RELIABILITY IMPROVEMENT OF RAILWAY VEHICLES: A REVIEW

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Abstract— Railway vehicles are mobile parts of the operating basis on railways that are used for the movement on the track. Reliability is an important factor in the operation of railway vehicles as they play an important role in ensuring the safety and efficiency of railway operations. The complexity of subsystem structures can affect vehicle reliability, and failure or damage to components can lead to operational disruption or system failure. Reliability improvement techniques focus on minimizing failures, reducing unplanned downtime, and ensuring efficient and safe operation of railway vehicles. These techniques include maintenance strategies, design optimization, spare parts management, training, skilled management, and reliability analysis. This paper aims to discuss these reliability improvement techniques globally and specifically examine the performance of railway vehicles in Indonesia. Prioritizing reliability improvement is applied to minimize unexpected breakdowns and failures, thereby improving passenger experience, punctuality, and safety. By reducing disruptions, reliability improvements contribute to smooth train travel, minimizing delays, and creating a safer environment. In addition, improved reliability in railway transportation systems increases efficiency, benefiting passenger satisfaction, economic growth and development. Safe, reliable, and efficient transportation facilitates the movement of goods and people, encourages trade and enhances regional connectivity, ultimately supporting sustainable economic development.

Keywords— reliability improvement, reliability analysis, maintenance strategy, design optimization, railway vehicle.

1. INTRODUCTION

The railway transportation system refers to the integrated network of infrastructure, operations, and services that enable the movement of people and goods via trains. It encompasses the physical tracks, stations, railway vehicles, signaling systems, and support facilities required for the efficient functioning of the railway network. The railway transportation system is designed to provide a safe, reliable, and efficient mode of transportation over land. It involves the coordination and integration of various components and stakeholders to ensure smooth operations and services [1].

Railway vehicles are mobile parts of the operating basis on railways that are used for the movement on the track [2]. These vehicles are divided into three groups: propulsive, driven (coach and wagon), and special railway vehicles. Railway vehicles play a crucial role in ensuring the reliability and operational safety of trains [3]. The structure of a railway vehicle is designed with various subsystems and components that work together to ensure optimal functionality, performance, and safety. The universal structure of railway vehicles is shown in Figure 1.

Reliability is one of the important factors in the operation of railway vehicles. Railway vehicle service reliability is a key performance indicator for any railway operator and customer satisfaction [4]. The structure in Figure 1 shows that in the context of reliability, the railway vehicle as a system will depend on its sub-systems. The subsystem structure's complexity can affect the railway vehicle's reliability [5]. The more complex the subsystem structure, the greater the possibility of failure or damage to one of the components or the relationship between the components. Weakness or damage to one part can impact the overall performance of the railway vehicle, resulting in operational disruption or system failure. Thus, designing a reliable system requires evaluating the impact of system and equipment failures that are inherent in the system [6].

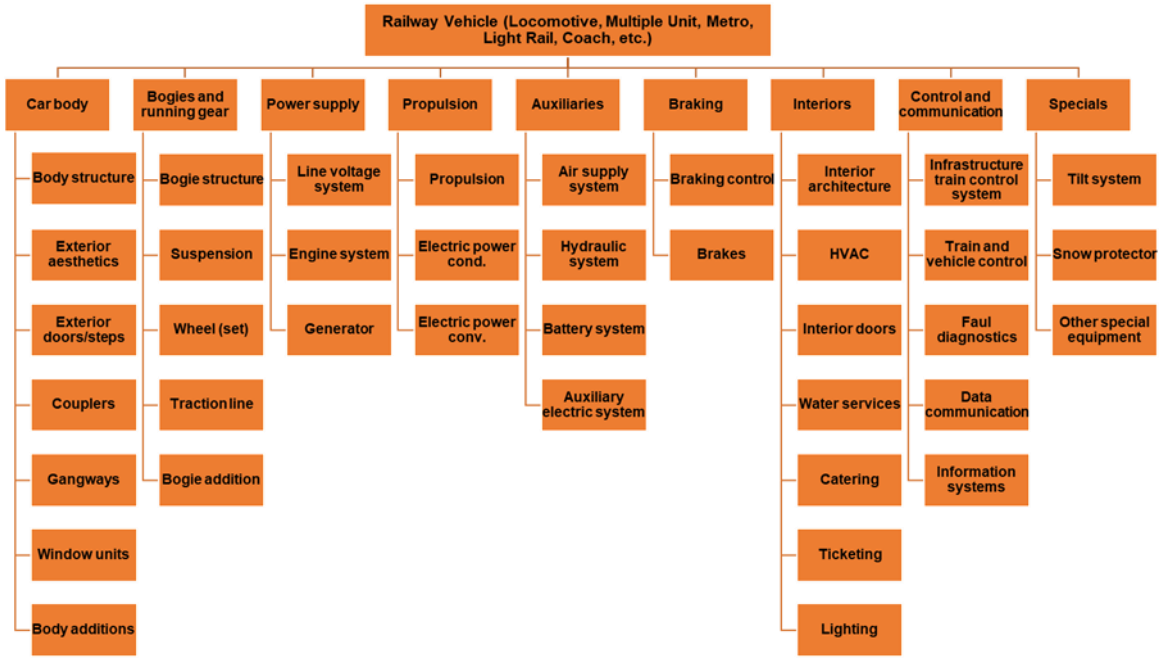


Figure 1. Structure of Railway Vehicles [7]

Reliability improvement refers to the efforts and measures taken to enhance the dependability, performance, and availability that focuses on minimizing failures, reducing unplanned downtime, and ensuring the efficient and safe operation of railway vehicles [8]. Reliability improvement techniques and strategies are employed to increase the overall reliability of the way vehicles and their subsystems. These techniques aim to identify potential failure modes, mitigate risks, and implement measures to prevent or minimize the impact of failures [9]. Some specific reliability improvement techniques for railway vehicles include maintenance strategies, design optimization, spare part management, training and skilled management, and reliability analysis.

This literature review aims to discuss reliability improvement techniques for railway vehicles in the world. This review paper also discusses the performance of railway vehicles in Indonesia. The application of reliability improvement also needs to be done so that train travel is safe, reliable, and efficient. Therefore, we will discuss reliability improvements that are suitable for implementation in Indonesia.

This review paper consists of four sections. In the first section, there is a brief explanation of the scope of this review. Section 2 summaries of 30 relevant researches. Section 3 discusses the method used to select the previous researches to be discussed. Section 4 presents the findings of previous researches. Section 5 discusses previous research that can be applied to railway vehicles in Indonesia. The last section provides the conclusion of this literature review.

2. PREVIOUS RESEARCHES

The following are summaries of 30 relevant articles to the literature review topic.

Table 1. Summary of Each Article

No	Authors, Year	Title	Summary
1.	Mayisela & Dorrell, 2019	Application of Reliability-Centered Maintenance for DC Traction Motors - A Review [10]	The paper reviews condition monitoring methods for the DC motors to apply an effective condition monitoring method for the 3 kV DC traction motors. The overall thek is aimed to ratucing unexpected failures, and maintenance costs and improving the 18E locomotive availability and reliability in South Africa.

No	Authors, Year	Title	Summary
2.	Rezvanizaniani et al., 2009	Reliability Analysis of the Rolling Stock Industry: A Case Study [11]	The paper explains that reliability analysis is required to identify the bottlenecks in the system and find the components or subsystems with low reliability for a desired level of performance. The paper focuses on collecting and analyzing field failure data over a period in Raja Passenger Train Company of Iran to determine the reliability of each type of wheel set over different time intervals.
3.	Ansori et al., 2021	Reliability Analysis on the Bogie System at Indonesian High-Speed Trains in The Design Phase to Improve Service Quality [12]	This paper focuses on maintaining the service quality of the Bogie system in terms of reliability at the design stage using qualitative analysis. The study aims to identify critical subsystems/components that affect the decline in reliability, build Reliability Block Diagram (RBD) from subsystems/components that have been identified in the bogie system, and develop designs to minimize the potential for a decline in reliability.
4.	X. Cheng et al., 2013	Reliability Analysis of Metro Door System Based on FMECA [13]	The paper presents a reliability analysis of the metro door system using the Failure Mode, Effects, and Criticality Analysis (FMECA) method. The major failure components of the door system are identified, and the criticality of failure modes is calculated. The results can be used for optimal design and maintenance of the metro door system.
5.	Kim & Jeong, 2013	Evaluation of the Adequacy of Maintenance Tasks Using the Failure Consequences of Railroad Vehicles [14]	The paper aims to improve the efficiency, reliability, and safety of railroad maintenance tasks by evaluating the consequences of failures. The brake system was selected for analysis, and failure causes, effects, and criticality was identified for 62 failure modes.
6.	Ten Wolde & Ghobbar, 2013	Optimizing Inspection Intervals—Reliability and Availability in Terms of a Cost Model: a Case Study on Railway Carriers [15]	This paper proposes a model to find the optimal inspection interval for railway carriers in terms of costs. The model combines actual failure and repair data with system availability to determine the most cost-effective inspection interval.
7.	Ciani et al., 2021	Condition-Based Maintenance of HVAC on a High-Speed Train for Fault Detection [16]	The paper proposes a new fuzzy-based decision-making diagram to optimize the maintenance plan for an HVAC system located on high-speed trains. The results of the proposed fuzzy approach highlight the importance of an accurate diagnostics and condition monitoring strategy to optimize the maintenance plan and minimize system availability.
8.	Xu et al., 2019	Advanced Maintenance Cycle Optimization of Urban Rail Transit Vehicles. [17]	The paper aims to optimize the advanced maintenance cycle of urban rail transit vehicles based on the reliability analysis of key components. The optimized maintenance cycle can increase the number of vehicles on the line and alleviate the contradiction between urban rail transit demand and capacity.

No	Authors, Year	Title	Summary
9.	Gong et al., 2022	Dynamic Preventive Maintenance Optimization of Subway Vehicle Traction System Considering Stages [18]	The paper proposes non-preventive failure maintenance, preventive maintenance, preventive update maintenance, and opportunistic maintenance. The maintenance strategy is optimized and solved based on the enumeration method to obtain single-component irregular preventive maintenance intervals and multi-component group preventive maintenance times.
10.	Y. H. Cheng & Tsao, 2010	Rolling Stock Maintenance Strategy Selection, Spares Parts' Estimation, and Replacements' Interval Calculation [19]	The paper proposes an approach for selecting a maintenance strategy for rolling stock and obtaining possible spare parts quantities and replacement intervals for the components of rolling stock. The empirical result indicates that preventive maintenance should be much more valued than corrective maintenance, and safety is considered the most crucial factor for the selection of a rolling stock maintenance strategy.
11.	Conradie et al., 2015	Quantifying System Reliability in Rail Transportation in an Ageing Fleet Environment [20]	The paper presents an approach to quantifying the reliability of rolling stock assets in the rail environment, making use of failure statistics. The methodology includes analyzing failure distributions and the interdependency of different systems to determine the impact of component failures on overall system reliability and to determine the reliability of individual train sets.
12.	Szkoda et al., 2021	Assessment of the Influence of Preventive Maintenance on the Reliability and Availability Indexes of Diesel Locomotives [21]	The paper investigates the impact of preventive maintenance on the reliability and availability indexes of diesel locomotives. The authors identified the weakest components of the rail vehicle that affect downtime and mean availability most significantly.
13.	Szkoda & Satora, 2019	The Application of Failure Mode and Effects Analysis (FMEA) for the Risk Assessment of Changes in the Maintenance System of Railway Vehicles [22]	The paper presents the application of Failure Mode and Effects Analysis (FMEA) for the risk assessment of changes in the maintenance system of railway vehicles, using the example of the 6Dg type shunting locomotive. The study demonstrates that changes to the maintenance plan can be made without compromising safety, provided that preventive safety measures are taken.
14.	Corman et al., 2017	Optimizing Preventive Maintenance Policy: a Data-Driven Application for a Light Rail Braking System [23]	The study uses work, maintenance, and failure data to model the reliability degradation of the system and its subsystems under the current maintenance policy by a Weibull distribution. The model is then used in a sequential optimization framework to determine preventive maintenance intervals to improve on the key performance indicators.

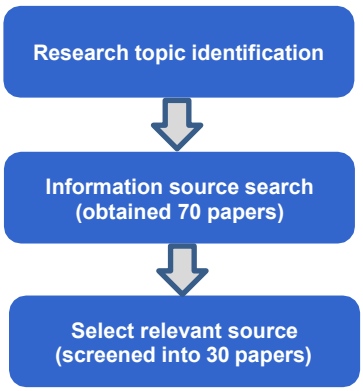
No	Authors, Year	Title	Summary
15.	Grenčík et al., 2018	Use of Risk Assessment Methods in Maintenance for More Reliable Rolling Stock Operation [24]	The paper discusses the use of risk assessment methods in maintenance for more reliable rolling stock operations. It presents methods of risk assessment and possibilities of their reduction in the design, operation and maintenance of railway vehicles.
16.	Lin et al., 2015	Reliability Analysis for Preventive Maintenance Based on Classical and Bayesian Semi-Parametric Degradation Approaches Using Locomotive Wheel-Sets as a Case Study [25]	This paper presents a reliability study using classical and Bayesian semi-parametric degradation approaches to model and analyze degradation data for determining reliability and supporting preventive maintenance strategy making. The study is demonstrated using a case study of locomotive wheel-set reliability.
17.	Lin et al., 2014	Reliability Analysis for Degradation of Locomotive Wheels using Parametric Bayesian Approach [26]	This paper uses a Bayesian survival analysis framework to explore the impact of a locomotive wheel's installed position on its service lifetime and to predict its reliability characteristics. The Bayesian Exponential Regression Model, Bayesian Weibull Regression Model and Bayesian Log-normal Regression Model are used to analyze the lifetime of locomotive wheels using degradation data and taking into account the position of the wheel.
18.	Eisenberger & Fink, 2017	Assessment of Maintenance Strategies for Railway Vehicles Using Petri-Nets [27]	The paper proposes the use of Abridged Petri Nets (APN) in combination with Monte-Carlo simulation for evaluating maintenance strategies for railway rolling stock components. The tool can be extended by pre-defining selected strategies that can be easily implemented within an overall decision support system.
19.	Lin et al., 2013	Bayesian Parametric Analysis for Reliability Study of Locomotive Wheels [28]	This paper proposes a new approach to study reliability of locomotive wheels with Bayesian framework, utilizing locomotive wheel degradation data sets that can be small or incomplete. A Markov Chain Monte Carlo (MCMC) computational method is also implemented. The results show that the locomotive wheels' lifetimes are dependent on installation positions.
20.	Li et al., 2009	Bogie Failure Mode Analysis for Railway Freight Car Based on FMECA [29]	The paper proposes the method of failure modes, effect and criticality analysis (FMECA) to improve the quality and reliability of bogies in railway freight cars. The method involves quantitative and qualitative evaluation of failure effects using computer aided technology to identify potential failure bottleneck problems and suggest corresponding modified measures.

No	Authors, Year	Title	Summary
21.	Ruijters, Guck, Drolenga, & Stoelinga, 2016	Fault Maintenance Trees: Reliability Centered Maintenance via Statistical Model Checking [30]	The paper proposes a framework called Fault Maintenance Trees (FMTs) that integrates fault tree analysis with maintenance to investigate the effect of different maintenance policies on the reliability and availability of a system. The framework supports a wide range of maintenance procedures and dependability measures, including the system reliability, availability, mean time to failure, as well as the maintenance and failure costs over time, split into different cost components.
22.	Ruijters, Guck, Drolenga, Peters, et al., 2016	Maintenance Analysis and Optimization Via Statistical Model Checking: Evaluating a Train Pneumatic Compressor [31]	This paper studies the effect of different maintenance strategies on a pneumatic compressor used in trains. The compressor is modelled as a fault maintenance tree (FMT) and analysed using statistical model checking to obtain key performance indicators such as system reliability, number of failures, and required unscheduled maintenance.
23.	Lee et al., 2012	A Study on Management System for Reliability Analysis in Advanced EMU [32]	The abstract of the paper states that the authors built a management system for reliability analysis of Advanced EMU using Product Data Management (PDM) and system engineering technology. The system was used to verify the reliability and safety of the 6-car production of Advanced EMU.
24.	Babeł & Szkoda, 2016	Diesel Locomotive Efficiency and Reliability Improvement as a Result of Power Unit Load Control System Modernization [33]	The paper proposes modernization of a diesel locomotive power unit load control using SM31 locomotive. An electronic rotations and power governor of a8C22W diesel engine is applied, developed in cooperation with Lokel (the Czech Republic) and Newag S.A. (Poland), in which a new optimal operational characteristic is realized in the locomotive.
25.	Melnik et al., 2019	Reliability Analysis of Metro Vehicles Operating in Poland [34]	The paper provides the reliability of two types of metro vehicles in Poland, which can be used by operators to improve maintenance and reduce downtime. The study shows that the rolling stock of both types is subject to a significant number of damages in the initial phase of exploitation, and that there are differences in the number and type of damage between the two types.
26.	Leite et al., 2022	Reliability and Availability Assessment of Railway Locomotive Bogies Under Correlated Failures [3]	The paper focuses on the reliability and availability assessment of railway locomotive bogies under correlated failures. It proposes a Discrete Event Simulation (DES) model to study the impact on the system, in terms of reliability and availability, under different scenarios with varying assumptions on the underlying failure modes, repairs, and on the failures correlation structure.

No	Authors, Year	Title	Summary
27.	Rezvanizaniani et al., 2008	Reliability Centered Maintenance for Rolling Stock: A Case Study in Coaches' Wheel sets of Passenger Trains of Iranian Railway [35]	The paper discusses the implementation of Reliability Centered Maintenance (RCM) to make maintenance of rolling stock of the Raja Passenger Train Corporation more cost-effective. It presents RCM implementation for the wheelsets, which is the most critical subsystem from the rolling stocks reliability point of view.
28.	Dinmohammadi et al., 2016	Risk Evaluation of Railway Rolling Stock Failures Using FMECA Technique: A Case Study of Passenger Door System [36]	The study identifies the most critical failure modes in the system with respect to both reliability and economic criteria, determines the levels of failure criticality, and provides possible methods for mitigation. A case study of the Class 380 train's door system operating on Scotland's railway network is provided to illustrate the risk evaluation methodology.
29.	(Alkali et al., 2016)	Rolling Stock Door System Reliability Improvement Using Maintenance Optimization [37]	This paper focuses on optimizing the maintenance of the door system of the Class 158 Diesel Multiple Unit DMU train fleet, which consists of several functionally dependent components and is operated in-service continuously. The paper conducts a failure analysis of the door system using the reliability centered maintenance approach and proposes a preventive maintenance strategy using specialist simulation software.
30.	(Alkali et al., 2017)	Towards Implementing Condition Based Maintenance Policy for Rolling Stock Critical System [38]	The paper discusses the implementation of condition-based maintenance (CBM) policy for rolling stock critical system, specifically for the Class 158 Diesel Multiple Unit (DMU) train door system. The CBM analysis is used to optimize maintenance tasks and improve reliability and availability of service operation.

3. RESEARCH METHOD

Articles relevant to the topic were obtained from several publishers including IEEE Xplore, MDPI, Research Gate, Research Online, SAGE, Science Direct, and Wiley Online Library. In searching the articles, keywords such as railway vehicles, rolling stock, reliability, and reliability improvement were used. In addition, the year of research was also filtered from 2008-2022. The framework for searching articles is shown in Figure 2.



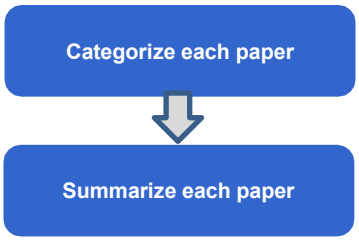


Figure 2. Framework for Articles Search

4. FINDINGS

The following data on the number of articles based on the year of publication is presented in Figure 3.

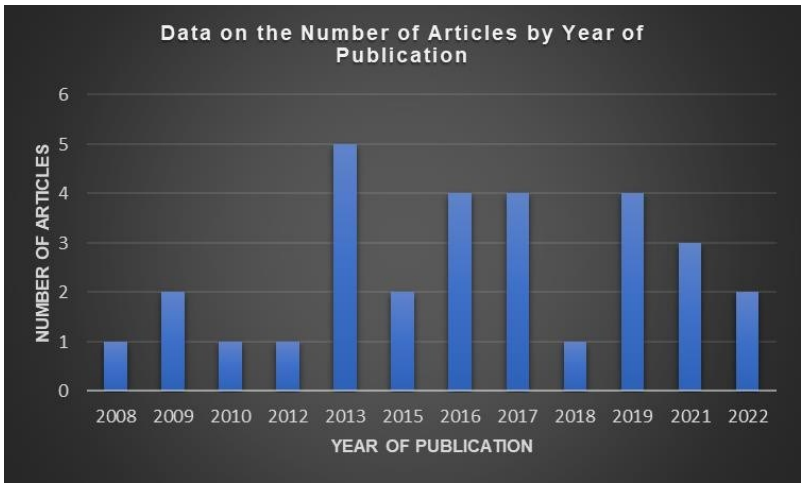


Figure 3. Data on the Number of Articles by Years of Publication

Based on Figure 3, there are fluctuations in the number of articles on reliability improvement for railway vehicles from year to year. There are years with a relatively low number of articles, such as 2008, 2010, 2012, and 2018. However, there are still many articles related to reliability improvement in the last 3 years, especially when compared to the number of articles between 2008-2012. This fact indicates that the topic of reliability improvement is still of interest to researchers as it is important to improve the quality of railway transportation operations. In addition, today's rail vehicle systems are becoming increasingly complex with the implementation of higher levels of automation (GOA3 & GOA4), so the challenge of improving reliability is growing.

The following data on the percentage of the number of articles based on the paper category is shown in Figure 4.

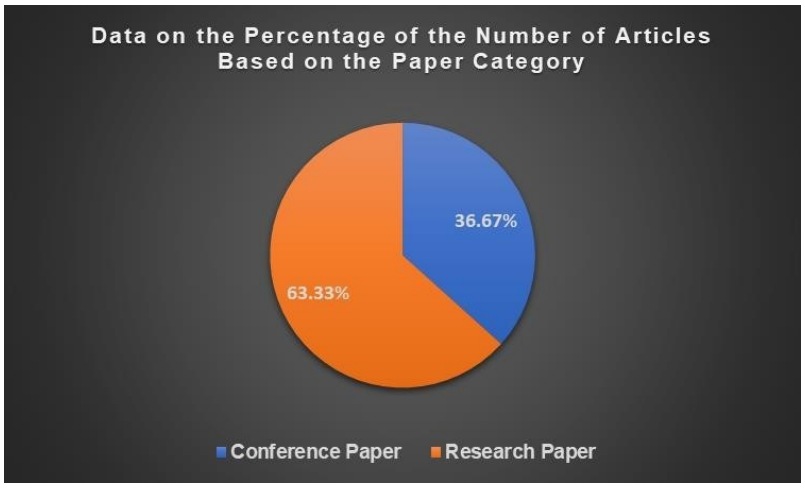


Figure 4. Data on the Percentage of the Number of Articles Based on the Paper Category

Based on Figure 4, it can be concluded that most articles that discuss reliability improvement for railway vehicles are published in the form of research papers, with a percentage of 63.33%. Meanwhile, the percentage of articles in the form of conference papers is lower with a percentage of 36.67%. Research papers have a dominant role in publications related to reliability improvement for railway vehicles. Although the percentage of conference papers is lower than research papers, this academic conference forum is needed because it can provide space for researchers to share their findings directly with the audience.

The following data on the number of articles based on the object of the case study is depicted in Figure 5.

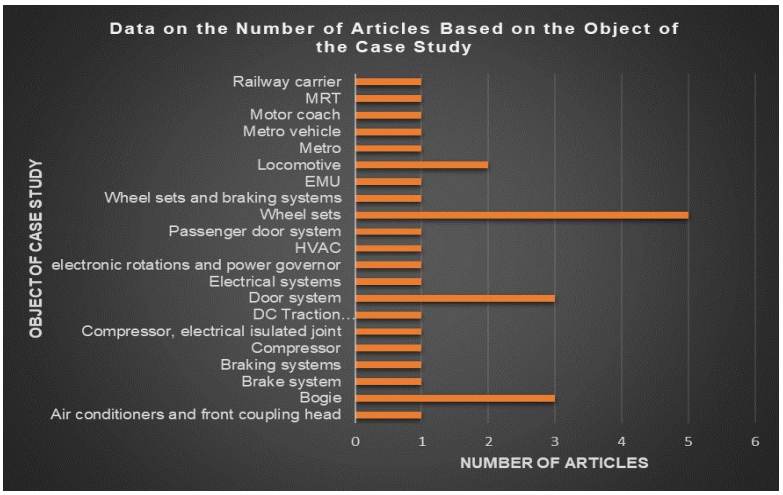


Figure 5. Data on the Number of Articles Based on the Object of the Case Study

Based on Figure 5, The focus of research in improving reliability lies on numerous systems and subsystems within railway vehicles. There are 8 systems and 22 subsystems as the object of discussion. Systems in railway vehicles that are the object of discussion include EMU, locomotive, metro, motor coach, MRT, and railway carrier. Subsystems including bogies, braking systems, door systems, wheelsets, and various other systems are also discussed. This analysis illustrates the diversity and complexity of aspects considered in an effort to improve the overall reliability of rail vehicles.

The following is the percentage data regarding reliability improvement techniques in articles shown in Figure 6.

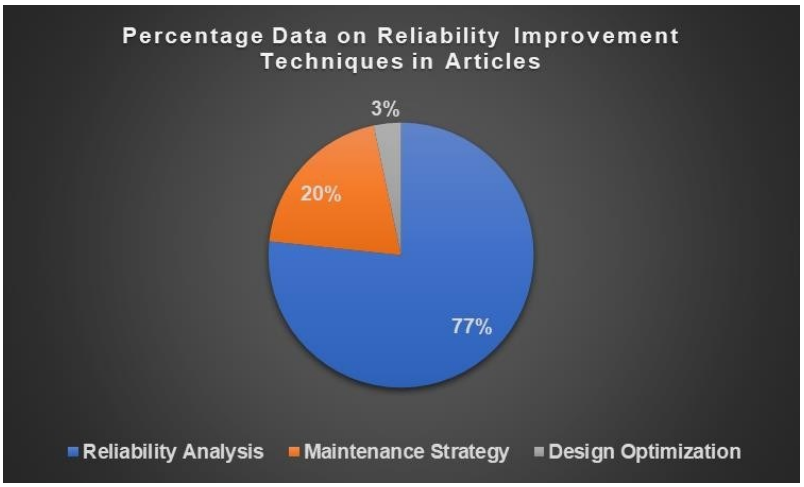


Figure 6. Percentage Data on Reliability Improvement Techniques in Articles

According to the data shown in Figure 6, 77% of the articles discuss reliability analysis techniques, 20% of the articles discuss maintenance strategy, and 3% of the articles discuss design optimization. Researches that apply reliability analysis in reliability improvement include [3], [11], [12], [13], [14], [15], [17], [19]–[22] [23]–[32], [34], [36]. Meanwhile, another researches that practice maintenance strategies for reliability improvement include [10], [16], [18], [35], [37], [38]. In addition, the only research that performs design optimization in reliability improvement is [33]. All three techniques aim to improve the reliability of railway vehicles.

5. DISCUSSION

Indonesia is one of the countries that has an important railway transportation system in connecting various regions. However, just like any other transportation system, train operations sometimes experience disruptions due to problems with railway vehicles. Disruptions in train operations can cause inconvenience to passengers, schedule delays, and potential safety issues [39]. Such disruptions can be caused by various factors such as mechanical failure, electrical malfunction, or problems with the braking system, among others. Therefore, it is imperative to focus on improving the reliability of railway vehicles to more effectively address the disruptions that still occur.

By prioritizing reliability improvement, the goals are to minimize the occurrence of unexpected breakdowns and failures in the railway system [40]. This involves applying various techniques and strategies to improve the performance and durability of railway vehicles, such as locomotives, trains, and cars. In Indonesia's railway vehicle reliability improvement efforts, techniques such as comprehensive reliability analysis, appropriate maintenance strategies, and design optimization are highly relevant. They complement each other and can be effectively implemented to achieve significant reliability improvements.

First of all, reliability analysis plays an important role in understanding the performance and weaknesses of railway vehicles [41]. By collecting and analyzing historical data, reliability analysis helps identify components that frequently fail or require repair. This information forms the basis for taking necessary preventive measures, including repair or replacement of failure-prone components. Thus, reliability analysis helps to reduce the risk of sudden failures and extend the service life of the vehicle.

Furthermore, an effective maintenance strategy plays a role in maintaining the optimal condition of railway vehicles [42]. Through a planned maintenance schedule, including preventive maintenance and scheduled repairs, railway vehicles can be properly maintained and guarded against possible failures. Routine inspections, replacement of components that have reached a certain age or operating hours, and planned maintenance are important steps in implementing an effective maintenance strategy. With a good maintenance strategy in place, trains can operate more reliably, reducing unexpected disruptions and disturbances that can affect reliability and safety [43].

In addition, design optimization is another aspect that contributes to improving the reliability of railway vehicles [44]. By applying proper design principles, such as using durable materials, considering environmental factors, and accounting for operational loads, railway vehicles can be designed with higher reliability. Thus, design optimization plays a role in improving the reliability and overall performance of the vehicle.

Reliability improvement efforts on railway vehicles can make a significant contribution in reducing operational disruptions, thereby improving passenger experience, time accuracy, and overall safety. By reducing unexpected breakdowns and failures, reliability improvements can bring tangible benefits in maintaining smooth rail travel, avoiding costly delays for passengers, and creating a safer environment. Furthermore, improving reliability in railway transportation systems also has a positive impact in terms of efficiency. By addressing frequent disruptions, train operations can run more smoothly and planned. This not only improves passenger satisfaction but also supports the country's economic growth and development. With safe, reliable, and efficient transportation, the movement of goods and people become easier, trade can flourish, and connectivity between regions can be improved, ultimately contributing to sustainable economic development.

6. CONCLUSION

This literature review provides reliability improvement techniques for railway vehicles in the world. This paper also discusses that reliability improvement in railway vehicles involves measures to enhance dependability, minimize failures, and ensure efficient operation. Techniques like reliability analysis, maintenance strategies, and design optimization are crucial for achieving higher reliability. These techniques identify weaknesses, implement preventive actions, and maintain optimal conditions. Improving reliability in Indonesia's railway vehicles is essential to address disruptions and improve passenger experience. It involves comprehensive reliability analysis, effective maintenance, and optimized design. By reducing breakdowns and failures, reliability improvements enhance safety, efficiency, and economic growth.

Future research can focus on three key areas in improving the reliability of railway vehicles. First, the application of intelligent technologies such as IoT and AI can assist in the real-time collection and analysis of operational data to detect problems quickly. Second, the development of more advanced reliability analysis methods can provide deeper insights into the factors affecting vehicle reliability. Finally, the optimization of maintenance strategies with advanced predictive maintenance methods, the use of failure prediction technologies, and big data analysis can help identify and fix problems before serious failures occur.

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