Improving the Effectiveness of Rolling Stock Maintenance: A Systematic Literature Review

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Abstract

Urban transportation currently has a very important or crucial role because it is one of the factors that strongly support the ongoing economy. One of the transportation modes that is currently had a very high demand in Greater Jakarta is Kereta Rel Listrik (KRL). KRL need to provide not only availability and facility, but also focus on reliability and safety. Had a good operational strategy, especially in the maintenance of rolling stock should be done. Reliability centered maintenance (RCM) is one of approach to optimize the rolling stock maintenance practices given that several critical components have been operating for certain number of periods. The maintenance concept that focuses on reliability brings a good on determining treatment decisions or maintenance strategies. It is also minimized the technical problem in operation by knowing its failure mode. Purpose of this research is to provide an overview of the reliability concepts for rolling stock maintenance from several research journals. This paper contains of several up-to-date literature for improving the effectiveness of rolling stock maintenance from each case of journals and papers. Future maintenance work is based on establishing reliability-based systems. To provide high reliability rolling stock, it is important to introduce reliability analysis methods and to make use of new management indices that consider the impact of faults on transport and cost performance.

Keywords
FMEA, Railway, Reliability Centered Maintenance, Remote Condition Monitoring, Rolling Stock

1. Introduction
Rolling stock in railway industry is a vehicle that can move on rail roads, has special characteristic and advantage to transport passenger and goods in mass quantity, punctuality, saving energy safety and has a low level of pollution and is more efficient for long-distance and in city transportation. Rolling stock that serve public transportation must be safe in operation. Rolling stock maintenance plays an essential role in offering customers safe and reliable transport by ensuring that rolling stock is always in good order. Current rolling stock maintenance in Indonesian Railways Company is based on the concept of preventive maintenance according to the law of Ministry of Transport. In other words, repairs and maintenance are carried out before equipment fails to ensure that operations continue normally. Preventive maintenance is composed of the following parts: wear and tear prevention, rolling stock and equipment suffer some natural wear and tear during normal operations. Regular rolling stock maintenance, including lubrication, replenishment and replacement of consumables, cleaning, adjustment, etc., helps ameliorate this wear and tear. Rolling stock maintenance, including inspection, replacement, and repair of worn parts, plays an important role in fault and accident prevention.

When rolling stock maintenance is performed over the long term, large amounts of data are collected on various types of rolling stock and parts. Analysis of these data from various perspectives provides information on procedures for measuring, evaluating and repairing wear and tear. In addition, such information is very useful in designing and developing new rolling stock. Although preventive maintenance is the basis of rolling stock maintenance, unfortunately, faults and accidents still sometimes occur Purpose of this research is to provide an overview of the reliability concepts for rolling stock maintenance from several research journals. This paper's review contains of an up-to-date literature for improving the effectiveness of rolling stock maintenance from each case of journals and papers. In these cases, rolling stock maintenance also includes repair of damaged equipment and parts. Another role of rolling stock maintenance is rebuilding old rolling stock and performing upgrade work to prevent accidents and to improve service. Rolling stock maintenance laws Based on the PP 56 2009 regarding the operation of rail transport Law, the Ministry of Transport regulating basic railway technologies. These regulations specify that rolling stock shall maintain among interval: daily, monthly, six-monthly, yearly, two-yearly and four-yearly and also shall not be used if it cannot be operated safely. In addition, ministerial notices that are related to inspection of facilities and rolling stock based on the ministerial ordinances, cover three types of inspections in terms of the general rules for inspection interval and contents: conditions/function inspection (called Scheduled (or Rostered) Inspection); inspection of critical parts (called Important Parts Inspection) and General Inspection.

2. Literature Review

The rail transportation system is undergoing extensive transformation in recent times. As we know that recently, demand of railways transportation has increased rapidly. (Rezvanizaniani et al., 2019). Achieving the level of service quality of rail traffic that is determined in a certain time interval safely is the goal of the railway system. Thus, more advanced technology and a more modern railway system to achieve the specified goals. Also, railway industries want to improve system performance to serv high quality railway services while operating the railway system efficiently (YUN et al., 2013a). Rolling stock maintenance can be categorized into two types: failure-based maintenance (corrective maintenance) and life-based maintenance (preventive Maintenance). The time interval in preventive maintenance can be scheduled depends on the total cost in maintenance activity and life distribution of the components. However, when the random failure occurs in some components, corrective maintenance is unavoidable. The total maintenance cost depends on the percentages in performing corrective maintenance and preventive maintenance (Cheng et al., 2006a). Failure in service can cause service delays and passenger dissatisfaction, so rolling stock maintenance is necessary. Moreover, it also causes an increase in maintenance costs (Alkali et al., 2016). All special railway facilities for transporting people, including passenger trains, electric double units, diesel double units, and diesel electric double units to be operated must be inspected according to the stipulated schedule. This is to support the operation of the railway and ensure travel safety. The maintenance quality determined by several aspects, some of them: maintenance strategy, location, spare parts, working procedure, skill, inspection equipment, and support facilities (Hidayat and Mahardiono, 2015). Preventive railway maintenance is a job that is carried out periodically to upkeep condition (status) or to monitor rolling stock equipment during to minimize the possibility of failure mode. It can be analyze based on the data obtained during the monitoring process, this is used to determine the appropriate prevention (Macedo et al., 2017). The challenge of the maintenance function to proofing reliability by managing of equipment management and maintenance strategy formulation has been one of the important contents of the company's daily management. Preventive maintenance strategy forward based on reliability centered maintenance (RCM). Key indicators of equipment reliability, such as mean time to repair restoration (MTTR), mean time between failure (MTBF) and availability, fault analyzes were performed, and relevant results calculated. Then, the process failure mode and effect analysis (PFMEA) of the filling machine was implemented, and a fault tree analysis (FTA) of potential failure modes with high-risk priority numbers was also completed. Then the filling equipment prevention and maintenance strategy is established based on the RCM. Corrective maintenance is a task normally performed to identify, isolate, and resolve faults. Whereas predictive maintenance techniques are generally designed to determine and predict failure conditions (Zeng et al., 2021).

The optimization of preventive maintenance planning that well-established widely known as reliability-centered maintenance (RCM). The first step that used to identifying the most critical item in terms of safety and reliability is analyze by failure modes and effects analysis (FMEA). After getting the critical items that effect on rolling stock reliability maintenance tasks should be selected due to optimal failure modes prevention (Ciani et al., 2021). RCM is a key technology in the evolution of smart trains, enabling increased reliability at lower costs. The cost management approach associated with implementing RCM on rail relies on specific business-to-business commercial agreements and predetermined fees. It lacks the flexibility needed to fully exploit data generated in the "big data" era, where automated model development often requires access to multiple data resources from across industries (Alzahrani, 2021). Initially the determination of maintenance actions based on the principle of safety has been used and combined with high-precision inspection through maintenance standard. In this area, ongoing condition-based monitoring is used to inform the decision-making based on rolling stock analysis during their operation. With the development of technology to carry out real-time monitoring and measurements in rolling stock maintenance are used by maintenance engineers to make maintenance decisions. The following is a focus on increasing critical items on the practicality and quality of such measurements. Improving the cost-effectiveness of maintenance can be achieved by reducing urgent and costly unplanned incidents. the condition monitoring system is implemented on an ongoing basis. This presents difficulties because a single measurement system that observes a large area or in other words requires a low cost to be used in large volumes (Entezami et al., 2020). The implementation of preventive maintenance and corrective maintenance sometimes does not run optimally in a company. Therefore, a maintenance system was developed to increase the reliability of the machine. The method used is Reliability Centered Maintenance (RCM) with the aim of determining maintenance time intervals and estimated maintenance costs. RCM is done by analyzing the failure with FMECA. The result of this analysis is the RPN value which shows the rail bearings, spindle bearings and hoses as critical components of the system (Hamro Afiva et al., 2019).

3. Methods

The type of this research is based on systematic literature review of academic journal according to reliability concept and technological developments for rolling stock maintenance. This paper's review contains of an up-to-date literature for improving the effectiveness of rolling stock maintenance from each case of journals and papers. From this review of the journal led the author to conclude how the development of the effectiveness of rolling stock maintenance. The data searching process was limited to contributions published between 2004 and 2022. Specific information related to each stage of the research review is provided in the Figure 1.

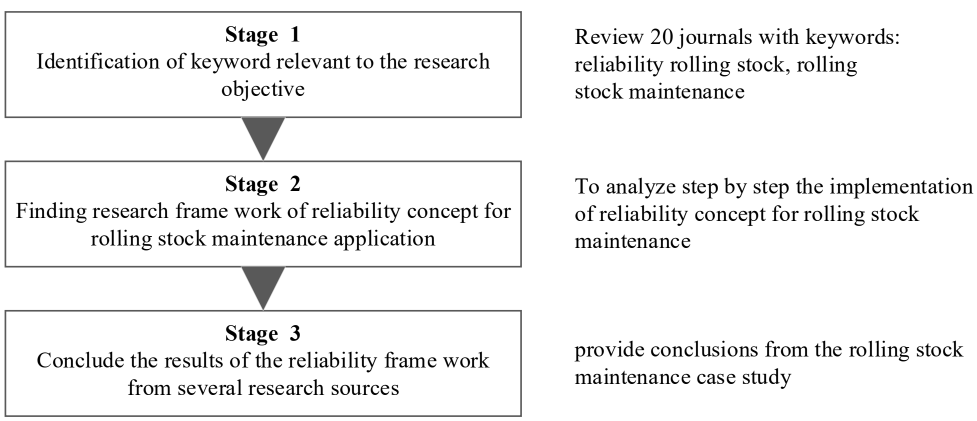

Figure 1. Research stage

4. Data Collection

Table 1. Data collection

Definition	Author
……. To develop I4.0TIM used Literature review and online survey. One of the evidences that can help train operators in implementing Industry 4.0 technology is through I4.0TIM face validation.	(Wippel et al., 2021)
RCM is possible to detect fault cases on railways. Therefore, RCM can be utilized in system health monitoring. For companies that implement RCM, they need support from management. There is a major concern, namely having sufficient resources and areas of competence in both offline and online CBM techniques. Then the company only needs to work with CBM tools and techniques.	(Singh et al., 2020)
Building trust of rolling stock maintenance must reflected of increasing the confidence of stakeholders who are responsible to the event of maintenance registration system is designed to analyze the quality of the maintenance.……… information maintenance management. Reflected on the potential of BT in increasing the confidence of stakeholders who are responsible for the maintenance of rolling stock. The event of maintenance registration system is designed to analyze the quality of the maintenance.	(Abbas et al., 2020)

Definition	Author
On railways in the UK, a cab-based track (rail) monitoring system has been developed utilizing the on-board GSM-R cabin radio. The type, location, and severity of track defects can be reported using the system through the addition of low-cost sensors. This improves network security and performance by efficiently directing maintenance crews to fault locations and minimizing time spent on maintenance and inspections.	(Balouchi et al., 2021)
Reliability-centered maintenance (RCM) is preventive maintenance planning. Optimization of the maintenance plan for HVAC systems located in high-speed trains is the main discussion in this paper. The first step of the RCM procedure identifies the most critical items through failure mode and effect analysis and then proposes the optimal maintenance task through RCM.	(Ciani et al., 2021)
Intelligent Railway Transport Systems by NRZ (Zimbabwe National Railways) Zimbabwe. The adoption of this technology is on an increasing trend in both developed and developing countries. Rail Tracker in Tanzania has improved rail services in the country. Also, in Uganda and the Kenya Rift Valley Railway (RVR) has introduced GPS technology for rail lines. Whereas In India, a system is used to detect defects in rolling stock while in transit. When this system is implemented, it significantly improves the efficiency, safety, and service quality of railway operations.	(Shambira & Mandiudza, 2021)
Failure Mode, Effects and Criticality Analysis (FMECA) analysis for analyses one of component systems in railways. The study of rolling stock mandatory components that ensure safety and reliability and maintenance costs. The beginning of the discussion of this paper explains the use of analytical methods trough FMECA which was carried out highlighting the main criticality of the rolling stock components.	(Catelani et al., 2021)
Predictive maintenance with information technology, input data in the form of condition monitoring results taken through 2 (two) sources, namely based on sensor readings that are installed directly on the components of the rolling stock (remote condition monitoring) and based on data on the results of maintenance (condition monitoring) by maintenance operator when the rolling stock undergoes periodic maintenance. The results of sensor readings and maintenance data are stored online and in real time through a cloud system and then analyzed by a competent maintenance engineer to decide on maintenance actions, evaluate performance and develop rolling stock designs.	(Alzahrani, 2021)
The use of on-board sensor devices has been developed and implemented to monitor the track conditions of regional railway lines in Japan. To detect and isolate track disturbances from car body vibrations, field tests and SIMPACK simulation studies are used.	(Tsunashima, 2019)
One of the operational technical failures is affected by the defects of shaft bearings. It is clearly decrease efficiencies in rolling stock operation. During the operation bearing with good condition produce certain levels of vibration and noise, so it can compare with defects bearing, because there have different substantial changes in vibration and noise levels. Early detection needs to be done, before the damage becomes serious.	((Entezami et al., 2020)
This study presents the results of the application of RCM with a comprehensive analysis and its application to the Diesel Multiple Unit (DMU) Class 158 train door system. The analysis is carried out on the door system as a complex system. Potential cost and safety/operational savings explained through RCM Cost Analysis. Therefore, maintenance intervals can only be extended if maintenance-related safety critical systems are upgraded.	(Alkali et al., 2016)
In supporting the operation of train journeys and ensuring the safety of their journeys, inspections must be carried out according to the schedule set at the maintenance sites, namely at Balai Yasa and Depo. the quality of maintenance is also determined by the availability of spare parts which also determined by the availability of work and inspection equipment, conditions, locations, and support facilities. Evaluation of equipment at Balai Yasa and Depot supports train maintenance and preparation of minimum equipment requirements that must be carried out with the goal of being met and achieving train maintenance.	(Hidayat & Mahardiono, 2015)
In this study, the discussion is carried out on preventive maintenance scheduling for the rolling stock system. In this study consider the life cycle costs and system availability to optimize the PM interval of the subsystem and the rolling stock system. A RAM S/W Simulation as an AvSim module is used to estimate system availability and life cycle costs.	(YUN et al., 2013)
This study presents an analysis of failure data in the rolling stock industry. The frequency of failure analysis describe that the wheelset is one of the most critically component of a passenger train (rolling stock). This study shows that type I-wheel set, is the most reliable type of wheel set, which can be operated up to 27568 Km without less than 90% reduction in reliability…….	(Rezvanizaniani et al., 2009)
This study aims to provide information about the method of rolling stock maintenance strategy that considers the important interactions between the decision-making levels and the criteria. The methodology of this study adopted the ANP which was used to evaluate. The authors consistently use the results of the empirical method for ANP to determine the probability ratio between preventive maintenance and corrective maintenance which includes the possibility to determine the number of spare parts and replacement intervals of rolling stock components.	(Cheng et al., 2006)
In this study, a predictive maintenance system in rolling stock maintenance, called RCM, has been implemented to improve service quality. RCM is integrated with two other types of maintenance techniques, namely Centralized Maintenance Reliability (RCM1) and Remote Condition Monitoring (RCM2). This system consists of an Unobserved Components model arranged in a State Space framework, where the unknown system elements are estimated with the Maximum Likelihood…..	(Pedregal et al., 2004)
Monitoring the condition of the current rail system has become a phenomenon of global importance in the last few decades. Approaches to monitoring the applied to the rolling stock currently operating is a very important and challenging point. because this if it can be done correctly it can maintain reliability and reduce rolling stock maintenance costs through media ranging from applications connected to sensors mounted on rolling stock.	(Kostrzewski & Melnik, 2021)
Based on this study which aims to analyze, evaluate and determine the selection of maintenance methods for rolling stock carried out by railway operators, especially in businesses undergoing rolling stock maintenance. The first study identified maintenance strategies, and then the six maintenance strategies adopted by the company were identified. Finally, the data collected from the survey was analyzed using an index of importance to complete the ranking analysis.	(Idris et al., 2022)
NedTrain is responsible for the maintenance of the carriages. The life cycle is 30-40 years during which the condition of the asset is maintained to meet its performance requirements and enhanced to meet customer expectations over its life. Currently rolling stock is maintained at fixed maintenance intervals of 3 months with in between service checks repairs.	(Ceng & van Dongen, 2013)
Keeping the railway infrastructure in good operating condition at a low cost is the goal, also taking into account the limited resources available in what concerns crew members. The deterioration of equipment with use and age and a good preventive maintenance program can greatly reduce their unreliability in the sense that expected failures can be anticipated. We propose a	(Macedo et al., 2017)

Definition	Author
mixed integer programming formulation for the scheduling problem of preventive railway maintenance activities and the Variable Neighborhood Search (VNS) algorithm for solving large problems.	

The results according to the data review in Table 1; nearly 20-review paper's reliability concepts for rolling stock maintenance have been published in the last two decades. All data were cited from every research: origin and full referral journal, authors, institutions and countries placed, as they were, main topics journal and summery of the research.

5. Results and Discussion

From this research of literature review was found at least four criteria of reliability concept implementation in railways industry, the largest criteria of reliability concept in railways industry that is often used is remote condition monitoring about 40% of research journal, generally the authors concluded that remote condition monitoring is take lot of effectiveness and mainly used to analyze components before running to failure. 35% criteria of reliability concept implementation are to get failure analysis. Then 25% of that researcher using reliability concept to decide proper maintenance selection. (Rezvanizaniani et al., 2009) express that rolling stock which originally only applied maintenance based on fixed time may not be in accordance with the maintenance requirements per each component of the rolling stock. Rolling stock maintenance with fixed time interval had some of disadvantages as follows:

- Rolling stock performance cannot be calculated.
- Low-cost effectiveness, especially when rolling stock is rarely used.
- If rolling stock is fully utilized, the minimum allowable condition may be reached too early.

Thus, rolling stock maintenance requires an analysis of the selection of maintenance task and schedule, while safety is the most important factor and is the focus in maintaining passenger satisfaction in the rolling stock industry, currently, the most effective and widely used in rolling stock maintenance optimization strategy is RCM. The benefits of applying the RCM method directly impacting the condition of the rolling stock that have been proven to offer significant benefits in increasing reliability and availability which can remind productivity by reducing rolling stock failures. When failures are recognized, the consequences must be considered. Therefore, the RCM strategy was chosen to be implemented to increase maintenance productivity (Rezvanizaniani et al., 2009). The focus of RCM implementation is to eliminate faults that may cause serious accidents such as: train fire, derailment, decoupling, opening of automatic doors while running, loss of control. Maintenance countermeasures are taken from both the hardware and software aspects with the aim of eliminating these types of faults. Taking effective countermeasures to hardware faults Countermeasures to hardware that should be taken urgently are handled either jointly by branch offices or are targeted as Obligatory, Replacement. Both are mandated by head office and are executed by branch offices under the head office budget. Clearly understanding the wear and tear trends by fling stock and parts and trends in fault occurrence are important aspects in taking effective: countermeasures to hardware faults; reliability analysis is performed, and appropriate countermeasures are taken. Eliminating faults due to human error About 15% to 20% of all faults are due to human error. Such faults are characterized by repetition of the same mistake and prevention requires continuous monitoring for problems in the rolling stock maintenance and work systems as well. adoption of pro-active systems for upgrading working procedures. It is important to recognize human error as a cause of lowered reliability and to take positive countermeasures such as providing education and training in technology, skills and knowledge, and publishing company-wide notices, maintenance bulletins, videos, etc., detailing faults and important checks. Generally rolling stock reliability means that rolling stock has required functional quality during the specified period. Since rolling stock is composed of various equipment and parts, these components are also subject to reliability requirements. The normal function of equipment and parts decreases during use due to age related wear, deformation, deterioration, etc., ultimately resulting in the occurrence of faults and reduced reliability. The reduced reliability ultimately results in the rolling stock becoming unsuitable for operations or inoperable. This is classified as a rolling stock fault. Figure 2 shows the basic of increasing rolling stock reliability.

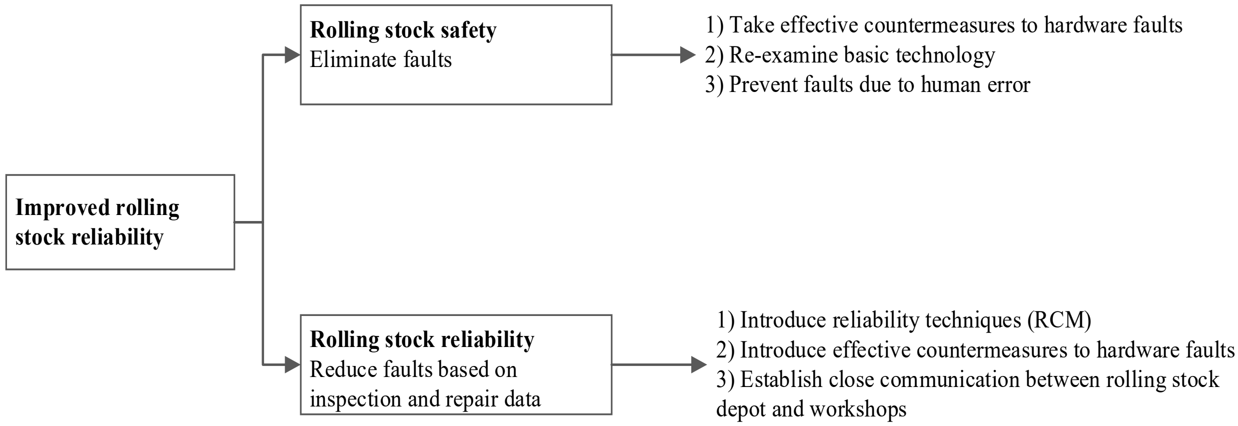

Figure 2. Improving rolling stock reliability

This has evolved into the three-step reliability management system aiming to provide effectiveness of rolling stock maintenance as the basis of reliability management described below:

Step 1 Introduction of reliability management methods based on train downtime
- Understanding impact of rolling-stock faults on customers
- Understanding priority of type of rolling stock fault and countermeasures

Step 2 Introduction of separate reliability management methods for different types of equipment
- Execution of reliability analysis for parts and equipment with large impact of train operation
- Review of maintenance contents by depot and by workshop in accordance with improving reliability.

Step 3 Introduction of reliability management methods based on cost performance
- Ranking repaired by age of equipment and parts
- Review of maintenance costs

Reliability-centered maintenance (RCM) is the optimal mix of reactive, time-based, or interval-based, condition-based, and proactive maintenance practices. These key maintenance strategies, rather than being implemented independently, are integrated to leverage each other's strengths to maximize facility and equipment reliability while minimizing lifecycle costs. Total productive maintenance (TPM), total maintenance assurance, preventive maintenance, reliability centered maintenance (RCM), and many other innovative approaches to maintenance issues all aim to increase machine effectiveness and ultimately increase productivity as depicted in Figure 3 (Islam, 2010).

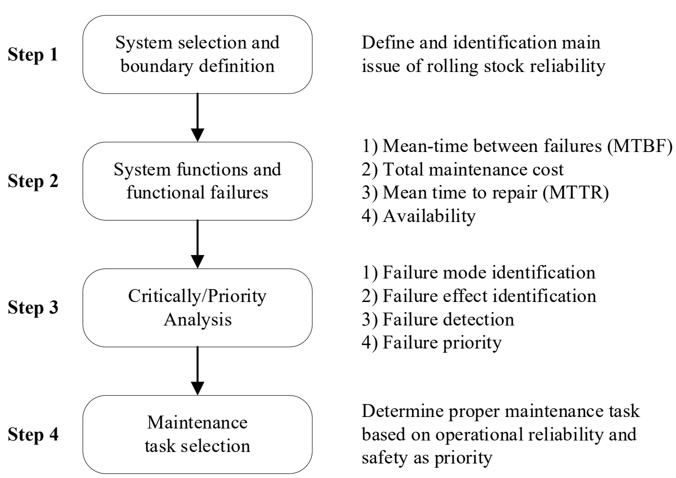

Figure 3. The framework of RCM

The application of the RCM framework will assist the expert in determining the treatment program. The preventive maintenance based on fixed time intervals makes simple maintenance scheduling, however, to ensure the desired of maintenance productivity will be very difficult if the rolling stock is in different uses. Thus, any malfunction of the rolling stock depending on its impact on the whole system, will require certain maintenance tasks. RCM to all maintenance units and the complexity of the work must be used following step:

Step 1. The first RCM systematic approach used to implement maintained system functions, identify failure modes, prioritize failures used to implement maintained system functions, identify failure modes, prioritize failure modes, and perform PM tasks.

Step 2. Second stage is to measure that failure on rolling stock has serious problem that effect to the management standard by knowing system function and functional failures through:

1) Mean-time between failures (MTBF).
2) Total maintenance cost.
3) Mean-time to repair (MTTR).
4) Availability.

Step 3. The next stage is to analyze the critically factor of potential to occur in each rolling stock component that has a high impact on safety, operational failure and maintenance costs. Equipment failure impacting to performance of rolling stock requires analysis considering generating critical analysis to work priority (risk priority number). In general, the failure mode, effect, and criticality analysis (FMEA/FMECA) require identification of the following basic information, the algorithm for calculating equipment criticality is presented. Several approaches are proposed in the literature to find a threshold value that distinguishes the critical failure mode from the negligible mode after performing the FMECA procedure. Some of them are imprecise and inefficient while others are just qualitative procedures to identify two data sets. To overcome the subjectivity of setting a threshold between acceptance and non-acceptance of risk, a new analytical procedure has been proposed in this paper. This method begins with the aim of identifying two distinct subsets characterized by two distinct trends: the first subset of the RPN grows gradually and the second undergoes a sudden increase. (Catelani et al., 2021).

Step 4. Logical tree analysis (LTA) is a decision tree structure to determine the appropriate maintenance task. From this figure, where decisions are made operational reliability and safety, operational comfort, and cost efficiency. To select optimal maintenance task, each failure mode is assessment trough some quality questions determined by maintenance expertise or top management. The first question is asked: Did the failure affected to safety and followed by did the operator can detect or monitor the failure mode in normal operation, know that something abnormal or detrimental had occurred at the plant? The operator does not need to know exactly what is wrong for the answer to be yes.

6. Conclusion

Improving rolling stock reliability. Previous fault-prevention management focused mainly on the number of faults using parameters such as the number of faults per million-operation km. However, indices based only on the simple number of cases do not quantify the effects of differences such as traffic density and track section conditions. For example, a 10-minute stoppage due to a fault is counted in the same manner as a complete stoppage in operations. Clearly, this is not an accurate index of faults. Future maintenance work is based on establishing reliability-based systems. To provide high reliability rolling stock, it is important to introduce reliability analysis methods and to make use of new management indices that consider the impact of faults on transport and cost performance. The basic considerations for introducing reliability methods are listed:

Awareness of impact on customers
- Individual management of equipment with large impact on train diagrams when fault develops
- Achievement of effective repair of faults

Awareness of cost performance
- Company-wide awareness of cost-effective fault prevention
- Ranking maintenance method by railway line and elapsed time

Development started in 1988 and the system was put into use gradually from 1991 until it became operational in 1995. In addition, this Railway Management System is positioned as part of the Integrated Railway Operation System. Especially for components that require maintenance selection with condition monitoring, with recent developments in sensors and information technology (IT), conditions at railway facilities can be continuously monitored using sensors installed in rolling stock (Tsunashima, 2019). Purpose of systematization, the various data collected on rolling stock used to be recorded, documented, and saved by each rolling stock depot and workshop. In addition, data on faults was input by depots into operations office computers and by workshops into the workshop Information Management System. However. Since both sets of data were managed separately, it was not used to the best effect. Consequently, a new system was developed for the following purposes:

- To integrate and share data collected by depots and worships, etc.
- To make effective use of collected data in improving rolling stock reliability.
- To make rolling stock management and inspection planning responsive and efficient.

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