*Journal of Railway Transportation and Technology*
*Vol. 5 No. 1 (2026) 25-35*
*eSSN: 2830-6880*

# Failure Analysis and Maintenance Strategy of Pneumatic System Components in Rail-Road Loader KGT/V

**M Karil Samba Athari[1], Ocky Soelistyo Pribadi[2], Erni Basri[3] , Fadli Rozaq[4], Probo Hardini[5]**

[1,2,3,4]Politeknik Transportasi Darat Indonesia-STTD, Jl. Raya Setu No.89, Bekasi, 17520, Indonesia
[5]Universitas Jenderal Soedirman, Jl. Mayjen. Sungkono Km. 5, Blater, Purbalingga, Jawa Tengah 53371, Indonesia

**Article Info**

***Article history:***

Received July 22, 2025
Revised March 31, 2026
Accepted March 31, 2026

***Keywords:***

Rail-Road Loader KGT/V
Pneumatic System
Condensation
FMEA
RCM
TOPSIS
Air Dryer

**ABSTRACT**

The Rail-Road Loader KGT/V is a multifunctional heavy equipment used for railway track maintenance and repair, with a pneumatic system playing a vital role in braking and stabilization mechanisms. This study aims to analyze the failure of pneumatic system components in the Rail-Road Loader KGT/V unit, primarily caused by air moisture and condensation, and to formulate solutions for improving system reliability. The research applies several methods, including downtime analysis, Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), Failure Modes and Effects Analysis (FMEA), Reliability Centered Maintenance (RCM), and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). Results indicate that high humidity at the operational sites triggers failures in key components such as seals, valves, and pressure sensors, leading to increased equipment downtime. The installation of an air dryer is identified as the most effective technical solution to mitigate condensation issues. According to the TOPSIS analysis, implementing an air dryer ranks highest among proposed alternatives. This study recommends installing air dryers and developing a systematic maintenance procedure to enhance the reliability of the pneumatic system and ensure safer operational performance of the Rail-Road Loader KGT/V.

***Corresponding Author:***

M Karil Samba Athari
Politeknik Transportasi Darat Indonesia-STTD
Jl. Raya Setu No.89, Bekasi, 17520, Indonesia
Email: karil.ptdi@gmail.com

## 1. INTRODUCTION

Rail-Road Loader KGT/V is a dual-mode heavy-duty vehicle that operates both on conventional roads and railway tracks. It is extensively employed in railway infrastructure maintenance tasks such as transporting, lifting, and installing track components. This machine integrates two primary systems: a hydraulic system for mechanical movements such as boom, arm, and bucket operation, and a pneumatic system responsible for braking and stabilization during rail operations [1].

Although the operational hours of the Rail-Road Loader KGT/V at the Railway Maintenance Center in Ngrombo are under 2000 hours, indicating the equipment is still in its early-use phase [2], significant performance degradation has been observed, particularly in the pneumatic system. Moisture contamination is the main factor contributing to the deterioration of pneumatic components. Aging rubber seals lose elasticity, develop microcracks, and become increasingly prone to leakage when exposed to humid air [3]. Humidity is a critical factor, especially in tropical environments like Central Java and South Sumatra, where relative humidity levels often exceed 90% [4]. Condensation from moist compressed air leads to corrosion, clogging, and pressure instability, compromising the performance of pneumatic systems [5], [6]. Inadequate moisture control causes internal corrosion in components and impairs braking reliability [7], [8].

Despite regular maintenance, operational logs from 2022 to 2024 show repeated failures in valves, seals, and pressure sensors due to residual condensation. The current pneumatic system is only equipped with a condensate separator, which is inadequate for effective moisture removal in high-humidity conditions [6]. Limitations of conventional air dryer controls in industrial pneumatic systems, highlighting the need for modern moisture management components [9]. Studies emphasize the importance of minimizing energy losses and overconsumption in compressed air systems during operation [10]. Advanced solutions such as air dryers are recommended. Desiccant dryers are suitable for tropical applications, offering dew points as low as –40°C [11], [12], [13]. The critical role of adsorption dryers in ensuring pneumatic reliability in railway environments [14]. The use of separation–condensation and throttling devices in improving air quality and reducing corrosion [15]. Support the integration of automated dryer systems for increased operational resilience [9].

Moisture-related damage extends to component performance and operator safety. Inadequate control of environmental factors in assemblies can lead to premature failure, which applies to compressed air systems in humid conditions [16]. Economically, these failures are impactful. Government Regulation No. 15 of 2016 mandates a service fee of IDR 1,550,000 per day for the operation of multipurpose equipment in railway maintenance [17]. In addition, the Ministry of Transportation provides a framework for SOP development in maintenance activities to reduce inefficiencies [18]. Thus, downtime due to pneumatic failures leads to tangible financial losses.

Reliability metrics such as Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR) are vital in quantifying system performance. [19], [20], [21] provide methods to analyze system reliability using these indices. [22] offer further insights into availability modeling for repairable systems. To determine failure causes and their consequences, this study employs Failure Mode and Effect Analysis (FMEA), which evaluates Severity, Occurrence, and Detection to derive a Risk Priority Number (RPN) [23]. Supporting this, [24], [25], [26] have demonstrated effective integration of FMEA in engineering risk management. In the context of rail-based systems, [27] also analyzed FMEA for braking failures in light vehicles.

This research extends FMEA with a Reliability-Centered Maintenance (RCM) approach to develop a maintenance strategy aligned with critical failure points. [28] describe the importance of integrating RCM into maintenance management to optimize system dependability. Other implementations in transportation and infrastructure systems are highlighted by [29], [30]. Finally, the study applies the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) for evaluating multiple maintenance alternatives. TOPSIS is favored for its ability to balance multiple conflicting criteria in decision-making [31], [32], [33], [34]. This study's novelty lies in its integrative framework combining FMEA, RCM, and TOPSIS within the specific context of pneumatic degradation due to humidity in tropical railway environments. Most previous studies address these methodologies in isolation. Here, they are unified to produce a structured and practical maintenance plan aimed at minimizing failures and extending system life for Rail-Road Loader KGT/V.

## 2. RESEARCH METHOD

### 2.1. Mixed-Methods Framework and Research Site

This study employs a mixed-methods approach that integrates both qualitative and quantitative analyses to evaluate and mitigate failure risks in the pneumatic system of the Rail-Road Loader KGT/V. The research was conducted at the Railway Maintenance Center in Ngrombo, Central Java over a 23-week period from January to July 2025.

### 2.2. Sources of Primary and Secondary Data

Field observations and literature reviews were conducted to understand the system's operational context. Secondary data were sourced from maintenance logs, manuals, and regional humidity records [4]. Primary data were obtained through structured interviews with six experienced operators and technicians selected via purposive sampling [35].

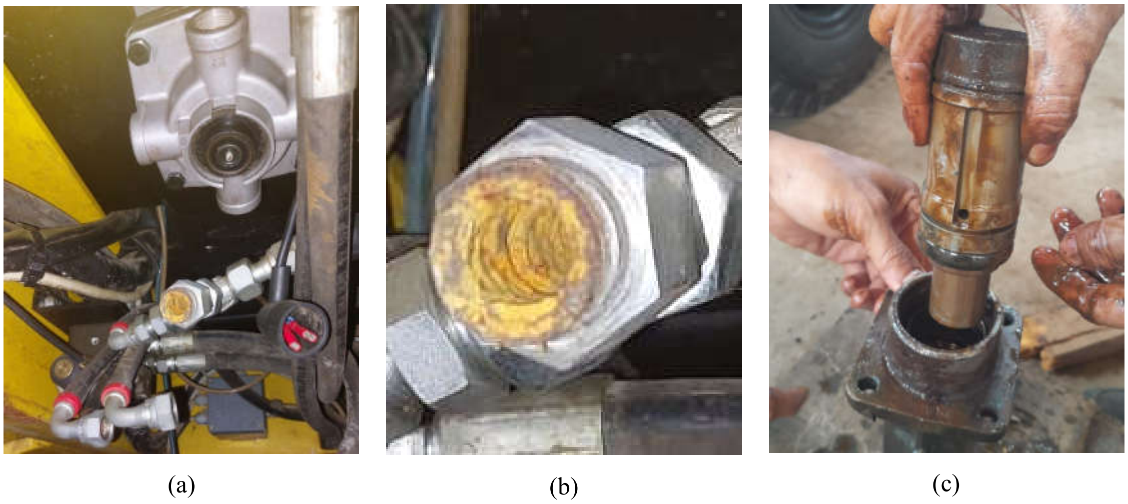
(a) (b) (c)

**Figure 1**. Effects of Condensation in the Pneumatic System,
(a) and (b) Corrosion, (c) Leakage

### 2.3. Statistical Testing for Validity and Reliability

Instrument validation was carried out using SPSS. Validity was confirmed through Principal Component Analysis (PCA) with Varimax Rotation, while reliability was tested using Cronbach's Alpha. Instruments with alpha values greater than 0.7 were considered reliable [36].

**Table 1** Rotated Component Matrix of Principal Component Analysis (PCA) with Varimax Rotation

| **Rotated Component Matrix[a]** | Component | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Braking Problem | .566 | .606 | .027 | -.524 |
| Air Pressure Issue | -.178 | .090 | .839 | -.202 |
| Air Pressure Inspection | .950 | .193 | .067 | .223 |
| Leakage | .177 | .509 | .219 | -.806 |
| Emergency Condition | -.073 | -.219 | .945 | -.185 |
| Routine Inspection | -.014 | -.999 | -.015 | .035 |
| Spare Part Limitation | .150 | .229 | -.130 | .868 |
| Effectiveness of Drain Valve and Condensate Separator | .278 | .535 | .710 | .184 |
| System Reliability | .640 | .625 | .384 | .198 |
| Training | -.628 | -.697 | .307 | -.002 |
| Improveme | -.935 | .018 | .255 | .233 |

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.[a]

a. Rotation converged in 7 iterations.

**Table 2** Component Transformation Matrix of Principal Component Analysis (PCA) with Varimax Rotation

| Component | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | .702 | .696 | .110 | -.105 |
| 2 | -.292 | .097 | .864 | -.399 |
| 3 | -.013 | .085 | .407 | .910 |
| 4 | .650 | -.706 | .277 | -.048 |

**Component Transformation Matrix**

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

**Table 3** – Reliability Statistics Each Component with Cronbach's Alpha

| **Reliability Statistics Component 1** | |
|---|---|
| Cronbach's Alpha | N of Items |
| .833 | 2 |
| **Reliability Statistics Component 2** | |
| Cronbach's Alpha | N of Items |
| .899 | 2 |
| **Reliability Statistics Component 3** | |
| Cronbach's Alpha | N of Items |
| .710 | 5 |

### 2.4. Calculation of MTBF, MTTR, and Availability

Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), system availability (A) is calculated and determined by:

$$MTBF = \frac{Total\ Operating\ Time\ (Uptime)}{Number\ of\ Failures} \quad (1)$$

$$MTTR = \frac{Total\ Downtime}{Number\ of\ Failures} \quad (2)$$

$$Availability\ (A) = \frac{MTBF}{MTBF+MTTR} \quad (3)$$

**Table 4** – Engine Hour of Each Units

| Identity Number | Year | Date | Engine Hour |
|---|---|---|---|
| **SK 3 12 01** | 2022 | 02/02/2022 | 994 |
| | | 30/12/2022 | 1199 |
| | 2023 | 06/02/2023 | 1199 |
| | | 29/12/2023 | 1376,2 |
| | 2024 | 23/01/2024 | 1376,2 |
| | | 31/12/2024 | 1622,1 |
| **SK 3 14 01** | 2022 | 02/02/2022 | 1419,6 |
| | | 30/12/2022 | 1613 |
| | 2023 | 06/02/2023 | 1613 |
| | | 29/12/2023 | 1839 |
| | 2024 | 23/01/2024 | 1839 |
| | | 31/12/2024 | 2024,8 |
| **SK 3 14 02** | 2022 | 07/02/2022 | 762,1 |
| | | 25/11/2022 | 843 |
| | 2023 | 20/02/2023 | 843 |
| | | 29/12/2023 | 1040 |
| | 2024 | 01/04/2024 | 1040 |
| | | 31/12/2024 | 1223,2 |

**Table 5** – Open Item and Downtime of Each Units

| | **SK 3 12 01** | | **SK 3 14 01** | | **SK 3 14 02** | |
|---|---|---|---|---|---|---|
| No | Open Item | Downtime (days) | Open Item | Downtime (days) | Open Item | Downtime (days) |
| 1 | Unstable Air Pressure | 7 | Braking System Less Responsive | 6 | Less Responsive Braking | 4 |
| 2 | Stabilizer Malfunction | 10 | Unstable Air Pressure | 2 | | |
| 3 | Stabilizer Control Valve Leakage | 10 | | | | |
| 4 | Less Responsive Braking | 7 | | | | |
| **Total** | | **34** | | **8** | | **4** |

### 2.5. Identification and Ranking of Failure Modes (FMEA)

The FMEA process in this study includes the following steps:

1. Failure Mode Identification
   Identify various ways in which pneumatic system components can fail, such as pressure drops, damaged seals or valves, and excessive condensation affecting airflow.
2. Failure Cause Determination
   Evaluate the root causes of each failure mode, such as high humidity levels leading to condensation and damage to pneumatic components.
3. Failure Impact Assessment
   Rate each failure mode using Severity (S), Occurrence (O), and Detection (D) scales. These ratings help evaluate the impact of each failure on system performance (e.g., brake response delay or instability).
4. Risk Evaluation and Prioritization
   Calculate the Risk Priority Number (RPN) for each failure mode, each criterion is evaluated on a 1–10 scale, and the Risk Priority Number (RPN) is computed using:

$$RPN = S \times O \times D \tag{4}$$

**Table 6** – Severity Rating Scale

| Ranking | Severity | Description |
|---|---|---|
| **1** | No Effect | The equipment operates normally. |
| **2** | Very Minor Effect | Minor imperfection that does not affect the vehicle's performance. |
| **3** | Minor Effect | Slight disturbance in the pneumatic system with no significant operational impact. |
| **4** | Very Low Effect | Minor system disruption, but the equipment can still function without noticeable performance drop. |
| **5** | Low Effect | Slightly slower brake response or suboptimal stabilizer function. |
| **6** | Moderate Effect | The equipment remains safe to use, but with less responsive braking or inadequate stabilization, affecting operational efficiency. |
| **7** | High Effect | Significant pneumatic system disruption causing inefficient braking or difficulty stabilizing under certain conditions. |
| **8** | Very High Effect | Pneumatic system failure prevents safe operation; immediate repair is required. |
| **9** | Hazardous with Warning | Braking fails partially but provides a warning before total loss of function. |
| **10** | Hazardous without Warning | The equipment cannot be stopped safely and poses a risk of fatal accident. |

**Table 7** – Occurrence Rating Scale

| Ranking | Occurrance | Description |
|---|---|---|
| **1** | Almost Never | Pneumatic system failures almost never occur during the vehicle's operational life. |
| **2** | Rare | Pneumatic disturbances rarely occur and do not affect daily operations. |
| **3** | Very Low | Pneumatic failures are extremely rare and only appear under specific conditions without affecting overall performance. |

| | | |
|---|---|---|
| **4** | Low | Minor pneumatic issues occasionally occur but remain within acceptable limits. |
| **5** | Moderately Low | Issues such as slight air pressure drop or condensation accumulation begin to appear but do not interfere with core operations. |
| **6** | Moderate | Failures occur periodically, such as mild braking disturbances due to unstable air pressure. |
| **7** | Fairly High | Pneumatic system failures happen frequently, requiring more than one repair per year. |
| **8** | High | Serious pneumatic problems occur often and demand immediate attention. |
| **9** | Very High | Failures occur nearly every time the equipment is operated. |
| **10** | Almost Always | Pneumatic system failures are persistent, causing significant downtime and disrupting operations. |

**Table 8** – Detection Rating Scale

| Ranking | Detection | Description |
|---|---|---|
| **1** | Almost Certain | Routine inspections almost always detect pneumatic system failures before they occur. |
| **2** | Very High | Inspections are very likely to identify failure causes before they impact operations. |
| **3** | High | Inspections are likely to identify potential failure causes. |
| **4** | Moderately High | Inspections can still identify the source of disturbances. |
| **5** | Moderate | Inspections are somewhat capable of detecting certain failures. |
| **6** | Low | Causes of failures can only be detected through in-depth inspection and testing of specific components. |
| **7** | Very Low | Regular inspections rarely detect causes; failures are usually noticed after significant disturbances. |
| **8** | Slight | The system inspection occasionally detects failure causes, typically after clear damage symptoms emerge. |
| **9** | Very Slight | Failure detection is very difficult and only occurs after serious problems or degraded brake performance. |
| **10** | Uncertain | Routine inspections fail to detect the cause of failure; it becomes known only after total pneumatic failure occurs without warning. |

5. Corrective Actions

Based on the RPN results, corrective measures are identified to reduce the risk of failure and enhance system reliability, such as component replacement or system redesign.

### 2.6. Maintenance Strategy Development Based on Risk (RCM)

The highest-ranked failure modes from FMEA informed the RCM strategy, which includes selecting appropriate preventive or corrective actions based on failure consequences [28]. The steps of RCM implementation in this study include:

1. System Function Identification
   Defines primary and secondary functions of the pneumatic system, such as braking and stabilization.
2. Functional Failure Identification
   Determines how the system may fail to perform its functions.
3. Failure Mode Identification
   Explains specific causes of failure such as valve corrosion, unstable air pressure, or condensation accumulation.
4. Failure Effects Analysis
   Describes the consequences if failure occurs, ranging from minor operational disruptions to serious accidents.
5. Failure Consequences Analysis
   Assesses the impact on safety, environment, or operations, helping to prioritize actions.
6. Maintenance Task Selection
   Specifies whether preventive, predictive, or routine inspections are required.
7. Task Effectiveness Evaluation
   Assesses if the chosen actions are technically and economically feasible.

8. Documentation and RCM Integration
   Ensures all findings and actions are documented and integrated into maintenance management systems.

### 2.7. Selection of Optimal Maintenance Strategy (TOPSIS)

The TOPSIS method consists of the following steps [31]:

1. Identify Evaluation Criteria and Alternatives
   Define the factors to evaluate and the solution options to compare.
2. Construct the Decision Matrix
   Rate each alternative against each criterion using a scale (e.g., 1–5).
3. Normalize the Decision Matrix
   Adjust the scale using the formula:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^{2}}} \qquad (5)$$

4. Determine Criteria Weights with AHP
5. Use simplified Analytic Hierarchy Process (AHP) to weight the criteria by define objectives and structure, gather expert judgments, normalize and compute final weights.
6. Build the Weighted Matrix

$$v_{ij} = w_j \times r_{ij} \qquad (6)$$

7. Identify Positive and Negative Ideal Solutions, $A^{+}$ (best value for benefit criteria, lowest for cost), and $A^{-}$ (worst value for benefit criteria, highest for cost).
8. Calculate Distance to Ideal Solutions

$$D_i^{+} = \sqrt{\sum_{j=1}^{n} w_j \times \left(v_{ij} - A_j^{+}\right)^{2}} \qquad (7)$$

$$D_i^{-} = \sqrt{\sum_{j=1}^{n} w_j \times \left(v_{ij} - A_j^{-}\right)^{2}} \qquad (8)$$

9. Calculate Closeness Coefficient ($CC_i$)

$$CC_i = \frac{D_i^{-}}{D_i^{+} + D_i^{-}} \qquad (9)$$

10. Rank the Alternatives
    Sort alternatives from highest to lowest $CC_i$. The highest score indicates the optimal solution.

### 2.8. Integration and Impact of the Methodology

This integrated methodological framework ensured a structured, validated, and data-driven approach for improving the reliability and maintainability of the Rail-Road Loader KGT/V pneumatic system.

## 3. RESULTS AND DISCUSSION

This section presents the analytical results of the pneumatic system performance in Rail-Road Loader KGT/V and discusses various maintenance strategies. The analyses include downtime, MTBF, MTTR, availability, FMEA, RCM, and TOPSIS-based decision-making.

### 3.1. Performance Analysis: Downtime and Operational Cost

The performance analysis compared hydraulic and pneumatic systems based on total downtime and repair costs throughout 2024.

**Table 9** – Downtime Summary for Hydraulic and Pneumatic Systems

| System | Total Downtime (days) | Total Downtime Cost (IDR) |
|---|---|---|
| Hydraulic | 27 | 41,850,000 |
| Pneumatic | 46 | 71,300,000 |

The pneumatic system caused more downtime and incurred higher operational costs than the hydraulic system. Thus, this research focuses primarily on mitigating issues in the pneumatic subsystem.

### 3.2. Reliability Assessment: MTBF, MTTR, and Availability

Reliability metrics were calculated to quantify the operational performance of pneumatic components. The Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), and availability for both systems are summarized in Table 10.

**Table 10** – Reliability Metrics for Pneumatic and Hydraulic Systems

| System | MTBF (days) | MTTR (days) | Availability (%) |
|---|---|---|---|
| Hydraulic | 37 | 5 | 88.09% |
| Pneumatic | 53 | 17 | 75.71% |

Although the pneumatic system had a longer MTBF, its availability was significantly lower due to prolonged repair times. Further breakdown by unit reveals that SK 3 12 01 had the poorest reliability.

**Table 11** – Pneumatic System Reliability by Rail-Road Loader KGT/V Unit

| Unit | Downtime (days) | MTBF (days) | MTTR (days) | Availability (%) |
|---|---|---|---|---|
| SK 3 12 01 | 34 | 91.25 | 8.5 | 91.47% |
| SK 3 14 01 | 8 | 182.5 | 4 | 97.85% |
| SK 3 14 02 | 4 | 365 | 4 | 98.91% |

SK 3 14 02 showed the best performance, while SK 3 12 01 had the lowest reliability. This supports prioritizing system improvement actions on the latter.

### 3.3. Failure Modes and Effects Analysis (FMEA)

Failure Mode and Effects Analysis (FMEA) was applied to four key components in the pneumatic braking system: the pneumatic-hydraulic converter, regulating valve, pedal distributor, and priority valve. Severity, occurrence, and detection scores were rated on a scale of 1 to 10, and RPN was computed for each.

**Table 12** – FMEA Scoring of Pneumatic Components

| Components | Severity (S) | Occurrence (O) | Detection (D) | RPN |
|---|---|---|---|---|
| Convertisseur Pneumatique-Hydraulique | 7 | 7 | 6 | 294 |
| Priority Valve | 6 | 6 | 6 | 216 |
| Pedal Distributor | 5 | 5 | 5 | 125 |
| Regulating Valve | 6 | 4 | 4 | 96 |

The Convertisseur Pneumatique–Hydraulique is the most critical component, requiring urgent corrective measures.

### 3.4. Reliability-Centered Maintenance (RCM)

Reliability-Centered Maintenance (RCM) was used to translate FMEA results into actionable maintenance strategies. The proposed actions include:

**Table 13** – RCM Summary

| Action | Description |
|---|---|
| Air Dryer Installation | Selected desiccant-type air dryer expected to reduce failures by 50% and increase energy efficiency by 18% |
| Maintenance Quality Improvement | Routine inspections at 10, 50, and 250-hour intervals targeting the four components |
| Routine Component Replacement | Scheduled seal replacements during brake and stabilizer repairs |

### 3.5. TOPSIS-Based Decision Analysis

To determine the optimal maintenance strategy, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was used. Three alternatives were evaluated (Table 14) against four criteria (effectiveness, cost, ease of implementation, and impact on reliability), each weighted using a simplified AHP method (Table 15).

#### 3.5.1. Identification of Criteria and Alternatives

The evaluation criteria were defined based on literature review, interviews with technical personnel, and RCM results. Four criteria and three alternative solutions were identified:

**Table 14** – Maintenance Alternatives and Decision Matrix

| **Alternative** | **Effectiveness (C1)** | **Cost (C2)** | **Ease (C3)** | **Reliability Impact (C4)** |
|---|---|---|---|---|
| A1 – Air Dryer Installation | 4.67 | 3.67 | 4.42 | 4.67 |
| A2 – Maintenance Quality Improvement | 4.00 | 4.33 | 3.42 | 3.58 |
| A3 – Routine Component Replacement | 3.42 | 4.17 | 3.25 | 3.17 |

**Table 15** – Criteria Weights

| **Criterion** | **Weight** |
|---|---|
| C1 – Effectiveness | 0.272 |
| C2 – Implementation Cost | 0.198 |
| C3 – Ease of Implementation | 0.253 |
| C4 – System Reliability Impact | 0.277 |

The decision matrix was normalized, weighted, and processed to determine the ideal and anti-ideal solutions. Euclidean distances and closeness coefficients ($CC_i$) were then calculated, as shown in Table 16.

**Table 16** – Closeness Coefficients and Ranking

| **Alternative** | **$D^+$** | **$D^-$** | **$CC_i$** | **Rank** |
|---|---|---|---|---|
| **A1** | 0.051 | 0.055 | 0.520 | 1 |
| **A2** | 0.039 | 0.041 | 0.513 | 2 |
| **A3** | 0.057 | 0.059 | 0.509 | 3 |

The highest score was achieved by A1 – Air Dryer Installation (0.520), confirming its position as the closest to the ideal solution. This supports its selection as the most effective and reliable preventive strategy for mitigating humidity-related failures in the pneumatic system.

### 3.6. Summary of Discussion

This integrated analysis using FMEA, RCM, and TOPSIS confirms that the primary reliability issue lies in the pneumatic subsystem, especially the braking unit. Maintenance improvement through desiccant air dryer installation is the most impactful solution. Coupled with enhanced preventive maintenance and routine component renewal, this approach is expected to increase availability and reduce operational disruptions in the Rail-Road Loader KGT/V pneumatic system.

## 4. CONCLUSION

This study concluded that the pneumatic system of the Rail-Road Loader KGT/V at the Balai Perawatan Perkeretaapian Ngrombo experienced higher downtime and maintenance costs than the hydraulic system, with Unit SK 3 12 01 showing the lowest availability. FMEA analysis identified critical components such as the Pneumatic-Hydraulic Converter and moisture-induced failures as key issues. Through the application of Reliability-Centered Maintenance (RCM), a set of preventive strategies was proposed, including periodic inspection, component replacement, and air dryer installation. The TOPSIS method ranked air dryer installation as the most effective solution ($CC_i = 0.520$), followed closely by maintenance quality improvement and routine component replacement. These findings are consistent with the research objectives outlined in the Introduction, validating the analytical framework of integrating FMEA, RCM, and TOPSIS. Future research should evaluate the post-implementation impact on reliability metrics, explore cost-benefit outcomes, and extend this approach to other subsystems in railway maintenance to support more efficient asset management.

## ACKNOWLEDGEMENTS

The author gratefully acknowledges the invaluable support provided by the Railway Maintenance Center (Balai Perawatan Perkeretaapian Ngrombo), whose operational data and technical expertise significantly contributed to the success of this research. Sincere appreciation is extended to all engineers, operators, and maintenance personnel who participated in interviews and shared their field insights.

The author would also like to thank the academic supervisors and examiners at the Politeknik Transportasi Darat Indonesia-STTD for their guidance, critical feedback, and continuous encouragement throughout the research process.

Finally, heartfelt thanks are due to family and peers for their unwavering moral support during the completion of this work.

## REFERENCES

[1] Geismar, *GEISMAR RAIL-ROAD LOADER KGT/V USE AND MAINTENANCE HANDBOOK SERIAL NUMBER: 4811 - 4813*. 2014.

[2] E. Silitonga, H. B. Woesono, and D. S. Hadi, “Pengaruh Umur Alat terhadap Produktivitas Excavator pada Kegiatan Debarking di PT.TPL,” *Agroforetech*, vol. 3, pp. 543–549, Mar. 2025, Accessed: Jun. 02, 2025. [Online]. Available: https://jurnal.instiperjogja.ac.id/index.php/JOM/article/view/1873

[3] H. Sholih, J. Syurdiansyah, A. Saepudin, and W. Arso, “Analisis Kerusakan Pneumatic Caterpillar Untuk Meningkatkan Availability Performance Mesin Extruder Type 150 Caterpillar Pneumatic Damage Analysis To Improve Availability Performance Of Type 150 Extruder Engines,” *JMEMME*, vol. 6, no. 01, 2022, doi: 10.31289/jmemme.v6i1.6770.

[4] Badan Meteorologi Klimatologi dan Geofisika, “Rata-Rata Suhu Udara, Kelembaban, Tekanan Udara, Kecepatan Angin, Curah Hujan, dan Penyinaran Matahari Menurut Stasiun.”

[5] T. Kagawa, M. Cai, and H. Kameya, “OVERALL EFFICIENCY CONSIDERATION OF PNEUMATIC SYSTEMS INCLUDING COMPRESSOR, DRYER, PIPE AND ACTUATOR,” 2002.

[6] M. Jeřábek, M. Volf, and L. Richter, “Air Drying in an Industrial Compressor,” *MATEC Web of Conferences*, vol. 367, p. 00014, 2022, doi: 10.1051/matecconf/202236700014.

[7] Z. Xu, “Common faults and solutions of air brake system,” SPIE-Intl Soc Optical Eng, Sep. 2023, p. 74. doi: 10.1117/12.2689370.

[8] S. Xu, G. Wu, F. Liu, and X. Yang, “Influence of brake chamber pressure and effective cross-sectional area on time delay of pneumatic braking system,” in *Journal of Physics: Conference Series*, Institute of Physics, 2022. doi: 10.1088/1742-6596/2383/1/012150.

[9] R. Conklin and B. Hudgins, “Electronic Compressor and Air Dryer Control,” 1999.

[10] D. Gryboś and J. S. Leszczyński, “A Review of Energy Overconsumption Reduction Methods in the Utilization Stage in Compressed Air Systems,” Mar. 01, 2024, *Multidisciplinary Digital Publishing Institute (MDPI)*. doi: 10.3390/en17061495.

[11] Donaldson, “COMPRESSED AIR AND PROCESS FILTRATION,” 2022.

[12] Wabco, “PRODUCT CATALOGUE,” 2020. [Online]. Available: www.wabco-customercentre.com

[13] Y. Shi, M. Cai, W. Xu, and Y. Wang, “Methods to Evaluate and Measure Power of Pneumatic System and Their Applications,” *Chinese Journal of Mechanical Engineering (English Edition)*, vol. 32, no. 1, Dec. 2019, doi: 10.1186/s10033-019-0354-6.

[14] K. Matusiak, D. Goliwąs, and M. Kaluba, “Adsorption dryer for use in railways,” *Rail Vehicles/Pojazdy Szynowe*, no. 1–2, pp. 77–85, Aug. 2022, doi: 10.53502/rail-152486.

[15] O. Liaposhchenko, D. Bondar, M. Ochowiak, I. Pavlenko, and S. Włodarczak, “Modeling of Separation with Drying Processes for Compressed Air Using an Experimental Setup with Separation–Condensation and Throttling Devices,” *Energies* , vol. 17, no. 13, Jul. 2024, doi: 10.3390/en17133129.

[16] Govindarasu Anbarasu, T Sukumar, and Subramanian Vivek, “Failure Strength Optimization of a Cartridge Assembly Using Numerical and Experimental Analysis,” in *International Automotive CAE Conference – Road to Virtual World*, SAE International, Oct. 2024. doi: https://doi.org/10.4271/2024-28-0010.

[17] Pemerintah Republik Indonesia, “Peraturan Pemerintah Republik Indonesia Nomor 15 Tahun 2016 tentang Jenis dan Tarif atas Jenis Penerimaan Negara Bukan Pajak yang Berlaku pada Kementerian Perhubungan,” 2016.

[18] Menteri Perhubungan Republik Indonesia, “Peraturan Menteri Perhubungan Republik Indonesia Nomor PM 50 Tahun 2017 tentang Pedoman Penyusunan Peta Proses Bisnis dan Standar Operasional Prosedur di Lingkungan Kementerian Perhubungan,” 2017.

[19] P. Alavian, Y. Eun, K. Liu, S. M. Meerkov, and L. Zhang, “The (α, β)-Precise Estimates of MTBF and MTTR: Definition, Calculation, and Observation Time,” *IEEE Transactions on Automation Science and Engineering*, vol. 18, no. 3, pp. 1469–1477, Jul. 2021, doi: 10.1109/TASE.2020.3017134.

[20] S. V. Amari, “Bounds on MTBF of systems subjected to periodic maintenance,” *IEEE Trans Reliab*, vol. 55, no. 3, pp. 469–474, Sep. 2006, doi: 10.1109/TR.2006.879645.

[21] G. K. Inyiama and S. A. Oke, “Maintenance downtime evaluation in a process bottling plant,” *International Journal of Quality and Reliability Management*, vol. 38, no. 1, pp. 229–248, Jan. 2021, doi: 10.1108/IJQRM-12-2018-0340.

[22] A. Der Kiureghian, O. D. Ditlevsen, and J. Song, “Availability, reliability and downtime of systems with repairable components,” *Reliab Eng Syst Saf*, vol. 92, no. 2, pp. 231–242, Feb. 2007, doi: 10.1016/j.ress.2005.12.003.

[23] M. Ahmadi, S. Mohammad Hadji Molana, and S. Mojtaba Sajadi, “A hybrid FMEA-TOPSIS method for risk management, case study: Esfahan Mobarakeh Steel Company,” 2017.

[24] K. H. Chang, Y. C. Chang, and Y. T. Lee, “Integrating TOPSIS and DEMATEL methods to rank the risk of failure of FMEA,” *Int J Inf Technol Decis Mak*, vol. 13, no. 6, pp. 1229–1257, Nov. 2014, doi: 10.1142/S0219622014500758.

[25] J. Cho and M. Chae, “Systematic Approach of TOPSIS Decision-Making for Construction Method Based on Risk Reduction Feedback of Extended QFD-FMEA,” *Math Probl Eng*, vol. 2022, 2022, doi: 10.1155/2022/1458599.

[26] F. Sharifi, M. A. Vahdatzad, B. Barghi, and N. Azadeh-Fard, “Identifying and ranking risks using combined FMEA-TOPSIS method for new product development in the dairy industry and offering mitigation strategies: case study of Ramak Company,” *International Journal of System Assurance Engineering and Management*, vol. 13, no. 5, pp. 2790–2807, Oct. 2022, doi: 10.1007/s13198-022-01672-8.

[27] M. Sabri and M. R. Putra, “Analisa Kegagalan pada Sistem Rem Daihatsu Taft Hiline dengan Menggunakan Metode FMEA (Failure Mode and Effect Analysis),” *Talenta Conference Series: Energy and Engineering (EE)*, vol. 1, no. 2, pp. 181–190, Dec. 2018, doi: 10.32734/ee.v1i2.248.

[28] R. de Q. Souza and A. J. Álvares, “FMEA AND FTA ANALYSIS FOR APPLICATION OF THE RELIABILITY-CENTERED MAINTENANCE METHODOLOGY: CASE STUDY ON HYDRAULIC TURBINES,” 2015.

[29] A. Carazo, “Application of RCM and FMEA Methodology to Improve Industrial Maintenance Management: A Case Study of Fibers for Mattresses,” *Industrial Engineering Letters*, Jan. 2022, doi: 10.7176/iel/12-1-04.

[30] Z. Mian, S. Jia, X. Shi, C. Tang, J. Chen, and Y. Gao, “A Model-based RCM Analysis Method,” in *Proceedings - Companion of the 2020 IEEE 20th International Conference on Software Quality, Reliability, and Security, QRS-C 2020*, Institute of Electrical and Electronics Engineers Inc., Dec. 2020, pp. 301–307. doi: 10.1109/QRS-C51114.2020.00059.

[31] S. Chakraborty, “TOPSIS and Modified TOPSIS: A comparative analysis,” *Decision Analytics Journal*, vol. 2, p. 100021, Mar. 2022, doi: 10.1016/j.dajour.2021.100021.

[32] R. D. F. S. M. Russo and R. Camanho, “Criteria in AHP: A systematic review of literature,” in *Procedia Computer Science*, Elsevier B.V., 2015, pp. 1123–1132. doi: 10.1016/j.procs.2015.07.081.

[33] B. Zhou, J. Chen, Q. Wu, D. Pamučar, W. Wang, and L. Zhou, “RISK PRIORITY EVALUATION OF POWER TRANSFORMER PARTS BASED ON HYBRID FMEA FRAMEWORK UNDER HESITANT FUZZY ENVIRONMENT,” *Facta Universitatis, Series: Mechanical Engineering*, vol. 20, no. 2, pp. 399–420, Aug. 2022, doi: 10.22190/FUME220223013Z.

[34] F. Sharifi, M. A. Vahdatzad, B. Barghi, and N. Azadeh-Fard, “Identifying and ranking risks using combined FMEA-TOPSIS method for new product development in the dairy industry and offering mitigation strategies: case study of Ramak Company,” *International Journal of System Assurance Engineering and Management*, vol. 13, no. 5, pp. 2790–2807, Oct. 2022, doi: 10.1007/s13198-022-01672-8.

[35] R. S. Robinson, “Purposive Sampling,” in *Encyclopedia of Quality of Life and Well-Being Research*, F. Maggino, Ed., Cham: Springer International Publishing, 2023, pp. 5645–5647. doi: 10.1007/978-3-031-17299-1_2337.

[36] W. Budi Prasetyo, “RELIABILITAS DAN VALIDITAS KONSTRUK SKALA KONSEP DIRI UNTUK MAHASISWA INDONESIA,” *Jurnal Psikologi Universitas Diponegoro*, vol. 3, Jun. 2006, doi: https://doi.org/10.14710/jpu.3.1.1%20-%209.