Jurnal Sistem Teknik Industri
Journal homepage: https://talenta.usu.ac.id/jsti

Planning of a Preventive Maintenance System for Lathe Machines Using the RCM II and FMECA

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ARTICLE INFO

Article history:
Received 25 December 2025
Revised 2 February 2026
Accepted 6 February 2026
Available online 23 February 2026

E-ISSN: 2527-9408
P-ISSN: 1411-5247

How to cite:
F.F. Adsa, A. Ishak, and Anizar, "Planning of a Preventive Maintenance System for Lathe Machines Using the RCM II and FMECA," *J. Sist. Tek. Ind.*, vol. 28, no. 1, pp. 47–56, Feb. 2026.

http://doi.org/10.32734/register.v27i1.idarticle

ABSTRACT

Unplanned downtime and ineffective maintenance strategies remain major challenges in improving the reliability of production machinery in manufacturing industries. This study proposes a structured preventive maintenance system for a CW6293 lathe machine by integrating Reliability Centered Maintenance II (RCM II) and Failure Mode, Effects, and Criticality Analysis (FMECA). The novelty of this research lies in the systematic integration of risk-based criticality assessment, statistical reliability modeling, and maintenance task selection to develop an optimized maintenance framework. FMECA is employed to prioritize components based on severity, occurrence, and detection attributes, identifying the gearbox as the most critical component. Reliability analysis using Time Between Failure (TBF) and Time To Repair (TTR) data is conducted to determine appropriate maintenance intervals through Weibull and Normal distribution modeling. The RCM II decision logic is then applied to translate reliability characteristics and failure consequences into specific maintenance actions, namely scheduled discard and scheduled restoration tasks. This integrated approach enables the development of a proactive maintenance system that improves decision-making accuracy, enhances machine reliability, and supports a transition from reactive to risk-based preventive maintenance. The proposed framework demonstrates practical applicability for manufacturing environments and contributes to the advancement of maintenance engineering by combining reliability analysis, criticality evaluation, and structured maintenance policy design.

Keyword: Preventive Maintenance, Reliability Centered Maintenance II, Failure Mode Effect and Criticality Analysis

ABSTRAK

Downtime yang tidak terencana dan strategi pemeliharaan kurang efektif menjadi tantangan utama dalam meningkatkan keandalan mesin produksi di industri manufaktur. Penelitian ini mengusulkan suatu sistem *preventive maintenance* terstruktur untuk mesin bubut CW6293 dengan mengintegrasikan metode *Reliability Centered Maintenance II* (RCM II) dan *Failure Mode, Effects, and Criticality Analysis* (FMECA). Kebaruan penelitian terletak pada integrasi sistematis antara penilaian kritikalitas berbasis risiko, pemodelan keandalan secara statistik, serta pemilihan jenis tindakan pemeliharaan dalam satu kerangka kerja yang terpadu. Metode FMECA digunakan untuk memprioritaskan komponen berdasarkan atribut *severity*, *occurrence*, dan *detection*, sehingga *gearbox* teridentifikasi sebagai komponen paling kritis. Analisis keandalan menggunakan data *Time Between Failure* (TBF) dan *Time To Repair* (TTR) dilakukan untuk menentukan interval pemeliharaan tepat melalui pemodelan distribusi Weibull dan Normal. Logika keputusan RCM II diterapkan untuk menerjemahkan karakteristik keandalan dan konsekuensi kegagalan menjadi tindakan pemeliharaan spesifik, yaitu *scheduled discard task* dan *scheduled restoration task*. Pendekatan terintegrasi ini memungkinkan pengembangan sistem pemeliharaan proaktif untuk meningkatkan ketepatan pengambilan keputusan, keandalan mesin, serta mendukung peralihan dari pemeliharaan reaktif ke *preventive maintenance* berbasis risiko. Kerangka kerja yang diusulkan

memiliki penerapan praktis pada lingkungan manufaktur dan memberikan kontribusi terhadap pengembangan ilmu rekayasa pemeliharaan.
Keyword: Pemeliharaan Preventif, Reliability Centered Maintenance II, Failure Mode Effect and Criticality Analysis

1. Introduction

The manufacturing industry in Indonesia has experienced significant growth in line with technological advances, particularly in efforts to improve production efficiency and quality. The application of modern technology has encouraged companies to optimize their production processes, which in turn has increased demand for reliable and efficient machine maintenance systems. In the context of global competition, the reliability of production machinery has become a key factor in maintaining competitiveness and meeting market demand in a timely manner [1]. The reliability of production equipment not only ensures smooth operational performance but also directly affects the productivity and operating costs of a company. Machine downtime due to unexpected failures can lead to reduced output, increased repair costs, and potential failure to meet production targets. Companies must implement appropriate maintenance strategies to minimize the risk of sudden failures and maximize production efficiency [2] [3].

Manufacturing company engaged in the palm oil machinery component sector, faces challenges in maintaining the reliability of its production equipment, particularly its lathes. Data on the frequency of failures and downtime of the CW6293 lathe shows significant variation in failure rates and downtime duration over the past year. This condition highlights the need for a more structured and reliability-based maintenance system. The current maintenance system at manufacturing workshop is still dominated by reactive maintenance, where corrective maintenance actions are only taken after a failure occurs. Corrective maintenance is still used as a temporary solution, but this approach is inefficient in controlling damage and high operational costs due to its unplanned nature. The need for a more systematic and risk-based method is important to improve machine maintenance performance.

This study proposes solving this problem with preventive maintenance designed using the Reliability Centered Maintenance II (RCM II) and Failure Mode Effect and Criticality Analysis (FMECA) methods. The RCM II method provides a systematic framework for evaluating machine functions and identifying potential failure modes and preventive measures. FMECA helps analyze and classify component failure risks so that maintenance priorities can be determined based on criticality levels. The integration of these two methods enables the determination of an optimal preventive maintenance schedule, not only reducing downtime but also lowering maintenance costs. Companies can switch from corrective maintenance to a more effective and efficient preventive maintenance strategy to support machine reliability and smooth production process productivity [4].

RCM II provides a systematic framework for developing maintenance strategies that consider reliability, safety, environmental, and cost aspects. By identifying the main functions of equipment, failure modes, and the consequences of each failure, companies can design maintenance schedules efficiently. FMECA complements this process through criticality analysis, allowing maintenance priorities to be focused on components that pose the highest risk to operational continuity [5]. The stages of the RCM II process include defining the functions and performance standards of assets, identifying functional failures, analyzing the causes of failure, describing the impact of each failure, evaluating the consequences of failure, determining proactive or default maintenance actions, and developing a maintenance schedule and implementation plan [6].

The novelty of this study lies in the development of an integrated preventive maintenance planning framework that combines risk-based criticality analysis FMECA, statistical reliability modeling of components MTBF and MTTR, and RCM II decision logic into a unified approach. Unlike previous studies that typically apply these methods separately or focus primarily on maintenance cost evaluation, this research emphasizes the systematic determination of maintenance task types and maintenance intervals based on failure characteristics and their consequences. This integrated approach is expected to enhance the accuracy of maintenance decision-making and support the transition from reactive maintenance to reliability based preventive maintenance.

The implementation of RCM II and FMECA is expected to improve the reliability of lathes at manufacturing workshop, reduce the frequency of failures, and lower overall maintenance costs. This strategy also supports the achievement of production targets and maintains product quality consistency, which is very important in the highly competitive palm oil processing industry. The concepts of preventive and predictive maintenance serve to prevent failures before they occur. The classification of maintenance activities, ranging from planned to unplanned maintenance, provides a basis for companies to choose strategies that suit their operational characteristics and production needs. Empirical evidence shows that RCM II and FMECA are highly effective in improving maintenance efficiency in various industrial sectors [7].

2. Research Methodology

This research is classified as action research, which aims to provide practical solutions in the context of manufacturing industry operations. The main focus of the research is on machine maintenance, specifically designing preventive maintenance with a systematic approach to improve the reliability of production machines. To support this objective, the research is directed at explaining the location, time, and selection of the research site.

This research was conducted in a manufacturing workshop located in Medan, North Sumatra. The research period spanned from August to December 2024, ensuring that the collected and analyzed data reflected the actual operational conditions of the machine over the previous year. The selection of the research location and time frame was based on the availability of historical maintenance and failure data. This consideration subsequently formed the basis for determining the most relevant research object for analysis. The research object was focused on a lathe machine that exhibited the highest downtime frequency based on historical failure data. This selection was justified by the significant impact of the machine on production continuity and maintenance costs, indicating that improvements in its maintenance system would yield substantial operational benefits. The data used in this study included machine failure and repair records over one operational period, which were considered sufficiently representative for reliability analysis. The application of the Reliability Centered Maintenance II (RCM II) method to this machine is expected to result in an effective and efficient maintenance planning strategy. To clarify the direction of the research, the relationships among the analyzed variables are further explained through a conceptual framework.

The conceptual framework of the study explains the relationship between the variables analyzed. The independent variables include maintenance intervals and maintenance costs based on the results of Failure Mode Effect and Criticality Analysis (FMECA), Mean Time Between Failure (MTBF), and Mean Time To Repair (MTTR). The dependent variable is preventive maintenance planning by integrating the data and evaluation to produce maintenance schedules and actions. This framework directs the research stages to proceed systematically according to the planned flow of activities.

The research stages were carried out sequentially through a structured workflow consisting of four main phases. The first phase involved system study preparation, including system selection, boundary definition, system description, and in-depth functional analysis using a Functional Block Diagram (FBD). This method was employed to systematically illustrate the relationships among subsystems and the functional flow of the machine, thereby facilitating the identification of potential failure points. The second phase focused on identifying critical components using Failure Mode, Effects, and Criticality Analysis (FMECA) to map failure modes, impact levels, and component criticality. FMECA was selected due to its ability to integrate qualitative and quantitative analysis through severity, occurrence, and detection parameters, enabling objective and risk-based maintenance prioritization. Once critical components were identified, reliability analysis was conducted using Time Between Failure (TBF) and Time To Repair (TTR) data. Statistical distribution modeling was applied to estimate MTBF and MTTR as the basis for determining maintenance intervals. The research then proceeded to the selection of appropriate maintenance strategies for each failure mode. In the third phase, maintenance strategies were determined based on evaluations using the RCM II Decision Diagram by analyzing the required maintenance actions to preserve system reliability. This phase concluded with documentation in the RCM II Decision Worksheet as a reference for preventive maintenance implementation. Maintenance intervals were calculated using statistical methods and mathematical models derived from MTBF and MTTR data, which subsequently served as the basis for cost comparison analysis in the following phase.

The final phase involved a cost comparison analysis by comparing current maintenance costs with the estimated costs of the proposed maintenance strategy. This analysis aimed to ensure that the proposed solution is not only effective in improving reliability but also economically efficient. Data processing was conducted systematically through specific stages, which are described in the subsequent paragraphs. This analysis aims to ensure that the solution is not only effective in improving reliability but also efficient in terms of operational costs [8]. The data processing is carried out systematically with specific steps described in the following paragraphs.

The data processing method involves several systematic steps, starting with defining the scope of the system. FBD is created to visually describe the functions and interactions between machine components. Failure modes and effects are identified through FMECA by combining qualitative and quantitative analysis, and calculating RPN as an indicator of maintenance priority. The next step directs the analysis towards determining preventive maintenance intervals from damage data patterns.

After the failure data distribution pattern is identified, the MTBF and MTTR parameters are selected to calculate the preventive maintenance time interval. The RCM II Decision Worksheet is used to determine the appropriate type of proactive action, such as scheduled discard tasks and scheduled restoration tasks, for each failure mode. The selection of these actions considers early detection, failure consequences, and the goal of reducing downtime. The final step in the planning process is to calculate the cost requirements for the proposed maintenance strategy. Maintenance cost calculations include labor, material, and downtime loss cost components. The cost estimate results form the basis for evaluating the efficiency of the preventive maintenance strategy compared to the corrective maintenance system in the company [9].

3. Results and Discussion

3.1. Historical Data on Component Failures in CW6293 Lathe Machine

Machine failure data provided by factory technicians includes the date and time of failure, date and time of repair, and date and time when the machine returned to operation, as shown in Table 1.

Table 1. Frequency of Component Failures in CW6293 Lathe Machines (September 2023-August 2024)

No	Component	Date of Failure	Time of Failure	Date of Repair	Time of Repair	Date of Operation	Time of Operation
1	Spindle	11/09/2023	15:57	11/09/2023	16:02	13/09/2023	08:00
2	Gearbox	06/12/2023	16:01	06/12/2023	16:11	07/12/2023	14:32
3	Chuck	09/12/2023	14:40	09/12/2023	14:45	13/12/2023	16:00
4	Gearbox	07/03/2024	16:24	07/03/2024	16:48	08/03/2024	13:54
5	Gearbox	08/04/2024	09:02	08/04/2024	09:34	10/04/2024	12:10
6	Ball Screw (Lead Screw)	10/04/2024	11:50	10/04/2024	12:00	11/04/2024	08:10
7	Panel Control	28/04/2024	15:45	28/04/2024	15:58	06/05/2024	09:10
8	Gearbox	20/05/2024	13:58	20/05/2024	14:27	21/05/2024	16:17
9	Kopling	26/05/2024	08:31	26/05/2024	08:37	27/05/2024	08:51
10	Rel Geser (Sliding Ways)	08/06/2024	11:10	08/06/2024	11:19	15/06/2024	08:09
11	Cutter	22/06/2024	11:12	22/06/2024	11:18	25/06/2024	08:12
12	Clutch	03/07/2024	10:01	03/07/2024	10:10	05/07/2024	11:11
13	Cutter	25/07/2024	11:28	25/07/2024	11:35	27/07/2024	16:31
14	Gearbox	10/08/2024	10:10	12/08/2024	10:34	10/08/2024	14:56
15	Lathe Motor	19/08/2024	13:51	19/08/2024	14:07	21/08/2024	08:55

Based on engine component failure data collected from September 2023 to August 2024, it was identified that gearboxes experienced the highest failure rate compared to other components. The high failure rate indicates that gearboxes have a relatively low reliability level and play an important role in the smooth operation of the engine as a whole. Failures in the gearbox disrupt the power transmission process between the drive motor and the main engine components, thereby halting production activities [10]. This condition makes the gearbox a vital component that directly affects the stability of productivity and the sustainability of the production process at the manufacturing workshop.

Visual analysis results show that the gearbox contributes most significantly to the total frequency of machine failures during the observation period. The presentation of data in a Pareto chart reveals that most of the cumulative failure percentage is concentrated in this component. These findings confirm that the gearbox is included in the category of critical components that must be prioritized in maintenance activities. The determination of the gearbox as a critical component is not only based on its high failure frequency, but is also supported by a Pareto diagram analysis, which serves as a decision-making tool in formulating engine maintenance strategies, as shown in Figure 1.

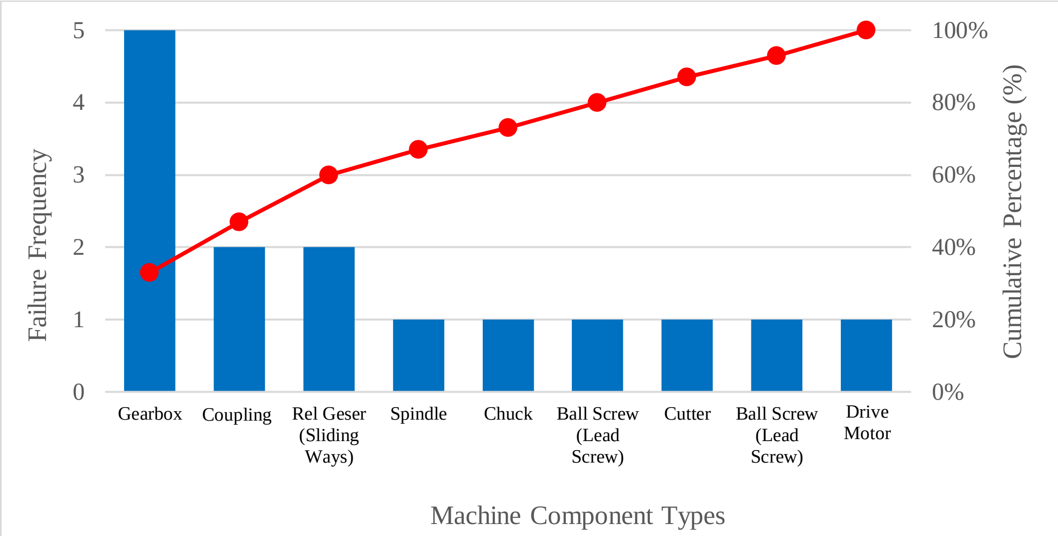

Figure 1. Pareto Diagram of Lathe Component Failures

Based on the interpretation of the Pareto chart, it was identified that the gearbox showed the highest failure rate during the observation period from September 2023 to August 2024. This condition confirms the position of the gearbox as the most vital component in the CW6293 lathe system because its function plays a direct role in power transmission between the drive motor and the main production elements. Failure of the gearbox causes a total shutdown of production activities, so this part is considered a critical component that needs to be given top priority in preventive maintenance planning to maintain machine reliability and the production process.

3.2. Identification of Causes of Failure

The process of identifying high downtime on the CW6293 lathe was carried out through in-depth analysis using a fishbone diagram. This approach aimed to track the main causes contributing to operational problems in the machine system. Based on direct observation and interviews with operators, several dominant factors were identified as causes of increased downtime frequency, including human factors (Man), machinery or equipment (Machine), work methods (Method), and materials (Material). Each of these factors has the potential to affect machine reliability. Descriptions of the causes of failure identified based on observation are presented in Table 2.

Based on Table 2, it was identified that the factors causing failure in gearbox components originated from four main aspects: human (Man), machine (Machine), method (Method), and material (Material). After the causal factors and corrective actions were identified, the overall analysis results were illustrated in a fishbone diagram, as shown in Figure 2.

Table 2. Causes of Gearbox Component Failure

Factor	Causes of Failure	Maintenance Actions
Man	Operators do not have a sufficient understanding of the correct gearbox operating procedures, often leading to errors when adjusting speed and shifting gears.	Conduct regular technical training sessions for operators that focus on correct gearbox operating procedures and basic maintenance procedures.
	There is lack of discipline in conducting routine inspections of lubricant oil condition and gearbox operating temperature	Strengthen supervision and establish a scheduled inspection system supported by detailed operator activity records.
Machine	Transmission gear damage occurs due to inadequate lubrication or deteriorating oil quality.	Create a routine preventive maintenance schedule to ensure optimal lubrication performance.
	Bearing wear is caused by misalignment between the drive shaft and gearbox that is not immediately repaired.	Perform periodic alignment inspections to ensure the correct position of the shaft and gearbox.
Method	The absence of a structured preventive maintenance schedule results in maintenance only being performed after a failure has occurred.	Develop and implement a preventive maintenance plan based on operating hours and the actual condition of the machine.
	There are no documented standard operating procedures (SOPs) for gearbox inspection activities.	Formulate and implement standard SOPs for gearbox inspection, lubrication, and component replacement processes.
Material	Parts such as gears or bearings are made of low-quality or non-standard materials.	Replace components with parts that meet industry standards and appropriate technical specifications.

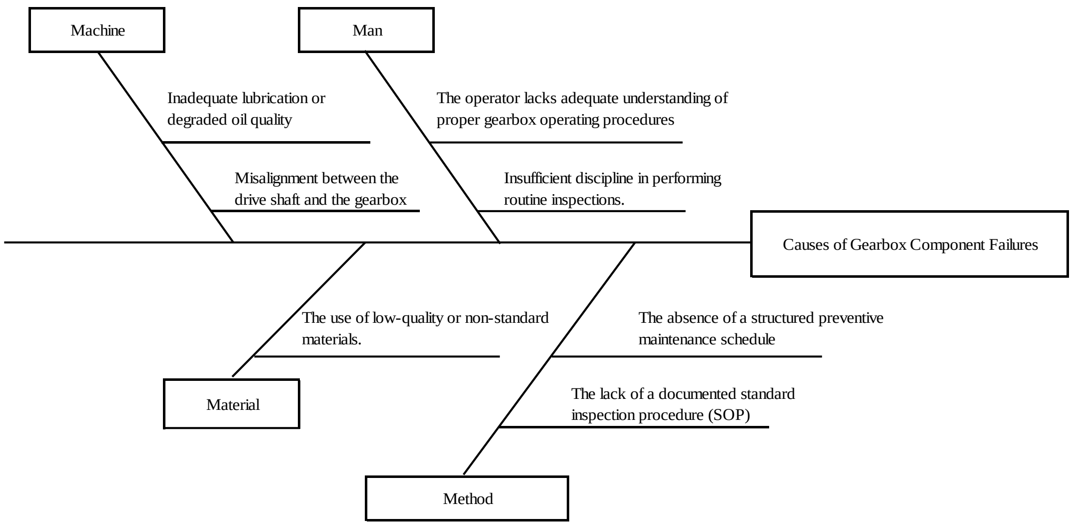

Figure 2. Fishbone Diagram of Gearbox Component Failure Causes

3.3. System Description and Functional Analysis

This stage provides a detailed explanation of the system being studied and analyzes its functions using functional block diagrams to understand the role of the machine in the overall process.

1. System Description. The CW6293 lathe cutting system functions to shape and cut workpieces by rotating the material against a static cutting tool. This process enables the production of components with high precision and accuracy according to the required specifications. The CW6293 lathe operates on the principle of material removal, where the workpiece mounted on the chuck rotates, while the cutting tool moves linearly to gradually remove material until the desired dimensions are achieved. This machine is equipped with various types of cutting tools that can be used for straight cutting, step cutting, and thread forming operations, depending on manufacturing requirements [11].

2. Functional Block Diagram (FBD). The development of functional block diagrams aims to illustrate a simplified form of the sequence of processes in the analyzed subsystem. This diagram provides a systematic representation of the relationships between components and the workflow of the CW6293 lathe. In general, FBD helps visualize how energy inputs and operational commands are converted into mechanical movements that perform the cutting process. The functional block diagram of the CW6293 lathe is shown in Figure 3.

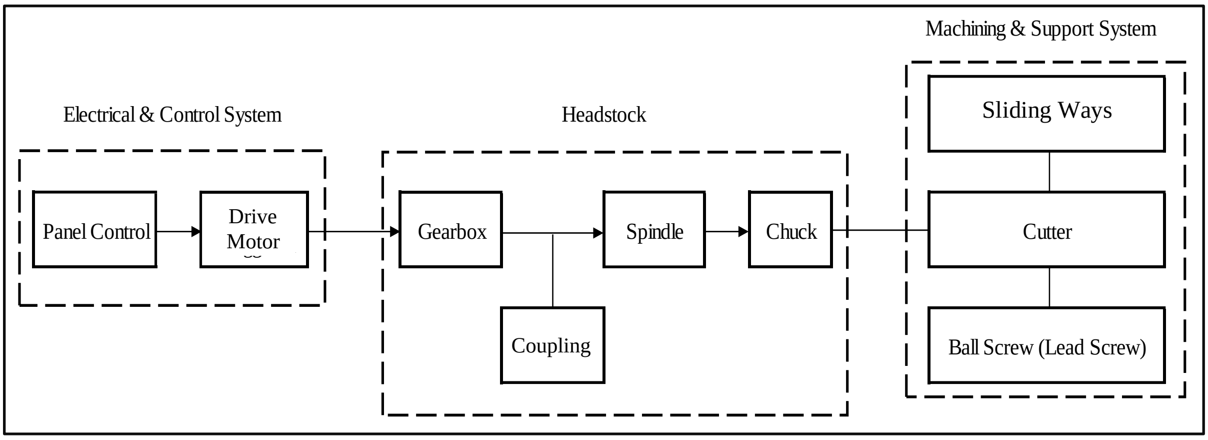

Figure 3. Functional Block Diagram of the CW6293 Lathe Machine

The electrical & control subsystem functions as the control center and main power source, consisting of a control panel and drive motor. The control panel is responsible for regulating the flow of electrical power and sending operational signals to machine components in accordance with specific process requirements. Meanwhile, the drive motor converts electrical energy into mechanical power to rotate the main transmission system.

The headstock subsystem functions to transmit power input from the control system to the machining system. This subsystem consists of a gearbox, coupling, spindle, and chuck. The gearbox adjusts the spindle rotation speed according to process requirements, the coupling transmits torque from the motor to the spindle, and the spindle drives the chuck, which securely holds the workpiece in place. The resulting rotational movement is then channeled to the machining & support system subsystem, which includes slide rails, cutting tools, and ball screws. This subsystem performs the workpiece cutting process through precise linear movement between the cutting tool and the rotating material. The slide rails ensure carriage stability, the ball screws convert rotational motion into accurate translational motion, and the cutting tools remove material according to the specified cutting parameters [12].

3.4. Failure Mode, Effects, And Criticality Analysis (FMECA)

Failure Mode, Effects, and Criticality Analysis (FMECA) is a structured analytical method that combines two main components: Failure Mode Effect Analysis (FMEA) and Criticality Analysis (CA). The FMECA process begins with the implementation of FMEA, which systematically identifies and evaluates potential failures in a system, covering system boundaries, key functions, operating conditions, failure mechanisms, and resulting consequences. Once this stage is complete, the procedure continues with CA to determine the priority of corrective actions based on the level of risk through the Criticality Number (Cr). A higher Cr value indicates a higher level of component failure risk [13].

In its application, FMEA is carried out by analyzing possible failure points and calculating the Risk Priority Number (RPN), which is obtained by multiplying three parameters: Severity (S), Occurrence (O), and Detection (D). The parameter assessment in this study was carried out by the operational manager based on the results of direct interviews. The summary of RPN values and component criticality levels for the CW6293 lathe machine are presented in Table 3.

Based on the data listed in Table 3, it shows that of the nine components that failed between September 2023 and August 2024, one component had the highest RPN value. This component is classified as critical and falls into the unacceptable risk category. The component with the highest risk level is the gearbox.

Table 3. Failure Mode, Effects, And Criticality Analysis (FMECA)

Component	Severity	Occurrence	Detection	RPN	Criticality	Risk Category
Spindle	7	5	3	105	High	Tolerable
Chuck	6	4	4	96	High	Tolerable
Gearbox	8	7	5	280	Critical	Unacceptable
Clutch	7	5	4	140	High	Tolerable
Ball Screw (Lead Screw)	5	5	4	100	High	Tolerable
Cutter	6	6	3	108	High	Tolerable
Sliding Ways	7	6	4	168	High	Tolerable
Lathe Motor	7	5	5	175	High	Tolerable
Panel Control	6	5	4	120	High	Tolerable

3.5. Determination of MTBF and MTTR Parameters for Critical Components

This study uses Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR) values as the main basis for determining gearbox maintenance intervals. These two parameters provide quantitative information about the average time between failures and the average duration required for repair activities. The MTBF and MTTR values calculated are not only used to set maintenance schedules but also to estimate preventive maintenance costs with greater accuracy. The application of maintenance strategies based on these indicators can improve operational efficiency from both a technical and economic perspective [13]. The results of the MTBF and MTTR analysis for gearbox components are presented in Table 4.

Table 4. MTBF and MTTR Analysis Results for Gearbox Components

No	Component	Distribution	Parameter	Value	MTBF/MTTR
1	Gearbox	Weibull	η	419,449	MTBF = 371,53 Hours
			β	207,641	
		Normal	μ	72,460	MTTR = 7,2460 Hours

Based on the analysis results presented in Table 4, the gearbox component recorded a Mean Time Between Failure (MTBF) of 371.53 hours following a Weibull distribution, and a Mean Time To Repair (MTTR) of 7.2460 hours following a normal distribution. The MTBF value indicates that the gearbox has a relatively high level of reliability before the next failure occurs, while the MTTR value represents the average duration required to complete repairs and return the machine to normal condition. The relationship between MTBF and MTTR is a critical factor in determining the appropriate maintenance strategy. The difference between these two parameters indicates a higher level of machine availability, meaning that the system is able to operate for longer than the time required for repairs.

3.6. Reliability Centered Maintenance II (RCM II)

Failure mode identification and critical component determination are obtained through Failure Mode Effect and Criticality Analysis (FMECA) and are then used as the basis for developing the RCM II Decision Worksheet. In the RCM II methodology, preventive maintenance activities are categorized into three main types: scheduled on condition tasks, scheduled discard tasks, and scheduled restoration tasks [14].

The classification of maintenance tasks is determined based on several key criteria, including the system's ability to detect hidden failures, potential hazards to worker safety, possible violations of health and environmental standards, and the overall impact on operational performance, such as production output, product quality, and maintenance costs. The results of the maintenance task classification for gearboxes are presented in Table 5.

Based on the results of the maintenance action classification in Table 5, appropriate maintenance intervals have been determined for two critical gearbox component failure modes, namely scheduled discard tasks and scheduled restoration tasks. The gearbox has the main function of regulating the spindle rotation speed, with one of the common failure modes characterized by abnormal noise due to gear wear. This damage can cause interference with other machine components. The recommended action is a scheduled discard task, which includes periodic oil changes and gear condition inspections at 21.38 days intervals.

Another failure mode in the form of excessive vibration due to bearing damage can potentially reduce production output quality. To prevent this problem, the recommended action is a scheduled restoration task, including gearbox maintenance and replacement of worn parts at a maintenance interval of 22.28 days.

Table 5. Gearbox Component Maintenance Intervals

Component	FM	Proposed Maintenance Task	Interval (Days)
Gearbox	1	*Scheduled Discard Task*. Perform periodic inspections while ensuring proper lubrication to maintain optimal gearbox performance and prevent component wear.	21,38
	2	*Scheduled Restoration Task*. Perform routine inspections to identify early signs of machine damage and restore components to functional condition before major failure occurs.	22,28

3.7. Maintenance Cost

This study uses maintenance cost analysis to identify and measure the costs incurred under corrective maintenance conditions and projected after the implementation of preventive maintenance. In the calculation process, the maintenance interval of critical components is considered as one of the main determining factors. Costs include labor costs, production losses due to machine failure, and preventive maintenance costs incurred to minimize potential downtime [15]. The results of this analysis are used to compare the total corrective maintenance costs with the planned expenditures for preventive maintenance, as recommended. The results of the maintenance cost comparison are presented in Table 6.

Table 6. Comparison of Corrective Maintenance and Preventive Maintenance Costs

No	Component	Maintenance	Annual Cost (IDR)	Monthly Cost (IDR)
1	Gearbox	Corrective Maintenance	48.500.000	4.041.667
		Preventive Maintenance	20.828.571	1.735.714
		Cost Savings	27.671.429	2.305.953

Based on the cost analysis listed in Table 6, the total expenditure for corrective maintenance of gearbox components for one year reaches IDR 48,500,000, with an average monthly cost of IDR 4,041,667. The proposed preventive maintenance only requires IDR 20,828,571 per year, or around IDR 1,735,714 per month. This difference shows a monthly cost efficiency of IDR 2,305,953, which is achieved through the proposed maintenance strategy based on Reliability Centered Maintenance II (RCM II). In addition to improving machine reliability and operational readiness, the RCM II approach also provides significant economic benefits by reducing maintenance expenses through preventive maintenance planning.

4. Conclusion

This study develops a reliability-based preventive maintenance planning framework by integrating Failure Mode, Effects, and Criticality Analysis (FMECA), statistical reliability modeling using MTBF and MTTR, and the RCM II decision-making logic. The main contribution of this research lies in the methodological engineering activity that systematically connects component criticality analysis, failure characteristics, and the determination of maintenance task types and intervals within a unified decision-making framework. This approach enables a transition from reactive maintenance to risk- and reliability-based preventive maintenance, while providing practical and implementable technical recommendations to improve machine reliability and reduce downtime.

The development of effective maintenance planning to reduce the risk of downtime on the CW6293 lathe during production successfully recommended a preventive maintenance strategy using the RCM II method, integrated with FMECA analysis. The proposed maintenance system for gearbox components includes scheduled discard tasks to address noise issues during operation by replacing oil periodically, and scheduled restoration tasks to reduce excessive vibration through routine servicing. These measures are strategically designed to minimize operational disruptions.

The implementation of RCM II has proven effective in improving machine reliability and productivity by determining efficient maintenance intervals, significantly reducing corrective maintenance costs. The recommended maintenance intervals are 21.38 days for scheduled disposal tasks and 22.28 days for scheduled recovery tasks. The estimated annual maintenance cost based on this strategy is IDR. 20,828,571. This study acknowledges several limitations. The reliability analysis and failure prediction rely entirely on historical failure data within a specific observation period, which may not fully represent long-term operational variability. In addition, the absence of condition monitoring systems limits the implementation of real-time predictive maintenance approaches. The maintenance cost analysis considers the proportion of labor costs, material or spare part costs, and production loss due to downtime, with downtime cost emerging as the dominant component in corrective maintenance. This dominance is directly related to failure frequency and repair duration predicted through MTBF and MTTR. Therefore, future research is recommended to integrate condition monitoring technologies and predictive analytics to improve failure prediction accuracy and enhance maintenance cost control effectiveness.

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