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Evaluation of Vehicle Component Maintenance and Care Strategy using The Reliability Centered Maintenance Method

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ABSTRACT

This study aims to evaluate the vehicle maintenance strategy at PT XYZ, an intercity bus operator (AKAP) managing a mixed fleet consisting of Hino RK, Hino RM, and Mercedes-Benz units, and to develop an optimized preventive maintenance schedule for critical wheel system components. A quantitative descriptive approach was applied using historical failure data from January 2024 to December 2025 which recorded 1,299 incidents. The Reliability Centered Maintenance (RCM) method was employed by integrating Pareto analysis for critical system identification, Failure Mode and Effects Analysis (FMEA) for risk prioritization, Logic Tree Analysis (LTA) for failure classification, and Mean Time Between Failure (MTBF) calculation to determine maintenance intervals. The wheel system was identified as the most critical system with a contribution of 403 failures or 31.02 percent. FMEA revealed that the Hino RK fleet carries the highest risk, with bearing and wheel hub reaching maximum RPN values of 512 and 504 respectively. Five components were classified as Safety Problems (Category A) and the wheel seal as a Hidden Failure (Category D). MTBF based intervals range from 59 days for the RK fleet tire to 2,693 days for the RK fleet rim, with tire inspection being the most frequent maintenance requirement across all fleet types. Implementation of an RCM based preventive maintenance regime using a Condition Directed (CD) strategy for five detectable components and a Time Directed (TD) strategy for the wheel seal offers a structured transition from the existing reactive system. The findings provide fleet specific maintenance schedules and cost estimates that support reduced unplanned downtime, improved safety compliance, and optimized maintenance expenditure for AKAP bus operators.

Keywords: *Bus Maintenance, FMEA, Logic Tree Analysis, MTBF, Reliability Centered Maintenance*

Introduction

Intercity buses form a critical backbone of land transportation in Indonesia, connecting major urban centers while operating under high-frequency schedules that impose considerable mechanical stress on vehicle components [1], [2], [3]. Critical systems, including braking mechanisms, tires, suspension assemblies, steering systems, and power transmission, are particularly vulnerable to progressive degradation when not maintained proactively [4]. Government Regulation No. 55 of 2012 mandates roadworthiness compliance across ten structural systems, establishing a legal and safety imperative for proactive fleet maintenance [5]. Failure to comply poses life-threatening risks to passengers, especially on long-distance routes where mechanical failures have limited opportunity for early detection [6], [7].

Official investigations confirm deferred maintenance as a direct contributor to bus accident fatalities. KNKT's investigation of the 2024 Subang bus accident identified brake booster valve leakage and an expired roadworthiness certificate as causes of 11 fatalities [8], and a 2022 Mojokerto Hino bus crash was similarly attributed to deferred brake maintenance [9]. These cases reflect broader evidence that mechanical failures from insufficient maintenance contribute significantly to bus accident severity [7], [10], reinforcing the need for structured preventive maintenance programs.

PT XYZ operates 17 AKAP bus units on the Surabaya–Jakarta–Bandung corridor. Its maintenance is predominantly reactive, with repairs initiated only upon driver-reported failures, resulting in 17 sudden on-road breakdowns (September 2024–December 2025). Reactive maintenance increases emergency procurement costs [11], causes unplanned downtime, and threatens passenger safety. Facilities implementing preventive maintenance experience up to 48.5% lower unplanned downtime [12], [13].

To address these challenges, this study applies Reliability Centered Maintenance (RCM), a structured methodology that integrates functional analysis, failure mode identification, and consequence assessment [14], [15], demonstrated to improve fleet effectiveness by up to 30% [16]. MTBF analysis quantifies failure intervals and establishes optimal preventive schedules [17], [18], combining Pareto analysis, FMEA, LTA, and MTBF into a unified safety-oriented framework.

Prior RCM studies have focused predominantly on heavy equipment, industrial machinery, and freight vehicle [19], [20], [21], [22], [23]. Three critical gaps remain: (1) RCM applications to public passenger buses are scarce [24]; (2) maintenance interval studies rarely link failure modes to safety consequences [25]; and (3) no existing study applies RCM to a mixed-fleet AKAP operator with heterogeneous vehicle types [26]. This study addresses all three gaps by integrating FMEA, LTA, MTBF, and cost analysis within a unified RCM framework.

This study aims to identify critical components through RCM-FMEA-LTA integration and develop optimized maintenance schedules using MTBF. Its threefold contribution is: (1) demonstrating RCM applicability in a public passenger bus context with safety consequence assessment; (2) integrating FMEA, LTA, MTBF, and cost analysis into a unified framework; and (3) providing fleet-specific maintenance strategies for a mixed-fleet AKAP operator, not previously demonstrated in Indonesian transport literature.

Research Methods

This study employs a quantitative descriptive approach to evaluate vehicle maintenance performance based on historical failure and maintenance data [27]. The research was conducted at the operational pool of PT XYZ, located in Sidoarjo, East Java, which serves as the main center for fleet operations, inspection, and maintenance activities. The observation period covered January 2024 to December 2025.

The population of this study consists of all bus units operated by the company, totaling 17 units. These vehicles include three types, namely Hino RK, Hino RM, and Mercedes-Benz, which have different operational characteristics and maintenance histories. Due to the relatively small population size, a total sampling technique was applied, in which all units were included as research samples to ensure comprehensive analysis.

Data were collected through three techniques: observation of maintenance practices, semi-structured interviews with mechanics to determine component functions, failure modes, causes, safety impacts, and detection methods (informing FMEA S, O, D values) [28], [29]. S, O, and D scores were assigned by all 17 bus drivers who directly operate the vehicles on a daily basis and have firsthand experience with component failure symptoms during operation. Each driver independently completed FMEA scoring sheets based on their operational experience with their respective vehicle units, namely Hino RK, Hino RM, and Mercedes-Benz. The highest RPN value per component was selected as the representative score for each fleet type to ensure that the most critical risk level is captured in the analysis. Discrepancies greater than two points among drivers were resolved through structured consensus facilitated by the lead researcher. This procedure reduces subjective bias, consistent with Liu and Tang (2022) [30], [31]. Documentation was used to collect secondary data including maintenance records, repair history, spare part replacement data, and operational reports.

Data analysis combined RCM, MTBF, and maintenance cost analysis, as shown in Figure 1(a).

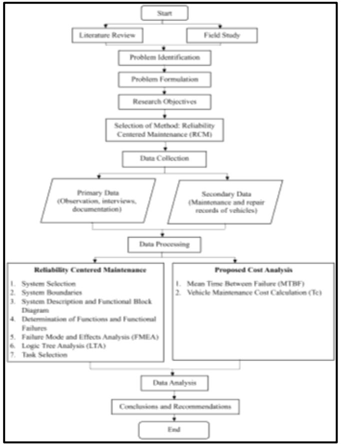

Figure 1. (a) Research Flowchart

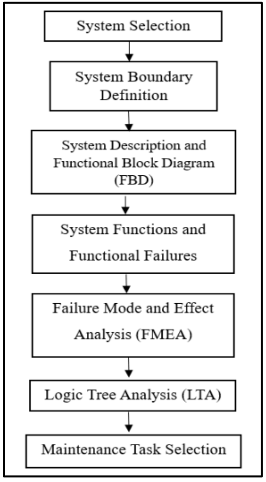

Figure 2. (b) RCM Sequential Analysis Procedure

Data Preprocessing and Reliability

Prior to analysis, all 1,299 failure records were preprocessed through four steps: (1) completeness screening to exclude records missing failure date, vehicle unit, system, or component; (2) component name standardization to resolve naming inconsistencies and prevent double-counting; (3) verification of anomalous entries with responsible mechanics; and (4) classification of all validated records by vehicle system under the ten-system structure of Government Regulation No. 55 of 2012. The resulting dataset provides the foundation for FMEA scoring, MTBF calculation, and cost estimation.

All analyses were conducted separately per fleet type to enable risk comparison. The Hino RK fleet operates on the full Surabaya–Jakarta corridor at 12.18 hrs/day, compared to 11.90 hrs (RM) and 12.56 hrs (Mercedes-Benz). These operational profiles, combined with differences in load capacity and vehicle age, contextualize fleet-specific variations in failure frequency and RPN values.

Integrated Analytical Framework

The analytical framework is structured as a sequential and interdependent pipeline. Pareto analysis identifies critical systems and defines the analysis scope, followed by FMEA to evaluate failure risks and prioritize components based on RPN. The FMEA results serve as input for Logic Tree Analysis (LTA) to classify failure modes according to safety and operational consequences. Subsequently, MTBF analysis determines optimal maintenance intervals, and cost analysis assesses the economic feasibility of the proposed strategy.

This integrated framework provides a comprehensive decision-support system by combining risk assessment, reliability evaluation, and economic analysis, offering advantages over standalone RCM applications.

Reliability Centered Maintenance (RCM) Procedure

The RCM analysis consists of several stages, as illustrated in Figure 1(b). System selection was carried out using Pareto analysis on classified failure data. System boundaries were defined to prevent scope overlap, and Functional Block Diagrams (FBD) were developed to illustrate component relationships [32], [33].

Function and functional failure analysis identified each component's main functions and potential failures. FMEA evaluated failure risks using Severity (S), Occurrence (O), and Detection (D) scores adapted from Nurfarizi et al. [34], adjusted to the AKAP bus operational context (Table 1).

Table 1. FMEA Scoring Scales for Severity, Occurrence, and Detection

Score	Severity	Occurrence	Detection
1	No effect	Never observed	Clearly detectable
2	Very minor – Unnoticed by worker	> 12 months	Very high detection
3	Minor – Noticed but no significant impact	10 – 12 months	High detection
4	Very low – Function change, most workers aware	8 – 9 months	Moderately high detection
5	Low – Reduced comfort in function use	6 – 7 months	Moderate detection
6	Moderate – Loss of comfort in function use	4 – 5 months	Low detection
7	High – Degraded primary function	3 months	Very low detection
8	Very high – Primary function lost with warning	2 months	Very low and difficult to detect
9	Hazardous with warning – Primary function failure with aler	1 month	Very low and very difficult to detect
10	Hazardous without warning – Complete failure	< 1 month	Cannot be detected

The Risk Priority Number (RPN) is calculated using:

$$RPN = S \times O \times D \qquad (1)$$

RPN values were classified into three categories following Zakaria et al. [35]: High (501–1,000), Medium (251–500), and Low (1–250), calibrated to the 10-point S×O×D scale. LTA was applied to classify failure modes using three sequential criteria: Evident, Safety, and Outage (Table 2). Maintenance strategies were then assigned as TD, CD, or FF.

Table 2. Logic Tree Analysis Decision Logic for Failure Classification

Evident	Safety	Outage	Category	Description
No	-	-	D	Hidden Failure: failure is not observable during normal operation
Yes	Yes	-	A	Safety Problem: failure has direct consequences on passenger or road safety
Yes	No	Yes	B	Outage Problem: failure causes complete operational stoppage and significant economic loss
Yes	No	No	C	Economic Problem: failure causes minor or insignificant economic loss only

To determine maintenance intervals, Mean Time Between Failure (MTBF) was calculated as:

$$MTBF = \frac{Total\ Operating\ Time}{Number\ of\ Failures} \tag{2}$$

Total operating time was defined as cumulative operational hours per vehicle from company logs. MTBF was selected for its suitability to systems with relatively stable failure rates.

Finally, maintenance cost analysis was conducted using:

$$T_c = (C_m + C_r) \times F_m \tag{3}$$

Where T_c is the total maintenance cost, C_m the spare part procurement cost, C_r the mechanic labor cost, and F_m the frequency of failure mode occurrence; this analysis enables comparison between reactive maintenance costs and proposed preventive maintenance strategies, although it is based on historical data and expert judgment, which may introduce inherent limitations despite efforts to ensure data reliability and scoring consistency.

Results and Discussion

The maintenance system at PT XYZ follows a structured procedure but remains predominantly reactive, as maintenance is typically initiated after driver-reported failures rather than systematic inspections, causing early signs of component degradation to be overlooked and increasing the risk of unexpected breakdowns and operational disruptions. Routine activities such as engine oil and filter replacement are performed periodically, but maintenance of other critical components is not systematically scheduled and is mostly conducted after failure, indicating that the current strategy is not fully aligned with preventive maintenance principles and reduces overall system reliability.

Failure Data Analysis and Critical System Identification

Based on the recapitulation of failure data, a total of 1,299 failure incidents were recorded during the observation period. As shown in Figure 2, the wheel system contributed the highest number of failures with 403 incidents or 31.02 percent. The engine system ranked second with 30.18 percent, followed by the braking system with 17.47 percent.

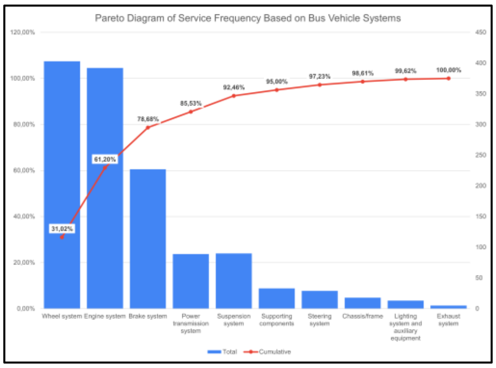

Figure 3. Pareto Diagram of Service Frequency Based on Bus Vehicle Systems

The Pareto analysis indicates that the wheel system is the most critical system due to its dominant contribution to total failures. Therefore, this study focuses on the wheel system as the primary object of RCM analysis. This finding is consistent with the operational characteristics of buses, where wheel-related components are continuously subjected to dynamic loads, road conditions, and environmental exposure.

Functional Analysis of Wheel System

The wheel system comprises interconnected components: hub, bearing, seal, rim, bolts and nuts, and tires, each essential for stability, load distribution, and traction. The Functional Block Diagram (FBD) shows the hub as the central element transmitting rotational energy, the bearing reducing friction and supporting load, seals preventing contamination, and tires providing road traction. Failure of any component can significantly impact vehicle performance and safety, indicating a high level of interdependency within the system.

Table 3. Wheel System Component Functions and Functional Failures

Component	Function	Functional Failure
Wheel Hub	Distributes rotational energy	Cracked/loose → instability
Bearing	Supports load & rotation	Worn/loose/seized
Wheel Seal	Retains lubricant & blocks contaminants	Leakage → bearing damage
Rim (Velg)	Transfers load to tire	Bent/cracked → vibration
Wheel Bolts & Nuts	Secures hub–rim connection	Loose/broken → detachment risk
Tire (Ban)	Provides traction & stability	Punctured/worn → loss of control

Failure Mode and Effects Analysis (FMEA)

Table 4 presents a comparative summary of the maximum RPN values across the three fleet types for each wheel system component, derived from FMEA scoring sheets completed by all 17 bus drivers based on their firsthand operational experience. The highest RPN value per component was selected as the representative score for each fleet type to ensure the most critical risk level is captured in the analysis. This consolidated view enables cross-fleet risk benchmarking and highlights which vehicle type poses the greatest maintenance risk for each component.

Table 4. Comparative Maximum RPN Analysis Across Fleet Types

Component	RM Max RPN	RK Max RPN	Mercedes Max RPN	Highest Risk Level
Wheel Hub	252	504	336	High (RK)
Bearing	84	512	180	High (RK)
Wheel Seal	200	450	150	Medium
Rim (Velg)	10	300	80	Medium
Bolts & Nuts	192	140	378	Medium
Tire	360	450	280	Medium

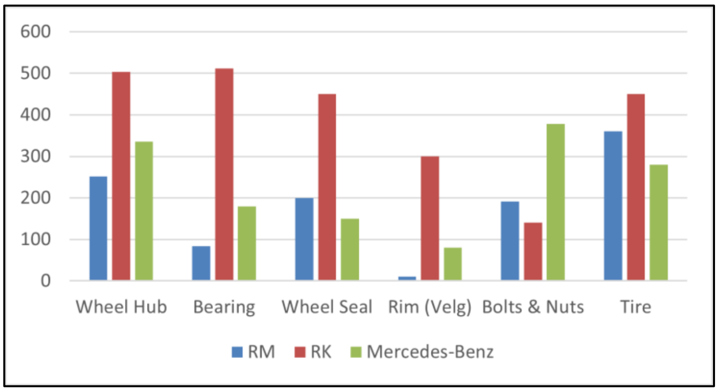

Figure 4. Comparative Analysis of Maximum RPN Values by Fleet Type

The Hino RK fleet exhibits the highest risk profile, with the wheel hub (RPN 504) and bearing (RPN 512—the highest across all components) classified as high risk due to high occurrence and low detectability, driven by intensive operation on the full Surabaya–Jakarta corridor, longer operating time (12.18 hours/day), heavier loads, and greater thermal stress, which increase Severity and Occurrence, as also reflected in the bolt-and-nut interval gap (207 vs. 2,087 days). The tire shows consistently high (medium-risk) RPN across all fleets (RM 360, RK 450, Mercedes-Benz 280) due to universal exposure to road variability, load fluctuations, and pressure management. The Mercedes-Benz fleet records moderate hub risk (RPN 336) but the highest bolt-and-nut RPN (378), indicating a fleet-specific vulnerability in fastener management. Wheel seal and rim risks are generally lower, although the RK seal (RPN 450) remains critical as a hidden failure not easily detected during operation. Overall, the results confirm that the RK fleet requires the most intensive maintenance, particularly for bearing and hub, while tires require the most frequent monitoring across all fleets due to their high risk and shortest MTBF interval.

These findings are consistent with Sugianto et al. (2025) [24] and da Silva et al. (2023) [25], confirming the criticality of wheel components and the advantage of integrating risk-based maintenance with RCM. Unlike previous RCM studies [19], [20], [21], [22], [23], this study shows that LTA-based safety classification leads to different maintenance decisions, particularly the Time Directed strategy for the wheel seal that would not emerge from RPN alone. Furthermore, Wang et al. (2023) [36] support the fleet-differentiated approach, demonstrating that heterogeneous systems require fleet-specific maintenance policies, highlighting the limitations of uniform scheduling in mixed-fleet AKAP operations.

Logic Tree Analysis (LTA)

LTA was applied uniformly across all three fleet types, as the results were consistent [37]. Table 5 presents the LTA results for the wheel system components.

Table 5. Logic Tree Analysis – Wheel System Components

Component	Failure Mode	Cause (Key Factors)	Category
Wheel Hub	Crack / wear / loose bolts	Overload, rough road, torque issue	A (Safety Problem)
Bearing	Wear / loosen / seizure	Lubrication failure, contamination	A (Safety Problem)
Wheel Seal	Tear / brittle	Aging, installation error	D (Hidden Failure)
Rim (Velg)	Bent / crack / corrosion	Road impact, overload	A (Safety Problem)
Bolts & Nuts	Loose / wear / break	Improper torque, poor inspection	A (Safety Problem)
Tire (Ban)	Puncture / burst / uneven	Pressure error, overload, road damage	A (Safety Problem)

Five components namely wheel hub, bearing, rim, bolts and nuts, and tire are classified as Category A which means Safety Problem. These components show evident failure symptoms such as vibration, abnormal noise, and wheel wobble. These components also have direct safety consequences including the risk of wheel detachment and vehicle instability, and have the potential to cause operational outage. Although the bearing falls under Category A, this component primarily manifests safety risks such as overheating and seizure before causing a complete operational stoppage.

The wheel seal is classified as Category D which means Hidden Failure. Unlike other components, seal deterioration in the form of gradual hardening and micro cracking does not produce immediately observable symptoms during normal vehicle operation. Grease leakage may occur without operator awareness, progressively degrading bearing lubrication until bearing failure becomes evident. This hidden nature necessitates a time-based replacement strategy rather than condition monitoring.

Maintenance Task Selection

Based on the LTA classification, maintenance tasks were selected using a six-question decision logic framework, as illustrated in Figure 4. The framework sequentially evaluates the applicability of Time Directed (TD), Condition Directed (CD), and Failure Finding (FF) actions based on failure characteristics and effectiveness. The final selected task is confirmed for effectiveness before assignment. The results of this selection are presented in Table 6.

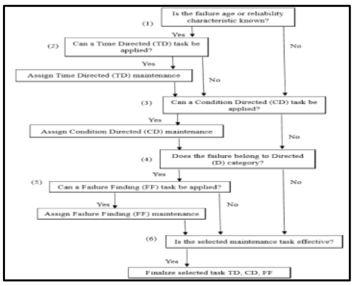

Figure 5. Decision Logic Framework for Maintenance Task Selection

Table 6. Maintenance Task Selection – Wheel System Components

Component	Failure Mode	Q1	Q2	Q3	Q4	Q5	Q6	Selected Action
Wheel Hub	Cracked/worn/loose bolts	Y	N	Y	N	N	Y	CD
Bearing	Worn, loose, or seized	Y	N	Y	N	N	Y	CD
Wheel Seal	Torn or brittle	Y	Y	N	N	N	Y	TD
Bolts & Nuts	Loose, worn, or broken	Y	N	Y	N	N	Y	CD
Rim (Velg)	Bent, cracked, corroded	Y	N	Y	N	N	Y	CD
Tire (Ban)	Punctured/burst/uneven	Y	N	Y	N	N	Y	CD

Condition Directed (CD) maintenance is applied to wheel hubs, bearings, rims, bolts and nuts, and tires, as their failures can be detected through observable symptoms, enabling condition-based intervention for improved efficiency and safety. In contrast, Time Directed (TD) maintenance is assigned to the wheel seal due to its hidden failure nature, requiring scheduled replacement based on MTBF to prevent undetectable degradation and subsequent bearing damage.

MTBF-Based Maintenance Interval Calculation

MTBF values were calculated from total operational hours and failure counts for each component and fleet, then converted into days using fleet-specific averages, with the results and corresponding maintenance actions presented in Table 7.

Table 7. MTBF for Critical Components

Component	RK (days)	RM (days)	Mercedes (days)	Type
Wheel Hub	-	-	-	CD
Bearing	299	696	366	CD
Wheel Seal	269	348	209	TD
Bolts & Nuts	207	2,087	1,462	CD
Rim	2,693	2,087	–	CD
Tire	59	65	77	CD

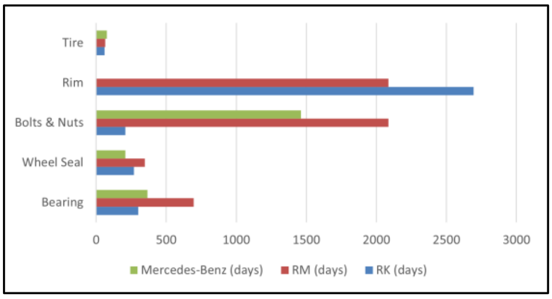

Figure 6. MTBF-based maintenance intervals per component per fleet type (log scale). Mercedes-Benz rim is excluded due to zero recorded failures during the observation period

The tire records the shortest interval across all fleets (RK: 59 days, RM: 65 days, Mercedes: 77 days), confirming it as the most frequently maintained component due to continuous road contact and load variation. The wheel seal receives TD replacement at 269 days (RK), 348 days (RM), and 209 days (Mercedes-Benz); the shorter Mercedes interval reflects 7 recorded failures over 18,365 operational hours, possibly linked to sealing material differences. Bearing intervals range from 299 days (RK) to 696 days (RM), with the longer RM interval reflecting lower load severity. Bolts and nuts show the widest variation (RK: 207 days vs. RM: 2,087 days), consistent with FMEA findings. Rim intervals are long (RK: 2,693 days; RM: 2,087 days), with no Mercedes-Benz rim failures recorded. The wheel hub recorded zero failures (undefined MTBF), but routine CD inspection remains mandatory given its Category A classification.

A sensitivity analysis with a 20% increase in failure frequency reduces the RK tire interval from 59 to ~49 days, bearing from 299 to ~249 days, and bolts and nuts from 207 to ~173 days, indicating moderate sensitivity to operational conditions. Therefore, annual re-evaluation of maintenance intervals is recommended, particularly with changes in route or load conditions.

Maintenance Cost Estimation

Table 8 presents the total maintenance cost per failure event per fleet type, calculated using $Tc = (Cm + Cr) \times Fm$ with $Fm = 1$ as the cost comparison baseline.

Table 8. Total Maintenance Cost per Fleet

Fleet Type	Total Cost per Failure (IDR)
Hino RK	Rp 13,310,000
Hino RM	Rp 16,145,000
Mercedes-Benz	Rp 21,461,000

The Mercedes-Benz fleet incurs the highest per-event cost (Rp21,461,000), driven by higher spare parts prices (wheel hub: Rp4,550,000–5,885,000 vs. Rp870,000–1,240,000 for RK). The RM fleet records Rp16,145,000 and the RK fleet the lowest at Rp13,310,000. For the RK fleet, increased inspection frequency is economically justified given its high-risk profile and low per-event cost. The Mercedes-Benz fleet's higher cost necessitates selective condition-based replacement, prioritizing safety-critical components (Category A) over economic ones. This trade-off underscores that maintenance frequency decisions should be driven by LTA category rather than cost alone. Tires (Rp4,350,000) and rims (Rp4,102,000–4,406,000) are the largest individual cost items, making tire pressure management the most impactful cost control lever.

The recorded 17 sudden breakdown incidents between September 2024 and December 2025 represent reactive maintenance costs that extend beyond spare part replacement, encompassing emergency labor, unplanned downtime, and potential service cancellation penalties. Based on established benchmarks, facilities implementing preventive maintenance strategies experience unplanned downtime up to 48.5% lower than reactive approaches [12]. To quantify this projection more concretely, Table 9 presents a two-year cost comparison between the reactive maintenance expenditure and the proposed preventive maintenance schedule across all fleet types.

Table 9. Two-Years Cost Comparison: Reactive vs Preventive Maintenance per Fleet Type

Fleet Type	Reactive Cost (IDR)	Preventive Cost (IDR)	Saving (IDR)	Saving (%)
Hino RK	253,407,000	64,356,000	189,051,000	74.6%
Hino RM	178,478,500	57,797,000	120,681,500	67.6%
Mercedes-Benz	107,115,000	50,846,000	56,269,000	52.5%
Total	**539,000,500**	**172,999,000**	**366,001,500**	**67.9%**

The projected two-year saving across all fleets totals IDR 366,001,500 (67.9% reduction). The RK fleet yields the highest absolute saving (IDR 189,051,000; 74.6%), consistent with its elevated risk profile. The Mercedes-Benz fleet, despite the highest per-event cost, records the lowest percentage saving (52.5%) due to higher preventive parts costs. These projections confirm that transitioning to preventive maintenance is economically justified across all fleet types, with the RK fleet presenting the strongest financial case, although the estimates remain dependent on historical data.

Maintenance Recommendations

The fleet-differentiated maintenance approach is supported by prior studies showing that heterogeneous systems require fleet-specific maintenance policies [36]. Based on the integrated RCM analysis (FMEA, LTA, task selection, and MTBF), Table 10 summarizes the recommended maintenance schedule for all fleets.

Table 10. Maintenance Recommendations

Component	Category	RK Interval	RM Interval	Mercedes Interval	Maintenance Type
Wheel Hub	Safety Problem	Routine	Routine	Routine	CD
Bearing	Safety Problem	299 days	696 days	366 days	CD
Wheel Seal	Hidden Failure	269 days	348 days	209 days	TD
Bolts & Nuts	Safety Problem	207 days	2087 days	1462 days	CD
Rim	Safety Problem	2693 days	2087 days	Routine	CD
Tire	Safety Problem	59 days	65 days	77 days	CD

The results indicate that tires require the most frequent monitoring due to continuous road exposure and direct safety impact. The wheel seal is the only component assigned a Time Directed (TD) strategy due to its hidden failure nature, with replacement intervals derived from MTBF. Other components, bearing, bolts and nuts, and rim, follow Condition Directed (CD) strategies with fleet-specific intervals, with bolts and nuts showing the greatest variation, highlighting fastener vulnerability in RK units. The wheel hub, despite no recorded failures, still requires routine CD inspection due to its safety-critical classification. Overall, these recommendations represent a shift from reactive to proactive maintenance.

For effective implementation, the company should establish standardized inspection checklists, maintain component condition records per unit, and provide targeted training for mechanics.

Limitations

This study has several limitations. First, it relies on two years of historical maintenance data, which may not capture long-term patterns or seasonal effects. Second, the limited fleet size (17 units) constrains the statistical robustness of MTBF estimates, particularly for low-failure components. Third, FMEA scoring is based on the judgment of 17 bus drivers who, while possessing firsthand operational experience, may have limited technical knowledge of component mechanics compared to professional mechanics or independent experts, introducing potential subjectivity despite structured consensus facilitated by the lead researcher. Fourth, the absence of real-time condition monitoring limits visibility of actual degradation between inspections. Fifth, MTBF assumes a constant failure rate, which may not apply to all components; future studies should consider Weibull analysis for more robust estimation. Accordingly, the proposed maintenance schedule should be treated as a baseline and refined through continuous data updates and periodic evaluation.

Conclusion

This study applied Reliability Centered Maintenance (RCM) to evaluate and optimize the maintenance strategy of PT XYZ, a mixed-fleet AKAP operator. Analysis of 1,299 failure incidents identified the wheel system as the most critical system (403 failures; 31.02%). FMEA revealed the Hino RK fleet as the highest-risk fleet, with bearing (RPN 512) and wheel hub (RPN 504) classified as high-risk components. The tire exhibits the shortest MTBF (59–77 days), making it the most frequently serviced component. LTA classified five components (wheel hub, bearing, rim, bolts and nuts, tire) as Category A (Safety Problem) and the wheel seal as Category D (Hidden Failure), directly informing Condition Directed (CD) strategies for detectable components and Time Directed (TD) for the wheel seal.

MTBF-based interval calculations produced fleet-specific preventive schedules, while cost simulation confirmed that the Mercedes-Benz fleet incurs the highest per-event cost (Rp21,461,000), reinforcing the economic case for proactive maintenance. The projected 67.9% cost reduction further confirms that transitioning to RCM-based preventive maintenance is justified across all fleets. These findings highlight that mixed-fleet operators should adopt fleet-differentiated rather than uniform maintenance schedules. This study makes three contributions: (1) methodologically, a replicable Pareto → FMEA → LTA → MTBF → cost pipeline that operationalizes RCM as an integrated decision-support system; (2) theoretically, empirical evidence that fleet heterogeneity produces divergent risk profiles requiring differentiated policies, extending Wang et al. (2023) [36]; and (3) practically, a scalable framework for implementing evidence-based preventive maintenance in AKAP operations.

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