IJMECIE International Journal of Mechanical, Electrical and Civil Engineering
E-ISSN: 3047-4531
P-ISSN: 3047-4523

Research Article

Design of Preventive Maintenance on the Electrical System of Agitator for Seed Precipitation Tank at PT Borneo Alumina Indonesia

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Abstract: PT Borneo Alumina Indonesia is a company engaged in processing bauxite into alumina, where the reliability of the agitator system in the seed precipitation tank plays a crucial role in maintaining continuous production. However, failures in the agitator electrical system can lead to significant downtime, resulting in operational losses and decreased production efficiency. Therefore, this study aims to design an effective preventive maintenance schedule to improve system reliability and optimize production performance. The research applies Failure Mode and Effects Analysis (FMEA), Risk-Based Maintenance (RBM), and Reliability-Centered Maintenance (RCM), supported by Weibull distribution analysis to evaluate failure characteristics and determine optimal maintenance intervals. The results show that the proposed preventive maintenance strategy is effective in improving system reliability, with an increase of up to 13% compared to conditions without preventive maintenance. The maintenance plan includes routine inspections of critical components, as well as scheduled replacements at one-, two-, and three-year intervals integrated with annual overhauls. In addition, the implementation of this maintenance schedule reduces annual downtime to 3.84%, enabling alumina production to reach up to 96% of the theoretical capacity of 1,000,000 tons per year. In conclusion, the proposed maintenance strategy not only enhances equipment reliability but also supports sustainable operational efficiency in alumina production processes.

Keywords: FMEA; Preventive Maintenance; RBM; RCM; Weibull Distribution.

Received: May 10, 2026
Revised: May 26, 2026
Accepted: June 23, 2026
Published: June 26, 2026
Curr. Ver.: June 26, 2026

1. Introduction

In modern industrial systems, maintenance plays a critical role in ensuring reliability and minimizing unexpected failures. The integration of predictive maintenance and data-driven approaches has significantly improved system performance and operational efficiency (Carvalho et al., 2021; Tao et al., 2022). In PT Borneo Alumina Indonesia, the seed precipitation stage within the Bayer Process requires agitator systems to ensure homogeneous mixing and optimal chemical reactions. The electrical system of the agitator plays a vital role in maintaining stable operation, where failures can result in significant downtime, decreased production efficiency, and financial losses. However, most previous studies focus on data-driven approaches, while limited research integrates reliability analysis with preventive maintenance scheduling in industrial agitator systems (Zhang et al., 2022; Wang et al., 2023).

Various maintenance approaches have been previously applied to improve equipment reliability. Methods such as Failure Mode and Effects Analysis are widely used to identify potential failure modes and prioritize risks, while Reliability Centered Maintenance provides structured decision-making for selecting appropriate maintenance actions. In addition, Risk Based Maintenance focuses on optimizing maintenance strategies based on risk levels.

Reliability modeling techniques, particularly the Weibull Distribution, are also commonly used to analyze failure characteristics and predict equipment lifetime.

Despite their extensive application, these methods have inherent strengths and limitations. FMEA is effective in identifying critical components but relies on subjective assessment. RCM offers a comprehensive framework but requires significant time and data for implementation. RBM efficiently prioritizes maintenance resources; however, it may not fully represent stochastic failure behavior. Furthermore, previous studies often focus on reliability improvement without quantitatively linking maintenance strategies to production performance, especially in terms of downtime and production loss.

Based on these limitations, the main research problem addressed in this study is how to design an optimal preventive maintenance strategy for the agitator electrical system that not only enhances reliability but also minimizes production losses. This study proposes an integrated approach combining FMEA, RBM, and RCM methods with Weibull-based simulation to evaluate the effectiveness of preventive maintenance scheduling. The approach utilizes historical Time Between Failure (TBF) data to model system reliability and assess the impact of maintenance intervals on equipment performance and production output.

2. Literature Review

Preventive Maintenance in Industrial Systems

Preventive maintenance (PM) is widely applied in industrial systems to reduce unexpected failures and improve equipment reliability. In process industries, maintenance strategies are essential to ensure system availability and minimize operational disruptions. Previous studies indicate that effective preventive maintenance can significantly improve reliability and reduce lifecycle costs by minimizing unexpected failures and downtime. However, excessive maintenance frequency may increase downtime and reduce production efficiency, highlighting the need for optimal maintenance scheduling strategies[1].

Failure Analysis using Failure Mode and Effects Analysis

Failure Mode and Effect Analysis (FMEA) is widely used to identify potential failures and prioritize maintenance actions. Recent developments have integrated data-driven approaches into FMEA to improve maintenance planning (Filz et al., 2021; Behnia et al., 2023). However, the method relies heavily on expert judgment in determining severity, occurrence, and detection, which may introduce subjectivity in the analysis.

Maintenance Decision Framework using Reliability Centered Maintenance

Reliability Centered Maintenance (RCM) is widely used as a decision-making framework to determine optimal maintenance strategies based on system reliability and failure consequences (Selvik & Aven, 2011). RCM has been widely applied across industries such as power systems, oil and gas, and manufacturing, demonstrating its effectiveness in optimizing maintenance planning. Nevertheless, RCM implementation can be complex and requires extensive data and analysis, which may limit its practical application in some industrial environments.

Risk-Based Approach using Risk Based Maintenance

This study integrates Reliability Centered Maintenance (RCM) and Risk-Based Maintenance (RBM) approaches to develop an effective maintenance strategy that considers both system reliability and failure risk (Selvik & Aven, 2011). It evaluates failure probability and consequences to determine risk levels and prioritize maintenance actions. Research shows that RBM effectively reduces operational risks and improves maintenance efficiency by focusing resources on high-risk components. However, RBM may not fully capture stochastic failure behavior, particularly when failure data is limited or uncertain.

Reliability Modeling using Weibull Distribution

The Weibull distribution is one of the most widely used models in reliability engineering due to its flexibility in representing various failure patterns. It is commonly used to estimate failure probability, reliability functions, and equipment lifetime based on historical data. Reliability analysis using statistical approaches such as Weibull distribution is commonly used to model equipment failure behavior (Khalil et al., 2022). However, the accuracy of the model depends heavily on the availability and quality of failure data.

Research Gap and Contribution

Based on the reviewed literature, it can be observed that many studies apply individual methods such as FMEA, RCM, RBM, or Weibull analysis to improve equipment reliability. While these approaches have proven effective, most studies focus primarily on reliability improvement without quantitatively linking maintenance strategies to production performance, particularly in terms of downtime and production output. Therefore, this study proposes an integrated approach combining FMEA, RBM, and RCM with Weibull-based simulation to design an optimal preventive maintenance schedule. Unlike previous studies, this research not only evaluates reliability improvement but also quantitatively analyzes the impact of maintenance scheduling on downtime and production capacity. This approach is expected to provide a more comprehensive solution for maintenance optimization in industrial systems, particularly in PT Borneo Alumina Indonesia.

3. Materials and Method

The research begins with collecting data on electrical components and failure history (Time Between Failure/TBF). Then, FMEA is used to identify critical components based on the Risk Priority Number (RPN). After that, RBM is applied to determine maintenance intervals, while RCM is used to define maintenance activities. Finally, Weibull simulation is performed to analyze system reliability and evaluate the impact of preventive maintenance on production.

Algorithm/Pseudocode

As shown in Algorithm 1, the proposed method integrates reliability analysis and maintenance planning into a systematic framework.

Table 1. Algorithm/Pseudocode.

Algorithm 1. Preventive Maintenance Design for Agitator System
INPUT: Failure data (TBF), component data, operating hours
OUTPUT: Maintenance schedule, reliability value, production impact
1: Collect electrical component and failure data
2: Identify failure modes using FMEA
3: Calculate Risk Priority Number (RPN)
4: Select critical components using Pareto analysis
5: Determine maintenance interval using RBM
6: Define maintenance actions using RCM
7: Estimate Weibull parameters (β, η)
8: Perform reliability simulation
9: Analyze downtime and production impact
10: Determine optimal maintenance schedule

Formatting of Mathematical Components

Risk Priority Number (RPN)

Risk Priority Number is calculated using Eq. (1):

$$RPN = S \times O \times D \tag{1}$$

where $S$is severity, $O$is occurrence, and $D$is detection. Eq. (1) is used to determine the priority level of each component failure.

Weibull Reliability Function

The reliability function based on Weibull distribution is expressed in Eq. (2):

$$R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}} \tag{2}$$

where $R(t)$is reliability, $t$is time, $beta$is the shape parameter, and $eta$is the scale parameter. Eq. (2) is used to evaluate system reliability over time.

Downtime Calculation

Downtime percentage is calculated using Eq. (3):

$$Downtime(\%) = \frac{\text{Total } Downtime \text{Total}}{\text{Jam Operasional}} x\ 100\% \tag{3}$$

This equation is used to determine the proportion of operational time lost due to maintenance activities.

Production Loss Calculation

Production loss due to downtime is calculated using Eq. (4):

$$Production\ Loss = Capacity\ x\ Downtime(\%) \tag{4}$$

This equation is used to estimate the reduction in annual production caused by maintenance scheduling.

4. Results and Discussion

This section presents the results of the preventive maintenance design applied to the agitator electrical system in PT Borneo Alumina Indonesia. The analysis includes component identification, reliability evaluation, maintenance scheduling, and production impact assessment. The study utilizes operational data and failure history (Time Between Failure/TBF) obtained from industrial records. The analysis was performed using Python-based simulation to estimate reliability using the Weibull Distribution, while maintenance decisions were determined using Failure Mode and Effects Analysis, Risk Based Maintenance, and Reliability Centered Maintenance.

Component Identification and Critical Analysis

(a) (b)

Figure 1. (a) component of electrical control system (b) main drive equipment of agitator.

Table 2. Presents the main electrical components in the agitator system.

Component	Quantity	Function
Agitator Motor	1	Main drive
Oil Circulation Motor	1	Gear lubrication
MCCB	2	Circuit protection
Contactor	2	Control switching
Fuse	5	Circuit Control Protection
MCB	2	Circuit Control Protection
Push Button	6	Control input
Pilot Lamp	5	Status indication
Automatic Transfer Switch	1	Power Supply switching
Selector Switch	2	Control input
Thermal Overload Relay	2	Overload Protection

Reliability Analysis

The Weibull parameters obtained from TBF data are:

Shape parameter (β) = 7.1

Scale parameter (η) = 19043

Using Eq. (2), the reliability function is evaluated, showing that preventive maintenance significantly improves system reliability. Without maintenance, reliability decreases rapidly, while with preventive maintenance, reliability remains above 99% during the first year of operation. This result confirms that preventive maintenance effectively delays failure and extends equipment lifetime.

Downtime and Production Analysis

Based on maintenance scheduling, the annual downtime is calculated using Eq. (3), resulting in:

Total downtime = 336 hours/year

Total operating time = 8760 hours/year

Downtime = 3.84%

Using Eq. (4), production loss is calculated as:

Production capacity = 1,000,000 ton/year

Production loss = 38,400 ton/year

Thus, the actual production is: 961,600 ton/year (96% of capacity)

Effect of Maintenance Interval on Performance

Table 3 presents the relationship between maintenance intervals, equipment lifetime, and production output.

Table 3. Effect of Preventive Maintenance Interval.

Interval	Lifetime Increase	Production (Ton/Year)
3 Months	9 Years 5 Months	846,600
6 Months	6 Years 3 Months	923,300
1 Year	3 Years 2 Months	961,600
2 Year	1 Year 3 Months	961,600
5 Year	No increase	961,600

Discussion

The results show that preventive maintenance has a non-linear relationship with production performance. Short maintenance intervals (e.g., 3 months) significantly increase equipment lifetime but reduce production due to frequent downtime. On the other hand, longer intervals (2–3 years) maintain production levels but increase the risk of failure due to reduced maintenance frequency.

The optimal solution is achieved at a 1-year maintenance interval, which provides a balance between reliability and production efficiency. This finding supports the initial hypothesis that an integrated maintenance approach can optimize both system reliability and production output. The selected maintenance interval demonstrates a balance between reliability and production efficiency, similar to optimization models proposed in recent research (Wang et al., 2023).

Furthermore, the integration of FMEA, RBM, and RCM with Weibull simulation provides a comprehensive framework that not only identifies critical components but also quantifies the impact of maintenance on production. Compared to previous studies, this research offers a more holistic evaluation by linking reliability analysis with operational performance.

6. Conclusion

This study presents a preventive maintenance design for the agitator electrical system in PT Borneo Alumina Indonesia using an integrated approach combining Failure Mode and Effects Analysis, Risk Based Maintenance, Reliability Centered Maintenance, and Weibull Distribution. The results show that the proposed method effectively improves system performance, where reliability can be maintained at a high level and equipment lifetime increases up to 13% compared to conditions without preventive maintenance. In addition, the implementation of the maintenance schedule reduces annual downtime to 3.84%, enabling production to reach 96% of the theoretical capacity. The findings demonstrate that there is a strong relationship between maintenance scheduling, system reliability, and production performance. Short maintenance intervals tend to increase reliability but reduce production due to higher downtime, while longer intervals maintain production but increase the risk of failure. The optimal balance is achieved with a one-year maintenance interval, which supports both reliability and operational efficiency. These results are consistent with the research objective of developing an effective and efficient preventive maintenance strategy.

The findings support previous research indicating that maintenance optimization significantly improves system performance and reliability (Tao et al., 2022). This research contributes to the development of maintenance engineering by providing an integrated framework that not only evaluates equipment reliability but also quantifies its impact on production output. The proposed approach can be applied in similar industrial systems, particularly in mineral processing plants, to improve operational sustainability. However, this study has several limitations. The analysis is based on historical failure data and assumes stable operating conditions, which may not fully represent dynamic industrial environments. In addition, external factors such as human error and environmental conditions are not explicitly modeled. Therefore, future research is recommended to incorporate real-time monitoring systems, such as IoT-based predictive maintenance, and o explore more advanced simulation methods to improve accuracy and adaptability.

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