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Railway Spare Parts Supplier Selection Using Analytic Hierarchy Process: A Case Study of Rollingstock Spare Parts

Nurhannani Fasihah Zulkarnain[1], Nor Aziati Abdul Hamid[1,2]*, Mohamad Ali Selimin[1]

[1] *Department of Production and Operation Management, Faculty of Technology Management and Business, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, 86400, MALAYSIA*
[2] *Industry Centre of Excellence for Railway, Institute of Integrated Engineers, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, 86400, MALAYSIA*

*Corresponding Author: aziati@uthm.edu.my
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Abstract

The selection of spare parts from railway suppliers is a multifaceted process influenced by various factors, including cost, quality, delivery speed, and supplier reliability. Despite significant advancements in supply chain management and inventory control, notable research gaps persist in this domain. A particular deficiency exists in Malaysia, where there is a lack of focused research on the selection of suitable and dependable suppliers, a challenge frequently encountered by rail operators in the country. This study aims to address this gap by examining the current issues related to the performance of suppliers of rolling stock spare parts for a major railway operator in Malaysia. The research employs the Analytic Hierarchy Process (AHP) to analyze the critical criteria for selecting suppliers of rolling stock spare parts and to propose enhancements to the existing supplier selection process at the operator's maintenance depot. The study specifically targets the electrified multiple unit type 93 version 2 and utilizes a quantitative approach through an online survey questionnaire. The survey was completed by procurement staff, maintenance personnel, warehouse staff, and senior engineers, with a total sample size of 17 respondents, all of whom possess a minimum of three years of experience in asset maintenance and procurement. AHP and pairwise comparison methods were utilized for data analysis and collection. The findings revealed a consistent comparison matrix between the two primary criteria: Inventory Aspect and Maintenance Aspect, with Alternative 1 identified as the optimal choice, thereby suggesting effective strategies for rail supplier selection. In conclusion, rail operators can utilize the ranking criteria established in this study to select the most suitable spare parts suppliers, thereby mitigating risks and enhancing spare parts inventory.

1. Introduction

The selection of rolling stock spare parts suppliers is vital for ensuring high train availability, cost-effective maintenance, and overall operational efficiency. For industries with significant investment assets such as railroad companies, maintenance of assets and equipment is crucial (Li *et al.*, 2017). To meet system requirements for availability; high levels of service, cost effectiveness, maintenance management are crucial. The cost of total maintenance is influenced by the availability of spare parts, labor capacity, and maintenance (Turan *et al.*, 2020). Original Equipment Manufacturers (OEMs) can contribute to minimizing downtime and maximizing availability of the equipment or products throughout the usable life span by selling after-sales services and spare parts (Topan *et al.*, 2020). Accordingly, learning how to obtain a reliable supply of spare parts is important. Estimating the demand for spare parts depends on the quantity of equipment, the behavior of parts failure, and the organization's acknowledged maintenance policy (Van der Auweraer & Boute, 2019). The selection process is crucial as it ensures that the railway company receives high-quality spare parts that meet their requirements and comply with standards. Since the demands for mobility are growing and the state of technology is changing so quickly, railway operation must be able to meet these demands. To address the demand, one of the important train systems is rolling stock. Rolling stock interacts closely with all other structural elements of the rail network, including the tracks, tunnels, station platforms, catenaries of the electrical system, control, signaling, and communication systems, as well as the system for managing operations and maintenance. There are various factors to be considered in supplier selection specifically for rolling stock spare parts such as; quality, cost, reliability and safety (Asmara & Kusumah, 2021). According to Liao & Kao (2010), Multi Criteria Decision-Making (MCDM) methodology for supplier selection is presented in various literary works to evaluate some vendors using a set of criteria to fulfill organizational requirements. Suppliers can be evaluated both qualitatively and quantitatively using evaluation using multi-criteria considerations (R. Kumar *et al.*, 2019).

Selecting the right rolling stock spare parts suppliers is crucial to train availability for several reasons. First is to minimize the downtime by selecting reliable suppliers with appropriate quality of the product/equipment. Using high-quality spare parts from trusted suppliers minimizes the likelihood of breakdowns and repairs, leading to more reliable train operations. Using high-quality components minimizes the frequency of replacements, which in turn decreases the total maintenance expenses throughout the trains' lifespan. Secondly. choosing the right spare parts guarantees their compatibility with the specific train models, preventing problems that may occur from using parts that do not match. Third, a strong relationship with suppliers enables just-in-time inventory management, minimizing the necessity to maintain large stock levels that can tie up financial resources. Besides that, collaborating with several trustworthy suppliers minimizes the risks linked to depending on just one supplier, which helps maintain a consistent supply of spare parts. The most important point of good selection of suppliers is well established suppliers will provide high-quality spare parts that can help to extend the lifespan of trains, allowing them to function effectively for extended durations without requiring significant repairs. Regularly utilizing top-notch, dependable components ensures the safety and dependability of train services, which is closely associated with their availability.

KTMB is currently facing challenges related to the performance of suppliers for rolling stock railway spare parts. As the company increasingly relies on suppliers for spare parts and services that were once handled internally, the supplier selection process has become crucial in purchasing activities (Seitz *et al.*, 2020). The reliance on dependable suppliers is growing, particularly for imported spare parts, which can result in longer maintenance lead times, high currency exchange rates, delayed services, and budget approval issues. Additionally, the critical nature of inventory, warranty, and the lifespan of railway equipment and spare parts maintenance poses significant risks. Any of these factors can lead to rolling stock failures and impact supplier performance (Hu *et al.*, 2017). Understanding lead times for parts is essential for effective stock management, as it influences decisions on which parts to maintain in inventory. Therefore, addressing these challenges is vital for the efficient operation of the railway system. KTMB must ensure that its spare parts inventory aligns with maintenance strategies while keeping costs low (min-max inventory). The company employs a centrally managed procurement system, although some procurement processes still rely on a semi-manual workflow. The procurement department of KTMB indicates that the lead time for each replacement item, whether sourced locally or internationally, is quite lengthy. Local orders may take between 1 to 3 months to be delivered, while international orders can take 3 to 6 months to reach the depot. If downtime is not a pressing issue for the company, spare parts that can be quickly and easily obtained may be excluded from the stock plan. However, delays in receiving spare parts can disrupt operations and lead to increased production costs. When an ordered item takes too long to arrive, the company may have to place an order with an external supplier to compensate for the shortage. Additionally, this situation restricts the train's availability for improvements, as the company must dedicate time to rolling stock maintenance.

To address these challenges, it is crucial to implement the Analytical Hierarchy Process (AHP) method at KTMB Batu Gajah to determine the key criteria for selecting suppliers of rolling stock railway spare parts. The AHP method serves as a decision-making tool that aids in assessing criteria and choosing the most appropriate supplier. By utilizing the AHP approach, it is possible to pinpoint the most important factors and select the best provider for KTMB Batu Gajah. Additionally, there is a need to enhance the current spare part supplier selection process at KTMB Batu Gajah. The AHP method can be employed to analyze the criteria, as well as to design a supplier performance monitoring system and develop a supplier evaluation system. These enhancements could contribute to the efficient operation of the railway system, reduce maintenance costs, and improve the quality of spare parts. The management of railway spare parts supply chains in Asian countries encounters major challenges that hinder efficiency and operational effectiveness. Significant issues include logistical obstacles, high inventory expenses, and outdated infrastructure. Logistical difficulties arise from the complexity of aligning local supply chains with global market standards (Banomyong, 2010), along with regulatory requirements that drive up costs and complicate procedures (Banomyong, 2010). Inventory management is also a concern (Huang & Xu, 2024), as the high costs of maintaining spare parts for rolling stock and unpredictable demand patterns result in planning and resource allocation inefficiencies (Krasheninin *et al.*, 2021). Additionally, infrastructure issues worsen these challenges, as many Asian nations depend on aging rolling stock (Krasheninin *et al.*, 2021) and lack centralized service centers (Krasheninin *et al.*, 2021)., which leads to delayed repairs and diminished service quality.

However, some Asian countries are starting to adopt advanced technologies and innovative strategies to modernize their supply chains. This includes initiatives aimed at improving sustainability, optimizing inventory, and streamlining logistics. These advancements indicate a gradual transition towards a more efficient and competitive railway supply chain system, positioning the region for enhanced supply chain performance in the future. By addressing these challenges through modernization, railway operations could see significant improvements, contributing to economic growth and increased service reliability throughout the region. The supply chains for spare parts of railways encounter multiple challenges because of obsolete processes and equipment. Inadequate demand planning, which depends on past performance and human experience, causes component supply to either exceed or fall short of real demand by more than 30%, which causes maintenance delays and increased expenses. It is not uncommon for warehouses to have parts for out-of-date train types in stock, along with other rarely used items that have been held for years in excessively large stocks. Limitations placed by regulations on supplier alternatives make it difficult to manage several providers, which affects delivery reliability and encourages spot purchases. Aside from that, unclear data roles, obsolete spare part, redundant inventory, real time monitoring and outdated IT systems lead to insufficient or inaccurate master data, which impedes openness and data-driven planning (Idris *et al.*, 2023). Maintenance facilities experience inefficiencies, delays, and untracked inventory because of siloed operations, in which spare-part supply chain companies run independently from repair shops. In the context of KTMB supply chain, the most highlighted issues are insufficient comprehensive studies on the selection of suppliers for rolling stock railway spare parts among railway operators in Malaysia. Hence lack of best practices can be referred. Current literature fails to adequately tackle the specific challenges and needs of the railway sector in supplier selection.

KTMB is currently facing issues such as long lead times, high costs of spare parts, outdated spare parts, excess inventory, the need for real-time monitoring, and delays in services, which underscore the necessity for a more efficient supplier selection process. Given the current challenges faced by the company, supplier selection decisions are made with a focus on the company's specific needs. By using a single criterion for choosing suppliers, researchers can identify those that excel in various aspects and can fulfill the company's requirements. To address this gap, the proposed research intends to utilize the Analytic Hierarchy Process (AHP) model to assess the criteria for choosing suppliers of rolling stock railway spare parts at KTMB. By implementing AHP, the research aims to enhance cost efficiency, operational effectiveness, and the selection of dependable and efficient suppliers, thus filling the existing research void in railway spare parts supplier selection. Additionally, the study examines the criteria and processes for selecting suppliers but also categorizes and analyzes different multi-criteria decision-making methods used for supplier evaluation. The study addresses the need to select suppliers that meet the criteria for replacement parts for rolling stock in the railway sector. For this research, Analytic Hierarchy Process (AHP) model has been used to evaluate the criteria for selecting supplier of rolling stock railway spare part at KTMB. AHP approach supports the multi-criteria decision selection process so that each criterion's relative value may be evaluated. According to Saranya *et al.* (2021), AHP is more relevant than other processes because it is a systematic and transparent method of decision-making that utilizes the components' hierarchy to support decision-making. It provides an accurate method for measuring the weights of various criteria, which is critical for solving complex issues with large stakes. Furthermore, AHP features support multi-criteria decision-making, which is advantageous when there are conflicts across criteria, and it builds collaboration among stakeholders with different perspectives and objectives. The right choice of suppliers assists in cost reduction and the selection of relevant and efficient suppliers.

This research was carried out at the KTMB Batu Gajah maintenance depot, where data was collected from the maintenance management information system utilized by KTMB. The researcher chose KTMB Batu Gajah as the primary site due to its dual role as a storage facility for rolling stock, including Intercity motive power, and as a center for thorough inspections of rolling stock damage. Additionally, the depot functions as a testing ground for newly arrived motive power or rolling stock, underscoring its essential role in both storage and initial testing. This combination of functions makes KTMB Batu Gajah an ideal setting for the study, offering valuable insights into the storage, inspection, and testing processes that are vital for the effective management of motive power and rolling stock in the transportation sector. The researcher also concentrated on the criteria for selecting suppliers of railway spare parts for rolling stock among the services offered by KTMB. Specifically, the focus of this study is on the procurement of Electric Multiple Unit (EMU) spare parts for the Electric Train Services (ETS) at KTMB Batu Gajah. The KTM Depot Batu Gajah (KTMB Depoh Batu Gajah) is an important facility within Malaysia's railway system, managed by Keretapi Tanah Melayu Berhad (KTMB). Situated in Batu Gajah, Perak, this depot plays several essential roles in the maintenance, repair, and operation of KTMB's trains. Furthermore, the researcher examined the criteria for selecting suppliers of rolling stock spare parts for the Electric Train Services (ETS) version 2. According to the Agensi Pengangkutan Awam Darat (APAD) (2021), the study emphasizes ETS because it recorded the highest ridership and number of trips compared to other KTMB services from 2017 to 2020. The importance of a study is defined by its ability to enhance knowledge and address research gaps in a specific field. It provides valuable insights, bridges knowledge deficiencies, and deepens understanding. A study's significance lies in its potential to inform reality, influence strategies, and shape future research directions, ultimately leading to advancements in the relevant area and benefiting railway operators. Therefore, this study aims to examine the current challenges related to the performance of suppliers for rolling stock railway spare parts, analyze the key criteria for selecting these suppliers using the AHP method, and propose improvements to the existing supplier selection process at KTMB Batu Gajah. Ultimately, the goal of this research is to identify the most effective supplier selection approach that KTMB can adopt to streamline the evaluation and decision-making process for selecting ETS KTMB suppliers using AHP software. Additionally, this study aspires to help KTMB enhance its supplier selection process.

2. Literature Review

2.1 Railway Spare Parts Supplier Selection

Existing literature on railway management and procurement has primarily focused on general supplier selection processes and criteria, with limited attention given to the specific domain of railway spare parts suppliers. A research gap exists in understanding the unique challenges and requirements associated with selecting suppliers for railway spare parts, including factors such as compatibility, reliability, availability, and pricing (Asmara & Kusumah, 2021). Furthermore, while some studies concentrate on looking at supplier selection in the broader transportation sector, there is a lack of research addressing the complex and specific needs of the railway the industry (Reszewski & Schaar, 2023). Filling this research gap is critical for developing effective and efficient railway-specific supplier selection techniques that can optimize spare parts procurement, minimize maintenance costs, and improve the overall dependability and performance of railway systems.

A supplier is a company or individual who sells commodities, products, or services to another company, sometimes known as the buyer or the customer. According Taherdoost & Brard (2019),supplier selection is the process through which businesses identify, analyses, and contract with suppliers. Suppliers play an important role in the supply chain in business transactions by assuring the availability and delivery of vital goods to satisfy the buyer's demands. They are an essential component of the wider business ecosystem since they facilitate the development, distribution, and consumption of products and services. Suppliers might vary substantially based on the sector and the products or services they provide. Manufacturers, dealers, distributors, and even individual artists might be included. Their major goal is to meet the buyer's needs by delivering the requested goods or services on time, commonly in exchange for monetary compensation. Certain features of effective suppliers contribute to their dependability and value to the buyer. According to Kumar *et al.* (2019), these characteristics may include constant product quality, competitive price, delivery schedule adherence, excellent customer service, and the flexibility to react to changing market needs. Establishing and maintaining good supplier connections is critical for organizations to guarantee a stable and efficient supply chain, minimizing interruptions and maximizing operational performance.

Nowadays, in a globalized economy, suppliers frequently operate in highly competitive surroundings, attempting to separate themselves from their competitors. They may concentrate on providing distinct value propositions such as new goods, outstanding customer service, or environmentally friendly and ethical business techniques. A well-managed supplier base is critical for organizations to maintain a competitive advantage and fulfil their strategic objectives. In summary, a supplier is an entity that offers materials, products, or services to a buyer, so serving as an important link in the supply chain. They help businesses run smoothly by assuring the availability and distribution of resources needed for production and consumption. Relationships between buyers and suppliers are critical for attaining efficiency, competitiveness, and customer satisfaction.

2.1.1 Inventory Aspect

The inventory aspect is a crucial factor to consider when selecting a railway spare part supplier. A reliable supplier should be able maintain a well-stocked inventory of railway-specific spare parts on hand. According to Kumar (2023), a comprehensive inventory management system that ensures the availability of a wide range of spare parts specific to the railway industry is crucial for supplier selection. This guarantees that the supplier able to fulfil orders efficiently and minimize downtime in case of equipment breakdowns or maintenance needs. An ideal inventory should include a diverse selection of replacement parts for all types and models of railway equipment. Furthermore, the provider should have efficient inventory management systems in place to monitor stock levels, determine demand patterns, and forecast future requirements. Effective inventory management systems that monitor stock levels, evaluate demand trends and forecast future demands are critical to maintaining a smooth and effective organization (Kumar, 2023). The following is an inventory of factors considered by KTMB Batu Gajah while selecting a supplier selection design:

- Lead Time (LT): The overall duration required for delivering the item starting from the date when the order is placed or received.
- Unit Price (UP): A metric used to denote the cost of specific goods or services that are exchanged with customers or consumers in return for monetary value.
- Supplier Capacity (SC): The proactive identification, assessment, and mitigation of risks that could potentially affect a company's capability to obtain products and services from its suppliers.
- Geographical Location (GL): Geographical Location (GL) pertains to the specific physical area where a statistical unit is situated, and where data is gathered and disseminated.

2.1.2 Maintenance Aspect

The operations and procedures involved in ensuring the safe, efficient, and dependable functioning of railway infrastructure, rolling stock (trains), and related equipment are referred to as maintenance in the rail industry. Maintenance is the upkeep of equipment and assets to maintain them in great operating condition. It entails a wide range of tasks such as checking, repairing, and replacing parts, as well as cleaning and lubricating equipment. Maintenance is critical to the safety, reliability, and efficiency of equipment and assets. According to Catelani *et al.* (2020), maintenance involves all processes and management activities performed on a product during its intended lifespan in order to maintain or restore it to a defined state with essential functionality. The ease and speed with which the system may be restored after a failure is measured by maintainability. There are three categories of maintenance policies which is Corrective Maintenance (CM), Preventive Maintenance (PM) and Condition-Based Maintenance (CBM). Maintenance is essential for keeping the railway system in good working order, preventing breaks down, and minimising delays to train services. So, maintenance aspect that considered by KTMB Batu Gajah while selecting a supplier selection design is:

- Probability of Failure (PoF): Refers to the chance or probability that a machinery or component may experience a breakdown either immediately or within a specific timeframe.
- Availability of equipment (AoE): A measure that quantifies the percentage of time a machine can be utilized. It represents the duration during which a machine is operational and accessible for production.
- Time to Repair (TR): A metric employed by maintenance departments to gauge the average duration required to diagnose the cause of equipment failure and rectify it.

2.2 Analytical hierarchy Process (AHP) Methods

The Analytic Hierarchy Process (AHP) is an effective decision-making tool for supplier selection in the railway supply chain, helping decision-makers prioritize suppliers based on various critical criteria. According to Polat & Eray (2015), the Analytic Hierarchy Process (AHP), developed by Thomas Saaty, offers a structured approach to tackle complex decision-making issues by organizing them into a hierarchy of criteria and alternatives. This method has become highly popular and is recognized as one of the most commonly used techniques for multi-criteria decision making. The process begins by defining the primary objective and breaking it down into various criteria that aid in achieving that goal. Each criterion can be further subdivided, creating a hierarchical structure. The significance of these criteria is evaluated through pairwise comparisons, where decision-makers assess one criterion at a time and assign numerical values to indicate their relative importance (Polat & Eray, 2015b). AHP begins by identifying relevant criteria, such as cost, quality, delivery time, and flexibility. Studies indicate that price (43.84%), rejection rate (21.81%), and delivery time (9.44%) are particularly important in evaluating supplier (Hazza *et al.*, 2022; Isa *et al.*, 2021). Expert opinions, often gathered through surveys or the Delphi method, help establish these criteria (Gabriel, 2023; Hazza *et al.*, 2022). Then, AHP assigns weights to each criterion using pairwise comparisons to reflect their relative importance (Rafi & Yateno, 2022; Isa *et al.*, 2021), ensuring critical factors are prioritized. This is followed by ranking suppliers based on their performance against these weighted criteria.

To ensure decision accuracy, AHP includes consistency checks. This method combines qualitative and quantitative factors, helping decision-makers clarify preferences, understand trade-offs, and make informed, logical choices. While AHP provides a structured, systematic approach to supplier selection, it may have limitations in accounting for dynamic market changes or unexpected disruptions, which could impact supplier performance and alter decision outcomes. The literature on supplier selection and procurement efficiency in the railway industry has explored various decision criteria methods, including fuzzy logic, multi-objective optimization, and TOPSIS (Ayan *et al.*, 2023). However, there is a gap in determining the most suitable decision criteria method for selecting suppliers of rolling stock spare parts in the railway sector. Although the Analytic Hierarchy Process (AHP) is a widely used decision-making method, its application in supplier selection for rolling stock spare parts in the railway industry is underexplored (Yıldız & Yayla, 2015). Further research is needed to assess the effectiveness of AHP in this specific context and compare it with other decision criteria methods (Ayan *et al.*, 2023). Additionally, there is a need for research focusing on the development of supplier selection strategies that address the unique challenges associated with railway spare parts procurement. Bridging this research gap is crucial for the development of efficient supplier selection strategies tailored to the railway sector, leading to optimized spare parts sourcing, reduced maintenance costs, and improved overall reliability and performance of railway systems.

3. Research Methodology

The data sources used for calculating the Analytic Hierarchy Process (AHP) in selecting suppliers consist of expert opinions, historical performance data, financial statements, market information, operational metrics, and customer feedback. Insights from experts, obtained through surveys or interviews, assist in identifying and prioritizing criteria, while historical performance data indicates supplier reliability. To identify the pertinent criteria for supplier selection of rolling stock railway spare parts at KTMB Batu Gajah, a questionnaire survey was carried out targeting employees from various departments including maintenance, procurement, and managerial positions within KTMB. The survey involved the distribution of questionnaires to gather insights from these key stakeholders. Meanwhile, the financial reports provide information on the stability of suppliers, and industry data ensures adherence to standards. Additionally, internal operational data regarding inventory and lead times, along with customer satisfaction ratings, contributes further insights into the quality and responsiveness of suppliers. Collectively, these data sources facilitate a thorough, data-driven AHP model that supports well-informed decisions in supplier selection.

The Analytic Hierarchy Process (AHP) for selecting suppliers consists of several important steps to assess potential suppliers based on various criteria (Chettri *et al.*, 2020; Pebakirang *et al.*, 2017). Initially, relevant criteria such as presented in Figure 1 are determined. Next, pairwise comparisons are conducted to assign weights to each criterion (Galiotto & Cassel, 2021; Parung & Herowati, 2023), indicating their relative significance. Specific indicators are established for each sub-criterion to accurately evaluate supplier performance (Galiotto & Cassel, 2021), followed by the calculation of the relative weights of these indicators, taking their interrelationships into account (Galiotto & Cassel, 2021; Parung & Herowati, 2023). Ultimately, the model is applied in a real-world context to confirm its effectiveness (Galiotto & Cassel, 2021). Although AHP offers a structured approach, it can be complicated due to the requirement for numerous pairwise comparisons, especially when multiple decision-makers are involved. This complexity may prompt some organizations to opt for simpler or hybrid methods to facilitate the decision-making process. Hence in this study, the decision makers are only at 5 alternatives as shown in Fig. 1. In this study, there are seven supplier selection criteria that will be studied. It will be divided into two parts main criteria and sub-main criteria. The main criteria for this study are in terms of inventory and maintenance aspects while for the sub-main are lead time, unit price, supplier capacity, geographical location, probability of failure, availability of equipment and time to repair.

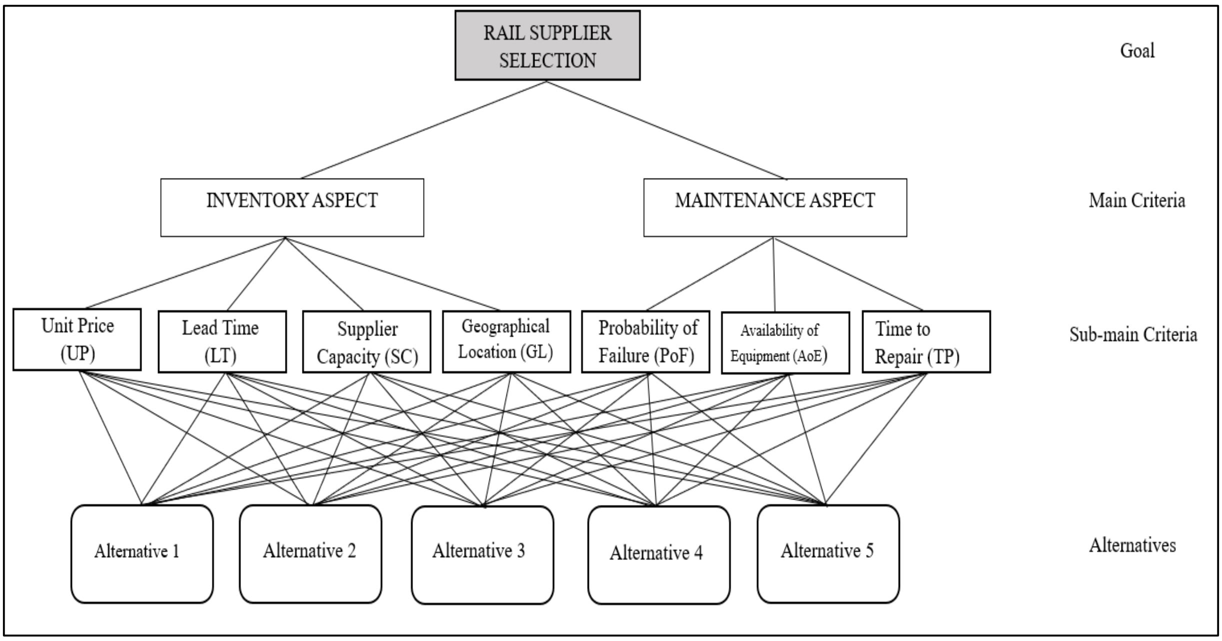


Fig. 1 *Framework of weight of criteria of supplier selection design*

3.1 Research Design

The research framework for assessing supplier selection through the Analytic Hierarchy Process (AHP) is most effectively implemented using a mixed-methods strategy, which integrates both qualitative and quantitative data gathering and analysis methods. This strategy facilitates a thorough assessment of the supplier selection process by utilizing expert opinions alongside empirical data, resulting in a more complete methodology. The initial phase of the research design prioritizes the collection of qualitative data to establish a foundation for the Analytic Hierarchy Process (AHP) model. This involves conducting expert interviews and surveys to gather insights from key stakeholders involved in the supplier selection process, including procurement and purchasing managers, maintenance managers, engineers, and technicians. These experts are expected to provide critical perspectives on the essential criteria for evaluating suppliers, such as supplier capability, lead time, and availability. This phase is crucial for identifying and defining the relevant criteria that will inform the evaluation process. It entails a comprehensive examination and analysis of the railway system at KTMB Batu Gajah, which may include assessing the current spare parts inventory, understanding operational requirements, and identifying the specific demands and challenges associated with supplier selection. The subsequent step involves the registration of potential suppliers. During this stage, the researcher will identify and document prospective suppliers capable of providing the necessary spare parts for the railway system. This process may include reaching out to various suppliers, collecting information regarding their capabilities, and recording their details for future reference.

The second phase of the research design is dedicated to the collection of quantitative data to facilitate the implementation of the Analytic Hierarchy Process (AHP). To acquire numerical data pertaining to the relative importance of the criteria and sub-criteria, a survey-based quantification approach will be employed. This methodology entails the use of structured surveys in which selected experts from various departments, including procurement, maintenance, and warehousing, engage in pairwise comparisons to evaluate the significance of each criterion in relation to others. The survey will encompass inquiries regarding product quality, pricing, delivery timelines, prior experience, and other critical factors influencing supplier selection. After the formulation of the questionnaires, data is collected from the respondents. In this study, employees who handle the inventory section which is procurement, maintenance, and spare part department have been selected as target respondent. Due to the lack of employees for each department, the total number of respondents that completed the survey is only 17 respondents. This phase involves the organization and compilation of the questionnaire responses in preparation for further analysis. The results of these surveys provide the numerical basis for establishing the relative weights of each criterion. Additionally, an analysis of historical performance data of suppliers was conducted to assess supplier performance against established metrics such as delivery times, defect rates, and customer satisfaction scores.

This analysis facilitates an objective evaluation of suppliers' capabilities and performance, which will be directly integrated into the AHP model for the purposes of ranking and comparison. The researcher gathered responses from the vendors following the distribution of the questionnaires. This stage also includes the organization and compilation of the questionnaire data for subsequent investigation. Upon completion of data collection, the next step involves simulating and analyzing the collected data using appropriate analytical techniques. As indicated in the title of the study, this may involve the application of the Analytic Hierarchy Process (AHP) to evaluate and compare alternative suppliers based on multiple criteria. The final stage is the reporting of findings. The researcher produced a comprehensive report summarizing the results and outcomes of the data analysis. Ultimately, based on the findings and data analysis, the researcher informed decisions regarding the optimal suppliers of railway spare parts for KTMB Batu Gajah. Recommendations were provided regarding which suppliers should be selected or prioritized based on their performance, reliability, and alignment with the requirements of the railway system. By adhering to these methodological steps, the researcher aims to establish an effective supplier selection process for railway spare parts, thereby enhancing the efficiency and reliability of the KTMB Batu Gajah railway system.

3.2 Research Instrument

A research instrument serves as a mechanism for the collection, measurement, and analysis of data pertinent to specific research inquiries. In the present study, the questionnaire method was selected as the primary research instrument. The researcher utilized a self-administered questionnaire, informed by relevant literature, to gather primary data from participants. The questionnaire survey represents a data collection methodology that entails posing a series of predetermined questions to respondents. This approach is frequently employed in the social sciences and market research to obtain organized and standardized information from many participants, thereby facilitating insights and trend evaluation. The questionnaire process is straightforward, as each participant is asked to respond to an identical set of questions in a specified order at a designated time (Ragab & Arisha, 2017). The researcher opted for this method due to its cost-effectiveness and ease of implementation. Questionnaire design encompasses the formulation of the structure and questions for a survey instrument intended for data collection on a particular issue. It is essential to consider all phases of survey design and execution during the development of a questionnaire. In this study, the researcher employed a paired survey approach to disseminate the questionnaire. As noted by Saaty (1990), this pairwise comparison technique facilitates the determination of the relative weights of the criteria associated with the primary objective. The principal criteria for this research include the inventory aspect and the maintenance aspect, while the sub-criteria for supplier selection encompass Lead Time (LT), Unit Price (UP), Supplier Capacity (SC), Geographical Location (GL), Probability of Failure (PoF), Availability of Equipment (AoE), and Time to Repair (TR). In Sections A and B, respondents are required to select answers for each question using nominal and ordinal scales. Subsequently, in Section C, the researcher presents pairwise survey questions that necessitate comparisons between each criterion. This process involves conducting pairwise comparisons using a numerical scale with nine levels to evaluate and compare specified options. For instance, when comparing alternative A to alternative B, a score of 1 indicates that both alternatives are of equal importance. Scores of 3, 5, 7, and 9 signify that alternative A is more significant than alternative B, with level 3 denoting moderate importance and level 9 indicating a greater degree of importance. Intermediate values are represented by scores of 2, 4, 6, and 8. Following this assessment, decision-makers will determine the preferred alternative rail suppliers. Table 1 shows the instruments that were used in each section of the survey questionnaire. The questionnaire is based on self-administered and previous research. Table 2 shows the level of comparing the criteria from the most important than, equally important and intermediate important.

Table 1 *Research instruments*

Content	Items	Measurement	Scale of measurement
Demographic	Gender	Nominal	-
	Age group	Ordinal	-
	Highest level of education	Nominal	-
	Department	Nominal	-
	Employed Status	Nominal	-
Job Knowledge	Work experienced	Nominal	-
	Total supplier registration	Ordinal	-
	How frequently did staff monitor or check the inventory system?	Ordinal	-
	Do inventories that are subject to considerable variation during the year require a periodic review?	Nominal	-
	Are preferred suppliers/vendors with previous record of railway maintenance satisfied with the product and services provided?	Nominal	-
	What are current issues related to supplier's performance of rolling stock railway spare parts at KTMB Batu Gajah?	Nominal	-
	Which of the following is the main challenges or issues currently faced in the supplier selection process for railway spare parts at KTMB Batu Gajah?	Nominal	-
	Are there any specific challenges related to supplier selection for railway spare parts at KTMB Batu Gajah?	Nominal	-
	What is the improvement to be made to the current spare part supplier selection process?	Nominal	-

Table 2 *Comparison table among criteria*

Criteria A					Rating Scale					Criteria B
	1	2	3	4	5	6	7	8	9	

3.3 Data Analysis

When it is necessary to consider both qualitative and quantitative aspects of a decision, the Analytic Hierarchy Process (AHP) serves as a robust and adaptable decision-making framework that assists individuals in establishing priorities and arriving at the most favorable conclusion. The AHP not only facilitates the identification of the optimal choice but also offers a clear rationale for its selection. This is accomplished by deconstructing intricate decisions into a series of pairwise comparisons, followed by the synthesis of the collected data. Fig. 2 illustrates the comprehensive procedure involved in employing the Analytic Hierarchy Process (AHP).

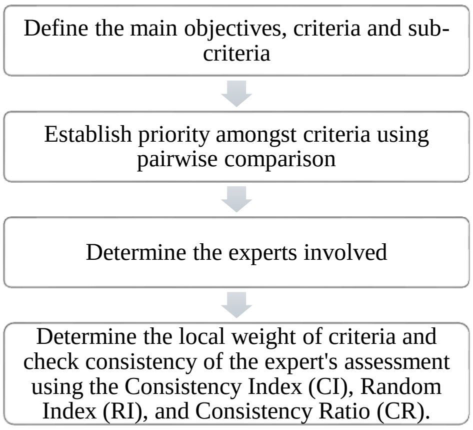


Fig. 2 *The procedure of use of the Analytical Hierarchy Process (AHP)*

The initial step involves the identification of primary objectives, criteria, and sub-criteria. Subsequently, priority among the criteria is established through pairwise comparison, and the relevant experts are identified. Following this, the local weights of the criteria are determined, and the consistency of the experts' evaluations is assessed using the Consistency Index (CI), Random Index (RI), and Consistency Ratio (CR). Once the decision hierarchy is established, a questionnaire is developed, comprising two distinct sections. In the first section, decision-makers are instructed to conduct pairwise comparisons of supplier selection criteria, utilizing Saaty's rating scale as depicted in Figure 1. The second section of the questionnaire requires decision-makers to evaluate alternative rail suppliers.

4. Results and Discussion

4.1 Respondent Background and Demographic profiles

Firstly, this data stated the summary on Section A. Based on the data, the percentage of Male respondent is higher than female respondent with a total percentage of 70.6% with a total of 12 respondents. The remaining respondent is female with percentage of 29.4% represent of 5 respondents. The highest percentages for the age group are 25-34 years old, which is 58.8% and 10 respondents. Next, the highest level of education shows that that Sijil Kemahiran stated a highest percentage with 41.2% (7 respondent) while HSC/ STPM/ Diploma/ Matriculation recorded the second highest percentages which is 35.3% (3 respondents). Furthermore, the department that receives the highest percentage is the maintenance department with 10respondent and 58.8%. Other than that, all respondents are full-time workers as their employed status with 100%. Next the highest working experience between 6-10 years is 47.1% with 8 respondents. The highest percentage of the total number of supplier registration is 0-50 supplier with 50% (10 respondents). Then, the highest number of staff frequently monitor or check the inventory system is monthly with 70.6% and 12 respondents. Finally, the majority of the respondent answered yes and agreed (100%) with inventory that is subject to significant changes throughout the year require periodic review and 64.7% agreed that a preferred supplier/vendor with a prior track record of rail maintenance is satisfied with the products and services provided.

4.2 The current issues and challenges related to supplier's performance of rolling stock railway spare parts at KTMB Batu Gajah

Fig. 3 illustrates the contemporary challenges associated with the performance of suppliers of rolling stock railway spare parts at KTMB Batu Gajah. The frequency of these challenges represents a significant concern within the railway sector. Ongoing issues regarding the performance of suppliers of rolling stock components continue to adversely affect operational efficiency. The recurrence of these challenges highlights the necessity of addressing and resolving matters related to the prompt and effective supply of spare parts. Fig. 3 and 4 depict the frequency of persistent issues and the primary challenges encountered in the supplier selection process at KTMB Batu Gajah. In Fig. 3, the result showed that the highest issues related to supplier's performance of rolling stock railway spare parts is price, which is 88.2%, followed by high lead time with 76.5%, then the third rank which recorded the same percentage which 58.8% is spare part failure rate and spare part production time. While in Fig. 4, the results showed that "Demand forecasting", "Low data accessibility and quality" recorded the highest percentage of the main challenges or issues currently faced in the supplier selection process with 76.5% and followed by and "Sourcing and procurement" which recorded the third highest which 64.7% (11 respondents).

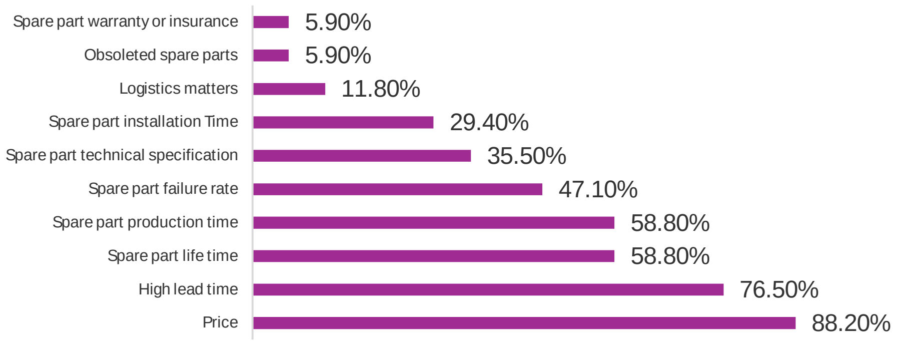


Fig. 3 *The current issues related to supplier's performance of rolling stock railway spare parts*

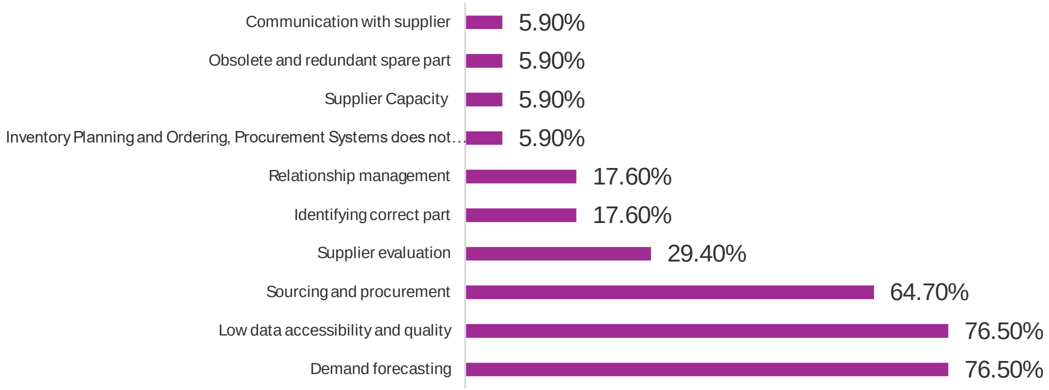


Fig. 4 *The main challenges or issues currently faced in the supplier selection process*

4.3 The most important criteria for selecting suppliers of rolling stock railway spare parts using the AHP method at KTMB Batu Gajah

In Fig. 5, the data highlighted the challenges to supplier selection for railway spare parts at KTMB Batu Gajah. The data highlights that supplier performance recorded the highest percentages, which were 76.5% and followed by the reliability and quality of spare parts 70.6%. This underscores a strong emphasis on suppliers meeting delivery expectations and ensuring the durability of rolling stock. Regulatory requirements and concerns about monopoly suppliers are recognized at a moderate level at 47.1%, indicating an awareness of compliance needs and the importance of a competitive supplier environment, followed by supplier management and selection, which 17.6% and the rest recorded which 5.9%. So based on the data, decision makers should calculate the most important criteria weight and take alternative to overcome the challenges or requirements related to supplier selection for railway spare parts that had currently faced in at KTMB Batu Gajah.

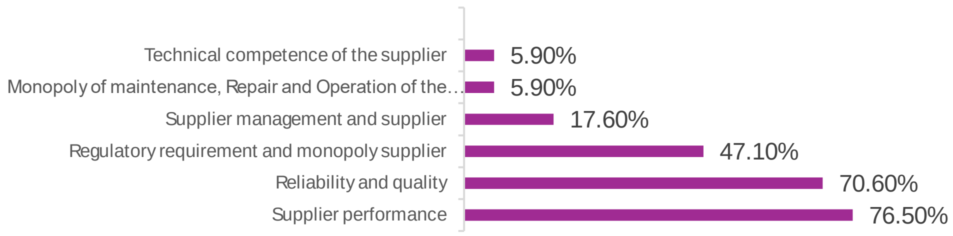
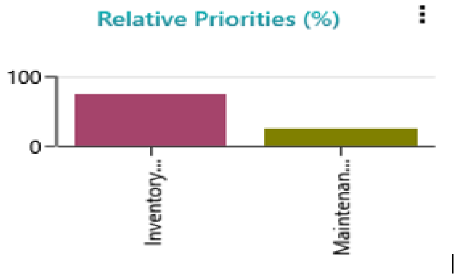


Fig. 5 *The specific challenges related to supplier selection for railways spare parts*

In this research, it is imperative to identify the optimal criteria for supplier selection, which will be utilized to compute the criteria weights through the Spice Logic Analytic Hierarchy Process software. As noted by Asmara and Kusumah (2021), the evaluation of expert assessments plays a critical role in decision-making processes. Key metrics such as the Consistency Index (CI), Random Index (RI), and Consistency Ratio (CR) are essential for ensuring the reliability of these evaluations. The Consistency Index quantifies the level of agreement among experts, while the Random Index serves as a reference point for evaluating the expected consistency that could arise by chance. The Consistency Ratio, which is calculated from the CI and RI, assesses the reliability of expert judgments by determining whether the observed consistency exceeds what could be expected randomly. A CR value of less than 0.1 indicates an acceptable assessment; conversely, if the results deviate from this threshold, the pairwise comparison matrix must be revised through further evaluation. According to the findings presented in Table 3, the inventory aspect is prioritized more significantly than the maintenance aspect, with respective values of 0.75 (75%) and 0.25 (25%).

Table 3 *Result for Relative Priorities and CR of Inventory aspect and Maintenance Aspect*



	Inventory Aspect	Maintenance Aspect	Priorities
Inventory Aspect	1	3	0.75
Maintenance Aspect	0.333	1	0.25

After developing the decision hierarchy, the result of the AHP method is presented in Table 4 and Table 5. From the findings, the result is that the matrix consistency ratio for the inventory aspect was calculated and found to be 0.087 while the matrix consistency for the maintenance aspect was calculated and found to be 0.075 which is lower than 0.10. Therefore, the comparison matrix between the two main criteria in pairs was found to be consistent. According to the findings presented in Table 4, the criteria related to inventory aspects indicate that Lead Time (LT) holds the highest weight at 41.7% in the context of rail supplier selection for this study. This is followed by Unit Price (UP), which accounts for 27.8%, while Supplier Capacity (SC) and Geographical Location (GL) are assigned weights of 14.8% and 15.7%, respectively, representing the lower end of the weight spectrum in this supplier selection issue. In terms of maintenance criteria, as illustrated in Table 4, Availability of Equipment (AoE) is assigned the highest weight at 61.9%, followed by Time to Repair (TR) at 28.4%. The criterion with the lowest weight affecting supplier selection is Probability of Failure (PoF), which is recorded at 15%.

Table 4 *Results for Consistency Ratio (CR) in Inventory Aspect*

Inventory Aspect 0.75	Lead Time (LT)	Unit Price (UP)	Supplier Capacity (SC)	Geographical Location (GL)	Priorities
Lead Time (LT)	1	3	2	2	0.417
Unit Price (UP)	0.333	1	3	2	0.278
Supplier Capacity (SC)	0.5	0.333	1	1	0.148
Geographical Location (GL)	0.5	0.5	1	1	0.157

* Consistency Ratio calculated as 0.087

Table 5 *Results for Consistency Ratio (CR) in Maintenance Aspect*

Maintenance Aspect 0.25	Probability of failure (PoF)	Availability of Equipment (AoE)	Time to Repair (TR)	Priorities
Probability of failure (PoF)	1	0.2	0.25	0.096
Availability of Equipment (AoE)	5	1	3	0.619
Time to Repair (TR)	4	0.333	1	0.284

* Consistency Ratio calculated as 0.075

4.5 The improvement to be made to the current spare parts supplier selection process at KTMB Batu Gajah

In the subsequent section, five decision makers (DMs)—namely the Chief Technology Officer (CTO), Depot Manager, Finance Manager, Procurement Manager, and Unit General Manager—evaluated rail suppliers based on seven criteria. As illustrated in Fig. 6, the data indicates a need for enhancements in the current spare parts supplier selection process. The highest percentages recorded pertain to inventory control (A1) and effective spare parts inventory management (A2), both of which achieved a score of 82.4%. This is followed by an understanding of supplier capabilities (A3) at 58.8%, while quality systems documentation and improvement methods (A4) and risk mitigation in supplier selection (A5) both recorded a percentage of 52.9%. The researcher posits that improvements to the current spare parts supplier selection process may serve as a viable alternative to address the identified issues.

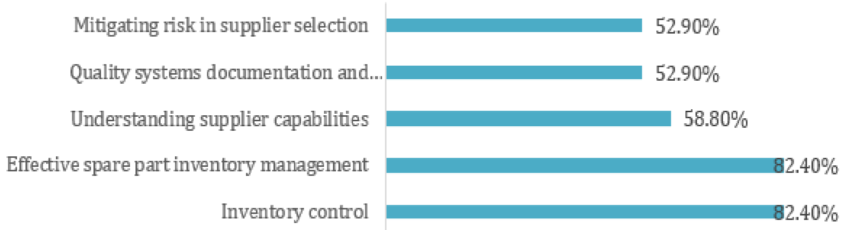


Fig. 6 *The improvement to be made to the current spare part supplier selection process*

Following the assessment of the frequency of necessary improvements, several evaluations have been conducted to identify the most suitable alternatives concerning the critical criteria and challenges encountered with suppliers at KTMB Batu Gajah. As indicated in Fig. 7, all relevant data regarding the criteria weighs and evaluations of alternative suppliers have been systematically compiled. The ranking of these alternatives was established based on the specified evaluation criteria. The spiderweb diagram presented in Figure 7 summarizes the sensitivity analysis attributes of all alternatives, revealing that Lead Time (LT), Unit Price (UP), Supplier Capacity (SC), and Time to Repair (TR) require enhancement, as they exhibited the highest variability percentages. In contrast, the attributes of Geographical Location (GL), Probability of Failure (PoF), and Availability of Equipment (AoE) demonstrated comparatively less significance against the other criteria. Consequently, the results indicate that Alternative 1 is recommended as the optimal choice for rail supplier selection, followed by Alternatives A4, A3, A5, and A2 in that order for the railway research conducted. Subsequently, Decision Makers (DMs) can utilize this information to make informed decisions regarding the alternatives to address the attributes illustrated in the Spider Diagram.

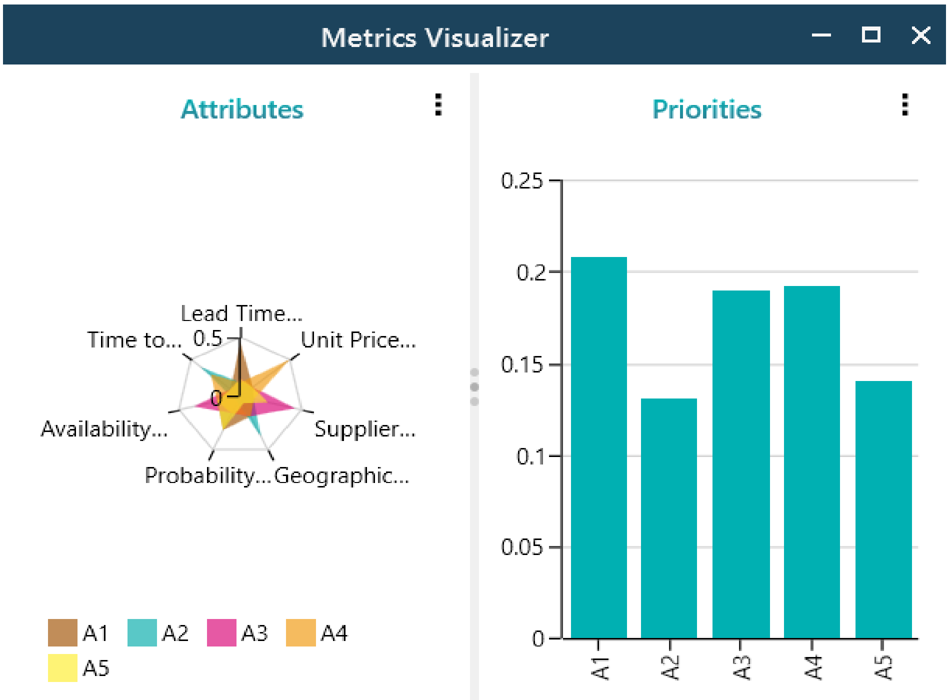


Fig. 7 *Results for the best Alternative to make decision of supplier selection*

5. Conclusion

By the conclusion of this study, all three research objectives were successfully achieved and addressed. A thorough analysis of the prevailing issues concerning supplier performance for rolling stock railway spare parts at KTMB Batu Gajah has identified significant challenges related to pricing, extended lead times, high failure rates of spare parts, and prolonged production times. Additionally, the challenges associated with the supplier selection process, as illustrated in Figure 4, reveal difficulties in demand forecasting, limited accessibility and quality of data, as well as issues in sourcing and procurement. The research conducted on supplier selection for railway spare parts at KTMB Batu Gajah, particularly in Section C, emphasized critical challenges and requirements, indicating that supplier performance, reliability, and the quality of spare parts are of paramount importance. Decision-makers were responsible for calculating essential criteria weights, and through the application of the Analytic Hierarchy Process (AHP), inventory considerations were prioritized over maintenance, with Lead Time recognized as the most significant factor. Key decision-makers, including the Chief Technology Officer, Depot Manager, Finance Manager, Procurement Manager, and Unit General Manager, evaluated rail suppliers based on seven criteria. The findings highlighted the necessity for enhancements in the existing spare part supplier selection process, with Alternative 1 identified as the optimal rail supplier selection to address the identified challenges. The comprehensive methodology employed in this research, which integrated AHP and evaluations from decision-makers, provided strategic insights for mitigating challenges in supplier selection, thereby facilitating informed decision-making for KTMB Batu Gajah.

This study contributes significantly to the domain of railway spare part procurement and supplier selection, particularly in the context of KTMB Batu Gajah. Initially, it provides a thorough examination of the current challenges encountered by KTMB Batu Gajah regarding supplier performance for rolling stock railway spare parts. These challenges include issues such as delivery delays, inadequate quality of spare parts, elevated costs, and concerns regarding reliability. The comprehensive nature of this research yields valuable insights into the specific difficulties faced by the organization, thereby offering a detailed perspective that may be applicable to similar entities within the railway industry. Furthermore, the research introduces and applies the Analytic Hierarchy Process (AHP) methodology for supplier selection, tailored to the distinct context of railway spare parts. By utilizing AHP to assign weights to selection criteria and assess supplier performance, the study provides a structured and systematic framework for decision-making that could serve as a beneficial model for other railway contexts. Additionally, this research addresses a notable gap in the existing literature by delivering specialized insights pertinent to the railway sector, specifically at KTMB Batu Gajah. This sector-focused analysis of supplier selection criteria, associated challenges, and the implementation of AHP enriches the academic discourse and lays the groundwork for future investigations in the areas of supplier management and railway spare part procurement.

Based on the findings of the study, the researcher proposes several recommendations aimed at addressing the challenges and limitations encountered. Firstly, it is acknowledged that the researcher faced significant constraints due to the limited availability of data pertaining to the railway industry, which hindered comprehensive analysis. Consequently, it is recommended that future researchers contribute additional scholarly articles focused on railway systems. Furthermore, the researcher advocates for the adoption of mixed research methodologies, integrating both quantitative and qualitative approaches, to facilitate a more nuanced understanding of safety and risk-related issues within the railway sector. The incorporation of qualitative methods is expected to enhance the depth of case study explorations and contribute valuable insights, particularly in fostering and advancing a robust safety culture within the railway industry. Additionally, given that the current study concentrated solely on the maintainability and failure analysis of brake pads (specifically the ETS 93 version 2), it is suggested that subsequent researchers investigate various types of rail services, such as commuter trains, light rail transit (LRT), or other ETS models. Moreover, there is potential for exploration of this topic across different transportation sectors.

In addition, the researcher recommends that the railway industry undertake improvements to transform its spare parts supply chain, as illustrated in Figure 8. The transformation involves seven key processes within the spare parts supply chain, and for rail operators to successfully implement these changes, they must adhere to five critical success factors: advanced and predictive planning, balanced inventory management, proactive supplier management, comprehensive and accurate master data, and seamless cross-functional connections. To initiate this transformation, operators can leverage digital advancements across various operational levels. In the context of rolling stock procurement, the development of a digital twin for each train car, encompassing detailed information and a standardized spare parts list, can significantly enhance spare parts planning. Additionally, demand planning should evolve from a traditional reliance on historical data to a model that incorporates real-time train conditions and mileage, thereby enabling more accurate forecasting. The utilization of digital tools and condition monitoring can streamline inventory planning, ordering, and scheduling, with artificial intelligence playing a pivotal role in predicting safety stock requirements. Effective supplier management, delivery oversight, and logistics can be achieved through the implementation of a digital supply chain control tower, which provides real-time tracking, risk analysis, and mitigation strategies. Maintenance departments can also benefit from digital tools that facilitate cross-functional planning, ensuring the timely availability and quality of materials, while real-time documentation supports defect recording and status assessment. Overall, the integration of digitization is poised to optimize railway operations, encompassing all aspects from procurement to maintenance.

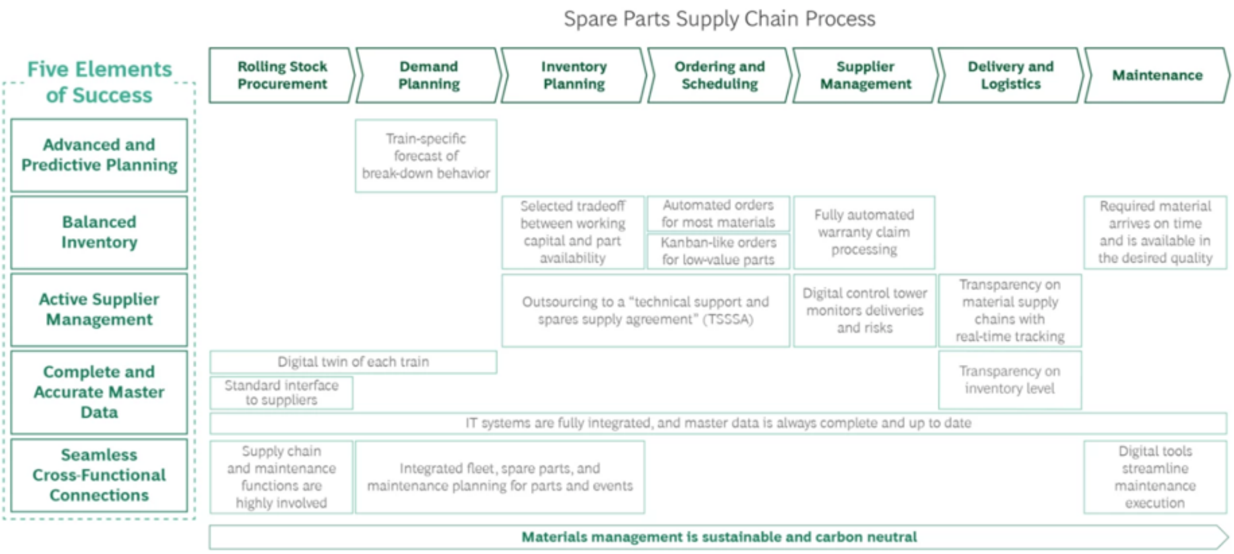


Fig. 8 *Recommendation for improvement to transform spare parts supply chain in railway industry*

Rail operators can enhance their spare-parts supply chain by establishing a specialized team tasked with identifying deficiencies and conceptualizing an improved future state. By dismantling interdepartmental barriers and implementing immediate improvements, such as data cleansing and procurement optimization, initial progress can be achieved. A comprehensive transformation initiative, which includes the introduction of new planning processes and a digital control tower, promotes interdepartmental collaboration. Maintenance departments provide data for procurement, which in turn delivers well-organized kits, while logistics and fleet operations exchange essential updates. Sustainability initiatives, such as obtaining CO2-neutral certifications, optimizing logistics, and minimizing waste, align with public expectations for a cost-effective and environmentally sustainable rail system. This transformation is expected to enhance operational efficiency, reduce maintenance durations, and increase train availability. Furthermore, as the current research primarily concentrates on supplier selection criteria to gain a broader understanding of the subject, it is recommended that future researchers investigate railway issues utilizing alternative software to yield more comprehensive findings. Additionally, conducting studies over extended periods is advised to obtain more robust data and improve the quality of reporting.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** *Nurhannahi Fasihah Zulkarnain*; **data collection:** *Nurhannani Fasihah Zulkarnain*; **analysis and interpretation of results:** *Nurhannani Fasihah Zulkarnain, Nor Aziati Abdul Hamid*; **draft manuscript preparation:** *Nor Aziati Abdul Hamid, Mohamad Ali Selimin*. All authors reviewed the results and approved the final version of the manuscript.

Appendix A

PAIRWISE SURVEY

What are the most important criteria for selecting suppliers of rolling stock railway spare parts using the AHP method at KTMB Batu Gajah?

The Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	Activity is strongly favored, and its dominance is demonstrated in practice
9	Extremely importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	An intermediate value	When compromise is needed

Evaluation of Main Criteria

1. **Inventory Aspect:** The process used to guarantee that a company has the appropriate number of supplies on hand. As long as internal and production controls are in place, the business can meet customer needs and maintain financial flexibility.
2. **Maintenance Aspect:** An essential ingredient in the successful running of a railway is a well-maintained system.

Main Important Criteria

Criteria A	Rating Scale									Criteria B
Inventory Aspect	1	2	3	4	5	6	7	8	9	Maintenance Aspect

Evaluation of Sub-main Criteria

Inventory Aspect

1. **Lead Time (LT):** *The total time needed in delivering the item from the day its order has been booked or received.*
2. **Unit Price (UP*):*** Unit Price is *a measurement used to indicate the price of particular goods or services to be exchanged with customers or consumers for money.*
3. **Supplier Capacity (SC):** The proactive identification, evaluation, and mitigation of risks that could impact a company's ability to get products and services from its suppliers.
4. **Geographical Location (GL):** Geographic location refers *to the physical place a statistical unit is located and for which statistics are collected and disseminated.*

Main Important Criteria

Criteria A	Rating Scale									Criteria B
Lead Time (LT)	1	2	3	4	5	6	7	8	9	Unit Price (UP)
Lead Time (LT)	1	2	3	4	5	6	7	8	9	Supplier Capacity (SC)
Lead Time (LT)	1	2	3	4	5	6	7	8	9	Geographical Location (GL)
Unit Price (UP)	1	2	3	4	5	6	7	8	9	Supplier Capacity (SC)
Unit Price (UP)	1	2	3	4	5	6	7	8	9	Geographical Location (GL)
Supplier Capacity (SC)	1	2	3	4	5	6	7	8	9	Geographical Location (GL)

Evaluation of Sub-main Criteria

Maintenance Aspect

1. **Probability of failure (PoF):** The likelihood that a piece of machinery or component may break down either immediately or over the course of a certain period of time.
2. **Availability of Equipment (AoE):** Is a metric used to measure the percentage of time a machine can be used. It is the amount of time in which a machine actually runs and is available for production.
3. **Time to repair (TR):** A *metric used by maintenance departments to measure the average time needed to determine the cause of and fix failed equipment.*

Main Important Criteria

Criteria A	Rating Scale									Criteria B
Probability of failure (PoF)	1	2	3	4	5	6	7	8	9	Availability of Equipment (AoE)
Probability of failure (PoF)	1	2	3	4	5	6	7	8	9	Time to Repair (TR)
Availability of Equipment (AoE):	1	2	3	4	5	6	7	8	9	Time to Repair (TR)

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