

Case Study

Strategy Practiced by Rolling Stock Maintenance: A Case Study Within the Urban Rail

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ABSTRACT

This research aims to analyse, evaluate and rank the maintenance strategy practised by the train operating companies, specifically by the rolling stock maintenance team. A quantitative method was adopted for data collection. A total of five train operating companies were chosen to participate in a survey that has been carefully designed. The research first identified the maintenance strategy associated with the rolling stock maintenance through systematic literature reviews. Afterwards, six maintenance strategies adopted by the companies were identified. The type of maintenance strategies identified was used to structure the survey questionnaire. Judgemental sampling was utilised for sampling purposes. Finally, the data collected from the survey were analysed using an importance index to complete the

ranking analysis. The research discovered that corrective and preventive maintenance strategies are the most commonly adopted among the five Malaysian train operating companies. This study also highlighted the factors that future studies should consider to establish predictive cost models for rolling stock maintenance.

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INTRODUCTION

This paper focuses on the main maintenance strategy practised by Malaysia's train operating companies (TOCs). All TOCs utilise an electric train for daily train services in Klang Valley. The selection of maintenance strategy creates a significant impact on the operational costs for any organisation. The consequence of the maintenance strategy creates financial impacts and affects the train and operation's reliability, availability, maintainability and safety.

Loubinoux et al. (2013) found that a TOC that operates a rail system needs to perform the maintenance tasks according to the maintenance strategy to operate and provide safe and reliable services. The TOC needs to ensure that the train operation complies with some requirements, such as punctuality, delivering a high level of safety and comfort to the passenger. Thus, in view of maintaining the railway asset, the TOC must apply some basic maintenance guiding principle, known as the maintenance strategy (Lai et al., 2015).

The selected maintenance strategy will affect the overall maintenance cost. In general, Malaysian urban rail systems is still lacking in studies on the best maintenance strategy and the maintenance cost related to the selected maintenance strategy. Therefore, this research aims to analyse, evaluate and rank the maintenance strategies practised by the rolling stock maintenance practitioners. Based on the identified maintenance strategies, the correlation analysis between the maintenance strategy and the incurred maintenance cost could be established in the next study.

Research Background

Rolling stock is a generic terminology in the railway industry referring to locomotives, wagons, carriages, or any vehicles used on the track. This rolling stock requires maintenance to preserve its condition. The British Standard BS 3811:1993 defines maintenance as 'the combination of all technical and administrative actions, including supervision actions, intended to retain an item in or restore it to, a state in which it can perform a required function. In order to sustain the rolling stock's performance, it is important to perform the maintenance activity; therefore, a maintenance strategy needs to be selected.

A study made by Méchain et al. (2020) found that maintenance of a large fleet in TOCs requires careful planning and resources management. The planning and resources involved largely depend on the maintenance strategy selected. A maintenance strategy is a strategic plan used to cover all aspects of maintenance management, setting the direction of the annual maintenance program, containing firm action plans to achieve a desired outcome for the organisation (Heizer et al., 2015). It can be simplified as a firm plan specifically intended for rolling stock preservation.

Research made by Eisenberger and Fink (2017) reported that efficient operation and maintenance needs to be increased due to the development of the railway industry.

The usage of articulated trains has increased the operation cost creating new challenges for organisations. However, the cost component-per-hour can be lessened if the TOC is proactive in maintaining its assets. Maximised number of trains during maintenance activity or “up to time” and the troubleshooting process depends mainly on the type of maintenance strategy applied during the assets’ operational life.

Albrice (2019) found a correlation between the costs associated with different maintenance strategies. It has been discovered that reactive maintenance contributed to the highest repair cost compared to predictive maintenance with the low repair cost. The finding indicated that the TOC should change to a predictive maintenance strategy for cost-saving. The need for an effective maintenance strategy contributes to high train availability and the increase in operational performance, creating significant profit for the operator.

Rolling Stock Maintenance Strategy

The typical maintenance strategies used in the railway industry, especially in the rolling stock department, are shown in Table 1. It consists of corrective maintenance, preventive maintenance, overhaul maintenance, predictive maintenance, refurbishment maintenance, condition-based maintenance and predictive maintenance.

The use of maintenance strategy depends on the organisational needs, either to gain a short-term benefit or long-term benefit. The short-term benefit includes low maintenance cost for non-critical equipment of a system, and the long-term benefit includes reliable performance referring to more crucial and expensive equipment or systems. The outcome of the literature review determined six common maintenance strategies in rolling stock

Table 1
Typical maintenance strategy for rolling stock maintenance

No.	Maintenance Strategy	Operational Term
1	Corrective Maintenance	To replace or repair faulty components with the intention to minimise the train downtime
2	Preventive Maintenance	To schedule maintenance activities at fixed time intervals
3	Overhaul Maintenance	To restore the train to its accepted specification or its fully operating level after years of operations without any upgrading work
4	Refurbishment Maintenance	To recondition and improve the trains inclusive of overhauling, upgrading and rectifying work to restore the train's condition
5	Condition based Maintenance	To perform diagnosis of the asset status, to predict the assets abnormality, and executes suitable maintenance actions such as repair and replacement before serious problems happen
6	Predictive Maintenance	To execute the maintenance activity based on a highly detailed forecast based on the previous performance data by using statistical analysis or mathematical formula

Sources: Adopted and adapted from Idris and Saad (2020), de Jonge (2017), Kwansup et al. (2016) and Jun and Shin (2015)

maintenance. The strategies consist of corrective maintenance, preventive maintenance, overhaul maintenance, refurbishment maintenance, condition-based maintenance and predictive maintenance.

Cheng and Tsao (2010) mentioned that corrective maintenance is performed in unavoidable situations and needs to be resolved when a component failure occurs. The need for corrective maintenance is to overcome unexpected failures during operation. As highlighted by Stenström et al. (2015), corrective maintenance for rolling stock refers to the task performed to identify, isolate and resolve a fault. Consequently, the malfunctioning equipment can be changed or restored to an operational condition. The change of parts should be within the tolerances or limits established for in-service operations.

With this corrective maintenance strategy, no actions are taken to prevent a fault since the only way to detect it is by waiting for equipment to fail.

To date, there are many preventive maintenance strategies adopted in rolling stock maintenance. As informed by Lin et al. (2019) for the rolling stock in the high-speed railway line in China, the preventive maintenance activities are carried out in a periodical manner involving a time-based maintenance interval as well as a distance-based maintenance cycle. It designates that a high-speed train needs to be maintained or repaired when its accumulated running mileage or time reaches the predefined thresholds. A research finding by Stenström et al. (2015) defined preventive maintenance as a task performed as planned to lessen the likelihood of its failure. Thus, this approach may assist infrastructure managers in recognising the asset's condition and the preventive action to be taken before the asset fails. It could lead to better reliability of the asset and system.

Overhaul maintenance is a maintenance strategy that refers to the process of restoring a train to its acceptable specification or fully operational condition after many years of use. This maintenance program is generally performed at long intervals, such as every five, seven or ten years, depending on the system's state (Idris & Saad, 2020). Um, et al. (2011) posited that in terms of safety, the train overhaul maintenance for the car body, car wheels and each part of the car is considered a critical system component.

Refurbishment is a train maintenance strategy that includes overhauling, upgrading and rectifying work to restore the train's condition and improve the system with the technological pull concept. Refurbishment is usually done when the asset or train has reached the end of its useful life (Idris & Saad, 2020).

Condition-based monitoring is based on monitoring huge volumes of data obtained from maintenance activities rather than performing inspection using the time interval basis. For instance, a railway track system used by the vehicle can be analysed to detect track displacement, and this data can be obtained every day from the operating trains. Analysing this data would allow practitioners to identify the speed at which the track

deteriorates or degrades. Therefore, the decision to conduct the required maintenance could be initiated at the optimum timing while accurately predicting track irregularity at the specific location (Yokoyama, 2015). Supported by Loubinoux et al. (2013), in reality, there is greater opportunity for the accurate wear of the equipment to be observed apart from when a pre-determined threshold is exceeded. In addition, it can also be done when the maintenance personnel spot a visible change in the usual condition, such as the noise created and visible abnormality.

Predictive maintenance is a technique designed to assist in determining the condition of equipment to predict when it is going to fail based on a highly detailed forecast. This approach promises cost savings over routine or time-based. It is because tasks are performed when warranted only (Stenström et al., 2015). The technology used in assisting the predictive maintenance suggested by Misra (2008) is vibration measurement and analysis, oil analysis, acoustic emission (ultrasonic), current motor analysis and infrared thermography. In the field of railroads, a great quantity of data is generated, which must be reviewed, deployed optimally, and utilised to help people make the best decisions possible while conserving resources and maintaining the railways' primary concept of passenger safety. For instance, a Greek railway company employs data mining techniques and applies machine learning techniques to create strategic decision support and a trained risk and control plan (Kalathas & Papoutsidakis, 2021). In addition, 17 years of inspection data for Portuguese TOC are used to predict wheel wear rates and survival curves, which are further incorporated into a Markov decision process (MDP) model (de Almeida Costa et al., 2020). MDP model is a mathematical framework for describing decision making in situations where outcomes are partly random and partly controlled by a decision-maker.

All of the listed maintenance strategies could be used by the TOCs depending on their financial plans and equipment or system conditions. However, the chosen strategy must consider the maintenance plan provided by the original equipment manufacturer, historical data from similar equipment or system used by the TOCs and supply chain management capability.

METHODS

The research started with the identification of the issues, problem statements and establishment of the research objectives, followed by the literature review to identify the maintenance strategy utilized for rolling stock maintenance. The third process was primary data collection from five TOCs. The fourth process was the analysis of the primary data using the Importance Index to rank the maintenance strategy. Finally, the discussion on the findings was established. The complete process flow is illustrated in Figure 1.

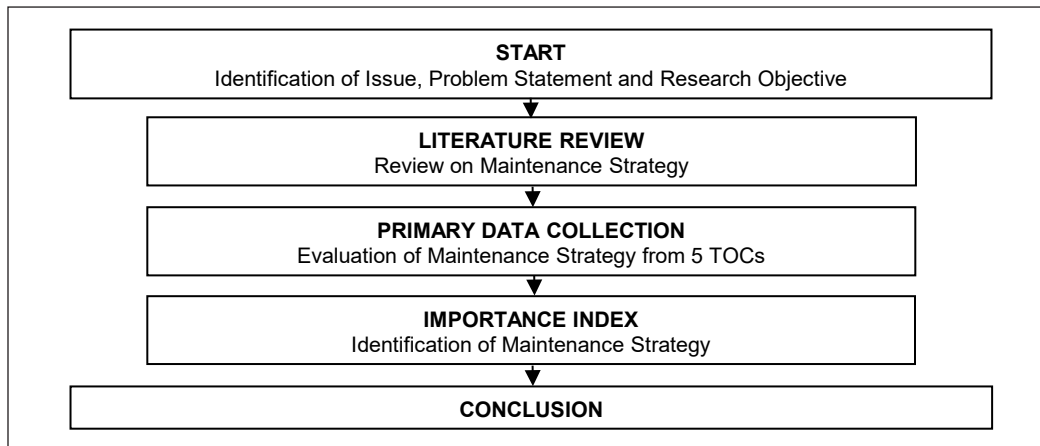


Figure 1. Research process flowchart

Survey

A survey was conducted on July 1st, 2020, where questionnaires were distributed to five TOCs in Malaysia to determine the maintenance strategy associated with rolling stock maintenance for the Malaysian urban rail. The five selected TOCs are the prominent train operators in Klang Valley. All TOC utilise electric trains for daily train services.

The questionnaire was adapted from research carried out by El-Haram and Horner (2002) and Ali et al. (2010), who suggested that the five-point Likert scale (5 = a great deal; 4 = quite a lot; 3 = to some degree; 2 = a little and 1 = Not at all) is appropriate to measure respondents' agreement and is able to rank the maintenance strategy using Importance Index.

The use of the Importance Index in identifying the factor ranking was also supported by Ali et al. (2010). Therefore, the analysis of the Importance index was conducted to identify and rank the maintenance strategy practised by the TOCs.

Judgemental sampling is a non-probability sampling technique used when the generalisation about the population is insignificant, and at the same time, the sampling frame is not available, or it is difficult to obtain (Kya et al., 2015). The respondents were nominated by their organisations representing subject matter experts (SME). The respondents consisted of managers, engineers, and executives at the strategic level with experience managing rolling stock maintenance. In total, 30 completed questionnaires formed a database for the ranking analysis. In addition, the respondents were asked to answer six questions related to the maintenance strategy used by their organisation. The scope of this research is limited to the maintenance of electric trains.

The collected data were systematically gathered using Microsoft Excel version 2016 to ensure data integrity and analysed using Statistical Software Package for Social Science (SPSS) version 26.

Reliability Test

The reliability test was conducted as a standard approach using Cronbach’s alpha value to determine the reliability of the survey instrument. From the test, it was found that Cronbach’s alpha value was identified to be at 0.735, which were acquired from the output of reliability statistics as shown in Table 2. Therefore, the Cronbach’s alpha test was performed to see if the surveys were reliable. Taber (2017) stated that Cronbach’s alpha values that lie in the range of 0.73 to 0.95 are highly reliable.

Therefore, the alpha value of 0.735 was considered reliable for this survey. In other words, the result of Cronbach’s alpha value showed that the survey was designed accurately to measure the variables of interest. Therefore, it was concluded that this research instrument has a high degree of reliability.

Table 2
Reliability test

Cronbach's Alpha	N of Items
0.735	6

Rank of the Maintenance Strategy

The maintenance strategy was ranked using an Importance Index derived from the formula as illustrated in Equation 1.

$$Importance\ Index = \left(\sum_{i=1}^5 w_i \times f_{xi} \right) \times \frac{100}{5n} \quad [1]$$

where:

w_i = Weight

f_{xi} = Survey Scale

n = Number of respondents

For illustration, the calculation of the Importance Index for the corrective maintenance strategy is shown in Table 3. All maintenance strategies were ranked in descending order. An example of the calculation of the Importance Index is illustrated in Equation 2. From the survey, 27 out of 30 respondents selected a weightage of 5, and it contributed

Table 3
Importance Index for corrective maintenance strategy

Level of importance	Weight (w)	Level of importance (f)	Importance Index (w x f)
A great deal	5	27	135
Quite a lot	4	2	8
To some degree	3	1	3
A little	2	0	0
Not at all	1	0	0
Total		30	146

to the Importance Index of 135. Therefore, the total Importance Index for the corrective maintenance strategy was 97.33 (as illustrated in Equation 2).

$$Importance\ Index = 146 \times \frac{100}{5 \times 30} = 97.33 \quad [2]$$

RESULT AND DISCUSSION

The demographic profile, which breaks down the job title, train operating companies and education level of respondents, are tabulated in Table 4.

Table 4
Demographic profile

No.	Description	Number	cumulative	(%)	cumulative (%)
1	Job Title				
1.1	Rolling stock engineers	14	14	47	47
1.2	Rolling stock executives	12	26	40	87
1.3	Rolling stock managers	3	29	10	97
1.4	Asset-management manager	1	30	3	100
2	Train Operating Companies				
2.1	TOC A	9	9	30	30
2.2	TOC B	7	16	23	53
2.3	TOC C	7	23	23	76
2.4	TOC D	6	19	20	96
2.5	TOC E	1	30	4	100
3	Highest Education				
3.1	Bachelor's degrees	18	18	60	60
3.2	Diploma	7	25	23	83
3.3	Master's degree	3	28	10	93
3.4	Certificate	2	30	7	100

As for the job title's breakdown, it can be observed that 47% of the respondents were rolling stock engineers, while 40% of the respondents were rolling stock executives. Meanwhile, 10% of the respondents were rolling stock managers, and finally, 3% were asset-management managers. In total, 30 respondents were involved. The demographic profile for job title distribution showed that most respondents were rolling stock engineers and executives.

According to the demographic analysis for TOC breakdown, from 30 respondents representing five TOCs that operate the urban rail systems in Malaysia, the results showed that 30% of the respondent were from TOC A and 23% were from both TOC B and TOC C. This was followed by 20% from TOC D, and finally 4% were from the TOC E.

The survey analysis for education breakdown showed that 60% of the respondents own bachelor's degrees, while 23% have diplomas. It was followed by 10% of respondents having master's degree and finally, 10% of the respondents own certificate as their highest educational qualification. The demographic for the highest education distribution showed that most of the respondents acquired a degree.

This research conducted surveys among five TOCs in Malaysia, as highlighted in Table 4. From the literature review, six maintenance strategies were identified and adopted in the survey. The results of the descriptive statistics are summarised in Table 5. From the descriptive statistic, it can be observed that the most practised maintenance strategies were the corrective maintenance and preventive maintenance strategies with the mean value of 4.87 and the lowest standard deviation value of 0.434 and 0.346.

Table 5
Descriptive statistics for maintenance strategy practiced by the 5 TOCs

Variables	Mean	Std. Dev	Minimum	Median	Maximum	Skewness	Kurtosis
CM	4.87	0.434	3	5	5	-3.495	12.514
PM	4.87	0.346	4	5	5	-2.273	3.386
OM	4.8	0.407	4	5	5	-1.58	0.527
RefM	4.43	0.935	1	5	5	-2.096	5.191
PdM	4.3	1.022	1	5	5	-1.49	2.106
CbM	4.1	1.155	1	4.5	5	-1.357	1.506

Note: CM-Corrective Maintenance, PM-Preventive Maintenance, OM-Overhaul Maintenance, RefM-Refurbishment Maintenance, PdM-Predictive Maintenance and CbM-Condition-based Maintenance

The Importance Index was used to identify the most practised maintenance strategy in Malaysia, and the results are depicted in Table 6. The corrective and preventive maintenance were the most used strategies with the Importance Index of 97.33. It was followed by an overhaul maintenance strategy with the Importance Index of 96.00. Refurbishment maintenance strategy was in third place with the Importance Index of 86.66. The fourth commonly adopted strategy was predictive maintenance with the Importance Index of 86.00. Finally, the least-used maintenance strategy was condition-based maintenance with the Importance Index of 82.00.

The maintenance strategy with the highest Importance Index will be further discussed. The maintenance strategies with the highest rank were corrective maintenance and preventive maintenance. Supported by Pun et al. (2017), for an organisation to maintain its asset, the most common maintenance strategies to be applied are corrective and preventive maintenance.

Corrective maintenance is proven to be one of the highest-ranked maintenance strategies used by the TOCs in Malaysia. In their research, Loubinoux et al. (2013) mentioned that

Table 6
Importance Index for maintenance strategy applied by TOC

Rank	Maintenance Strategy	Importance Index
1	Corrective Maintenance	97.33
	Preventive Maintenance	97.33
2	Overhaul Maintenance	96.00
3	Refurbishment Maintenance	86.66
4	Predictive Maintenance	86.00
6	Condition based Maintenance	82.00

corrective maintenance involves repairing equipment at least temporarily so that it is in good condition to perform its intended function and resume the operation.

According to the author, it may comprise fault diagnosis (detection, location, analysis), immediate corrective or palliative action (full functioning required or downgraded operation) and deferred corrective action. The challenge in performing corrective maintenance includes when the failure involves critical and expensive equipment. Then the equipment is hard to repair or replace and may jeopardize the train operation. It is worst if the failed equipment has no redundancies and may prolong the train downtime and increase the time-of-service interruption. The deepest concern is when the failed equipment affects the equipment and system safety.

There are a few main advantages of corrective maintenance: requiring less planning, being cost-effective and involving simple paperwork and procurement planning processes. Less planning is required because maintenance is implemented when the breakdown occurs. Besides that, for a non-critical asset, it may not cause service interruption and is considered a cost-effective maintenance strategy. It also involves a simple process because the equipment is fixed only when needed, contributing to the reduction in administrative paperwork and procurement planning. Finally, it is considered the best solution in some scenarios, such as when the failed equipment is less vital and requires minimal cost and time to fix after its failure.

The disadvantages of the corrective maintenance include uncertainties in the expenses, possibilities to contribute to collateral damage, decreased equipment reliability, safety issue and non-compliance issues. The uncertain expenses are due to the unplanned equipment downtime. The first failure may cause collateral damage to the secondary equipment. It may decrease equipment's reliability and increase the risk of service interruption. It might affect the safety of the passengers, employees, and the asset itself. The effect of corrective maintenance might also cause irregular compliance with the standard set by the authority.

Preventive maintenance was ranked as equally important as corrective maintenance. Cheng and Tsao (2010) discovered that the time intervals at which preventive maintenance is scheduled are dependent on both the life distribution of the equipment and train system

and the total cost involved in the maintenance activity. It is supported by Loubinoux et al. (2013), which described preventive maintenance as a systematic approach to maintain a system as required by the regulatory requirements.

The systematic approach also includes formal planning, clear and accurate descriptions of the work to be done, such as replacement of parts, lubrication, and cleaning. Upon completing the tasks, keeping a record of the maintenance work is crucial for future reference and traceability purposes. Preventive maintenance is applicable for natural phenomena such as wear and tear due to train movement. Preventive maintenance does not require any prior examination of the equipment or parts and can be carried out periodically. Since failures in a system's equipment could cause undesirable or catastrophic consequences such as safety issues, equipment damage, quality issues, unexpected system unavailability, long repair times and unplanned maintenance actions, preventive maintenance is preferred.

However, performing preventive maintenance too often is also undesirable and could be costly. Hence, a balance between the preventive maintenance frequency and the risk of failures must be determined (de Jonge, 2017). The challenges in performing preventive maintenance may include the lack of data to examine the best time to proceed with preventive maintenance and the rigorous maintenance schedules that need to be fulfilled. Subsequently, the poor direction of maintenance derived from the wrong assumption can cause a financial spike due to the excess procurement spares for all fleets and creating the need for a computerised maintenance management system (CMMS). Moreover, organisation favours gaining the short-term cost-benefit such as minimum spending in spares rather than long-term cost-benefit such as extensive cost for spare and C-suite executives prefer value-added programs rather than long-term strategic planning.

The advantages of preventive maintenance include fewer downtime, less interruption, retentive lifespan, convincing budget and improved system efficiency. Pieces of equipment downtime will occur, and more secure system reliability will be obtained to sustain the TOC reputations. It is because fewer system and equipment interruptions are expected. Preventive maintenance may extend rolling stock lifespan since it is able to minimise collateral damage. This maintenance strategy promises convincing budget and financial planning.

In addition, it may also improve the efficiency of the overall equipment and the system's reliability, which in turn permits the service to run uninterrupted. The disadvantages of preventive maintenance are the huge upfront costs, labour-intensive and unnecessary replacement. The labour-intensive work is mainly due to the schedule and procurement process needed. The costs of preventive maintenance may be greater than corrective maintenance, especially for the non-critical equipment or system.

When preventive maintenance strategy is used too broadly, it may lead to unnecessary replacement. In some cases, components, parts, or even the entire equipment should be

run to failure. For instance, a typical light bulb used in a passenger salon should be left to operate until it burns out. Nothing catastrophic happens if that lightbulb fails except for the emergency lighting system. Hence, premature or periodical replacement based on a predetermined schedule tends to waste resources.

Therefore, the TOCs must categorise and decide which maintenance strategy is suitable for each specific system. For the system with less critical equipment, corrective maintenance can be used. However, for the system that is critical in creating smooth daily train operation, the use of a preventive maintenance strategy is recommended.

CONCLUSION

The outcome of this research presented the six maintenance strategies practised by urban rails' rolling stock maintenance among the TOCs in Malaysia. After review and data analyses based on the Importance Index and rank analysis, the research found six maintenance strategies can be placed into five ranks according to the Importance Index scoring. This analysis led to several useful conclusions. For example, the most important maintenance strategies are corrective and preventive maintenance (first-ranked). Meanwhile, overhaul maintenance strategy was ranked second (second-ranked), followed by refurbishment maintenance strategy (third-ranked), predictive maintenance strategy (fourth-ranked) and finally, the condition-based maintenance strategy was ranked last (fifth-ranked).

This research is the pioneering research performed pertaining to the rolling stock maintenance strategy for Malaysia's railway industry. It is important for future research to include the correlation between the maintenance strategy implemented by the rolling stock practitioner with the cost incurred to the rolling stock maintenance. Therefore, identifying the best maintenance strategy with the minimum cost may help reduce the TOCs operational expenditure and sustain the financial needs.

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