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Review Article

Cost of Rolling Stock Maintenance in Urban Railway Operation: Literature Review and Direction

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ABSTRACT

The rolling stock might function at an optimum level in reliability, availability, maintainability, and safety with comprehensive maintenance. The past decade has seen rapid development in the management of maintenance costs in many sectors such as the automotive and aviation industry. However, there is a lack in a number of studies focusing on rolling stock maintenance costs. This article provides comprehensive knowledge on the rolling stock maintenance cost. Recently, the research found no specific literature reviews that focus on typical rolling stock maintenance costs. This paper attempts to review, identify and discuss the influential costs involved in rolling stock maintenance. This research systematically reviews and classifies a substantial number of published papers and suggests a classification of specific cost categories according to rolling stock needs. The results revealed that 27 variables have contributed to the rolling stock maintenance costs. The highest among the influential costs are 13.8% spare part cost, 11% life cycle cost, 6.4% preventive maintenance cost, and 4.6% for the workforce, corrective maintenance, and cost of ownership, respectively. The interrelationship between influential costs and their effects on rolling stock costs is further discussed. More importantly, the paper is intended to provide a comprehensive view of influential costs affecting rolling stock maintenance and

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give useful references for personnel working in the industry as well as researchers. This research has highlighted the possibility of future major studies to minimize the identified maintenance cost and industry to optimize its operational cost.

Keywords: Maintenance influential costs, rolling stock, systematic review, train, urban railway

INTRODUCTION

In the railway industry, one of the most significant segmentations is called rolling stock, which refers to any vehicle used on a railway. "Rolling stock maintenance is one of the key operational issues for a railway transportation company" (David & Eva, 2018). Rolling stock assets must be properly maintained to ensure that the rolling stock continues to function at an optimum level in reliability, availability, maintainability, and safety. As emphasized by Tönissen and Arts (2020) and Szkoda et al. (2020), it is crucial to have sufficient maintenance to ensure railway operations are in functioning order and prevent any breakdowns that lead to service interruption or any dangerous circumstances. Grenčík et al. (2018) and Rezvanizaniani et al. (2009) found that the consequences of rolling stock failures heaved very serious implications on operations, safety, economy, and the environment at large. Organizations attempt to maximize the maintenance process and minimize the cost of activities. The cost minimization could lead to additional profit and could aid in sustaining an organization financially in the long run. Jupe and Crompton (2006) highlighted that most railways' operational costs involve multimillion dollars per year and are subsidized by the government. As for now, there is a lack in numbers of studies that focus on influential generic costs that contribute to rolling stock maintenance. Therefore, all influential costs must be properly identified to minimize cost-related activities. Only then cost leadership strategy could be achieved.

The specific objectives of this paper are to identify categories of cost for rolling stock maintenance, identify and evaluate the influential cost for rolling stock maintenance and discuss the influential factors that affect rolling stock maintenance. The next section of this paper focuses on the categories of the cost involved in rolling stock maintenance. It is followed by a systematically conducted literature review on related influential costs. Finally, a detailed discussion on factors affecting rolling stock maintenance cost and critical observations on interrelated cause and effect analysis is provided.

The phrase "urban rail transit" refers to a variety of local rail systems that provide passenger service in and around urban and suburban regions. The following categories can be used to categorize urban rail systems, which may overlap because some systems or lines include elements of numerous types (Suhana, 2017; Lee, 2002). Examples of urban rail transits are trams, light rails, rapid transits, monorails, commuter rails, and others. However, non-urban rails or rural rails focus more on locomotive trains, diesel trains and electric trains that provide services for intercity journeys and freight services (Vuchic, 2007).

A total of 80 papers by various researchers between 1951 and 2020 were collected and analyzed. According to the literature review, 27 influential costs affect rolling stock maintenance. The variables' details, also known as influential costs, are discussed in the next section. Figure 1 reveals that researchers are interested in understanding and exploring how the influential costs contribute towards rolling stock maintenance. Some of the variables are repetitive throughout the reviewed papers. The reviews showed that researchers have a huge interest in understanding the costs involved in managing rolling stocks. It provided a clear indication that this study is necessary to complement the current research and close the knowledge gap in identifying overall influential rolling stock maintenance costs.

Besides that, the findings of this research would contribute to the growth of knowledge in this specific topic of study. There is a need for more knowledge or information that focuses on and technically analyses the rolling stock maintenance, and this paper should contribute to the existing knowledge on the subject matter. Apart from that, the findings of this study would also be a great source of references for rolling stock managers, train operating companies (TOCs) and researchers to manage and leverage the costs involved according to their research interest.

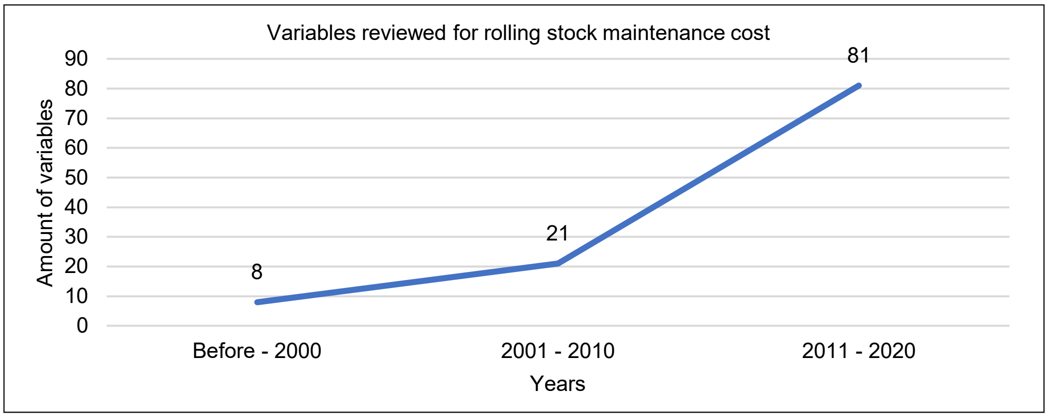

Figure 1. Papers reviewed for rolling stock maintenance cost

RESEARCH BACKGROUND

It is crucial for rolling stock practitioners or researchers to understand the process of planning, executing, monitoring, controlling the budget and leveraging it for financial sustainability. The cost categories and variables identified are illustrated in Table 1. Erguido et al. (2020) recently developed a comprehensive review on the cost structure for the life cycle of assets, specifically for rolling stocks. The authors emphasized that the cost for rolling stock maintenance is divided into two categories: capital expenditure (CAPEX) and operational expenditure (OPEX). CAPEX is divided further into development and investment cost, whereas OPEX only discusses operational costs. OPEX consists of preventive maintenance, corrective maintenance with failure impact and decommissioning.

Table 1
The variables categories and identification

Author	Variables	Cost Components
Erguido et al. (2020)	Capital Expenditure (CAPEX)	Development cost Investment cost
	Operational Expenditure (OPEX)	Operational cost + Preventive maintenance Corrective maintenance + failure impact Decommissioning
Nurcahyo et al. (2020)	Capital	Depreciation of railway assets
		Direct fixed costs i. Railway staff ii. Infrastructure iii. Insurance Direct variable costs i. Electricity ii. Security Train cleaning facilities
	Operation costs	Indirect fixed costs i. Employment ii. Office expenses iii. License and certification iv. Passenger service Indirect variable costs i. Marketing Human resource development
Brage-Ardao et al. (2015)	Car kilometers	Mileage from daily services
	Fleet	Number of trains
	Wages	Salary
	Rolling Stock (RS) maintenance staff hours	Man-hours
	Fleet availability at peak	Number of trains for service
	% RS maintenance staff hours contracted out	Outsource Work
	Average speed (km/h)	Average Speed
	RS Mean distance between failure	Mean distance between failure
	% Of rolling stock with Air Conditioning	Train with air conditioning system
	Rolling stock age (years)	Years for asset being utilized
	Age of the network (years)	Age of the rail system, i.e., Infra and system
Márquez (2007)	Capital Expenditure (CAPEX)	Design Development Acquisition Installation Staff training Manuals Documentation Tools and facilities for maintenance Replacement parts for assurance Withdrawal

Table 1 *(continue)*

Author	Variables	Cost Components
	Operational Expenditure (OPEX)	Manpower Operations Planned maintenance Storage Recruiting Corrective maintenance Penalizations for failure events/low Reliability
Murty and Naikan (1995)	Fixed cost	It includes equipment capital investment, structural specifications, instruments, and other accessories.
	Cost of material, fuel, packing, and marketing	Since production rates are proportional to supply, this cost varies linearly with variations in the supply of the plant/machinery.
	Cost of maintenance for achieving higher availability	Cost of spare parts, lubricants, repair tools, engineer and worker training, repair computer installation, online tracking, and software packages.
	Wages and salaries.	With availability, this is almost constant.

The cost components for the Mass Rapid Transit (MRT), as suggested by Rahmat Nurcahyo et al. (2020), are capital cost, operation cost and maintenance cost. The operation cost consists of indirect fixed cost and indirect variable cost. The authors also introduced a dedicated cost component which refers to the maintenance costs that cover the repair and maintenance cost of electric trains.

Meanwhile, variables identified by Brage-Ardao et al. (2015) show determinants of the rolling stock maintenance cost in metros. Research revealed that the comprehensive cost involved in managing the trains and other determinants are car kilometers, the number of fleets, wages, maintenance staff hours, fleet availability at peak time, percent of maintenance staff hours for outsourced work, average speed (km/h), the mean distance between failure, percent of rolling stock with air conditioning, rolling stock age (years) and age of the railway network (years).

According to Márquez (2007), cost characterization was made according to the different phases of the asset life cycle. The author emphasized that the main expenditures are capital and operational cost. The operational cost consists of the workforce, operations, planned maintenance, storage, recruiting, corrective maintenance and penalizations for the failure of events/low reliability. Corrective maintenance cost represents all expenses that are the result of efforts to keep physical assets in optimal working condition. It may involve inspection work, some repair and replacement work. In addition, Murty and Naikan (1995) also obtained similar findings on rolling stock maintenance in the context of cost variation. They identified the overall operating expenses as the main variables, which include the costs of the workforce, materials, external charges, taxes, depreciation, value provisions for contingencies and adjustments.

It is crucial for rolling stock practitioners or researchers to understand the process of planning, executing, monitoring, controlling the budget and leveraging it for financial sustainability. The cost categories and variables identified are illustrated in Table 1. Erguido et al. (2020) recently developed a comprehensive review on the cost structure for the life cycle of assets, specifically for rolling stocks. The authors emphasized that the cost for rolling stock maintenance is divided into two categories: capital expenditure (CAPEX) and operational expenditure (OPEX). CAPEX is divided further into development and investment costs, whereas OPEX only discusses operational costs. OPEX consists of preventive maintenance, corrective maintenance with failure impact and decommissioning.

Table 1, the influential rolling stock maintenance costs have been classified into various cost components. Therefore, further research is needed to identify the variables that influence the overall rolling stock maintenance costs.

LITERATURE FINDINGS

This literature review presents findings from papers by various researchers related to costs in operating rolling stock and rail maintenance. In total, 27 influential costs were identified, as illustrated in Table 2.

Table 2
Summary of rolling stock influential cost

No.	Variables	Researcher	Year	Rolling Stock	Rail
1	Downtime Cost	Erguido et al. (2020)	2020	/	x
		Andrés et al. (2015)	2015	/	x
		Gill (2014)	2014	x	/
		Cacchiani et al. (2008)	2008	/	x
2	Spare Part Cost	Mira et al. (2020)	2020	/	x
		Fourie and Tendayi (2016)	2016	/	x
		Lai et al. (2015)	2015	/	x
		Kraijema (2015)	2015	/	x
		Cheng et al. (2006)	2006	/	x
		Loubinoux et al. (2013)	2013	/	x
		Kara and Erdoğan (2013)	2013	/	x
		Palo (2012)	2012	/	x
		Tendayi and Fourie (2012)	2012	/	x
		Park et al. (2011)	2011	/	x
		Cadarso and Marín (2011)	2011	/	x
		Doganay and Bohlin (2010)	2010	/	x
		López-Pita et al. (2008)	2008	x	/
		Butler (1988)	1988	/	x
		Berechman and Giuliano (1984)	1984	x	/

Table 2 *(continue)*

No.	Variables	Researcher	Year	Rolling Stock	Rail
3	Shunting Cost	Mira et al. (2020)	2020	/	x
		Lusby et al. (2017)	2017	/	x
		Cadarso and Marín (2011)	2011	/	x
		Doganay and Bohlin (2010)	2010	/	x
		Peeters and Kroon (2008)	2008	/	x
4	Workforce	Jones et al. (2020)	2020	/	x
		Fourie and Tendayi (2016)	2016	/	x
		Brage-Ardao et al. (2015)	2015	/	x
		Asekun (2014)	2014	/	x
		Berechman and Giuliano (1984)	1984	x	/
5	Life Cycle Cost	Sarkar and Shastri (2020)	2020	/	x
		Khan et al. (2020)	2020	x	/
		Avenali et al. (2019)	2019	/	x
		Raczyński (2018)	2018	/	x
		Stern et al. (2017)	2017	x	/
		Fourie and Tendayi (2016)	2016	/	x
		Martinetti et al. (2015)	2015	/	x
		Kraijema (2015)	2015	/	x
		Palo (2014)	2014	/	x
		Ceng and van Dongen (2013)	2013	/	x
		Mulder et al. (2013)	2013	/	x
		van Abeelen (2012)	2012	/	x
		Choi et al. (2011)	2011	/	x
6	Depreciation	Anupriya et al. (2020)	2020	x	/
		Tomiyama et al. (2018)	2018	/	x
		Gleave (2015)	2015	x	/
		Alfieri et al. (2006)	2006	/	x
7	Inspection Cost	Abramov et al. (2018)	2018	/	x
		Lai et al. (2015)	2015	/	x
		Palo (2014)	2014	/	x
		Asekun (2014)	2014	/	x
8	Repair Cost	Stern et al. (2017)	2017	x	/
		Vaičiūnas and Lingaitis (2008)	2008	/	x
		Baumgartner (2001)	2001	/	x
		Mitchell (1951)	1951	/	x
9	Logistic	Stern et al. (2017)	2017	x	/
		Fourie and Tendayi (2016)	2016	/	x
		Gattuso and Restuccia (2014)	2014	x	/
		Doganay and Bohlin (2010)	2010	/	x
10	Fixed Cost	Kim et al. (2017)	2017	/	x
		Gattuso and Restuccia (2014)	2014	x	/
		Alfieri et al. (2006)	2006	/	x
		Berechman and Giuliano (1984)	1984	x	/

Table 2 *(continue)*

No.	Variables	Researcher	Year	Rolling Stock	Rail
11	Overhaul	Fourie and Tendayi (2016)	2016	/	x
		Butler (1988)	1988	/	x
12	Training Cost	Fourie and Tendayi (2016)	2016	/	x
		Esposito and Nocchia (2008)	2008	/	x
13	Cost of Ownership	Fourie and Tendayi (2016)	2016	/	x
		Kraijema (2015)	2015	/	x
		Puig et al. (2013)	2013	/	x
		Kim et al. (2009)	2009	x	/
		Alfieri et al. (2006)	2006	/	x
14	Incident Cost	Famurewa (2015)	2015	x	/
15	Direct Cost	Gleave (2015)	2015	x	/
		Famurewa (2015)	2015	x	/
		Schlake et al. (2011)	2011	/	x
		Schlake et al. (2011)	2011	/	x
16	Indirect Cost	Famurewa (2015)	2015	x	/
		Park et al. (2011)	2011	/	x
17	Penalty Cost	Andrés et al. (2015)	2015	/	x
		Park et al. (2011)	2011	/	x
18	Storage Cost	Stenström et al. (2015)	2015	/	x
		Kraijema (2015)	2015	/	x
		Fröhling and Hettasch (2010)	2010	/	x
		Doganay and Bohlin (2010)	2010	/	x
19	Preventive Maintenance Cost	Asekun (2014)	2014	/	x
		Palo (2014)	2014	/	x
		Park et al. (2011)	2011	/	x
		Cheng and Tsao (2010)	2010	/	x
		Butler (1988)	1988	/	x
20	Corrective Maintenance Cost	Stenström et al. (2015)	2015	/	x
		Kraijema (2015)	2015	/	x
		Palo (2014)	2014	/	x
		Gattuso and Restuccia (2014)	2014	x	/
		Loubinoux et al. (2013)	2013	/	x
21	Equipment/ Machinery	Asekun (2014)	2014	/	x
		Schlake et al. (2011)	2011	/	x
		Esposito and Nocchia (2008)	2008	/	x
		Wojtas (1989)	1989	/	x
22	Opportunity Cost	Asekun (2014)	2014	/	x
		Fioole et al. (2006)	2006	/	x
23	Inventory Cost	Park et al. (2011)	2011	/	x
		Park et al. (2011)	2011	/	x
		Fröhling and Hettasch (2010)	2010	/	x
		Kim et al. (2009)	2009	x	/
24	Hazard Cost	Asekun (2014)	2014	/	x
		Arup (2011)	2011	/	x

Table 2 *(continue)*

No.	Variables	Researcher	Year	Rolling Stock	Rail
25	Insurance	Gattuso and Restuccia (2014)	2014	x	/
26	Replacement Cost	Alfieri et al. (2006)	2006	/	x
27	Variable Cost	Gattuso and Restuccia (2014)	2014	/	x
		Alfieri et al. (2006)	2006	/	x

Note: / = Yes : X = No

The outcome of the systematic review shows the related influential costs involved in the management of rolling stock maintenance. A total of 27 variables were identified, as summarized in Table 3. The cost finding was presented and verified by local railway industry practitioners. Further analysis was performed to determine the frequency of identified influential costs in the reviewed articles. The research found that the highest influential costs are spare parts which are 13.8%, followed by life cycle cost, 11% and preventive maintenance cost, 6.4%. In addition to that, the cost of other variables includes workforce cost, cost of ownership, and shunting cost, which are 4.6%, respectively. Shunting cost is the cost of towing or pushing a train from one point to another. The shunting process is needed to move the train during maintenance activity from one maintenance pit to another. It is also required during service breakdown. Next is equipment cost, storage cost, depreciation cost, repair cost, logistic cost, fixed cost, inventory cost and inspection cost at 3.7% each, direct cost and downtime cost with 2.8%. Meanwhile, opportunity cost, training cost, hazard cost, penalty cost, overhaul, variable cost and the indirect cost covers 1.8%. Finally, the lowest costs are insurance, replacement cost and incident cost, which are 0.9%.

Table 3
List of identified influential rolling stock maintenance costs variable

No	Variable	f	(%)	No	Variable	f	(%)
1	Spare Part Cost	15	13.8	**15**	Inspection Cost	4	3.7
2	Life Cycle Cost	12	11	**16**	Downtime Cost	4	2.8
3	Preventive Maintenance Cost	7	6.4	**17**	Direct Cost	3	2.8
4	Workforce	5	4.6	**18**	Opportunity Cost	2	1.8
5	Corrective Maintenance Cost	5	4.6	**19**	Training Cost	2	1.8
6	Cost of Ownership	5	4.6	**20**	Hazard Cost	2	1.8
7	Shunting cost	5	4.6	**21**	Penalty Cost	2	1.8
8	Equipment/ Machinery	4	3.7	**22**	Overhaul	2	1.8
9	Storage Cost	4	3.7	**23**	Variable Cost	2	1.8
10	Depreciation Cost	4	3.7	**24**	Indirect Cost	2	1.8
11	Repair Cost	4	3.7	**25**	Insurance	1	0.9
12	Logistic	4	3.7	**26**	Replacement Cost	1	0.9
13	Fixed Cost	4	3.7	**27**	Incident Cost	1	0.9
14	Inventory Cost	4	3.7		**Grand Total**	**110**	**100**

Note: f = frequency

DISCUSSION

Research shows that there are a number of rules of thumb to follow when it comes to complex decision-making, such as identifying the most important variables using the 80/20 rules (Stenström et al., 2015). It is supported by Knights (2001), who emphasized the 80/20 rules, also known as Pareto analysis which is commonly used to identify maintenance priorities by ranking their relative cost according to failure. The Pareto 80/20 rules suggest that focusing on 20% of the causes would solve 80% of the effects. Therefore, this research will further discuss the top 20% of the identified variables, equivalent to six main variables most likely to have higher effects on the rolling stock maintenance costs. Out of these six variables, some are directly related, while others indirectly contribute to the rolling stock maintenance costs. The analysis using a pareto chart is illustrated in Figure 2.

The next section will cover the six main variables: spare part cost, life cycle cost, preventive maintenance cost, workforce, corrective maintenance cost and cost of ownership. However, it must be realized that in managing and operating rolling stock maintenance, those stated costs are interrelated. The costs have a cause-and-effect relationship with one another.

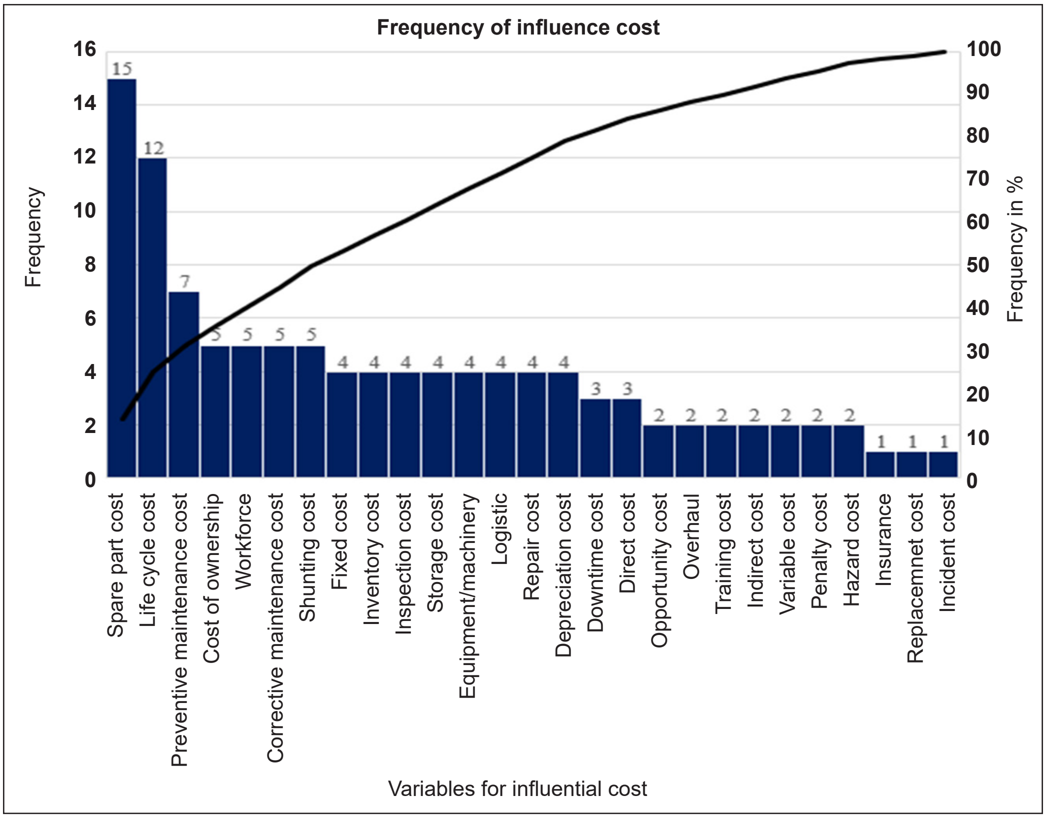

Figure 2. Frequency of influential cost

Spare Part Cost

Detailed research was carried out to identify factors related to spare parts. The ensuing explanation covers these factors: spares-related cost, logistic cost and supply chain inefficiency. Figure 3 shows the factors which lead to spare part cost being the highest contributor to the maintenance cost. The following discussion justifies the interrelationship between these factors.

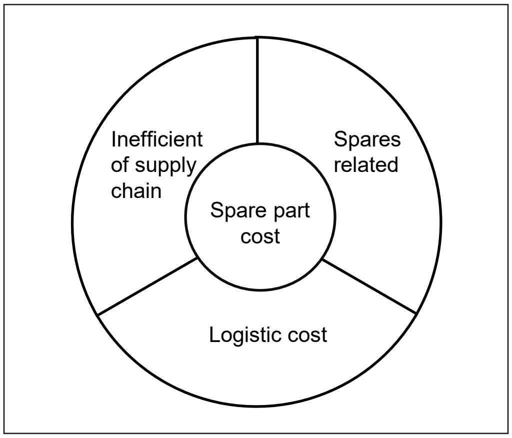

Figure 3. Factors that contribute to a rise in spare parts cost

The first factor that contributes to spare part costs is spares related issues. According to Fourie and Tendayi (2016), rolling stock practitioners must wisely plan the procurement strategy and not overspend on spares. Overspending on spares may lead to administrative costs, logistic costs and storage costs that need to be prevented. The authors emphasize that even if the objective is to maintain the high availability of trains, it is crucial for organizations to remain cost-effective. However, according to Lai et al. (2015), the excess spares from overspending could still have a positive impact. It can be used as spares in accidents or as samples for inspections. Lai et al. (2015) also emphasized that the excess spares could be used during emergencies. Even though the excess spares contribute to a higher maintenance cost, they could still be used for sample reviews during the procurement process. Likewise, Cadarso and Marín (2011) and Mira et al. (2020) emphasized that for urban rapid transit network to work at an optimum level, a few factors need to be considered, including adequate allocation of spares due to variation of fleets such as different materials/spares in the depots to support business as usual. The authors also point out that having suitable spares will allow TOC to fully utilize their vehicle for operations and have optimal mix formation of the trains during operating hours if the company uses a mixed fleet vehicle basis. Loubinoux et al. (2013) stated that for organizations to optimize the number of spare parts consumable items, the organization must ensure they are at a minimum level to maintain the equipment or vehicle until the end of its useful life cycle. Besides that, it may also help to minimize the stock holding cost. As for the rolling stock department, consumable items refer to items that may not be considered for further repair work, including parts beyond economical repair or that are low-cost.

According to Tendayi and Fourie (2012), one of the conclusions from their case study indicated that obsolete and redundant parts also result in high spare part costs. It could be the result of having various types of inventories because of obsolete and redundant spares purchased due to a lack of real-time spares monitoring systems. The authors also pointed out that due to the supply of important components, such as extended lead time and the desire to have a safety margin in case of unanticipated events, the business aims to have a safety stock that is approximately 20%. Since many sectors are now adopting the Just-In-Time method, this quantity is deemed excessive. The wheels of trains are considered a highly used mechanical part that causes high friction with running rails during operations. According to Tendayi and Fourie (2012), wheel profiling maintenance is very costly. The friction that occurs due to the constant use of the wheels will result in physical and technical degradation of the wheels. External factors due to track conditions may also cause damage to the wheels and require replacement and profiling work. If maintenance cannot properly plan the reprofiling and maintenance of the track condition, the wheel profiling will lead to higher spare part costs.

The second factor that affects spare part costs is the cost of logistics. In a separate study, Park et al. (2011) discovered that once the rolling stock department begins to purchase spares, they must include transportation costs, also known as logistics costs. The customer usually pays this logistic cost for items acquired from overseas, which involves the European supply chain. It is referred to as Freight on Board (FOB) origin. Most overseas or multinational companies do not provide logistic services and require buyers to arrange for collection and other logistical requirements.

The third factor that influences spare part costs is an inefficient supply chain. Tendayi and Fourie (2012) also stated that organizations tend to neglect the role of the sub-contractor in their supply chain, which results in inefficiency, whereas working together as strategic partners or business partners would be far more beneficial. In addition to that, they also stated that organizations would not be outsourced if their work is expensive; clients will opt for in-house services such as the winding of armatures for traction motors. However, if the organization has restrictions on facilities and competency, they could work with a vendor under strategic partnering and benefit from it. Jones et al. (2020) also emphasized that procurement of spares from overseas may lead to higher maintenance costs and recommends optimizing spare parts localization leading to more business opportunities inside the country and contributing to economic growth. Lee et al. (2020) highlighted that the supply chain must cover the recycling period because, at the disposal stage, those unused materials need to be disposed of carefully at a minimum cost.

Life Cycle Cost

Life cycle cost refers to a practice of accumulating all costs that an asset owner or TOC will experience over its lifetime. The original investment, potential further investments, and annually recurring expenditures, minus any salvage value, are all included in these costs. The rolling stock life cycle cost will increase due to factors illustrated in Figure 4.

The first factor contributing to life cycle cost is lack of expertise or the so-called learning curve, a common occurrence in all industries, especially when industry players must gain certain knowledge and experience to understand how the system works fully. More recently, Raczyński (2018) mentioned that this life-cycle cost could only be calculated using a specific approach with the assistance of the Subject Matter Expert (SME). The developed method is based on the experience generated during vehicle deployment. The author also found that, for an estimated period of 25 up to 30 years, rolling stock maintenance cost is equal to the vehicle acquisition cost. Besides that, it was also found that the cost of rolling stock maintenance for a 15-year life-cycle is about 40% to 50% of its acquisition cost. Energy consumption of rolling stock is about 15% to 20% of its acquisition cost, subjected to the characteristic of the route it operates on.

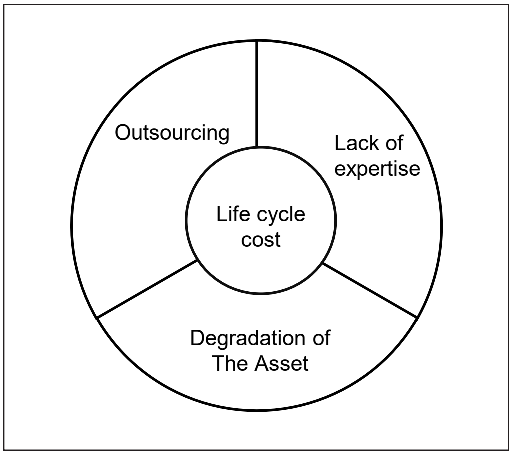

Figure 4. Factors that contribute to a rise in life cycle cost

Martinetti et al. (2015) also found that business owners and TOC should consider the total life-cycle cost for 30 years (subject to the train design) when deciding to add more rolling stock into their railway network to increase competition. It is important because the decision will affect the installation work during operations and logistic cost for the spare parts. Falco (2013) also supported that the fleet needs to be maintained to retain its performance requirements and further enhanced to meet customer requirements. The author also found that the life cycle for rolling stock is about 30–40 years when the fleet condition is maintained. The life cycle cost for the fleet is roughly 1/3 of the investment cost and 2/3 of subsequence maintenance. It is in line with Burstrom et al. (1994), who stated that the effort to complete the estimation of life cycle cost is challenging, expensive and time-consuming. The life cycle cost provides a comprehensive view of identified failures, improvements done, and the impact of the improvements through the life cycle cost. Considering the fact that the result of the life cycle cost after improvement is made according to the verification of the system reliability, it could lead to cost-effectiveness. Choi et al. (2011) also emphasized that the concept of life cycle cost should not be limited to the acquisition cost alone, and it must include all associated costs from the use up to the disposal of the assets. Fourie and Tendayi (2016) found that decision-makers in the railway, such as asset owners and TOC, always consider increasing the use of the life cycle costing concept in their capital expenditure decisions. It is so that they can anticipate the total expenditure and properly plan their expenses in a way that is beneficial to the business in the long run.

According to Mulder et al. (2013), during the acquisition stage, the designs of the trains must be carefully dealt with so that they will fulfill all the needs of the operational stage.

One of the factors that influence the maintenance cost is the design of the maintenance program, which must be in accordance with the train design to facilitate easy and fast replacement or repair work of the system and components which will subsequently result in low maintenance cost and reduced time consumption. The author also provided an example of the replacement time and cost for the compressor. The results show that with a good design, the replacement cost had reduced up to 66% from the cost for the initial design. According to Silva and Kaewunruen (2017) and Kaewunruen et al. (2019), in order to estimate the life-cycle cost, it is crucial for rolling stock designers to acknowledge the need for recycling during decommissioning, which can be seen through the applications of recyclable materials, proper material assemblies, ease of dissembling, retrofit capacity and labeling of materials. This research found that modern vehicles are also ready for decommissioning stage. A large variety of materials can be re-processed based on different recycling methods, and secondary raw materials can be reused.

The second factor that affects the life cycle cost is related to the degradation of the asset. Mechanical fatigue caused by mechanical parts often causes the degradation of rolling stock. Therefore, midlife refurbishment is needed; however, it requires a huge cost. According to Idris and Saad (2020), refurbishment maintenance usually involves one or all criteria such as overhauling, upgrading and rectifying work for the restoration and upgrade of the system due to issues relating to obsolescence because of the technology pull. As described by Chung and Lee (2012), the urban railway guideline practiced in Korea states that the life span of rolling stock is limited to 25 years. The authors also emphasized that the life span could be extended up to 40 years with regular safety tests. The lifespan for various railways all around the world is displayed in Table 4. According to Schwab Castella et al. (2009), the degradation also leads to the cost of life cycle impact assessment. The assessment is needed for the train to be disposed of according to the country's environmental policy. For instance, Korean metallic carriages are reused as restaurants.

The third factor that influences the life cycle cost is outsourced work. According to Kraijema (2015), one of the objectives of rolling stock maintenance is to achieve the lowest possible fleet life cycle cost. One of the outsourcing alternatives is using Service Level Agreement for cost-benefit while maintaining safety, availability, reliability and meeting passenger satisfaction. The author emphasizes that the main cost of operating light rail transit rolling stock include energy consumption and vehicle maintenance.

Table 4
Lifespan of rolling stocks for different countries (Chung & Lee, 2012)

No.	Line Provider	Lifespan (Year)
1	USA SEPTA EMU	30
2	USA New York Subway	40
3	Canada RAV EMU	30
4	Turky Mamaray EMU	50
5	Germany Hocodan EMU	45
6	Régie Autonome des Transports Parisiens	20-40
7	London Subway	30-50
8	Hongkong Subway	35

Apart from that, other insignificant costs were incurred due to false repair performed under SLA. Therefore, a detailed inspection before and after work by an appointed contractor and validation by an employer representative is needed to mitigate this issue. Stern et al. (2017) indicated that recently Original Equipment Manufacturers (OEM) or train suppliers have become more interested in being involved during the acquisition stage and providing advanced maintenance and data analytics technologies after this stage. It allows conventional rolling stock OEMs to use flexible and targeted tools to tap into the service market that covers rolling stock maintenance and overhaul programs. It assumes that in addition to selling new trains, the profit of rolling stock OEMs will also come from repair and maintenance over the entire life-cycle of the vehicle. This new market segmentation would also provide positive feedback for cost assessments of the acquisition stage and its life-cycle and thus help refine fleet planning and recommendation of technological changes to the components by the OEM and benefit the TOC in the long run.

Preventive Maintenance Cost

It is crucial for maintenance to ensure repairs and replacements are carried out in time for efficient operation. Since some failures might severely affect the safety of the passengers, it is important to take preventive measures by ensuring the maintenance work is completed in time and is according to some predefined schedule with limited resources (Budai et al., 2006; Macedo et al., 2017). Our study has found that the cost for preventive maintenance is due to lack of data, ineffective schedule, and unclear direction, as illustrated in Figure 5.

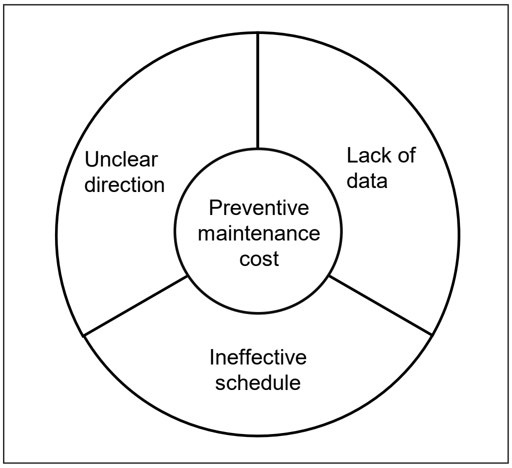

Figure 5. Factors that contribute to a rise in preventive maintenance cost

Stenström et al. (2015) found that a case study of historical data on rail infrastructure is performed to assess the preventive maintenance and corrective maintenance shares, along with a cost-benefit analysis to calculate the value of preventive maintenance. The findings show that preventive maintenance reflects between 10% and 30% of the overall maintenance cost. According to Palo (2014), the philosophy of preventive maintenance is to ensure the equipment or trains are maintained as a precautionary measure to avoid failure. Currently, the maintenance, repair, and overhaul contractors appointed for the Lussavaara Kirunava AB company by the Swedish rail performs preventive maintenance.

i. Travel Distance
ii. Visual inspections by maintenance personnel
iii. Safety alarms from the infrastructure manager

Kraijema (2015) found the maintenance policy is a collection of preventive maintenance activities performed at intervals based on fixed distance or time. These maintenance activities are believed to affect the subsystem's efficiency positively, and life expectancy, and components. The preventive maintenance cost typically consists of two main components: workforce cost and spare part cost.

The first factor that contributes to preventive maintenance costs is the lack of data. Preventive maintenance acts are performed either on a periodical or condition-based basis. Condition-based maintenance involves knowledge of the system's current state. In order to obtain this data is challenging and requires consistent effort. There are two methods for data collection: frequent inspections and condition monitoring. The key difference between the two methods is that checks are carried out at discrete intervals, and the term condition monitoring is used to track continuously. Based on Kraijema (2015), it is appropriate to replace 30% of components in the system. According to Butler (1988), when steam locomotives first appeared in the 19th century, their designs were very primitive. Maintenance concerns worsened due to insufficiently detailed drawings for repair and troubleshooting work. Apart from that, unsuitable spare parts were used, and manufacturers failed to conform to the design specifications. The inadequate drawings caused maintenance personnel to use the wrong parts for replacements, and this severely increased the spare part repair work and the cost of spare parts for replenishments. Similarly, Yang and Létourneau (2005) discovered that the employees occasionally put the incorrect axle number (e.g., 6 or 8 instead of 7) or on the incorrect side (left instead of right). These inaccuracies lead to wrong decisions and wrong maintenance actions resulting in increased preventive maintenance costs.

The second factor that affects the preventive maintenance cost is the non-accurate schedule. Asekun (2014) found that these maintenance techniques were sometimes unsuccessful. Typical maintenance practices in rolling stock companies widely focus on preventive maintenance, frequently leading to incorrect maintenance jobs, higher downtime, excessive maintenance tasks, and sometimes returning to corrective maintenance or breakdown maintenance when wrong preventives were carried out. In this situation, rolling stock practitioners need to efficiently handle these strategies by developing productive schedules for implementing the chosen maintenance strategy. Kwansup et al. (2016) observed that the preventive maintenance used by the Korean urban rail to maintain rolling stock vehicles also commonly disassembles, repairs, and replaces a component uniformly even without considering deterioration and aging conditions.

Meanwhile, for the Dutch TOC's NS Reizigers, these train units need regular preventive maintenance checks for every 30,000 km (Maróti & Kroon, 2007). According to Park et al. (2011), maintenance managers face problems with preventive maintenance scheduling for the rolling stock system. Maintenance managers must calculate the preventive maintenance interval for components in the rolling stock system to reduce the overall estimated life cycle costs by considering each subsystem's short-term and long-term preventive maintenance, such as overhaul programs. The cost of the system life cycle is used as a criterion for optimization. The empirical outcome of research conducted by Cheng and Tsao (2010) suggests that preventive maintenance should be rated for more than corrective maintenance. Rolling stock maintenance can be divided into two types: corrective maintenance and preventive maintenance. The periods at which preventive maintenance is scheduled to take place depend on both the life cycle of the components and the overall cost involved in the maintenance operation. However, corrective maintenance also cannot be avoided if the systems fail.

The third factor that influences the preventive maintenance cost is unclear direction. The TOC should have clear directions for every repair work that is needed. If the. Outsourcing for workforce, facilities and tools should only be an option if TOC does not have the means to solve these issues in-house. Tendayi and Fourie (2012) stated that organizations tend to neglect the role of the sub-contractor in their supply chain, even when they have an urgent need for it. In addition to that, the authors also stated that the organization should not be outsourcing the work, and it is better to do it in-house if they have the full capacity to do it. It was also supported by van Abeelen (2012), who mentioned that the cost related to maintenance should be pre-determined at the beginning of the project, including decisions on performing in-house or outsourcing maintenance work. It could be used to predetermine the necessary arrangements for managing a cost while the acquisition stage is completed.

Cost of Ownership

Another main influential cost for the rolling stock maintenance is the cost of ownership, as illustrated in Figure 6. Cost of ownership is an asset's purchase price plus operating costs. Assessing the overall cost of ownership involves taking a closer look at what the vehicle is and what it is worth over time. Past researchers have identified many factors that contribute to the rise in the cost of ownership which interrelates with the cost of maintaining rolling stock (Fourie & Tendayi, 2016). It is a result of acknowledging the importance of effective

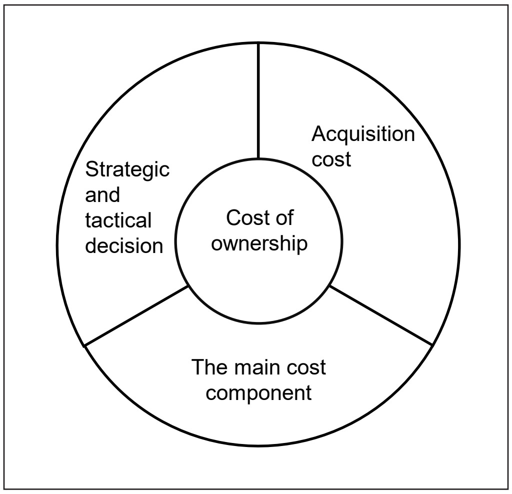

Figure 6. Factors that contribute to a rise in the cost of ownership

maintenance design and policy and incorporating it into the conventional economic life cycle costing method. The economic life cycle costing emphasizes the influence of effective maintenance and replacement strategy on the cost of ownership.

The first factor that contributes to the cost of ownership is the acquisition cost. Puig et al. (2013) found that the Netherlands Railways also experienced rolling stock maintenance, which represents 27% of the annual operating budget. The company invests approximately 12% of the annual budget in rolling stock acquisition. Therefore, the authors conclude that the yearly maintenance cost and any associated activities to maintain the fleet for the whole life cycle is more than double compared to the acquisition cost.

The second factor that affects the cost of ownership is the main cost components. Alfieri et al. (2006) and Kaminskas (2002) found that rolling stock is a vital factor for TOC to have an efficient distribution of railway rolling stock for its operation since it is one of the most significant cost components. The costs involved are purchasing, supplying, and maintaining rolling stock throughout its useful life. Since these costs are typically significant, the cost involved in managing rolling stock must be carefully determined. Alfieri et al. (2006) and Kaminskas (2002) also stated that there are two main factors that need to be scrutinized, namely, fixed rolling stock cost, referred to as acquisition and depreciation cost. In contrast, variable costs are related to power consumption and maintenance, such as inspection and scheduled or corrective repair work after running for a certain mileage.

The third factor that influences the cost of ownership is the lack of strategic and tactical decisions. According to Kraijema (2015), TOC such as Randstad Rail's experience shows that strategic and tactical decision-making processes in the organization will influence maintenance cost, especially to improve holistic objectives such as viability, reliability, safety and passenger satisfaction. The author suggested several important factors that need to be considered throughout the process, which are:

i. Increasing the success rate of repair work
ii. Overcoming failure of registration details
iii. Reducing calculation time of preventive maintenance model
iv. Improving quantifiable data input and including the total cost of failures during operation

Rolling stock maintenance management includes making huge capital investment decisions for service operators that cannot be changed frequently, which means that rolling stock becomes a strategic decision with a futuristic impact (David & Eva, 2018).

Workforce Cost

The next main variable that influences the rolling stock maintenance cost is workforce cost which is the amount of money an organization spends on its labor. It includes salary, compensation, benefits, fulfilling the country's statutory requirement, talent recruiting and developing workforce skills, knowledge, and attitude. The factors that affect the workforce cost are depicted in Figure 7.

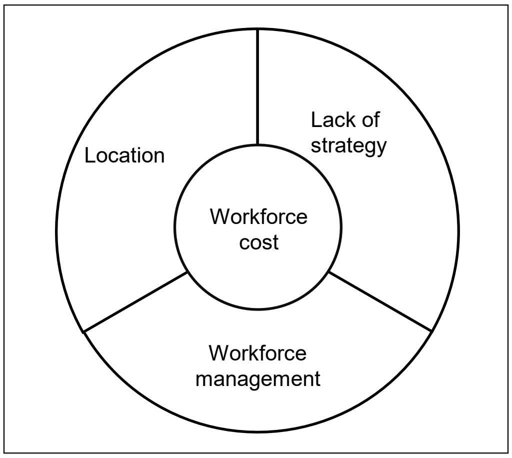

Figure 7. Factors that contribute to a rise in workforce cost

The first factor that contributes to workforce cost is caused by lack of strategy in workforce management. Brage-Ardao et al. (2015) concluded from their research that the TOC typically practices providing higher salaries to a lesser number of workers or hiring a higher number of workers with a lesser amount of salary, which has a direct association with higher maintenance costs. This effect can be mutually modulated by balancing between these two strategies. In this case, metros that offer very high salaries can prefer to hire a lesser number of employees, while companies that offer a smaller amount of salary can hire more people. Hence the final impact on cost management to rolling stock could be balanced between these two effects. Hence there appears to be strong evidence of economies of scale in per-car rolling stock operations, most likely due to labor specialization and maintenance routine automation.

The second factor that affects the workforce cost is workforce management. Research conducted by Asekun (2014) found that workforce, equipment, and material are the three key resources required for maintenance execution. These tools vary in their beneficial effects and are treated differently. The workforce has been proven to be the most vulnerable resource, making it incredibly difficult to manage. Maintenance management does not require the direct labor costs of personnel, but it can be used to plan, i.e., how, when and where maintenance work is to be done and ultimately has an impact on the task assigned.

The third factor that influences the workforce cost is associated with regional and location base. Workforce cost depends on the region where the maintenance is conducted (Raczyński, 2018). According to Stenström et al. (2015), workforce cost is also known as a direct cost. In addition to that, Fourie and Tendayi (2016) found that it is necessary to maintain the high availability of the fleet and retain cost-effectiveness and overspending on workforce and spare parts.

Corrective Maintenance Cost

The last main variable that affects rolling stock maintenance cost is the corrective maintenance cost. It is best described as any cost that incurs to fix a system malfunction so that the asset or system can be immediately restored to proper working condition. The cost depends on the extent of repairs needed and can range from moderately expensive to very expensive. If the repairs are easily fixable and isolated, the corrective maintenance cost might be lesser. Factors that influence corrective maintenance cost are as illustrated in Figure 8.

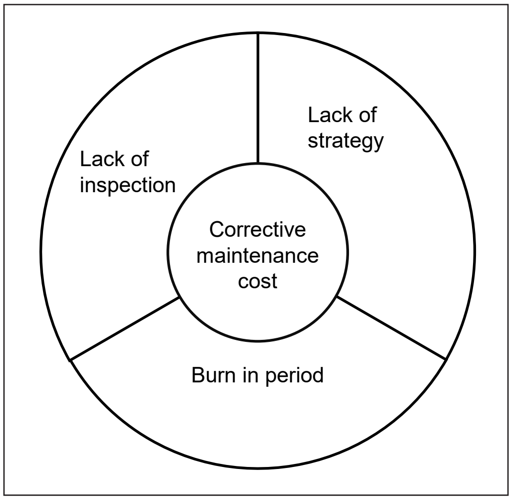

Figure 8. Factors that contribute to a rise in corrective maintenance cost

The first factor that contributes to corrective maintenance cost is the lack of strategy. Stenström et al. (2015) stated that the design or formulation of maintenance strategy and policies depend on a variety of factors like downtime costs, features of durability and asset redundancy. Consequently, to reduce costs, the balance between corrective maintenance and preventive maintenance differs between organizations and business objectives between TOCs. There is, however, a rule of thumb called the 80/20 rules of balance between corrective maintenance and preventive maintenance. A study by Cheng and Tsao (2010) estimates the optimal replacement period based on the 50 sample data obtained after maintenance from Taipei 's mass rapid transit, according to which the cost ratios of corrective maintenance and preventive are at 15:1 that is the cost of implementing corrections is 15 times greater than preventive maintenance.

The second factor affecting the corrective maintenance cost is the burn-in period Kraijema (2015) reveals that corrective maintenance is essentially reactive and performed only when the device fails to fulfill one of its functions. At the stage of the burn-in period, the high initial failure rate would decrease in time because defects in design, production, and installation are detected, and faulty components are replaced to meet the objectives, which are:

i. The system's useful life begins after the burn-in period, where failures occur spontaneously, and the failure rate is presumed to be constant.
ii. Aging effects can cause the failure rate to rise as the system's estimated lifetime is reached.

The third factor that influences the corrective maintenance cost is a lack of inspection. Palo (2014) found that the degradation process can be tracked to identify the faults before they change into defects, and the vehicle can be sent for corrective maintenance. A typical corrective maintenance cost comes from inspection and review of corrective maintenance activity. For instance, the cost for re-profiling a wheel will lead to the consumption of spares too. Therefore, a detailed inspection during corrective maintenance is vital as the decision made during maintenance will utilize spare parts.

CONCLUSION

The influential costs to rolling stock maintenance are crucial and need to be identified. In this research, the structured literature review focused on the highest influential costs that contribute to rolling stock maintenance. The findings of this study will help the TOCs identify the most influential costs and the interrelationship between factors of each of these variables. Based on specific papers reviewed, the influential rolling stock maintenance costs have been categorized into various disintegrated components. The systematic review presented in this paper found that many researchers are interested in the analyses of spare parts, which shows that the highest frequency of influential cost is spare part cost with 13.8%. It is one of the six main influential costs of rolling stock maintenance. The spare part cost is followed by life-cycle cost, which is 11%, preventive maintenance cost, 6.4% and workforce cost, corrective maintenance cost and cost of ownership, are 4.6%, respectively. The findings also show that each of these variables is affected by interrelated factors. This research investigates all the costs involved in rolling stock maintenance; systematic reviews presented a comprehensive analysis of influential costs affecting rolling stock maintenance and provided useful references for railway industries. Aside from that, the findings of the review can also be useful to researchers as well as academicians. A subsequent simulation model might be established using the identified cost to predict rolling stock expenses and budgeting purposes. It is expected that the TOCs operational expenditure on maintenance will be reduced, and company profit will be maximized in the long run of business.

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