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Planning Preventive Maintenance for Press Machine using Reliability Centered Maintenance (RCM) Method: A Case Study in a Plantation Company

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ABSTRACT

This research focuses on the organized preventive maintenance scheduling of screw press machine for palm oil processing machine in maintaining the company's productivity and product quality. The minimization of failure risk and productivity enhancement was investigated by means of Reliability Centered Maintenance (RCM) methodology. The preventive maintenance plan was developed based on Failure Modes and Effects Analysis (FMEA) for critical components such as worm screws, bearings, lengthening shafts, and press cages in determining risk and crucial factor which affects productivity. Reliability data from January to December 2023 indicated the initial conditions of these components. Data for this study were collected over a 12-month period, from January to December 2023, to characterize the baseline operational conditions of the system components. Through the application of the proposed reliability-centered maintenance approach, it was determined that achieving a target reliability level of 70% requires a structured maintenance schedule. This includes reconditioning the worm screws every 22 days using SS 304 electrode wire, replacing bearings at 22-day intervals prior to reaching their estimated technical lifespan, inspecting bolts and nuts on the lengthening shaft every 17 days, and inspecting and cleaning the press cage every 18 days. Failure Modes and Effects Analysis (FMEA) confirmed that the implementation of this maintenance strategy significantly reduces the risk of screw press machine failures, mitigates unplanned production downtime, and enhances overall operational efficiency. These improvements contribute to meeting production targets effectively in the context of a competitive global manufacturing environment.

Keywords: Preventive Maintenance; Oil industry; RCM; FMEA; Risk Analysis.

Abbreviations

CPO	Crude Palm Oil
FMEA	Failure Mode of Effect Analysis
GDP	Gross Domestic Product
LTA	Logic Tree Analysis
RCM	Reliability Centered Maintenance

1.0 INTRODUCTION

In Indonesia, the Palm Oil industry recorded a production of palm oil and palm kernel oil totalling 54.84 million tons in 2023. Of this amount, 50.07 million tons were crude palm oil (CPO) and 4.77 million tons were palm kernel oil (PKO) [1]. The processing of CPO is a significant sector contributing to Indonesia's GDP in which the process involves the use of critical processing machinery to ensure smooth production and high-quality final products. Therefore, the smooth operation of CPO processing is crucial to meet both domestic and international market demands as well as having optimal performance to ensure smooth production flow. Efficient and uninterrupted operation of production machines is essential to maintaining a smooth production flow. Scheduling preventive maintenance is expected to enhance maintenance efficiency and minimize total maintenance costs. One of the critical machines in the palm oil production process is the screw press, which plays a crucial role in separating oil from the fruit flesh. If this machine fails, it can negatively impact the overall productivity of the processing operation where maintenance process is often needed to improve the overall quality of the product [2].

Maintenance is a combination of managerial and technical activities aimed at controlling the wear rate of equipment, extending its service life, and restoring operational status after failure. These activities are tailored to the specific characteristics of each system and the strategic goals of the company [3]. Corrective Maintenance, Preventive Maintenance, and Predictive Maintenance are the three key categories of maintenance [4]. This

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research focuses on Preventive Maintenance which involves maintenance actions taken before a failure occurs. These actions are typically based on pre-established operational criteria, such as a time schedule or usage amount, or by monitoring the working conditions of the equipment. The goal is to prevent damage or failure by performing regular and planned maintenance. Lack of planning in preventive maintenance can result in a high risk of machine failures, potentially disrupting production flow due to unexpected damage or failures and incurring high repair costs that could have been prevented. Murthy et al. [5] described a strategic view of maintenance based on equipment condition, operational load, maintenance actions (strategies), and business goals. Equipment condition is influenced by operational load as well as maintenance actions. Operational load depends on production plans and decisions, which are influenced by commercial needs and market considerations.

Various planning on maintenance has been a focus for engineering research in recent years, including Reliability Centered Maintenance (RCM) which is a disciplined methodology used to identify preventive maintenance tasks to achieve inherent equipment reliability with minimal resource expenditure. This methodology involves in-depth analysis of equipment functions, failure modes, and the impact of those failures to determine the most effective and efficient maintenance tasks.

The main goals of RCM are to improve equipment reliability, optimize maintenance, reduce downtime, enhance safety and compliance, and efficiently use resources. Through RCM, organizations can generate lists of preventive maintenance tasks, detailed maintenance schedules, documentation of failure modes and impacts, reliability improvement plans, and integrated maintenance strategies. Thus, RCM is chosen in this research to help generate preventive maintenance strategies to achieve optimal equipment reliability and reduce unplanned machine downtime [6]. The RCM process recommends appropriate maintenance requirements for systems in their operational context which are reflected within the four main features of RCM as listed below [7]:

1. Maintaining system functions: This is the key feature to understanding the RCM process, as it emphasizes maintaining functions rather than equipment operation. It forces analysts to systematically understand the system functions that need to be maintained and how these functions can be lost in terms of functional failure, not equipment failure.
2. Identifying failure modes that can cause functional failure: Failure mode identification is conducted by examining each component to identify how it might fail and cause specific functional failures.
3. Prioritizing functional failures: Functional failures and related failure modes do not have the same level of importance. By prioritizing failure modes, it is possible to decide how to systematically allocate budget and resources.
4. Selecting applicable and effective maintenance tasks: Each failure mode is addressed according to its priority to identify potential preventive maintenance actions.

One of the analysis methods often involved within RCM is called Failure Modes and Effect Analysis (FMEA), which is an engineering technique used to define, identify, and eliminate known and potential problems, errors, etc., from systems, designs, processes, and services before they reach the customer [8]. FMEA is conducted during the product design or process development stage. However, performing it on existing products and processes can also be beneficial, such as in Reliability-Centered Maintenance (RCM) to develop an effective preventive maintenance program.

Over the past few years, several researchers have integrated the FMEA method into RCM as a tool to optimize the productivity. Kharmada et al. [9] stated that the concept of RCM with FMEA is a structured approach used to discover potential failure within industrial field such as manufacturing sectors. Denur et al. [10] performed a FMEA-based RCM implementation in ripple mill machine where the regression statistical analysis was performed with 17 failure mode being analysed to determine the overall failure rate. Another research performed by Sadradjad [11] displayed the application of RCM with the aim for maximum safety to ensure the stabilization during manufacturing process. Recently, Industrial Engineering research conducted by Banghart and Babski-Reeves [12] implemented FMEA in their RCM within aerospace industry where the risk identification is classified by using severity classes. In Palm Oil sector, the RCM method in implementing strategy improvement was executed by Sembiring and Koto Deli [13] where the output is a more robust schedule on the engine maintenance.

Based on the literature reviewed above, it can be seen that there is lack of focus in the implementation of FMEA-based RCM on Palm Oil or similar industrial sector within plantation area of coverage with only one similar research has been performed in the recent year. Therefore, the aim of this study is to design preventive maintenance for the press machine with the goal of minimizing failure risk and enhancing operational efficiency for palm oil case study. Consequently, this study aims to plan optimal maintenance to prevent machine breakdowns, ensuring that the production process runs smoothly and efficiently without significant interruptions.

2.0 METHODOLOGY

This research starts by identifying known and potential failure modes which is a crucial task in FMEA. By using data and knowledge about the process or product, each failure mode and potential effect is ranked based on the three factors:

- Severity: The consequences of failure when it occurs.
- Occurrence: The likelihood or frequency of failure.
- Detection: The likelihood of detecting the failure before the impact of its effects occurs.

These three factors are then combined into a single number called the Risk Priority Number (RPN) to reflect the priority of the identified failure modes [14]. The Risk Priority Number (RPN) is calculated using Eq.1 by multiplying the severity rating, occurrence rating, and detection rating:

$$\text{Risk Priority Number} = \text{Severity} \times \text{Occurrence} \times \text{Detection} \quad (1)$$

Assigning severity, occurrence, and detection ratings is typically done on a scale from 1 to 10 using weighted calculations as shown in both Table 1 and Table 2 below while Table 3 displays the Detection Evaluation Criteria:

Table 1. Occurrence evaluation criteria

Probability of Failure	Possible failure rates	Ranking
Very high: failure is almost inevitable	≥ 1 in 2	10
	1 in 3	9
High: repeated failures	1 in 8	8
	1 in 20	7
Moderate: occasional failures	1 in 80	6
	1 in 400	5
	1 in 2,000	4
Low: relatively few failures	1 in 15,000	3
	1 in 150,000	2
Remote: failure is unlikely	≤ 1 in 1,500,000	1

Table 2. Severity evaluation criteria

Effect	Criteria: severity of effect	Ranking
Hazardous - without warning	Very high severity ranking when a potential failure mode affects safe operation and/or involves noncompliance with regulations without warning	10
Hazardous-with warning	Very high severity ranking when a potential failure mode affects safe operation and/or involves noncompliance with regulations with warning	9
Very high	Product/item inoperable, with loss of primary function	8
High	Product/item operable, but at reduced level of performance. Customer dissatisfied	7
Moderate	Product/item operable, but may cause rework/repair and/or damage to equipment	6
Low	Product/item operable, but may cause slight inconvenience to related operations	5
Very low	Product/item operable, but possesses some defects (aesthetic and otherwise) noticeable to most customers	4
Minor	Product/item operable, but may possess some defects noticeable by discriminating customers	3
Very minor	Product/item operable, but is in noncompliance with company policy	2
None	No effect	1

Furthermore, the analysis moves towards Logic Tree Analysis (LTA) which is executed to further prioritize the resources to be allocated for each failure mode [15]. This particular action is executed due to the inequality of the failure modes and their impacts within the investigated plant area. Any logic scheme can be adopted to perform this ranking. The RCM process uses a simple and intuitive three-question decision structure, with questions answered with a simple yes or no. The LTA scheme is shown in Figure 1 and Figure 2 below.

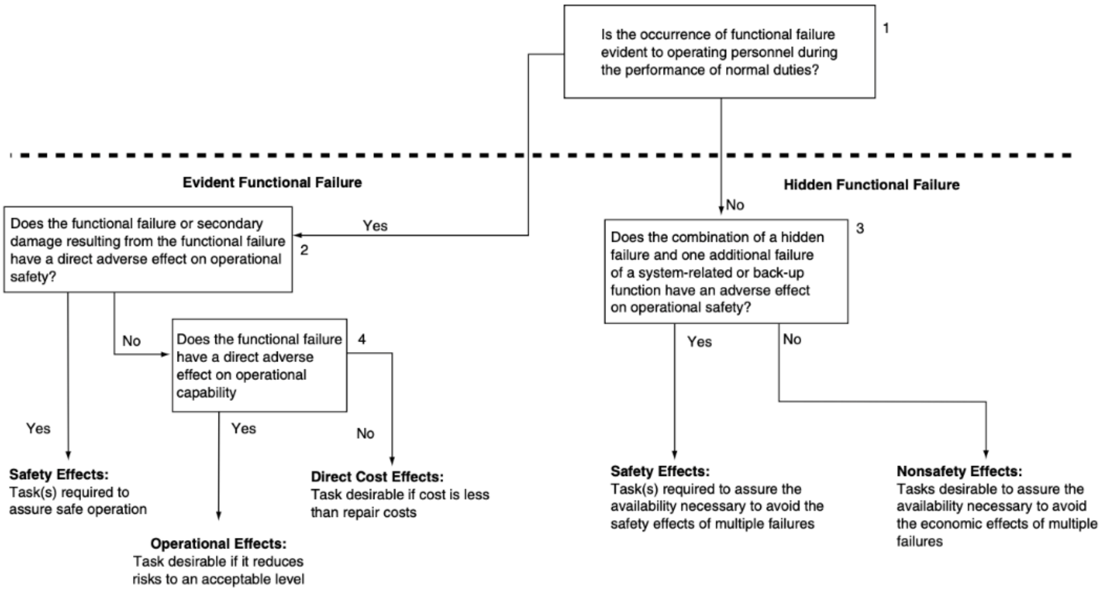

Figure 1. First-level LTA

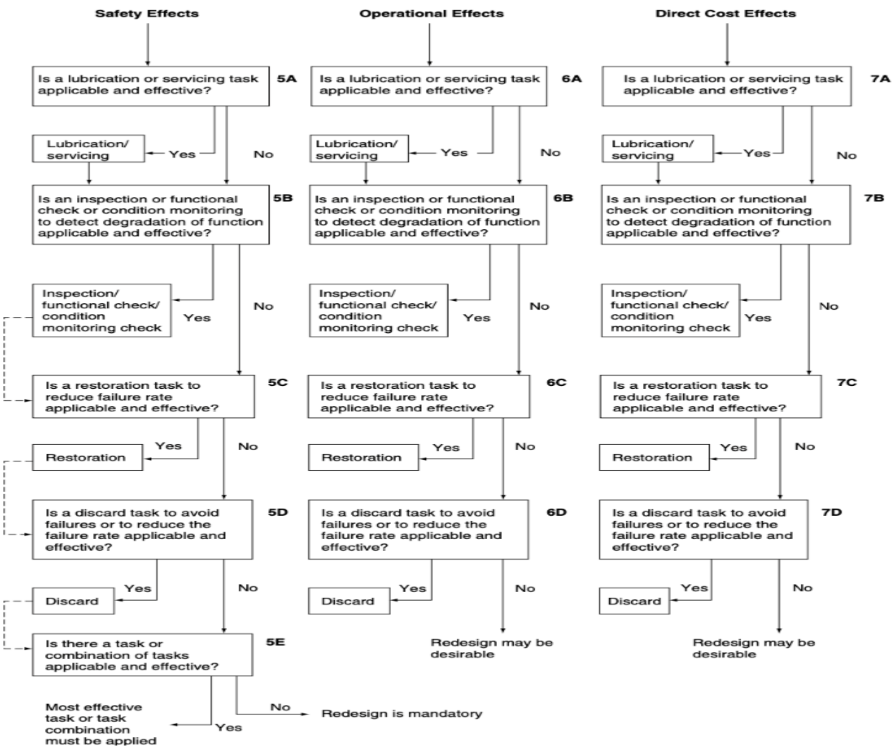

Figure 2. Second level LTA

3.0 RESULTS AND DISCUSSION

Based on the result that FMEA analysis produces, the sections for effect of failure (severity), occurrence of failure, and detectability were assessed by two experts from the company using a predetermined rating scale. These values were then used to calculate the Risk Priority Number (RPN) for each component. Table 4 displays the analysis based on FMEA within press machine component.

Once the RPN calculation was completed, the results were analysed using Pareto diagram in order to identify the components that cause the most disruption during production line. The Pareto diagram helps to visualize which component has the highest RPN values; thus, the main causes of disruptions are displayed by Figure 3 below.

Figure 3 shows that the Worm Screw and Bearing has the highest RPN values, each nearing 500, indicating that it is the most critical in terms of potential failure risk, followed by the Lengthening Shaft and Press Cage, which are 480 and 450 respectively. The Oil Seal, Drive Shaft, and Cone Guide contribute significantly less to the overall risk. Accompanying the bars is a cumulative percentage line (right y-axis), which demonstrates that the first four components account for nearly 90% of the total cumulative risk, exhibiting the classic Pareto principle where a few causes contribute to the majority of the effect. This analysis suggests that prioritizing improvements in the Worm Screw, Bearing, Lengthening Shaft, and Press Cage would yield the greatest impact in reducing overall system risk.

Table 3. FMEA of press machine components

FAILURE MODE AND EFFECTS ANALYSIS									
Item	Press Machine				FMEA number	1			
Responsible	Ruben Sihombing				Page	1 of 1			
Prepared by	Miranda H.				FMEA Date	12 March 2024			
Component	Component Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Process Controls	Detec	RPN
Worm Srew	Main component of CPO extraction machine	Extraction process stopped	Broken	9	Iron piece in, hydraulic load too high	6	Replacement worm screw	9	486
Drive Shaft	Drive medium	Main shaft rotation stops	Cracked	8	Looseness in worm screw holder, Oil empty	5	Component replacement, oil filling	5	200
Lengthening Shaft	Worm screw safety	Loose bolts/nuts	Broken	8	Hydraulic pressure, cracks in iron	6	Tightening bolts and nuts	9	432
Oil Seal	Prevent oil spillage	Engine movement is not smooth	Leaking oil, broken seal	9	Delay in oil filling	6	Regular oil filling	6	324
Bearing	Main shaft drive	Unstable rotation	Wear, damage	8	Empty oil, Usage exceeds capacity	6	Regular bearing replacement	9	432
Press Cage	Filter for pressing	Filtering ineffective	Wear	9	Clogged	5	Regular check-ups	9	405
Cone Guide	Fiber-pressing media dari worm screw	Fibre oil does not melt	Wall plate wear	3	Excessive working hours	3	Cone Guide lining plate replacement	3	27

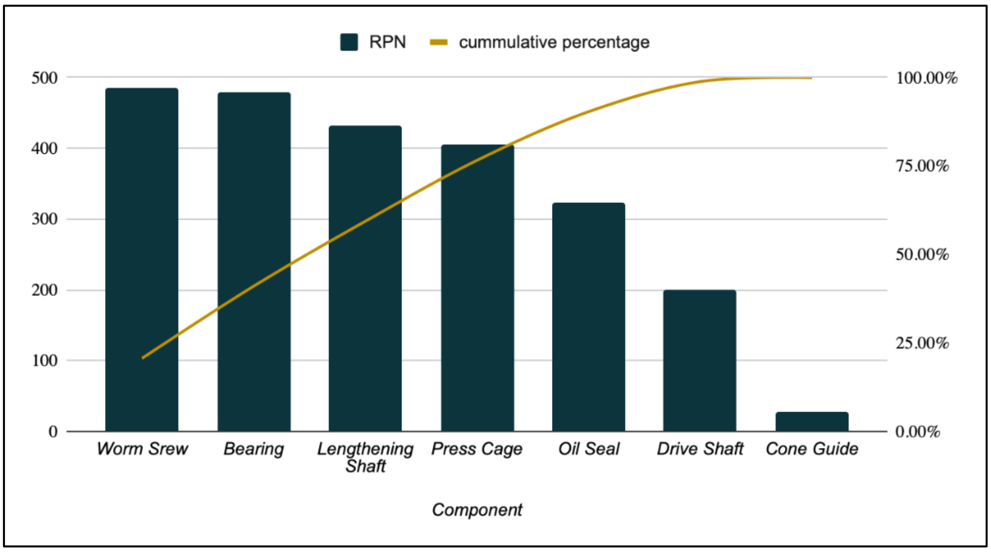

Figure 3. Pareto chart of RPN and cumulative percentage relationship for disruption analysis

Before calculating reliability values, it is advised to conduct distribution testing for the data of each critical component obtained. This distribution testing is crucial so that the calculated reliability values can approximate real conditions. The tested data include Time to Failure (TTF) calculated based on the historical occurrence time of component failures. Distribution testing is conducted through two statistical stages, which are Identification of Distribution Candidates or Index of Fit, that involve selecting the most suitable distribution for the available data. Furthermore, Testing Distribution Fit through Goodness of Fit Hypothesis Testing ensures that the distribution fits the actual data. Index of Fit and Goodness of Fit testing is conducted using Minitab statistical software. The selected distribution results corresponding to the input data are shown in Table 4.

Once the most suitable distribution is determined, parameters of that distribution are calculated. For instance, if a Weibull distribution is selected, parameters such as scale (λ) and shape (k) are estimated using methods like Maximum Likelihood Estimation (MLE). With these calculated distribution parameters, component reliability values at various operating times can be computed. Reliability R(t) is the probability that a component will not fail up to time *t*. Based on the obtained parameters, maintenance interval calculations are performed to ensure component reliability is maintained at a target reliability of 70%. This maintenance interval analysis uses the failure time distribution to ensure that maintenance is performed before the failure probability reaches an unacceptable level. The results of the maintenance interval calculations are described in Table 5.

By looking at the result displayed in Table 4 and Table 5 above, the Index of Fit and Goodness of Fit values for the Worm Screw component are 0.991 and 0.930 respectively, indicating compatibility with the Lognormal distribution, with location (μ) parameter of 6.663 and scale (σ) parameter of 0.760. The Mean Time to Failure (MTTF) for the Worm Screw is calculated at 1045.21 hours, indicating a current reliability of 45%, meaning a 45% probability that the component will continue to function without failure at present. Reliability Analysis (LTA) processes indicate that the failure of the worm screw can be detected by operators and significantly affects the operational capability of the system. In the second phase of LTA, restoration with SS 304 electrode welding wire and hard facing at the screw tip is required to repair and strengthen the component, thus enhancing reliability and lifespan, and minimizing failure risks to ensure more stable and efficient operations.

The Bearing component shows a high Index of Fit of 0.988, indicating the selected distribution accurately models the observed data, although the moderate Goodness of Fit of 0.548 still shows reasonable fit with the Lognormal distribution. This distribution has location (μ) parameter of 6.327 and scale (σ) parameter of 0.462, with a Mean Time to Failure (MTTF) for the Bearing of 622,492 hours and current reliability of 47%. This analysis validates the suitability of the Lognormal distribution for the Bearing and provides crucial metrics for maintenance planning. LTA indicates that Bearing failures can be observed by operators and affect system operational capability; thus, refurbishment with Bearing component replacement before the technical life span (>600 hours) is necessary to enhance machine reliability and lifespan, ensuring more stable and efficient production processes.

Table 4. Selected distributions for each critical press machine component

Component	Index of Fit	Goodness of Fit	Selected Distribution
Worm Screw	0.991	0.930	Lognormal
Bearing	0.988	0.548	Lognormal
Lengthening Shaft	0.969	0.299	Lognormal
Press Cage	0.983	>0.250	Weibull

Table 5. Maintenance interval calculations for components

Component	Initial R(t)	Maintenance Interval (Hours)	Maintenance Interval (Days)
Worm Screw	45%	525	22
Bearing	47%	533	22
Lengthening Shaft	41%	400	17
Press Cage	41%	439	18

After data processing and distribution testing for the Lengthening Shaft component, the Lognormal distribution is chosen as the most suitable with an Index of Fit of 0.969 and a Goodness of Fit of 0.299. The obtained parameters for the Lognormal distribution are location (μ) of 6.405 and scale (σ) of 0.787, with a Mean Time to Failure (MTTF) of 824,642 hours and current reliability of 41%. The first phase of LTA analysis shows that the component's failures are observed by operators and have a significant impact on operations. The second phase of LTA recommends routine maintenance and inspection of bolts and nuts to prevent physical damage and ensure component safety and specification compliance. These steps aim to extend lifespan, reduce failure risks, and maintain optimal performance of the lengthening shaft. The Weibull distribution is selected with an Index of Fit of 0.983 and a Goodness of Fit greater than 0.250 once the processing data and press cage distribution testing for press cage component have been processed. The obtained Weibull parameters are shape parameter of 2.334 and scale parameter of 829, with a Mean Time to Failure (MTTF) of 735,385 hours and current reliability of 41%. Analysis indicates Press Cage failures can be detected by operators and significantly affect operations. Regular maintenance and inspection actions are required, including crack inspection, shape changes, and residue cleaning, to identify potential structural failures and maintain cleanliness. These measures aim to extend lifespan, reduce failure risks, and ensure smooth pressing processes and machine availability during production.

To achieve the desired 70% reliability target, which aligns with industry best practices for maintaining an optimal balance between proactive and reactive maintenance, a preventive maintenance schedule has been strategically developed based on the findings from the Failure Mode and Effects Analysis (FMEA). This schedule outlines specific, time-based actions aimed at mitigating potential equipment failures before they occur. These actions include refurbishing the worm screw with SS 304 electrode welding every 22 days, replacing bearings prior to exceeding their technical lifespan at the same interval, inspecting and lengthening the shaft bolt and nut every 17 days, and inspecting and cleaning the press cage every 18 days. By implementing these targeted measures, the maintenance program is expected to enhance equipment reliability, reduce unplanned downtime, and move closer to achieving the 70% proactive maintenance benchmark.

4.0 CONCLUSION

The research which involves preventive maintenance analysis by means of RCM with FMEA analysis has been successfully completed with the objectives fulfilled in this research. To conclude this research, several points are highlighted as the findings of this research:

1. A preventive maintenance plan has been designed for the Screw Press machine to reduce failure risks and meet production targets which has been shown to find the critical factor in palm oil industry.
2. Four critical components selected based on FMEA analysis are the worm screw, bearing, lengthening shaft, and press cage.
3. Based on the history of damage and maintenance from January 2023 to December 2023, the initial reliabilities of these components are 45% for the worm screw, 47% for the bearing, and 41% for both the lengthening shaft and press cage.
4. In order to achieve the desired 70% reliability target, a preventive maintenance schedule based on FEMA result has been developed including various actions such as refurbishing the worm screw with SS 304 electrode welding for every 22 days, bearing replacement before exceeding the technical life span for every 22 days, lengthening shaft bolt and nut inspection for every 17 days, and press cage inspection and cleaning for every 18 days.
5. By implementing this plan, it is expected that the Screw Press machine will operate with increased reliability, minimize downtime due to component failures, and efficiently support production target achievement.

Despite fulfilling the objectives of this study, this study has limitations and shortcomings. As such, the following recommendations are provided for future research considerations to further improve the finding of this research. Further research could examine how preventive maintenance implementation directly affects machine performance, such as reducing failure frequency, extending component lifespan, and reducing unplanned downtime. In addition, future research can analyse the extent to which preventive maintenance contributes to achieving established production targets. These calculations could include evaluations of production disruption reduction and operational efficiency improvements.

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AUTHORS CONTRIBUTION

Dr. Dendi Prajadhiana Ishak from the Faculty of Industrial Engineering, University of Indonesia, is the leader of this research team, assisted by his research assistant, Ms. Miranda Hotmauli, who is affiliated with the same institution. This manuscript was cross-checked and edited by Dr. Keval Prajadhiana from Aalen University during the finalization of its content.

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