = \text{Components Cost} + \left( (\text{Technician Cost} + \text{Cost of Production Losses} \times Tf) \right) \]  
\[ CM = B \times \text{Components Cost} + \left( (\text{Technician Cost} + \text{Cost of Production Losses} \timesTp) \right) \]  
\[ TC = \frac{CF}{\alpha^B TM^{\beta-1}} + \frac{CM}{TM} \]

3. Case Study Result

The algorithm begins by determining the critical production line based on data with the highest frequency of downtime. This study focused on the production line with the highest downtime is the cylinder head production line with 9.14%. The following step was describing a system, which is needed to find out the components contained in the system and how it works according to its function [30]. In this study, the type of FMEA that is applied is the type of process [31], [32], because the research object is intended for one production line and based on spare part data from Company XYZ, each machine has the same characteristics. Important assumptions in the FMEA in this study are the analysis of assets as a database [2], [22], [33]–[37]. The identification and analysis results show that the production line has 67 functions, 108 functional failures, and 34 failure modes. After conducting the FMEA, a risk assessment (RPN) is then performed for each failure mode. This risk assessment was carried out by two sources are maintenance operators for the cylinder head production line, and maintenance line head for the cylinder head production line, where both employees are employees who are directly related to the maintenance process on the cylinder head production line and obtained five failure modes (only) that have a high critical level category, namely NC Fault, D-Link Fault, Machine Won't Process, Clamp / Unclamp Fault, and Master On Dead.

Determination of distribution and maintenance intervals using the help of Weibull ++ software. The recap of the test results can be seen in Table 1.

Table 2. Distribution Test Results and Maintenance Intervals

| Failure Mode | Optimal Distribution | Parameter | MTTF (hour) | MTTR (hour) | Optimal Maintenance Intervals (hour) | Reliability (Before) (%) | Reliability (After) (%) |
|--------------|----------------------|-----------|-------------|-------------|-------------------------------------|--------------------------|-------------------------|
| NC Fault     | 2P-Weibull           | \( \alpha \) = 309.006585, \( \beta \) = 1.5378, \( \gamma \) = - | 227.581188  | 1.71        | 96                                   | 53.5                     | 84.7                    |
| D-Link Fault | 2P-Weibull           | \( \alpha \) = 278.358289, \( \beta \) = 0.99464, \( \gamma \) = - | 247.995638  | 0.328       | 48                                   | 41                       | 84                      |
| Machine Won't Process Clamp / Unclamp Fault | 3P-Weibull | \( \alpha \) = 379.361004, \( \beta \) = 0.79413, \( \gamma \) = 156 | 588.089135  | 0.252       | 192                                   | 33                       | 85.7                    |
| Master On Dead | 3P-Weibull      | \( \alpha \) = 365.267551, \( \beta \) = 1.9269, \( \gamma \) = 381.5 | 705.507805  | 1.64        | 528                                   | 45.2                     | 84.2                    |

Determining the optimum interval for each component required the cost of preventive maintenance (CM) and repair costs (CF). Then also need to know the cost of labor, the cost of production losses, and the cost of replacing components. The recap of the calculation results can be seen in Table 2.
Table 3. Maintenance Cost Calculation Results

| Failure Mode          | Components Cost  | Technician Cost (/hour) | Cost of Production Losses | CF         | CM         | TC (/hour) |
|----------------------|------------------|-------------------------|---------------------------|------------|------------|------------|
| NC Fault             | Rp51,111,111     | Rp21,250                | Rp7,306,000               | Rp63,640.71| Rp53,162,741| Rp663,610  |
| D-Link Fault         | Rp19,125,000     | Rp21,250                | Rp7,306,000               | Rp21,528,338| Rp20,663,723| Rp508,566  |
| Machine Won't Process| Rp833,333        | Rp21,250                | Rp7,306,000               | Rp2,679,800| Rp3,984,051| Rp28,877   |
| Clamp / Unclamp Fault| Rp1,000,000      | Rp21,250                | Rp7,306,000               | Rp13,016,690| Rp1,586,180| Rp53,095   |
| Master On Dead       | Rp23,833,333     | Rp21,250                | Rp7,306,000               | Rp28,302,956| Rp25,665,146| Rp39,846   |

One of the advantages of this research is that we consider risk-based inspection in determining maintenance strategies [38]. NC Fault is a form of failure that occurs on the unit axis on the engine, one of which is on the G-Top machine where there is a 5-axis movement that is X, Y, Z, table, and magazine. In addition to the axis unit, NC Fault also occurs in the spindle unit. The NC unit includes a controller (C64T), power supply, servo/spindle amp, and a servo motor. Based on the FMEA analysis results, the cause of the NC Fault was due to damage from one of the NC units, such as rapid Y-axis, spindle motor, X-axis motor, sleeve, Z-axis, servo table encoder, servo amp magazine, broken power rest, motor encoder, the wrong auto-switch setting, and wrong base-position. Inspection can be carried out without interrupting the production process by checking the engine alarm with each alarm having meaning. After conducting an inspection, the operator can perform a scheduled discard task before failure so that it does not interfere with the production process.

D-Link is a branch or sector of an input device, and PLC (Programmable Logic Controller) output spread over parts of the machine called a sleeve. In the G-Top machine, there are seven sleeves. Based on the results of FMEA analysis, the cause of the D-Link Fault was primarily due to damage to the sleeve, but also due to damage to the relay, damage to the power supply, and the power limit switch cable loading off. The inspection that can be carried out by the operator is checking the PLC output, which is spread over the machine parts (sleeve). On the production machine, there are seven sleeves. Sleeve 1 is in the operational panel, which is useful for checking which sleeve is damaged if a problem occurs. Sleeve 2, 3, and 4 are useful for reaching wind and hydraulic supply areas. As for sleeve 5 is in the operational panel magazine to reach the wind supply area. Sleeve 6 and 7 are useful for reaching coolant areas. Knowing the experiencing damage sleeve (inspection results), the operator can perform a scheduled discard task.

The machine does not want the process to occur because the processing requirements have not been fulfilled. Operators must check the PLC program to determine the requirements that have not been met. Some conditions for the machine to be processed, namely door open, hydraulic off, master on, shift return, cycle completed, and so on. Based on the FMEA analysis results, the cause of these conditions was not fulfilled, so the machine did not want to process the broken light curtain limit switch cable, connector damage, advance compensation was low, and damage to the relay. The operator's inspection is to check the PLC program to see the conditions of the requirements such as door open, hydraulic off, master on, shift return, cycle completed. After conducting an inspection, the operator can perform scheduled restoration tasks following the cause of failure before failure so that it does not interfere with the production process.

Clamp / Unclamp Fault occurs due to incorrect position (not fit) of the workpiece that enters the machine, so the position of the workpiece is tilted, and the clamp is not fit with the workpiece. Based on the FMEA analysis results, the cause of the clamp / unclamp fault was due to operator errors,
proximity cables, and limit switch cables damaged or dirty and broken tools. An inspection done by
the operator is to check the operational panel, and if the clamp is not fit, a warning will automatically
appear. After conducting an inspection, the operator performs scheduled on-condition tasks to solve
the root of the problem.

Master On is a condition when the engine can be turned on if several machines' safety requirements
are met. Some examples of safety requirements for the G-Top engine are a mounted denchi lock, auto
subpanel, light curtain off a sensor, hydraulic off, emergency stop release, and so forth. Based on the
results of the FMEA analysis, the causes of the condition occurred are due to loosening of load limit
power switch cable, damage to the relay, and damage to the power supply. The operator's inspection
can be carried out to check the wiring (cable management in a network of machines supported by
several security tools). After conducting an inspection, the operator performs scheduled on-condition
tasks to solve the root of the problem.

SIPOC (Supplier, Input, Process, Output, Customer) diagrams can be made for the RCM
framework to clearly understand the specific relationship of the RCM framework for the maintenance
of production machinery, especially in the cylinder headline [18]. This framework helps as an initial
understanding if you want to implement RCM in determining its maintenance strategy. Suppliers and
customers determine the cross-functional teams and individuals who are stakeholders in providing
input and utilizing the respective outputs of the RCM framework. The input for the process considered
here is primarily the data needed for RCM. This data varies from design to field data and requires
individuals with their respective technical competencies to utilize RCM. In addition, RCM process
suppliers and customers are mostly the same groups of individuals, but they use different process
inputs and outputs. Therefore, in order for the ideal RCM framework to be implemented, these
stakeholders must participate in shaping the requirements for the process directly or indirectly. The
SIPOC for the RCM framework in Company XYZ is shown in Figure 1.

| Supplier          | Input                                                                 | Process          | Output                                | Customer                  |
|-------------------|----------------------------------------------------------------------|------------------|---------------------------------------|---------------------------|
| • Service &       | • Information Design                                                | RCM for Production| • Database Failure                    | • Quality                 |
| Maintenance       | • Machine Breakdown Data                                            | Machine          | • Maintenance Intervals               | • Design Engineering      |
| Design Engineering| • Field Inspection (Gerachi Genbutsu)                               | Output           | • Maintenance Strategy                | • Services & Data         |
| Product           | • CTQ (Critical to Quality)                                         |                  | • Data Optimization Maintenance       | • Spare Parts & Repair    |
| Integration       |                                                                     |                  |                                       | • Testing & Validation    |
| Team              |                                                                     |                  |                                       | Team                      |
| Quality Department|                                                                     |                  |                                       |                           |
| Machine Parts     |                                                                     |                  |                                       |                           |
| Manufacturers     |                                                                     |                  |                                       |                           |

**Figure 1.** SIPOC for RCM Framework

4. Conclusion
The study employed RCM to develop a maintenance strategy model that is better than what is
currently used. A case study has been performed in Company XYZ, located in Indonesia. The results
of the identification and analysis show the production line has 67 functions, 108 functional failures, 34
failure modes, and obtained 5 failure modes that have a high critical level category, namely NC Fault,
D-Link Fault, Machine Won't Process, Clamp / Unclamp Fault, and Master On Dead. By
implementing RCM, machine reliability can be increased by an average increase of 39.34% and
various strategies are obtained for each failure mode. The study also creates a new framework to
become a new maintenance policy for the company. The method that has been performed can be
beneficial for directors of the company to solve existing problems. Through such a method, we can use the results as a reference in the manufacturing company’s improvement in the future.

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