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Component Reliability and Fleet Utilization for Spare Parts Management at Sidotopo Locomotive Depot

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Abstract

Locomotive reliability and spare parts availability are essential for maintaining railway operational performance and service continuity. However, previous studies have generally focused on component reliability or inventory management separately, with limited attention to integrating component reliability, fleet utilization, and spare parts demand characteristics into a unified framework for spare parts management. This study aims to address this gap by developing a reliability-based approach for identifying critical spare parts at Sidotopo Locomotive Depot, Operational Region 8 Surabaya, PT Kereta Api Indonesia (Persero). Historical maintenance and operational data were analyzed using Pareto analysis, material reconciliation, expert judgment, reliability analysis, fleet utilization assessment, and demand pattern classification. The analysis identified four critical components: AEP5, Victaulic 3.5", Flexible Hose, and Deadman. Weibull, Lognormal, and Exponential distributions were evaluated, and all components were found to follow the Weibull distribution, indicating wear-out failure behavior. At 1,008 operating hours, AEP5 exhibited the highest reliability, whereas Flexible Hose showed the lowest. Demand analysis classified AEP5 and Flexible Hose as intermittent demand, while Victaulic 3.5" and Deadman were categorized as lumpy demand. Fleet utilization analysis further revealed differences in component operating performance, providing additional insight into replacement priorities. The findings demonstrate that integrating reliability, fleet utilization, and demand characteristics provides a comprehensive basis for identifying critical spare parts, supporting maintenance planning, and improving inventory management in railway operations.

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1. Introduction

Railway transportation plays a strategic role in supporting passenger mobility and freight distribution in Indonesia. As a mass transportation mode, railways offer several advantages, including high carrying capacity, energy efficiency, punctuality, and safety compared to other land transportation modes[1], [2], [3]. The importance of railway transportation has continued to increase alongside the growing demand for mobility and logistics services. According to data published by Statistics Indonesia (BPS) [2], [4], [5], the number of railway passengers in Java and Sumatra reached approximately 417.82 million in 2024, indicating a significant increase compared to previous years. During the period 2020–2024, railway passenger transportation experienced an average annual growth rate of 28.43%, while freight transportation increased by 11.01%. These trends highlight the growing demand for reliable locomotive operation to ensure service continuity and operational efficiency.

The increasing utilization of railway services directly increases locomotive operating intensity and maintenance requirements. Locomotives are expected to operate continuously with minimal failures to support safe, efficient, and punctual railway services [6], [7]. Therefore, component reliability and spare parts availability are essential for maintaining locomotive availability and reducing operational disruptions. Previous studies have shown that improving component reliability enhances maintenance effectiveness and railway operational performance [8].

Although previous studies have extensively investigated locomotive reliability, maintenance strategies, and spare parts inventory management, these aspects are generally evaluated separately. Limited research has integrated component reliability, locomotive fleet utilization, and spare parts demand characteristics into a unified framework for identifying critical spare parts and supporting inventory decision-making[9], [10]. This study addresses this gap by combining reliability analysis, fleet utilization assessment, and demand pattern classification to establish a comprehensive basis for reliability-based spare parts management at Sidotopo Locomotive Depot, Operational Region 8 Surabaya, PT Kereta Api Indonesia (Persero).

The maintenance performance evaluation shows that the overall network achieved a 91.34% operational success rate, with 8.66% of assets requiring maintenance and an idle rate of 5.07%. Most feeders demonstrated operational performance above 90%, indicating that the majority of distribution assets remain in serviceable condition. However, several feeders exhibited relatively higher maintenance and idle percentages, suggesting localized deterioration, equipment failures, or operational constraints that require corrective action. Conversely, feeders with high operational percentages and low maintenance requirements reflect more effective asset management and preventive maintenance practices [11], [12]. These findings indicate that although the overall condition of the distribution network is satisfactory, maintenance resources should be prioritized for feeders with elevated maintenance and idle rates to improve asset reliability, minimize service interruptions, and optimize operational efficiency.

Within the Indonesian railway system, PT Kereta Api Indonesia (Persero) operates several locomotive depots responsible for maintenance activities. Among them, Sidotopo Locomotive Depot (B080), located in Operational Region 8 Surabaya, is one of the largest maintenance facilities in eastern Java. Based on PT KAI operational data in 2024, the depot performed approximately 22% of preventive maintenance and 26% of corrective maintenance activities among all locomotive depots in Java, highlighting its strategic role in supporting locomotive readiness and railway operations [8], [9].

Despite achieving a locomotive availability rate of 92.44% in 2024, the depot also recorded one of the highest numbers of locomotive mission failures. This indicates that high availability does not necessarily reflect low component failure rates, particularly under intensive operating conditions. Therefore, component reliability analysis is required to better understand failure behavior and support more effective maintenance planning[6].

Maintenance records identified 129 component replacement events involving 19 component types across electrical, mechanical, and diesel-engine systems. Critical components, including AEP5, Victaulic 3.5-inch coupling, Flexible Hose, and Deadman, have a direct impact on locomotive operation. Failures of these components increase maintenance workload, repair time, and spare parts demand, making their identification essential for effective spare parts management [7].

Fleet utilization, represented by operating hours and travel distance, also influences component degradation and failure frequency. Higher utilization increases mechanical and thermal stresses, accelerating wear and reducing component reliability. As reported by Zomer et al., integrating utilization data with reliability analysis provides a more comprehensive basis for reliability-based asset management [13].

Previous studies have demonstrated the importance of reliability information for maintenance planning and spare parts management [4], [5]. Van Jaarsveld and Dekker emphasized the use of reliability data in inventory planning, while Zhu et al. showed that identifying critical components improves maintenance decision-making. However, most studies have examined reliability, fleet utilization, or spare parts management separately. Limited research has integrated these three aspects into a single framework for supporting reliability-based spare parts management, particularly in the context of Indonesian railway operations.

Therefore, this study analyzes component reliability, fleet utilization, and spare parts demand characteristics using maintenance and operational data from Sidotopo Locomotive Depot, Operational Region 8 Surabaya. The proposed approach aims to identify critical spare parts and provide a more comprehensive basis for maintenance planning and inventory decision-making at PT Kereta Api Indonesia (Persero).

2. Methods

This study was conducted at Sidotopo Locomotive Depot (B080), Operational Region 8 Surabaya, PT Kereta Api Indonesia (Persero), one of the largest locomotive maintenance centers in Indonesia. The analysis was based on secondary data obtained from maintenance records and locomotive operational databases. The dataset included locomotive operating hours, travel distance, maintenance dates, failed components, replacement quantities, and repair completion records, as seen in Figure 1.

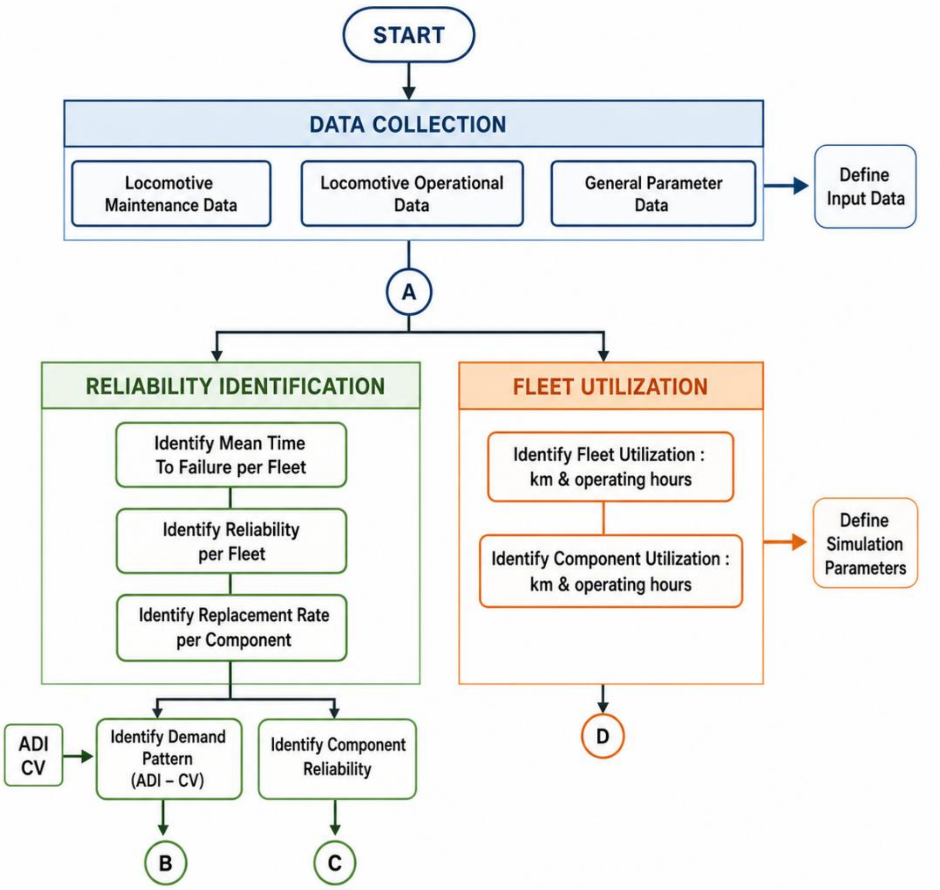

Figure 2. Research Methodology Flow

The research consisted of three main stages. First, fleet utilization was evaluated using locomotive operating hours and travel distance to identify utilization characteristics. Second, reliability analysis was performed by calculating Mean Time to Failure (MTTF), Mean Time Between Failures (MTBF), and Mean Time to Repair (MTTR). Component failure behavior was then modeled using Weibull, Lognormal, and Exponential distributions, with the best-fit distribution selected based on the Anderson–Darling and Kolmogorov–Smirnov goodness-of-fit tests.

Finally, reliability values were estimated for the identified critical components and used to determine maintenance priorities. Spare parts demand patterns were analyzed using the Average Demand Interval (ADI) and Coefficient of Variation (CV^2), and subsequently classified into Smooth, Intermittent, Erratic, or Lumpy demand according to the Syntetos–Boylan classification framework. The integration of reliability, fleet utilization, and demand pattern analyses provided the basis for identifying critical spare parts and supporting reliability-based maintenance and inventory management.

The integration of reliability analysis, fleet utilization assessment, and demand pattern classification provided a comprehensive basis for identifying critical locomotive components and supporting spare parts management decisions at the Sidotopo Locomotive Depot.

3.Results and Discussion

This section will systematically and structuredly explain how the research was conducted. The goal is to provide a clear overview of the research design and implementation to address the research problem formulation and achieve the stated objectives.

3.1 Company Overview

Sidotopo Locomotive Depot (B080), operated by PT Kereta Api Indonesia (Persero) under Operational Region 8 Surabaya, is one of the largest locomotive maintenance centers in Indonesia. The depot is responsible for inspection, preventive and corrective maintenance, component replacement, and repair activities to ensure locomotive availability and operational reliability in eastern Java.

The increasing demand for railway transportation has intensified locomotive utilization and maintenance requirements. According to Statistics Indonesia [8], passenger and freight railway services have continued to grow, increasing the need for reliable locomotive operation. In 2024, Sidotopo Depot performed approximately 22% of preventive maintenance and 26% of corrective maintenance activities among locomotive depots in Java, while maintaining a locomotive availability rate of 92.44%.

Despite this high availability, intensive locomotive operation increases component degradation, resulting in higher maintenance workloads, longer repair times, and greater spare parts demand. Previous studies have shown that component reliability is essential for supporting maintenance planning and spare parts management [10], [11]. In addition, fleet utilization, represented by operating hours and travel distance, influences component wear and failure probability.

Based on these conditions, this study analyzes maintenance and operational records from Sidotopo Locomotive Depot to evaluate component reliability and fleet utilization. The results provide a basis for identifying critical components and supporting reliability-based spare parts management and maintenance planning at PT Kereta Api Indonesia (Persero).

3.2 Initial Identification of Main Component Selection

The initial stage of the study involved identifying critical locomotive components using historical maintenance and component replacement records. Pareto analysis revealed that several components contributed significantly to the total number of replacements during the observation period, as seen in **Figure 2**. The components with the highest replacement frequencies were AEP5 (32 units), Victaulic 3.5" (20 units), Main Generator (12 units), Exciter (8 units), and Injector (8 units).

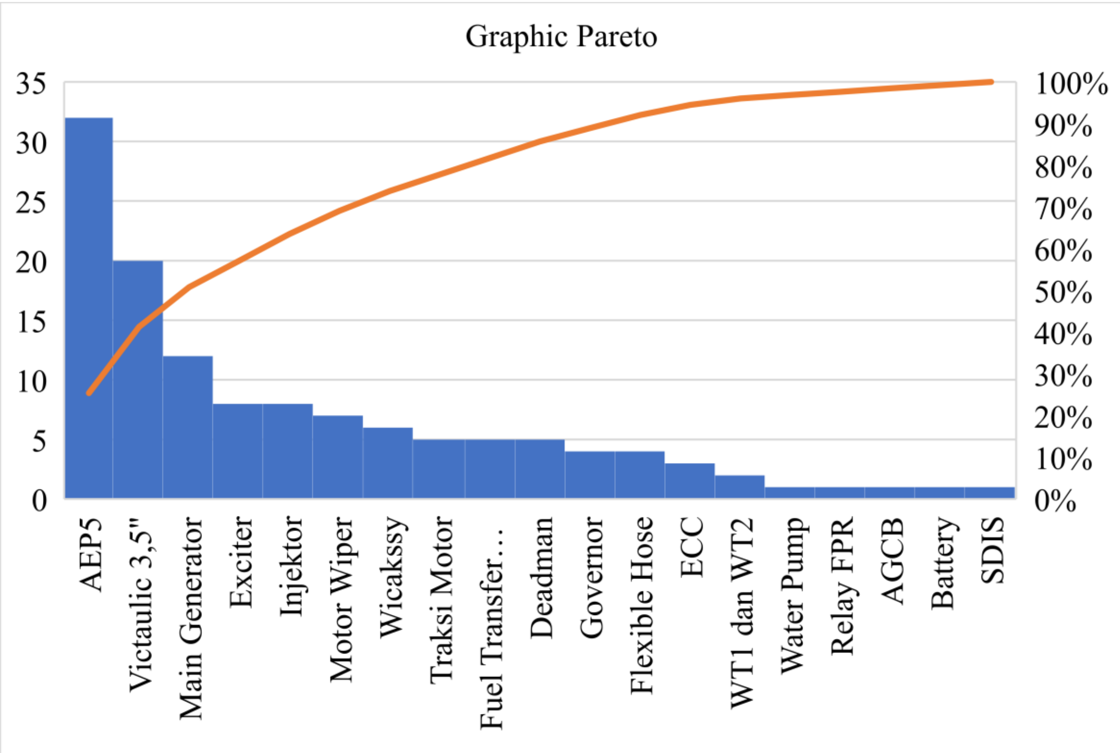

Figure 2. Graphic Pareto Main Component Selection

However, component selection was not based solely on replacement frequency. To ensure practical relevance, the selection process also considered material reconciliation records, procurement policies, data availability, component criticality, economic value, and operational impact. A Focus Group Discussion (FGD) involving five experts from maintenance engineering, material planning, inventory management, procurement, and locomotive operations was conducted to evaluate component suitability for further analysis.

The evaluation results indicated that not all frequently replaced components were appropriate research objects. Components such as Main Generator, Exciter, and Injector were excluded due to limited historical data, specific procurement characteristics, or lower relevance to material reconciliation priorities during the study period.

Based on the combined results of Pareto analysis, material reconciliation, and expert evaluation, four components were selected as the focus of this study: AEP5, Victaulic 3.5", Flexible Hose, and Deadman. These components represent different reliability and operational characteristics. AEP5 exhibited the highest replacement frequency, while Victaulic 3.5" had the highest unit cost. Flexible Hose and Deadman were selected because of their operational importance and recurring appearance in maintenance and material planning records.

Table 1. Calculation Results of MTTF, MTBF and MTTR for 4 Main Components

Component	Lokomotif/Armada	Failure	MTTF	MTBF	MTTR
Victaulic 3,5"	CC2061338	2	-	3480	24
	CC2061311	2	-	2304	24
Flexible Hose	CC2061314	1	5640	-	24
	CC2061329	2	-	3456	24
	CC2061337	2	-	96	24
	CC2061503	1	2976	-	24
	CC2017711	1	1368		24
Deadman	CC2030106	3	-	2160	24
	CC2030203	2	-	2976	24
	CC2018311	1	3888	-	24
AEP5	CC2061311	2	-	2304	24
	CC2039814	2	-	336	24

The selected components were subsequently used for reliability analysis, fleet utilization assessment, and critical component identification to support spare parts management at Sidotopo Locomotive Depot.

3.3 Component Reliability Identification

Reliability is a key factor in effective spare parts management because it supports failure prediction, maintenance planning, and inventory control. According to Ben-Daya et al. (2009) [3], reliability represents the probability that a component performs its intended function without failure over a specified period. Likewise, Van Jaarsveld and Dekker (2011) emphasized that spare parts demand is closely related to component reliability, making reliability analysis essential for inventory management. Recent studies have also shown that integrating reliability information into maintenance strategies improves spare parts availability and maintenance decision-making [1], [4], [8].

This study evaluated four critical locomotive components—AEP5, Victaulic 3.5", Flexible Hose, and Deadman—identified through Pareto analysis, material reconciliation, and expert judgment. Component reliability was assessed using Mean Time to Failure (MTTF), Mean Time Between Failures (MTBF), and Mean Time to Repair (MTTR) to characterize failure behavior and maintenance performance, as shown in **Table 1**.

The results reveal significant differences in reliability among the analyzed components. Flexible Hose exhibited the highest reliability, whereas AEP5 showed the lowest reliability and the highest replacement frequency, indicating its critical role in spare parts planning, as shown in **Table 2**. Victaulic 3.5" demonstrated relatively stable reliability but remained economically important because of its high replacement value. Meanwhile, Deadman showed moderate reliability with varying performance across locomotives. All components had a similar MTTR of approximately 24 hours, indicating that differences in maintenance performance were primarily influenced by failure frequency rather than repair duration.

These findings confirm that spare parts management should consider not only replacement demand but also component reliability and operational criticality. The results are consistent with Van Jaarsveld and Dekker (2011), Dendauw et al. (2021), and Al Khoury et al. (2024) [1], [4], [8], who emphasized that integrating reliability information into spare parts planning improves maintenance effectiveness, asset availability, and inventory management. Therefore, reliability analysis provides a robust foundation for identifying critical spare parts and supporting reliability-based maintenance at Sidotopo Locomotive Depot.

Table 2. Components Can be Ranked Based on Their Level of Reliability

Rank	Component	Reliability Indication
1	Flexible Hose	Very High Reliability (MTTF = 5,640 hours)
2	Deadman	High Reliability (MTTF = 3,888 hours)
3	Victaulic 3.5"	High Reliability (MTBF up to 3,480 hours)
4	AEP5	Moderate Reliability
5	Deadman (CC2017711)	Low Reliability (MTTF = 1,368 hours)
6	Flexible Hose (CC2061337)	Very Low Reliability (MTBF = 96 hours)

Determining the appropriate failure distribution is essential for reliability analysis because it affects the estimation of MTTF, reliability functions, and failure behavior. In this study, three commonly used reliability distributions—Weibull, Lognormal, and Exponential—were evaluated for the four critical components: Victaulic 3.5", Flexible Hose, Deadman, and AEP5 [3].

The best-fit distribution was selected using Anderson-Darling (AD) and Kolmogorov-Smirnov (KS) goodness-of-fit tests. The results consistently showed that the Weibull distribution provided the best fit for all components, as indicated by the lowest AD statistics and the highest KS p-values compared with the Lognormal and Exponential distributions (shown in **Figure 3**).

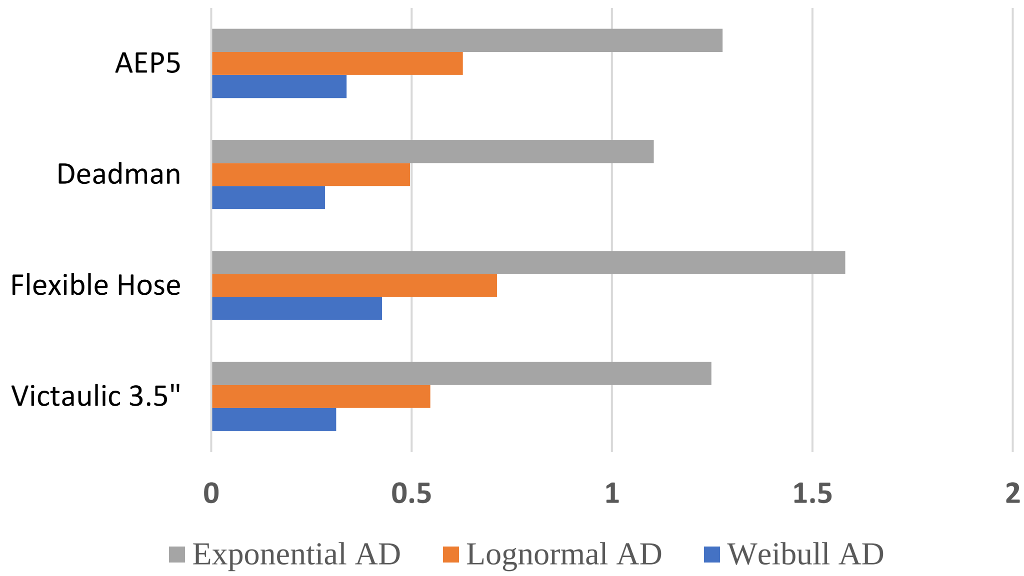

Figure 3. Goodness of Fit (Anderson-Darling)

The graph shows that the Weibull distribution has the smallest Anderson-Darling value compared to the Lognormal and Exponential distributions. This indicates that the Weibull distribution has the best fit to the component failure data. The comparison of P-Value - Kolmogorov-Smirnov means that a higher p-value indicates a better fit to the data. The **Figure 4** shows the Kolmogorov-Smirnov test graph.

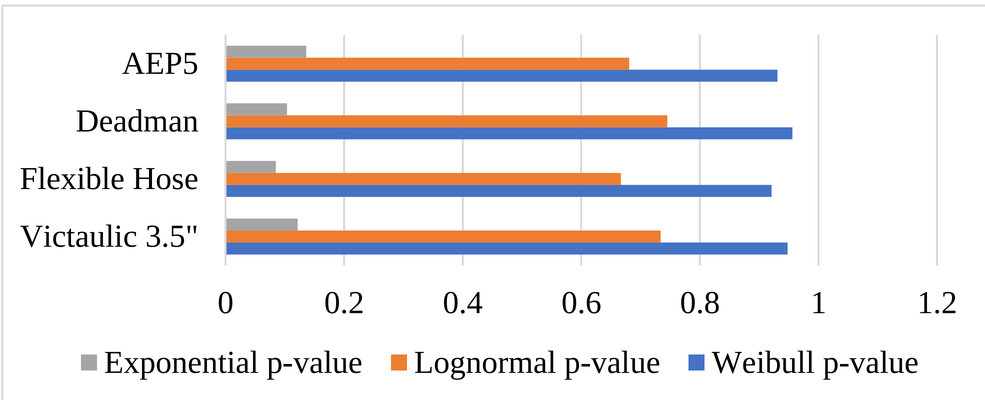

Figure 4. P-Value Kolmogorov-Smirnov Compare

Comparison of Mean Time to Failure (MTTF) components with higher MTTFs have a longer operational life before failure.

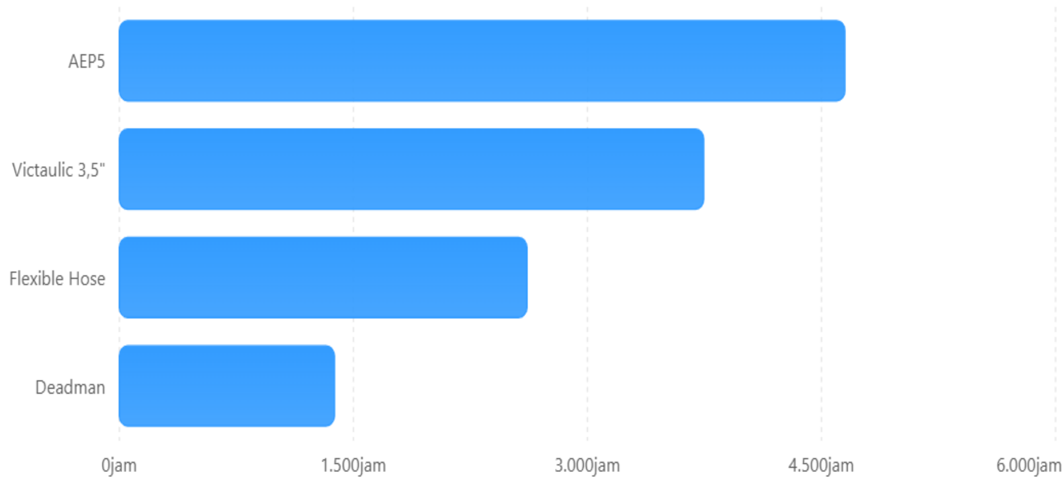

Figure 5. Comparison of Mean Time to Failure (MTTF)

MTTF values indicate that AEP5 has the longest service life, while Deadman has the shortest service life, requiring greater attention in inventory management and maintenance policies, as shown in **Figure 5**. Based on the goodness-of-fit results, all selected components (Victaulic 3.5", Flexible Hose, Deadman, and AEP5) were best represented by the Weibull distribution. Therefore, Weibull reliability functions were used to estimate the probability of each component remaining operational over time. Reliability values ranged from 0 to 1, where higher values indicate greater reliability and lower probabilities of failure.

The results show that all components experienced a gradual decline in reliability as operating hours increased, indicating progressive degradation and wear-out behavior. At 1,008 operating hours, the reliability values were 0.4727 for AEP5, 0.3753 for Victaulic 3.5", 0.1796 for Deadman, and 0.1370 for Flexible Hose. These findings confirm that the likelihood of component failure increases with longer operating periods, as shown in **Figure 6**.

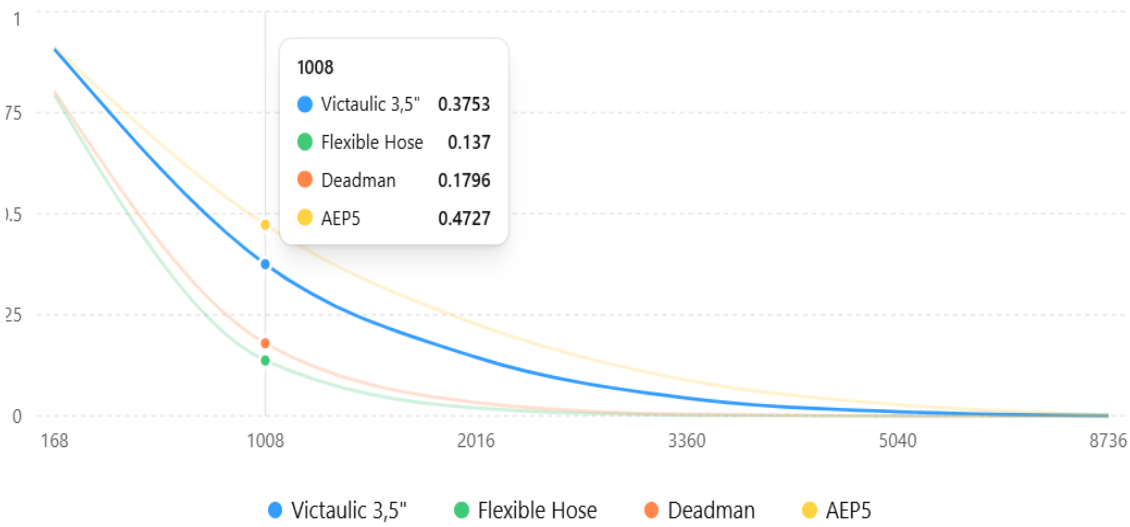

Figure 6. Reliability Curve of Main Locomotive Components

3.4 Analysis of Component Replacement Patterns (Demand)

Spare parts demand was analyzed using the Average Demand Interval (ADI) and Coefficient of Variation (CV^2) following the Syntetos–Boylan classification framework. ADI measures the frequency of demand occurrence, whereas CV^2 reflects the variability of demand quantities. This approach is widely used to characterize intermittent spare parts demand and support maintenance-oriented inventory decisions, as seen in **Table 3**.

Table 3. Demand Pattern Classification of Critical Components

Component	ADI	CV	CV^2	Demand Pattern
AEP5	26.5	0.4885	23.86%	Intermittent
Flexible Hose	13.25	0.1975	3.90%	Intermittent
Deadman	17.67	1.992	398.52%	Lumpy
Victaulic 3.5"	26.5	1.81	327.27%	Lumpy

The results indicate that the demand characteristics of locomotive spare parts are dominated by Intermittent and Lumpy demand patterns. AEP5 and Flexible Hose belong to the intermittent category, indicating infrequent demand with relatively low variability. In contrast, Deadman and Victaulic 3.5" exhibit lumpy demand characteristics, where demand occurs sporadically and with high variability, making future requirements more difficult to predict, as seen **Figure 7**.

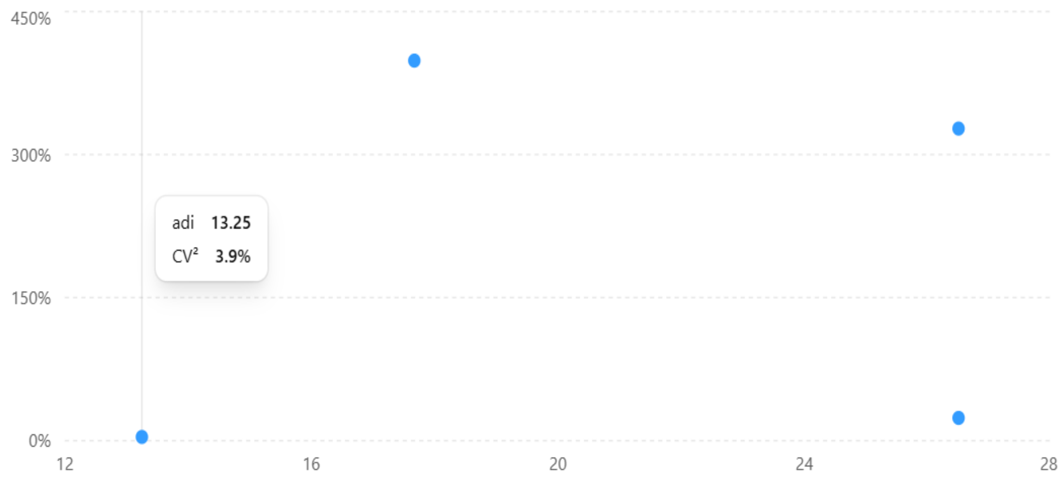

Figure 7. ADI–CV Classification Diagram

The ADI–CV diagram confirms that all selected components exhibit non-regular demand behavior. Such demand characteristics are commonly observed in maintenance spare parts, where requirements are primarily driven by component failures rather than continuous consumption, as seen in **Table 1**. Similar findings have been reported in railway and industrial maintenance studies, which highlight the limitations of conventional forecasting methods for intermittent and lumpy spare parts demand [5], [12]. To support maintenance planning and spare parts management, the selected components were further categorized according to their operational characteristics.

Table 2. Critical Characteristics of Selected Components

Component	Critical Characteristic
AEP5	Highest consumption frequency
Victaulic 3.5"	Highest unit cost
Deadman	Safety-critical component

The results indicate that each component presents a different management challenge. AEP5 requires attention due to its high consumption rate, Victaulic 3.5" due to its economic impact, Deadman because of its safety function, and Flexible Hose because of its relatively low reliability. These findings suggest that effective spare parts management should consider not only historical demand but also reliability, criticality, and operational consequences of component failures.

3.5 Fleet Utility Analysis

Fleet utilization was evaluated to determine the operational intensity experienced by locomotive components prior to failure, as seen in **Table 5**. Utilization was measured using operating distance and operating hours per failure event, providing an indication of the component's ability to withstand operational loads before replacement was required.

Table 5. Fleet Utilization of Critical Components

Rank	Component	Operating Hours per Failure (h)	Operating Distance per Failure (km)
1	Victaulic 3.5"	4.56	574.7
2	AEP5	6.62	489.05
3	Flexible Hose	7.77	417.71
4	Deadman	3.55	334.63

The results indicate that Victaulic 3.5" exhibited the highest utilization level, with an average operating distance of 574.70 km per failure, suggesting that the component can withstand relatively high operational loads before failure occurs. Similarly, AEP5 demonstrated a high utilization value of 489.05 km per failure, which is consistent with its superior reliability performance observed in the Weibull analysis.

In contrast, Deadman showed the lowest utilization level, with only 334.63 km per failure, indicating a higher susceptibility to failure under operational conditions. Considering that Deadman is a safety-critical component, this finding highlights the importance of close monitoring and maintenance attention. Meanwhile, Flexible

Hose recorded moderate utilization performance but experienced relatively frequent failures, suggesting that material degradation and repetitive loading may contribute significantly to its failure mechanism.

Overall, the utilization analysis confirms that component performance is influenced not only by reliability characteristics but also by operational exposure. Components with lower utilization values tend to experience failures at shorter operating distances, making them more vulnerable to operational disruptions. Therefore, integrating fleet utilization and reliability information provides a more comprehensive basis for identifying critical components and supporting spare parts management decisions at Sidotopo Locomotive Depot.

4. Conclusion

This study demonstrates that integrating component reliability, demand characteristics, and fleet utilization provides a comprehensive basis for identifying critical locomotive spare parts at Sidotopo Locomotive Depot. Four critical components—AEP5, Victaulic 3.5", Flexible Hose, and Deadman—were identified through Pareto analysis, material reconciliation, and expert evaluation. Reliability analysis showed that all components follow a Weibull distribution, indicating that failures are predominantly associated with wear-out mechanisms. Among the evaluated components, AEP5 exhibited the highest reliability, whereas Flexible Hose showed the lowest.

Demand pattern analysis classified AEP5 and Flexible Hose as intermittent demand, while Victaulic 3.5" and Deadman exhibited lumpy demand, indicating that spare parts demand is irregular and primarily driven by component failures. Fleet utilization analysis further showed differences in component operating performance, with Victaulic 3.5" demonstrating the highest operating distance before failure and Deadman the lowest, reflecting differences in component durability under operational conditions.

Overall, the findings indicate that spare parts management should integrate reliability performance, demand characteristics, fleet utilization, and component criticality, rather than relying solely on historical consumption data. AEP5 requires priority because of its high replacement frequency, Victaulic 3.5" because of its high economic value and durability, Deadman because of its safety-critical function, and Flexible Hose because of its relatively low reliability. These findings provide a practical basis for improving maintenance planning and reliability-based spare parts management at PT Kereta Api Indonesia (Persero).

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Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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