

An Analytical Study on Reducing The Duration of Unscheduled Breakdowns in Scania P410 Trucks Through A Risk-Based Maintenance Strategy Using The FMEA Method at The Mining Contractor PT XYZ

Muhammad Abdullah*, Fourry Handoko, Fuad Achmadi

Institut Teknologi Nasional Malang, Indonesia

Email: abdullahtriina@gmail.com*, fourry.handoko@scholar.itn.ac.id,
fuadachmadi@lecturer.itn.ac.id

Keywords

failure mode and effects analysis; heavy truck; maintenance strategy; physical availability; risk based maintenance; unscheduled breakdown

ABSTRACT

High durations of unscheduled breakdowns in Scania P410 heavy truck units at PT XYZ represent a major issue affecting operational performance and unit physical availability (PA). Historical data from September 2024 to February 2025 indicate that the proportion of unscheduled breakdowns reached 72%, exceeding the company target of 40%, thus necessitating an effective, risk-based maintenance strategy. A Risk-Based Maintenance (RBM) approach integrated with Failure Mode and Effects Analysis (FMEA) was employed to identify critical components and determine improvement priorities. The analysis used the Pareto method to identify the dominant components contributing to downtime, followed by a fishbone diagram to determine root causes of failures. Risk assessment was conducted using severity, occurrence, and detection parameters to calculate the Risk Priority Number (RPN). The results indicate that suspension and brake system components are the primary contributors to unscheduled breakdowns, accounting for approximately $\pm 40\%$ of total downtime. Proposed improvement strategies include component modification, enhancement of the lubrication system, improvements to the electrical system, and optimization of operational parameters. Implementation of RBM based on FMEA is expected to reduce the duration of unscheduled breakdowns and improve unit reliability, thereby supporting enhanced operational performance.

INTRODUCTION

Currently, many countries around the world are beginning to focus their energy policies on energy transition programs, particularly efforts to reduce dependence on coal. These policies are implemented through the development of new and renewable energy sources, carbon emission restrictions, and global commitments to mitigate the impacts of climate change (Abashidze et al., 2019; Iacobuta et al., 2018). This situation is gradually driving changes in the structure of global energy demand and placing coal under increasing pressure in the long term (Song & Wang, 2019; Q. Wang & Li, 2016; Zhao & Alexandroff, 2019).

Nevertheless, coal remains a key energy commodity, playing a crucial role in meeting electricity and industrial needs in various countries (Schernikau, 2017). Coal remains a relatively inexpensive, easily accessible energy source and is supported by established infrastructure. Therefore, amidst the global trend of reducing emissions, coal remains an attractive commodity and continues to offer promising opportunities for businesses in the

mining sector, both in terms of production, distribution, and domestic use and export (Adegboye et al., 2024; Gomes, 2025; Rao et al., 2024; H. Wang & Zhang, 2023).

On the other hand, global market dynamics indicate that coal prices have tended to stagnate in recent periods, even showing a downward trend. This price fluctuation is influenced by various factors, including the global economic slowdown, increased renewable energy capacity, and changes in energy policies in major consuming countries. However, these conditions have not necessarily hampered coal mining business activities. Industry players continue production activities to meet domestic market demand, particularly in the electricity and industrial sectors, and to fulfill export contracts to international markets, which still show significant demand (Heffron et al., 2020; Wu & Chen, 2017).

Thus, the coal mining industry currently faces a situation that demands increasingly high levels of efficiency and productivity. Price pressures and the demands of the energy transition are driving mining companies to optimize all operational aspects, from mine planning and heavy equipment utilization to transportation systems and operational cost management. This situation makes improving operational performance and equipment reliability key factors in maintaining the sustainability of coal mining businesses amidst the changing global energy landscape.

In the context of heavy equipment operations, maintenance strategy plays a critical role in determining unit reliability and Physical Availability (PA). Several previous studies have demonstrated the effectiveness of risk-based approaches in improving equipment performance. For instance, Senapati & Dalai (2025) evaluated risk-based maintenance approaches for mechanical equipment in mining operations and found that such approaches significantly reduce failure rates and improve overall equipment effectiveness. Similarly, Lopez & Kolios (2022) applied risk-based maintenance strategy selection for wind turbine components, demonstrating that prioritizing maintenance actions based on risk levels leads to more efficient resource allocation and reduced downtime. El-Thalji (2025) further emphasized that emerging practices in risk-based maintenance management, driven by industrial transitions, enable organizations to shift from reactive to proactive maintenance cultures.

Specifically, the Failure Mode and Effects Analysis (FMEA) method has been widely recognized as an effective tool for identifying critical components and determining maintenance priorities. Ardiansyah et al. (2023) implemented FMEA for heavy equipment workshop maintenance and successfully identified dominant failure modes that contributed to prolonged downtime. Hatala et al. (2023) combined FMEA with critical analysis (FMECA) for boiler systems, demonstrating that Risk Priority Number (RPN) calculations effectively guide maintenance interventions on high-risk components. Putra et al. (2025) further confirmed that RPN-based analysis provides objective criteria for determining which subcomponents require immediate attention. Martadinata et al. (2025) extended the application of RBM with FMEA to HVAC systems, showing that the method is adaptable across different mechanical systems. Taruna & Rusindiyanto (2025) applied FMEA-based preventive maintenance strategies for material handling systems, reporting significant reductions in unscheduled downtime. Additionally, Widotomo et al. (2024) improved risk-based maintenance management strategies through reliability-centered maintenance in coal crushing plants, highlighting the importance of integrating multiple analytical tools.

Despite the substantial body of research on RBM and FMEA, previous studies have generally not specifically highlighted the reduction of unscheduled breakdown duration in heavy truck units—particularly articulated dump trucks used in mining hauling operations—with an integrated approach between risk analysis and identification of root causes of damage. Most existing research focuses on stationary equipment (boilers, compressors, HVAC) or excavators and bulldozers, leaving a gap in the literature regarding heavy trucks such as the Scania P410, which operates under unique conditions including extreme road gradients, high dust exposure, and continuous hauling cycles. Furthermore, prior studies often report RPN values and propose maintenance strategies without explicitly measuring the before-and-after impact on unscheduled breakdown duration as a primary performance indicator.

The present study addresses this gap by focusing on the Scania P410 unit at PT XYZ, a mining contractor in Central Kalimantan. The duration of unplanned breakdowns (Unscheduled Breakdown/BUS) on the Scania P410 unit remains high, reducing Physical Availability (PA). The period of September 2024–February 2025 shows a ratio of planned breakdowns (Scheduled Breakdown/BS) and unplanned breakdowns of 28%:72%, far from the target of 60%:40%. Two main components, the Suspension and Brake System, contribute $\pm 40\%$ (577.2 hours) of the total BUS time, so focusing on repairs on these two components is expected to significantly reduce downtime. This study uses a Risk-Based Maintenance strategy with the Failure Mode and Effects Analysis (FMEA) method to identify dominant failure modes, analyze causes and impacts, and calculate the Risk Priority Number (RPN). This approach prioritizes components with the highest risk for maintenance, repair, and mitigation actions, so it is expected to significantly reduce BUS duration, increase PA, and support the achievement of production targets optimally and sustainably.

The limitations of this study include a focus on analyzing the causes of the high duration of unplanned breakdowns (unscheduled breakdowns) in Scania P410 model units. The research data was collected from 17 Scania P410 units operating at PT. XYZ, a company engaged in mining contracting services, between 2024 and 2025. The study period was limited to March 2025 and September 2025. Based on this background, the problem that arises is how to reduce the duration of unplanned breakdowns in Scania P410 units to support unit Physical Availability, ultimately supporting coal production at PT. XYZ.

The objectives of this study include analyzing the dominant causes of unscheduled breakdowns in 17 Scania P410 units through a Risk-Based Maintenance strategy using the Failure Mode and Effects Analysis (FMEA) method to identify critical components and subcomponents that have the potential to affect unit performance and Physical Availability. This study also aims to formulate and implement maintenance strategies for critical components and subcomponents, particularly the Suspension and Brake Systems, to reduce the duration of unplanned breakdowns and improve unit reliability. Furthermore, the study evaluates the effectiveness of maintenance strategies by comparing performance before and after repairs and formulates ongoing monitoring recommendations for continuous maintenance performance improvement.

The benefits of this research are divided into practical and theoretical benefits. Practically, the research is expected to improve the performance of the Scania P410 unit by reducing the duration of unplanned breakdowns and minimizing losses due to suboptimal unit operation. Theoretically, this research plays a role in the application of academic knowledge

to address company problems and support the implementation of effective maintenance management. Based on previous research, Risk-Based Maintenance (RBM) and Failure Mode and Effects Analysis (FMEA) methods have proven effective in identifying critical components, reducing downtime, and increasing the reliability and availability of mechanical and heavy equipment. However, previous research generally has not specifically highlighted the reduction of the duration of unscheduled breakdowns in heavy truck units with an integrated approach between risk analysis and identification of the root cause of damage. Therefore, this research focuses on reducing the duration of unscheduled breakdowns in the Scania P410 unit using RBM and FMEA to contribute to improving equipment reliability and company operational performance.

METHOD

Research Type

This research is a quantitative applied research using a case study approach. It aims to analyze and reduce the duration of unplanned breakdowns on Scania P410 Heavy Trucks at PT. XYZ. This approach was chosen because it allows for objective analysis of numerical data related to downtime duration and unit performance.

Research Object

The research was conducted on 17 Scania P410 units operating at PT. XYZ, located in a district in Central Kalimantan. The focus of the research was on components experiencing the highest breakdown duration and contributing the most to unit downtime.

Research Instrument

This research instrument was designed to support the analysis of reducing the duration of unplanned breakdowns on Scania P410 units at PT. XYZ. The instrument employed several methods. First, documentation through the Daily Breakdown Report, validated by the superior or maintenance team management, included the type of damage, downtime duration, and unit performance parameters, serving as the basis for quantitative analysis and the identification of critical components. Second, interviews with the maintenance team—including mechanics, planners, technical engineers, leaders, and supervisors—were conducted to obtain additional information to strengthen the data analysis and ensure the validity of the findings. Third, Pareto Analysis was used to classify components based on the duration of unplanned downtime, allowing repairs and maintenance strategies to focus on the most critical components. Fourth, Failure Mode and Effects Analysis (FMEA) was applied to identify potential failure modes in critical components and evaluate risk levels based on Severity, Occurrence, and Detection parameters; the calculation of the Risk Priority Number (RPN) helped determine the priority of treatment and repairs for components with the highest risk. Fifth, the Risk-Based Maintenance (RBM) principle was used to determine the most appropriate type of maintenance for critical components, including Preventive, Predictive, Condition-based, and Corrective, so that this data-driven maintenance strategy could continuously improve the performance and reliability of the Scania P410 unit.

Data collection

The data collection used includes various approaches, including:

1. Historical Data Analysis

Analysis of historical data in the form of Maintenance data that occurred on the Scania P410 unit in the period September 2024 to February 2025, for the data obtained from the history of maintenance/damage that has been summarized by the Maintenance Team, this recapitulation data is obtained from damage reports from the field, the following is the Flow of reporting and handling of unit repairs, according to figure 3.1 below;

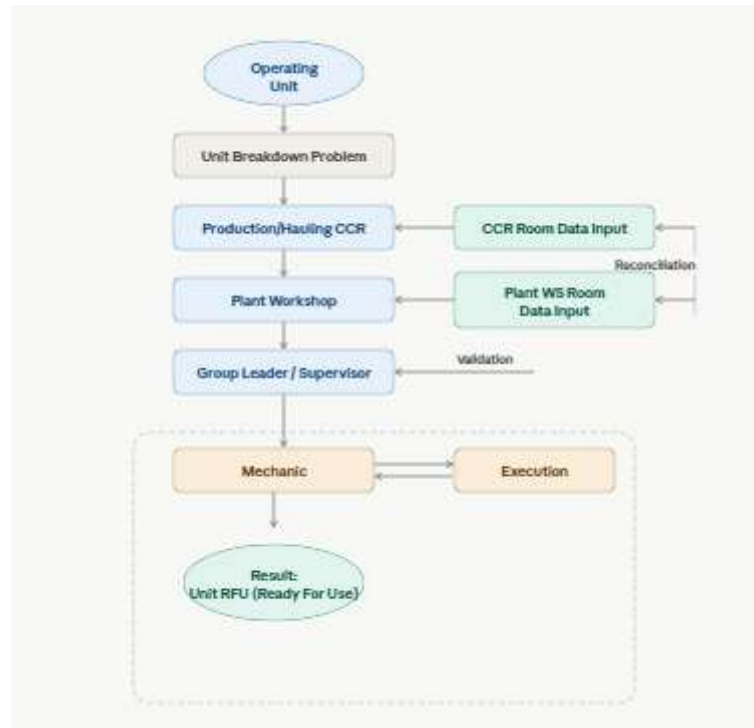


Figure 1. Unit Damage Reporting Flow

Source: Internal Company, 2023

Recapitulation data for each problem or unit damage report on the Scania P410 is recorded and validated by the superior. The report generally consists of a description and explanation, as shown in Table 1 below.

Table 1. Unit Damage Data Summary

No	Description	Information
1	Type Unit	Model Units
2	Unit Code	Scania P410 Specifications
3	Total Down	Problem duration from start info to finish
4	Status	Breadown Schedule / Unschedule
5	Description of Breakdown	Main Problem
6	Code Breakdown	Code Component
7	Sub Component	Sub Component problem
8	Component	Component Problem

Source: Internal Company, 2023

So that the data for further analysis is more specific to the Sub Components and Components that contribute the longest duration of unplanned damage to the Scania P410 unit.

Research Flow Chart

Research Flow Diagram according to Figure 3.2 below;

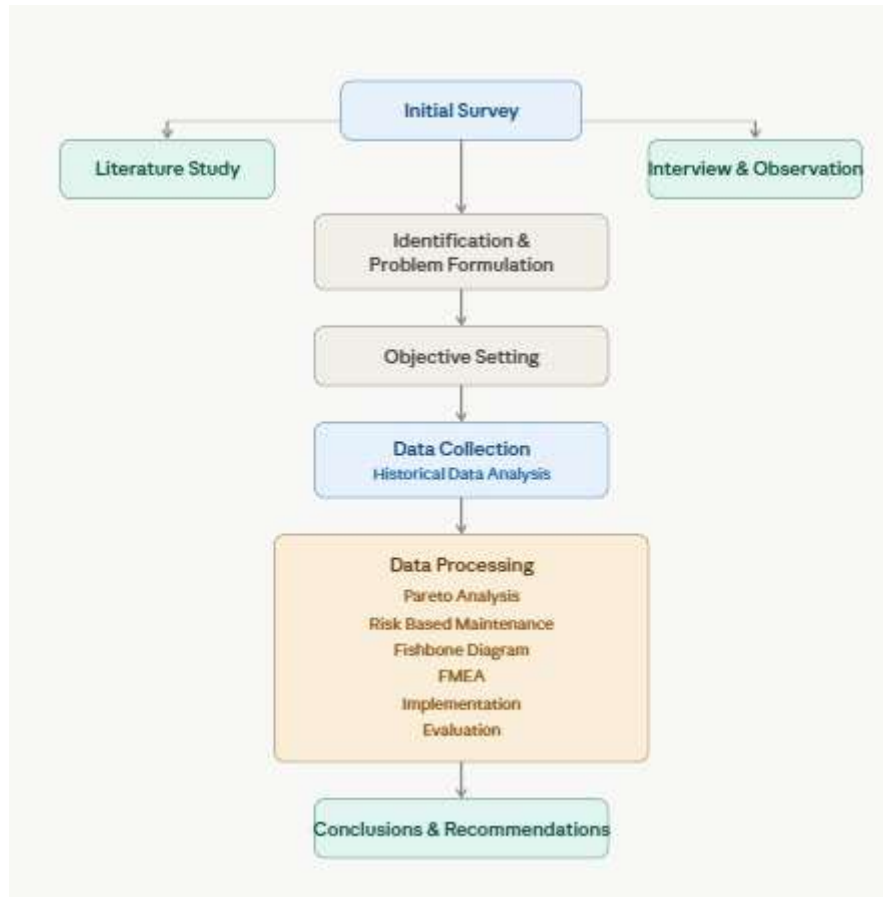


Figure 2. Research Flow

Source: Researcher documentation, 2025

RESULTS AND DISCUSSION

Risk Based Maintenance (RBM) Analysis

This section discusses the Risk-Based Maintenance (RBM) approach for the Scania P410 truck, with the primary goal of reducing unplanned breakdown times and increasing unit availability. This section will discuss the analysis focus, data collection, risk assessment results, and a discussion of maintenance strategies for dominant components based on identified risk levels.

The RBM approach in this study focuses on assessing the risk level of component failure based on a combination of the probability of failure and its operational consequences. Therefore, RBM is applied in an applied manner by adapting the main principles of Risk Assessment to suit the needs of the case study, without comprehensively applying the entire RBM Framework.

1. Focus of Risk Based Maintenance (RBM) Analysis

The focus of the RBM analysis in this study is the critical components that contribute the most to the duration of unscheduled breakdowns, namely the suspension and brake systems.

These components were selected based on historical data analysis results that indicated the highest level of risk for the duration of unplanned breakdowns. The analysis focused on:

- Identify potential failure modes
- Assessment of the level of failure risk
- Evaluate the impact on operations
- Risk-based maintenance strategy prioritization

With this approach, maintenance actions can be carried out in a more targeted manner based on the level of risk and impact on downtime duration.

2. Data Collection and RBM Instruments

Risk-Based Maintenance (RBM) analysis requires complete and valid data to objectively determine the risk level of component failure. In this study, the identification of potential causes of damage to the Suspension and Brake System was conducted using a Fishbone Diagram (Ishikawa) as a tool to identify contributing factors to failure.

The data used includes:

1. Historical failure reports, including Downtime duration, failure frequency, and type of failure on dominant components.
2. Routine maintenance records, used to assess the effectiveness of previous maintenance strategies and detect failure patterns.
3. Interview technicians and supervisors, to obtain information regarding technical constraints and factors that extend downtime duration.

The research instrument, a Fishbone Diagram, helps identify potential causes across various categories, such as Man, Machine, Method, and Material. The results of this identification form the basis for determining appropriate maintenance strategies, including Preventive, Predictive, and Corrective Maintenance, so that they can be implemented systematically and effectively.

3. Fishbone Diagrams

To analyze the root causes of long downtimes in the suspension and brake systems, this study used a fishbone diagram (Ishikawa diagram).

A fishbone diagram is a cause-and-effect identification tool that allows all potential causal factors to be systematically recorded and categorized into several key aspects, such as People, Materials, Machines, and Methods.

Figures 4.2 and 4.3 show several root causes that contribute to the long breakdown times of the suspension and brake system units on the Scania P410, namely:

a. Fishbone Diagram Suspension

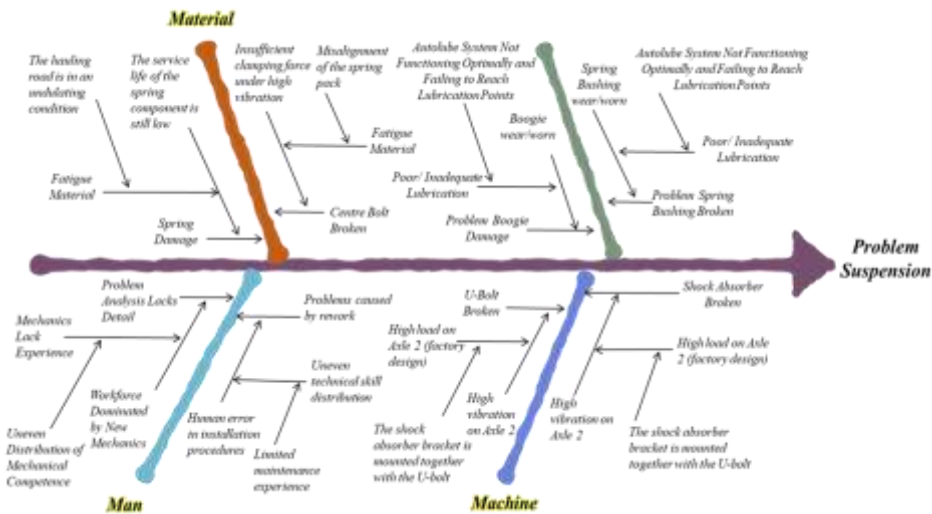


Figure 3. Fishbone Diagram of Suspension
Source: Researcher analysis results, 2025

Based on the Fishbone Diagram analysis (Figure 3), damage to suspension components is primarily influenced by four categories of factors: Human, Method, Material, and Machine. From a method perspective, damage to the boogie and spring bushings occurs due to a malfunctioning automatic lubrication system, preventing lubricant from reaching the correct points, accelerating wear, reducing suspension stability, and increasing component workload. Material factors include spring damage due to material fatigue from repeated dynamic loads and uneven road conditions, as well as center bolt breakage due to insufficient clamping force under high vibrations, both of which reduce vibration damping and system stability. In the machine category, shock absorbers and U-bolts experience damage due to high vibrations and heavy loads on axle 2, reducing vibration damping and component fastening strength. Human factors also play a role, with inexperienced new mechanics and rework errors leading to in-depth root cause identification and increasing the risk of recurrent damage. Thus, all of these factors are interrelated and have a significant impact on the overall performance of the suspension system.

b. Fishbone Diagram Brake System

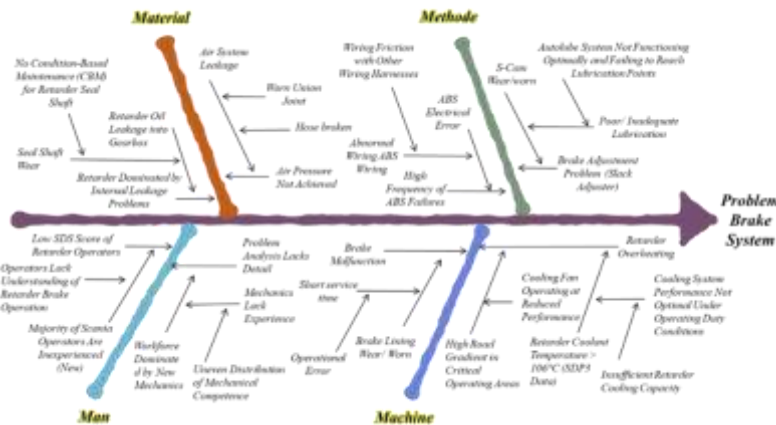


Figure 4. Fishbone Diagram of the Brake System
Source: Researcher analysis results, 2025

Based on the Fishbone Diagram analysis (Figure 4), brake system failures are categorized into Man, Method, Material, and Machine. From a method perspective, ABS failures often occur due to electrical faults and friction between wiring harnesses, as well as brake slack adjuster issues due to suboptimal lubrication, which accelerates wear and reduces brake performance. Material factors include retarder oil leaks due to worn seals and the lack of condition-based maintenance, and inadequate air pressure due to wear on hoses and connections, reducing brake system effectiveness. In the machine category, retarders overheat due to insufficient cooling capacity and high road gradients, while brake lining wear reduces braking capability. Human factors also play a role, with inexperienced mechanics and new operators leading to in-depth root cause identification and increasing the risk of operational errors and component wear. All of these factors contribute significantly to reduced brake system performance and stability.

4. Root Cause Determination and Maintenance Strategy

Based on the Fishbone Diagram and FMEA analysis on the Scania P410 Truck unit, several sub-components in the Suspension and Brake System were identified as the main causes of Unscheduled Breakdowns. Each sub-component was analyzed based on the severity of the impact (Severity), frequency of occurrence (Occurrence), and failure detection capability (Detection) to produce a Risk Priority Number (RPN) value. Sub-components with the highest RPN, such as Spring (630) and Retarder (800), were determined as the dominant root causes that require high priority attention in the maintenance strategy. The maintenance strategy focused on technical improvements and enhancements to the lubrication and cooling systems, including modifications to the Shock Absorber and U-Bolt brackets, the addition of Autolube Pump elements, ABS wiring protection, adjustments to the fan retarder timing, and the implementation of Condition Based Maintenance for leak and internal damage detection. This approach ensures proactive and systematic maintenance actions, reducing the risk of recurrent failures, increasing component durability, and maintaining optimal unit performance.

Implementation

1. Shock Absorber Axle Bracket Modification

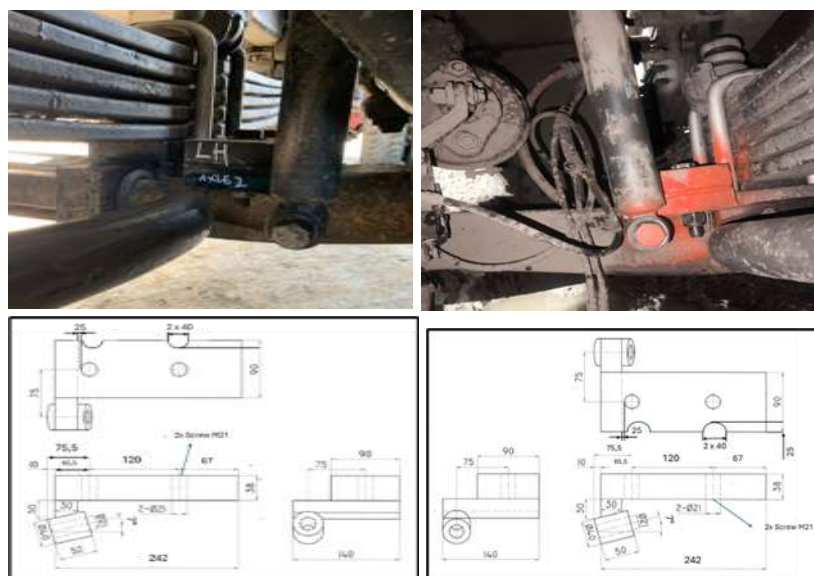


Figure 5. Shock absorber bracket modification

Source: Researcher Documentation at PT XYZ, 2025

Shock absorber bracket modifications are made to reduce excessive vibration in the shock absorber. The shock absorber is initially mounted with a U-bolt and anti-roll bar. With this modification, the shock absorber can move independently of the U-bolt and anti-roll bar, thereby extending the lifespan of the U-bolt.

2. Adding Autolube Pump Elements

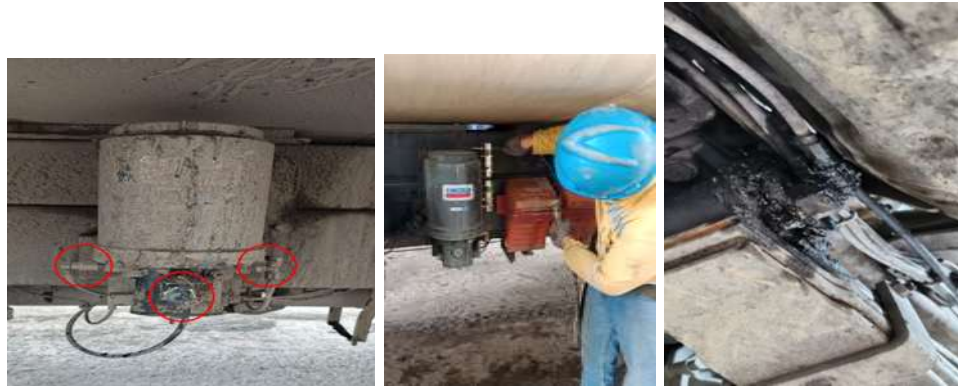


Figure 6. Adding Autolube Pump Elements

Source: Researcher Documentation at PT XYZ, 2025

The addition of three Autolube pump elements increases the grease flow rate in the system. This additional pump element ensures that subcomponents located far from the tank are properly lubricated, thus improving the durability of suspension and brake system parts.

3. Kawashima Wiring

Kawashima Wiring provides a protective guard for the wiring. ABS wiring is highly susceptible to friction, which can cause damage. Therefore, Kawashima ensures the wiring remains in good condition.

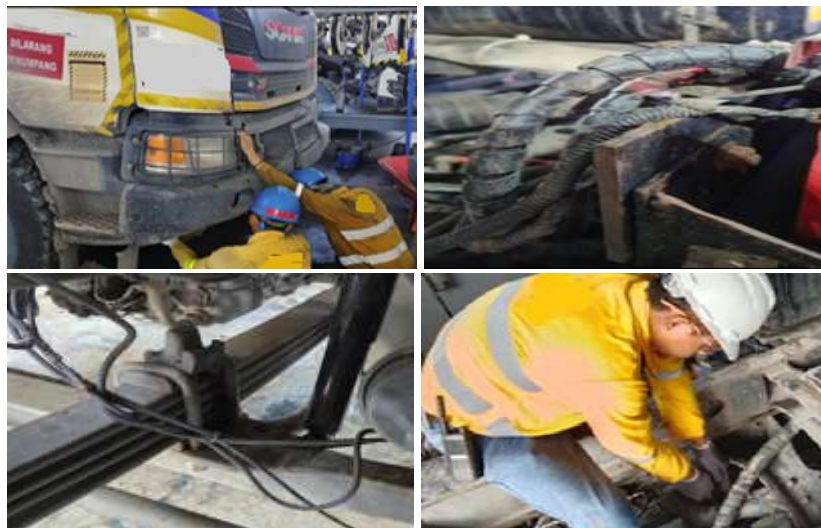


Figure 7. Kawashima Wiring

Source: Researcher Documentation at PT XYZ, 2025

4. Fan Cooling Parameter Setting +15 Degrees

Fan Cooling parameter settings are adjusted by adjusting the fan clutch timing to operate at a temperature 15 degrees faster than the default setting of 88 degrees. This setting is necessary because the unit operates under extreme conditions with a road gradient of >14

degrees. With this parameter setting, the fan will operate at a temperature of 73 degrees, optimizing system unit cooling.



Figure 8. Fan Cooling Parameter Setting +15 Degrees
 Source: Researcher Documentation at PT XYZ, 2025

5. Replacement Retarder (CBM and Internal leak during PI (Work Program))



Figure 9. Retarder Replacement
 Source: Researcher Documentation at PT XYZ, 2025

Retarder problems are dominated by internal and external leaks. The lifespan of retarder components is influenced by maintenance and operational factors, so the failure trend for each unit will vary. Therefore, Condition-Based Maintenance (CBM) is implemented to detect failures, with detailed activity checks for oil levels at each PI and component leak inspections..

6. STD Operation Retarder Campaign with Stickers on the unit



Figure 10. Sticker campaign related to retarder operation

Source: Researcher Documentation at PT XYZ, 2025

The retarder functions as an auxiliary brake to assist the main braking system. However, field observations indicate that the retarder is often used as the main brake, increasing the workload and risk of damage to the retarder components. Therefore, retarder use should comply with established operational requirements, which are outlined in the form of a warning sticker on the unit as a reminder to the operator.

Results

Based on the results of the implementation of the maintenance strategy designed through the Risk Based Maintenance (RBM) approach with the FMEA method, there was a decrease in the duration of Unscheduled Breakdown time on the Suspension and Brake System components of the Scania P410 unit. A comparison of performance before implementation (September 2024 to February 2025) and after implementation (June to August 2025) is shown in Figure 4.10 and Figure 4.11. The results of the analysis show that the Suspension component experienced a decrease in the duration of Unscheduled Breakdown time by 20%, from 302.47 hours to 242.93 hours. Meanwhile, the Brake System component showed a more significant decrease, namely 45%, from 274.73 hours to 151.66 hours.

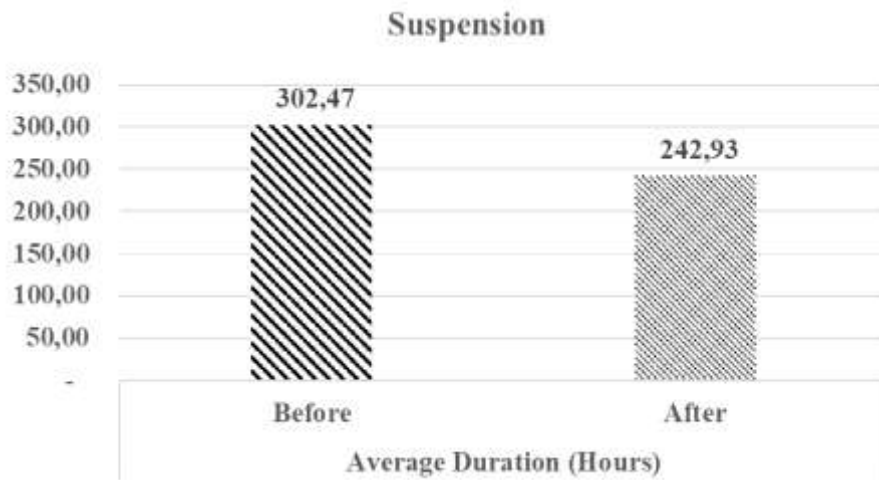


Figure 11. Average duration of BUS suspension

Source: Historical Data of PT XYZ, processed by researchers, 2025

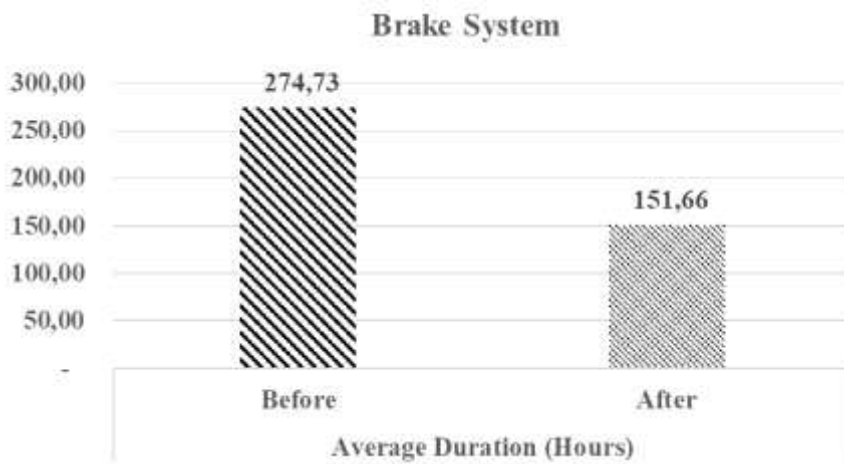


Figure 12. Average duration of the BUS brake system

Source: Historical Data of PT XYZ, processed by researchers, 2025

This decrease indicates that the corrective actions taken have been effective in reducing the duration of unplanned breakdowns. Details of each suspension and brake system subcomponent are shown in Figures 11 and 12.

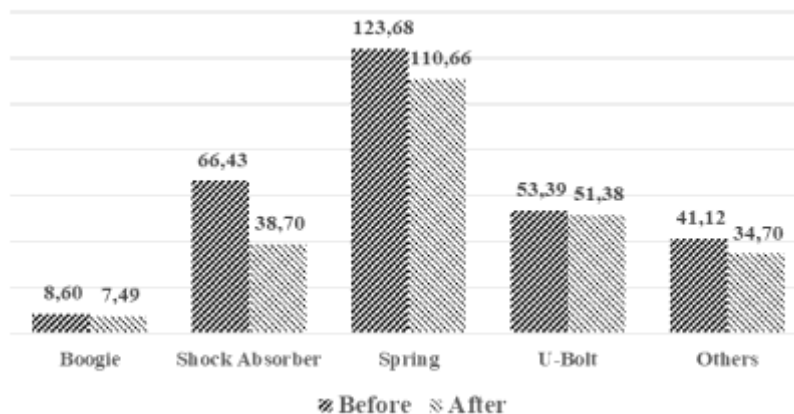


Figure 13. Average duration of BUS sub component suspension

Source: Historical Data of PT XYZ, processed by researchers, 2025

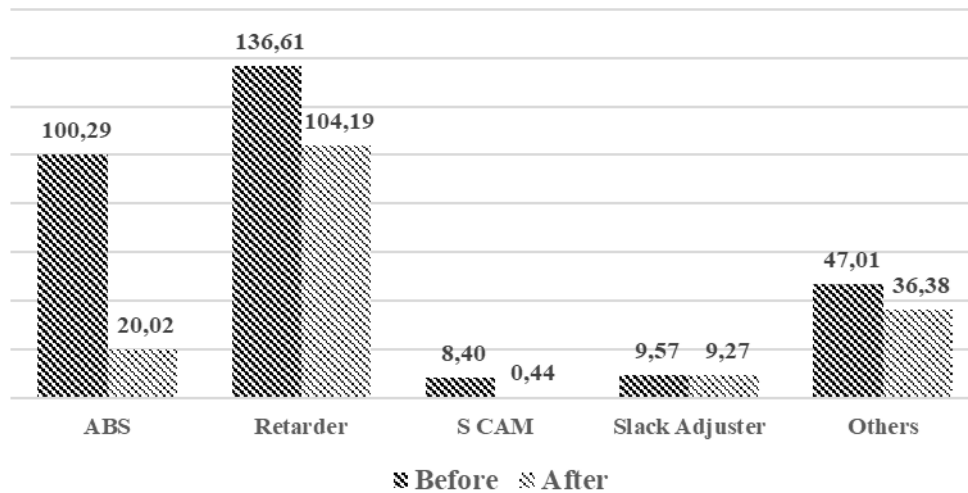


Figure 14. Average BUS brake system sub-component duration

Source: Historical Data of PT XYZ, processed by researchers, 2025

Based on actual data from June to August 2025, as shown in Figure 14, the average ratio of scheduled breakdowns (BS) was 38% and unscheduled breakdowns (BUS) was 62%. This comparison indicates that the majority of unit downtime is still dominated by unplanned breakdowns (Unscheduled Breakdowns/BUS). This result indicates that the composition of scheduled breakdowns/BS and unscheduled breakdowns/BUS has not met the company's target of 60% BS and 40% BUS. The 62% BUS proportion indicates that the duration of unscheduled breakdowns is influenced not only by the two components focused on in this study but also by downtime contributions from other components not included in this study. Components outside the suspension and brake systems continued to contribute relatively stable downtime during the observation period, so the aggregate decrease in total unit downtime was not as significant as the decrease in the dominant sub-components. Furthermore, the implementation of the maintenance strategy in this study focused on priority components based on the Pareto Analysis results, resulting in the most significant improvement impacts occurring in these subcomponents. Meanwhile, downtime in subcomponents categories B and C has not experienced significant changes because no specific maintenance interventions have been implemented.

However, compared to the conditions before the implementation of the improvements, there was a 10% decrease in the duration of Unscheduled Breakdowns on the Scania P410 unit. This decrease indicates that the implemented improvements have a positive impact on controlling unplanned breakdowns and increasing unit reliability.

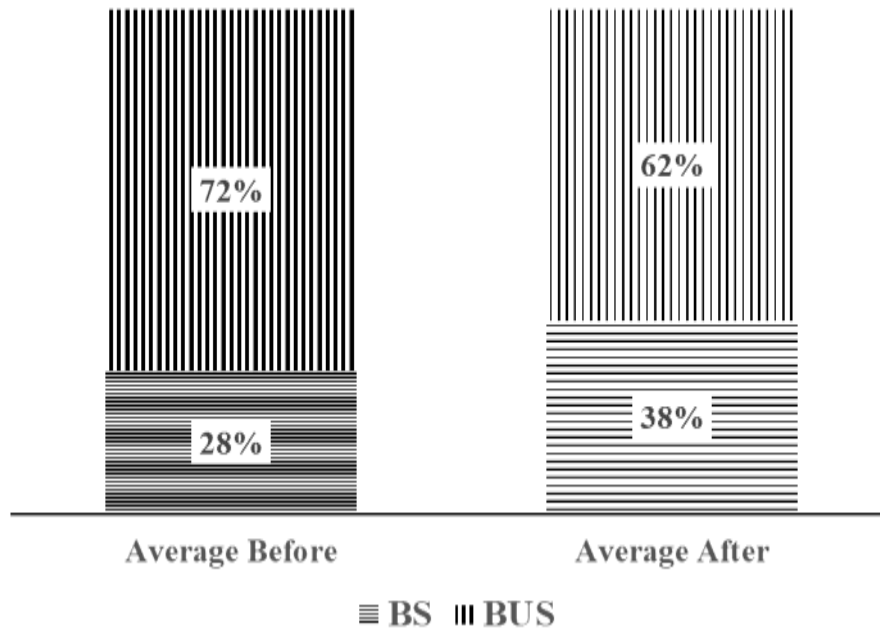


Figure 15. Average BS vs BUS (before and after implementation)

Source: Historical Data of PT XYZ, processed by researchers, 2025

CONCLUSION

The conclusion of this study shows that the implementation of the Risk-Based Maintenance (RBM) strategy with the Failure Mode and Effects Analysis (FMEA) method provides a systematic and targeted approach in handling Unscheduled Breakdown (BUS) problems on the Scania P410 unit, allowing the company to focus repair efforts on critical components, thereby improving unit performance, especially Physical Availability (PA). Repairs focused on the Suspension and Brake System components have proven effective in reducing the duration of unplanned breakdowns, thus increasing the overall reliability of the unit. To ensure the sustainability of the repair results, periodic maintenance performance evaluation is required by comparing conditions before and after implementation, supported by adequate maintenance monitoring tools so that the effectiveness of the implemented strategy can be monitored, controlled, and continuously improved.

Based on the findings and limitations of this study, it is recommended that PT XYZ extend the RBM-FMEA approach to other critical components, such as the engine cooling, transmission, and electrical systems, which continue to contribute to the remaining 62% of BUS proportion. The company should also implement a digital-based maintenance monitoring system to enable real-time failure data recording and more accurate RPN calculations, while conducting regular training for mechanics and operators to minimize human-related failure factors identified in the fishbone diagram analysis. For future researchers, it is suggested to expand the study period to at least one full year to assess long-term sustainability, incorporate a cost-benefit analysis to evaluate economic impacts, and consider developing a predictive maintenance model using IoT-based sensors on critical components for early failure detection.

REFERENCES

- Abashidze, A. K., Solntsev, A. M., & Akshalova, R. D. (2019). Climate change mitigation and renewable energy sources: International legal issues. *Institute of Scientific Communications Conference*, 1068–1075.
- Adegboye, O., Olateju, A. P., & Okolo, I. P. (2024). Localized battery material processing hubs: Assessing industrial policy for green growth and supply chain sovereignty in the Global South. *International Journal of Computer Applications Technology and Research*, 13(12), 38–53.
- Ardiansyah, R., Widyaningrum, D., & Jufriyanto, M. (2023). Upaya perawatan peralatan bengkel alat berat PT. BMI dengan metode FMEA. *Jurnal Sains dan Teknologi*, 5(2), 660–668. <https://doi.org/10.55338/saintek.v5i2.2082>
- El-Thalji, I. (2025). Emerging practices in risk-based maintenance management driven by industrial transitions: Multi-case studies and reflections. *Applied Sciences*, 15(3), 1199. <https://doi.org/10.3390/app15031199>
- Gomes, C. (2025). *Clean coal as a transitional buffer: A critical study of livelihood strategies amid South Africa's energy decarbonisation*.
- Hatala, M. H., Sukarsono, B. P., & Nukertamanda, D. (2023). Risk and reliability improvement analysis of boiler system using the Failure Mode Effect Analysis & Critical Analysis (FMECA) method. *Spektrum Industri*, 21(1), 8–20. <https://doi.org/10.12928/si.v21i1.98>
- Heffron, R., Körner, M.-F., Wagner, J., Weibelzahl, M., & Fridgen, G. (2020). Industrial demand-side flexibility: A key element of a just energy transition and industrial development. *Applied Energy*, 269, 115026.
- Iacobuta, G., Dubash, N. K., Upadhyaya, P., Deribe, M., & Höhne, N. (2018). National climate change mitigation legislation, strategy and targets: A global update. *Climate Policy*, 18(9), 1114–1132.
- Lopez, J. C., & Kolios, A. (2022). Risk-based maintenance strategy selection for wind turbine composite blades. *Energy Reports*, 8, 5541–5561. <https://doi.org/10.1016/j.egy.2022.04.019>
- Martadinata, M. I., Hariri, A., Amalia, D., Soleh, A. M., Sunardi, Setiyo, Suryan, V., Suprihartini, Y., & Sukahir. (2025). Risk-based maintenance dengan metode Failure Mode and Effects Analysis (FMEA) untuk peningkatan keandalan sistem pendingin udara di gedung komersil. *Journal of Information Technology and Computer Science (INTECOMS)*, 8(6).
- Putra, R. A., Lestari, A. S. K., & Sari, R. A. (2025). Analisis Risk Priority Number (RPN) menggunakan Failure Mode and Effects Analysis (FMEA) terhadap hasil inspeksi airworthiness. *Jurnal Mahasiswa Dirgantara (JMD)*, 4(2), 84–89. <https://doi.org/10.35894/jmd.v4i2.177>
- Rao, A., Srivastava, M., Parihar, J. S., Chavriya, S., & Hosen, M. (2024). Minerals at the crossroads: Economic policies, global trade, and renewable energy in the Global South. *Resources Policy*, 97, 105257.
- Schernikau, L. (2017). *Economics of the international coal trade: Why coal continues to power the world*. Springer.
- Senapati, B., & Dalai, B. (2025). Evaluating risk-based maintenance approaches for mechanical equipment in mining operations. *Airo International Journal*, 2(3).
- Song, Y., & Wang, N. (2019). Exploring temporal and spatial evolution of global coal supply-demand and flow structure. *Energy*, 168, 1073–1080.
- Taruna, E. E., & Rusindiyanto. (2025). FMEA-based preventive maintenance strategy for airlock systems material handling at PT XYZ. *International Journal of Mechanical, Electrical and Civil Engineering (IJMECIE)*, 2(3).

<https://doi.org/10.61132/ijmecie.v2i3.303>

- Wang, H., & Zhang, D. (2023). Examining the interplay between fossil fuel mining, sustainable growth, and economic prosperity. *Resources Policy*, 87, 104324.
- Wang, Q., & Li, R. (2016). Journey to burning half of global coal: Trajectory and drivers of China's coal use. *Renewable and Sustainable Energy Reviews*, 58, 341–346.
- Widotomo, G., Nurkertamanda, D., & Suliantoro, H. (2024). Improving analysis of risk-based maintenance management strategies through reliability centered maintenance: Case study: Coal crushing plant, Central Kalimantan, Indonesia. *Advance Sustainable Science, Engineering and Technology (ASSET)*, 6(1), 0240109-01–0240109-08. <https://doi.org/10.26877/asset.v6i1.17529>
- Wu, X. F., & Chen, G. Q. (2017). Global primary energy use associated with production, consumption and international trade. *Energy Policy*, 111, 85–94.
- Zhao, S., & Alexandroff, A. (2019). Current and future struggles to eliminate coal. *Energy Policy*, 129, 511–520.