

The Challenges Affecting the Reliability and Maintainability of Rolling Stock Operating in the Thabazimbi Channel

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Abstract

The paper presents the results of the case study conducted in the South African railway sector. This research aimed to identify the challenges that affect the Thabazimbi channel of rolling stock, identify critical success factors and the level of adoption to improve and optimize the reliability and maintenance of rolling stock. The study found that critical success factors had been well adopted in the study area. Age-related failures, vandalism, financial resources and weather conditions have been identified as key factors affecting reliability. It was suggested that the company use benchmarking to develop, maintain and improve its current state of affairs. The company should invest in security to combat vandalism and identify non-value-added activities to reduce maintenance costs. The organization should consider implementing an overhaul program and replacing components with high failure rates to address age-related factors. Although the results showed that senior management was committed to improving reliability, the company still needs to develop an integrated asset management policy that adheres to international asset management standards such as ISO55000 to reduce maintenance costs.

Keywords

Maintenance, Railway, Reliability, Rolling Stock

1. Introduction

Railway transport is considered to be one of the safest and most efficient modes of transport. Railway transport plays an essential role in the advancement of the global economy. However, one of the challenges facing the railway system is the reliability of rolling stock and special infrastructure on the African continent. As a result, asset managers in the rail sector have shifted the focus from increasing the competitiveness of the sector to addressing unforeseeable system failures. In South Africa, the rail sector is positioning itself to be among the top five rail sectors in the world by 2030 (George, et al., 2018). The claims are shown in the number of infrastructure development projects and the acquisition of new rolling stock. The rail network in South Africa is estimated at 23 500 km of the rail network, of which 1 600 km is mainly for export commodities and the remainder for domestic flows. The rail sector plays and continues to play a strategic role in linking ports and production hubs. The South African rail network enables smooth trade between neighbouring countries. Approximately fourteen percent (14 percent) of South African freight goods are transported annually by the rail sector.

There is evidence in the literature that the rail sector in South Africa has challenges of reliability and maintenance of its rolling stock (Makhanya; 2016). Some of the factors affecting reliability include the ageing of locomotives and the operating environment (Dibakoane, 2013). Other factors include old rail infrastructure, theft and vandalism. Previous research focused on specific areas such as the Natal corridor (Makhanya; 2016) and the export of coal (Seshabela, 2018) and ignored the Thabazimbi channel, which is also a major part of the South African rail network. The lack of knowledge on the factors affecting the reliability of rolling stock in the Thabazimbi channel has been identified as an

opportunity to expand knowledge on the factors affecting the reliability of rolling stock particularly locomotives in the South African rail sector.

1.1 Objectives

The purpose of the research was to identify and explore the challenges affecting the reliability and maintenance of rolling stock operating in the Thabazimbi channel. It also sought to explore the success factors in improving the reliability of rolling stock. The research methods and data collection was set up to meet the following objectives,

- a) To determine the critical success factors to improve the reliability of rolling stock and level of adoption in the Thabazimbi Channel.
- b) To determine the challenges affecting the reliability of rolling stock operating in the Thabazimbi channel.
- c) To propose an improvement strategy that can support improving the reliability of rolling stock in the Thabazimbi channel.

2. Literature Review

2.1 Factors affecting reliability

The use and performance of rolling stock during operation are both influenced by reliability (Fröhling and Rossouw, 2019). The likelihood that a system or object will perform its intended function for a specified period under specified operating conditions without failure is defined as reliability. Reliability is one of the metrics that are used to measure quality. It is applied whenever a system or asset is expected to behave in a certain way. It is a user-oriented quality factor related to system operation (Sillivant, 2015). According to Park, et al. (2017) reliability is the ability of a component or asset to perform as expected over a given time without disappointment.

According to Dibakoane (2013), reliability engineering is the process of integrating system, product, and service elements in such a way that they meet customer requirements at the lowest possible cost. As a result, design, manufacturing, and material selection are all factors that influence reliability. Puntis and Wally (2009) maintain that reliability depends on understanding and maintaining excellent engineering practices during product design to ensure that the product performs its intended function throughout the design life cycle. Also, the authors argued that the achievement of the method of reliability relies on regular measurement in terms of availability and reliability. Availability is a measure of the number of active and available fleets at any given time and is usually expressed as a percentage. This study did not attempt to investigate all the variables shown in the field of reliability and maintenance. This research focused on the challenges that affect the reliability and maintenance of rolling stock operating in the Thabazimbi Channel. Also, this research aims to identify the success factors that can be applied in the South African rail industry and to improve the reliability and maintenance of rolling stock. Table 1. provides a summary of the factors affecting reliability as identified in the literature.

Table 1. Summary of Challenges Affecting the Reliability of Rolling Stock

Challenge	Description	Author	Country
Integrated asset management	Reliability and performance of assets is dependent on the integrated logistic support between different departments like engineering, supply chain and resource management	(Gandhare, et al., 2014; Guo, et al., 2013; Vlckova, et al., 2016)	India China Czech Republic
Asset Condition	The performance of the rolling stock is influenced by age, design and the environment that the asset is operating on.	(van Baaren, et al., 2016; Chan Park, et al., 2017; Ouedraogo, et al., 2018)	Netherlands France South Korea
Theft	Theft and vandalism of infrastructure affect the performance of the rolling stock.	(Golybenko, et al., 2012; Yamamoto, et al., 2012;	Ukraine Japan Poland

Challenge	Description	Author	Country
		Restel & Wolniewicz, 2017)	
Weather	Climate changes have an impact on the reliability of an asset to function effectively.	(Dibakoane, 2013; Makhanya, et al., 2016; Seshabela, et al., 2018)	South Africa South Africa South Africa
Training	The skills and capabilities of the asset owners, maintainers and operators determine the useful life of the asset like a locomotive.	(Cang & Tuan, 2012; Dibakoane, 2013; Pathirathna, et al., 2018)	South Africa Sri Lanka Vietnam
Maintenance policies	Maintenance policies should support the functionality and the condition of an asset by eliminating potential failures.	(Yuan, 2016; Ramagaga, 2018; Seshabela, et al., 2018)	Norway South Africa South Africa
Funding	The organisation should put aside a budget to support maintenance activities.	(Gandhare, et al., 2014; Conradie, et al., 2015; Restel & Wolniewicz, 2017)	China Poland South Africa

2.1 Critical success factors

The second goal of the study was to identify the critical success factors that can help improve the reliability and maintainability of rolling stock in the Thabazimbi channel. Several critical success factors were identified during the literature review, including improved organizational culture, improved reliability programs, and regular training for locomotive maintenance personnel. According to Vujovic, et al. (2012), to reap the benefits of healthy and productive fleet performance, an organization should develop a reliability program as a continuous improvement strategy. This section summarizes the critical success factors identified in the literature that should be in place and secured for railway companies to optimize reliability and maintenance costs. Table 2. shows the critical success factors in the first column, the description in the second column, the author(s) and the country where the study was conducted in the last two columns. These success factors are consistent with the goals of this study.

Table 2. Critical success factors to improve Reliability

Factor	Description	Author	Country
Organisational culture	Organisational culture defines how things are performed in an organisation.	(Yuan, et al., 2011; Ahmad, et al., 2012; Khorshidi, et al., 2015)	Malaysia Australia China
Organisational policies	Reliability and maintenance policies should be linked with other organisational policies.	(Zhang, et al., 2011; Hein, et al., 2017; Naledi, 2018)	South Africa China Germany
Reliability programmes	Reliability management should be treated as a continuous strategy.	(Onwunta, et al., 2011; Vujovic, et al., 2012; Ghosh, et al., 2017)	Croatia India South Africa
Asset management	Heavy haul company should benchmark their asset management policy with proven asset management strategies such as ISO 55 000 and PAS 55 to comply with the international best practice.	(Apiwattananon, et al., 2010; Zhang, et al., 2011; Silivant, 2015)	USA Thailand China
Real-time monitoring tools	Railway organisations should invest in modern technological devices to help them determine potential locomotive failure beforehand.	(Silivant, 2015; van Baaren, et al., 2016; Hein, et al., 2017)	Netherlands Germany USA

Factor	Description	Author	Country
Training	The skills and capabilities of the asset owners, maintainers and operators determine the useful life of the asset like a locomotive.	(Iwakami, et al., 2014; Yu, 2017; Bannikov, et al., 2018)	Ukraine Japan China
Capital funding	The organisation should invest in new rail equipment, infrastructure and effective railway systems.	(Vicente & Fernando, 2012; Lewis, et al., 2014; George, et al., 2018)	England Argentina South Africa

The literature discussed in this article offered insight and knowledge on the critical aspects of reliability and maintenance activities. The theory also explored the global railway principles that helped the research team to formulate data collection tools to achieve the research objectives.

3. Research Methodology

This was an exploratory research design to gain an in-depth understanding of the factors affecting the reliability of the case study organisation. In line with the purpose of the research the case study as selected was a preferred method for the current research. The case study result can not be generalised or transferred from one setting to another but it provides a rich understanding of the phenomenon in its setting (Uma & Roger, 2009). The case study also allows the use of multiple data sources and triangulation which made it a preferable research method in this study.

3.1 Study settings

The Thabazimbi channel operates with a variety of assets, including 807 wagons and 234 locomotives, to deliver goods to ports and mines. The Thabazimbi Channel has a rail line of approximately 1874 km consisting of a double and a single-track rail line. A total of 777 km of dual-track rail was electrified by 3 kV DC and used by electric locomotives. While diesel locomotives were used on a single-line rail, which was approximately 1097 km from the Natal corridor line to the Thabazimbi channel. The lines have an axle loading restriction of 20 tons per axle, being upgraded to 22 tons per axle to accommodate the new diesel locomotives. The channel had employed more than 2000 staff members to support the operations and the maintenance of rolling stock and infrastructure. However, not all the staff members had the access to computers with the internet to participate in this research. The study also targeted a total of 51 managers who were involved in maintenance activities. Figure 1. illustrates the geographical network of the Thabazimbi Channel.

3.2 Data Collection

The research used two types of data sources which were questionnaires and operational data to collect the information needed to meet the objectives of the study. The questionnaires were drawn up from the literature reviewed and validated using two experts and a statistician from the University of Johannesburg. Experts were asked to check the wording, the length of the question and whether the questions addressed the concept of interest. The questionnaire was sent to 51 maintenance managers who had access to computers with the internet and were involved in locomotive maintenance. Participants were identified from the global email address of the case study company. The questionnaire was distributed using SurveyMonkey. The first part of the questionnaire asked the participants whether they agreed to participate in the study using yes and no. The participant who had chosen yes was allowed to proceed with the questions, but those who had chosen no were prevented from participating in the research. The data was collected over two weeks from 05 to 16 August 2019.

Operational data was collected through a four-step process, the first of which was the approval of the study in the case study organization. The approval of the study in the case study organization involved a meeting with the Head of Operation to explain the purpose of the study and the benefits of the study in the organization. The second process involves the development of a data collection plan that includes the type of data required, the reason for each type of data, the frequency of data collection and the person responsible for providing that information. The third was the

development of a database for the storage of information received from the organization. The fourth process consisted of data purification, which involved the identification of duplication, the removal of information unnecessary for the study and the preparation of data for analysis. The research team was authorized to analyze the system records from August 2018 to July 2019. The subsequent section provides an analysis and conclusion based on the two types of data sources.



Figure 1. Thabazimbi Rail network

4. Results

4.1 Numeric result

Fifty-one participants were invited to partake in the study and the research received a total of thirty-eight responses which makes up a 75% response rate. The study used the 95% confidence level to calculate sample representation and to calculate the margin of error. Using the tools built-in SurveyMonk the margin of error in the current research was $\pm 8.106\%$. Therefore with a 95% confidence level, the true population scores were between $\pm 8.106\%$ of the observed values. The questionnaire was distributed to all management teams working in the maintenance section who had access to computers with the internet and company e-mail. The company's global address provided the list of all the employees working in the study area. Table 3 provide the characteristic of the sample which participated in this research. The majority (45%) had working experience ranging from 6-10 years followed by members (24%) who had experience ranging from 1 to 5 years. The results indicated that the majority (39%) of the participants had a four-year degree. Both the level of experience and educational level demonstrated that the participant had sufficient knowledge of the subject to participate in this research.

Table 3. Demographic information

Items	Frequency	Related percentage	Cumulative percentage
<i>Level of Experience in the Organisation</i>			
1-5 years	9	24%	24%
6-10 years	17	45%	68%
11-20 years	8	21%	89%
20 and above	4	11%	100%
Total	38	100%	
<i>Educational Levels</i>			
Secondary school qualification	0	0%	0%
Matric qualification	6	16%	16%
Three-year degree	14	37%	53%
Four-year degree (BSc hons, B tech)	15	39%	92%
Master's degree	3	8%	100%
PhD or equivalent	0	0%	100%
Total	38	100%	

4.2 Critical success factors for improving reliability

In this section, the participants were requested to select their level of agreement with the items in Table 4 on a five-point Likert scale. Some items had missing values and were excluded from the analysis. The items had a higher internal consistency of (Cronbach's alpha = 0.822) which confirmed that the items were measuring the same concept. The research found that the overall organisational culture support reliability improvement and there is a policy to support reliability improvement the two-item had the weighted mean = 4.30 respectively. The respondents also indicated that the reliability programs (weighted mean = 4.19) assist in monitoring the effectiveness of the maintenance activities. The result also shows that senior management has linked maintenance activities to the business strategy and the organisation provide funding for rehabilitation programs (weighted mean = 4 respectively). Overall the scale has a weighted mean of 4.06 which shows that majority of the respondents agreed with the items.

Table 4. Critical success factors

Items	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Weighted average
The overall organizational culture support reliability improvement	0	1	5	13	18	4.30
There is a policy in place to support reliability management	1	1	3	13	19	4.30
A reliability program provides an appropriate means of monitoring the effectiveness of a maintenance program	1	1	4	15	16	4.19
Senior management has linked rolling stock maintenance to the business strategy	0	2	8	15	12	4.00
The organization invests funding to rehabilitate its rail infrastructure	1	2	6	15	13	4.00
There is regular staff training on the locomotive maintenance	0	4	7	15	11	3.89
The organization uses modern technology to identify locomotive faults	1	3	9	15	9	3.76

4.3 Challenges affecting the fleet performance

In this section, the participants were presented with the items in Table 5 and were asked to indicate based on their opinions whether the performance of the fleet had ever been affected by any of the items. The respondents were requested to select their answers from never = 1; rarely = 2; sometimes = 3; very often = 4 to always = 5. The items had a higher internal consistency of (Cronbach's alpha = 0.762). Again, the items which had the missing values were excluded from the analysis. The ageing fleet was identified as the main challenge with a weighted mean of 4.20 which was followed by vandalism (weighted mean = 4.17). The financial resource come up in third place with the weighted mean of 4.11 followed by weather conditions (weighted mean = 4.09). Overall, the participant agreed that the fleet performance was affected by all the factors in Table 4.

Table 5. Challenges affecting the fleet performance

Item	Never	Rarely	Sometimes	Very often	Always	Weighted average
Aging fleet	0	1	4	17	13	4.20
Vandalism	0	3	7	6	19	4.17
Financial resources	0	0	8	15	12	4.11
Weather condition	0	2	6	13	13	4.09
Integrated asset management policy	0	2	6	16	10	4.00
Maintenance strategy	0	4	11	8	12	3.80
Skills of the maintenance employees	0	3	9	14	8	3.79

4.2 The goodness of fit Test

This part presents the results obtained from the heavy haul company asset management system database. Statistical software Minitab 20 was utilised to determine which distribution model was best appropriate to handle the data of locomotive failures. The result provided four distributions which are Weibull distribution, lognormal, Exponential and normal distribution (Table 6). Rao and Mohsin (2018), maintains that Weibull and Gamma distributions are the most used distributions models to analyse failures for assets like locomotives. As such this research used Weibull distribution which demonstrated a good fit ($r = 0.962$).

Table 6. Goodness of Fit

Distribution	Anderson-Darling (adj)	Correlation Coefficient
Weibull	29.561	0.962
Lognormal	5.287	0.991
Exponential	84.586	*
Normal	144.102	0.836

4.3 Graphical results

Figure 2. shows the fleet reliability analysis from the operational data based on the Weibull distribution. The Weibull distribution uses two main parameters to judge the condition of the asset that is the shape parameter (β) and the scale parameter (α) (Rao and Mohsin, 2018). The $\beta < 1$ indicate the decrease failures over time; $\beta = 1$ indicate the constant failures while $\beta > 1$ shows the increase failures over time. In this research, the fleet had the $\beta = 0.993$ which shows that the failures were decreasing with time. The decreasing failure rate was also confirmed by the hazard function. The scale parameter is defined as a point where at least 63.21% of the total population would have experienced one or more failures. The fleet also had a mean between failures of 24.7 days based on 1524 previous failures.

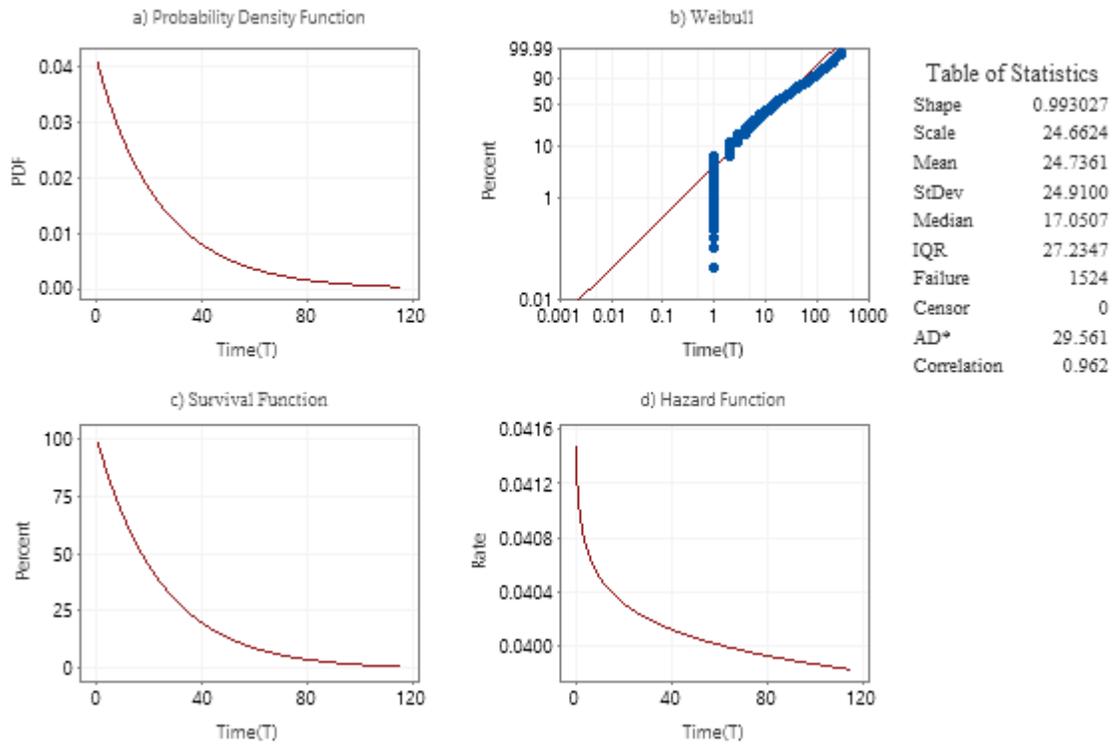


Figure 2. Weibull distribution analysis

4.4 High failures

After analysing the fleet reliability the next process was to go through the failure reports and group different failure modes with the support of the maintenance team. This section presents the ranking of the fleet failure modes from the highest frequency to the lowest in the Pareto Chart (Figure 3.). A total of 13 failure modes were found to be responsible for 80% of the total failures of the fleet. No operation (NOOP) accounted for the highest 23% of the total failures, which was followed by trippings and not starting (Nstarting) at 11% each respectively. Water and brakes related failures accounted for 6% each, power, shutdown and lighting accounted for 4% each. The air pressure, engine and vigilance related failures accounted for 3% each. The Pareto analysis shows that the main failures were due to maintenance issues or mechanical breakdowns.

5. Proposed Improvements

The findings revealed that critical success factors were well-adopted in the Thabazimbi channel, with the majority of the items having a weighted mean greater than 3.5 and Weibull analysis indicating that failures were decreasing over time. It was suggested that the company use benchmarking to develop, maintain, and improve its current state. The ageing fleet was identified as one of the most important factors affecting fleet reliability which was confirmed by the no-operation failure mode found from the operational data. To address age-related factors, the organization should consider implementing an overhaul program and replacing components with failure rates similar to those found in Figure 3. Vandalism was identified as the second factor affecting fleet reliability, while financial resources were identified as the third factor. The company should invest in security to combat vandalism and identify non-value-adding activities to reduce maintenance costs.

The fleet's performance was also strongly affected by weather and climate change. Since weather and climate change are uncontrollable factors, the system should be able to withstand the weather conditions that should have been specified during the design phase (Kumar, 2008). Integrate asset management policy is a systematic approach to ensuring that assets perform as intended through design and that the risk associated with the asset is adequately understood within the organization (Makhanya, et al., 2016). Even though the results indicated that senior management

was committed to improving reliability, the company still needs to develop an integrated asset management policy following international asset management standards such as ISO55000 and skills developments.

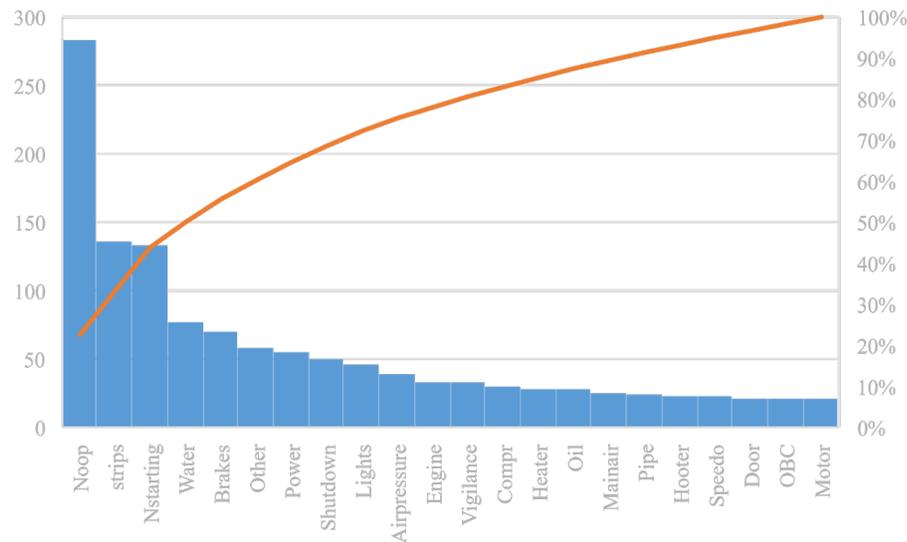


Figure 3. Pareto chart for fleet failure modes

5.1 Validation

The study used multiple data collection methods to collect the information related to critical success factors and the adoption in the study setting and factors affecting fleet reliability. Table 7. shows the differences between the operational data, questionnaire and literature review as the baseline. The ✓ indicates that there was evidence for the item from the data set and × shows that there was no evidence for the item from the data set. The questionnaire revealed that critical success factors identified in the literature were widely adopted in the study area. However, operational data had some limitations in identifying some factors, but both the questionnaire and operational data confirmed that the study area's reliability program provides the means to monitor reliability. The majority of the secondary data used in this study came from an asset management system that was designed to track fleet reliability. There was evidence that the company had capital allocated for the rehabilitation program during the research, but the research team was not authorized to analyze the data. Similarities between different data sources confirm the validity of the result.

Table 7. Critical success factors

Literature reviewed	Questionnaire	Operational data
The overall organizational culture support reliability improvement	✓	×
There is a policy in place to support reliability management	✓	×
A reliability program provides an appropriate means of monitoring the effectiveness of a maintenance program	✓	✓
Senior management has linked rolling stock maintenance to the business strategy	✓	×
The organization invests funding to rehabilitate its rail infrastructure	✓	✓
There is regular staff training on the locomotive maintenance	✓	×

Table 8. shows the similarities and differences related to challenges affecting fleet reliability. Both the secondary data and operational data confirmed the information from the literature suggesting that rolling stock is highly affected by

age-related failures. Although the operational date result shows that the failures were decreasing with time but the majority of the failures were age-related and cable theft which was part of vandalism. There were sufficient similarities between the three data sources as a result, we conducted that the study had both validity and reliability.

Table 8. Challenges Affecting the Reliability of Rolling Stock

Literature reviewed	Questionnaire	Operational data
Ageing fleet	✓	✓
Vandalism	✓	✓
Financial resources	✓	✗
Weather condition	✓	✓
Integrated asset management policy	✓	✓
Maintenance strategy	✓	✓
Skills of the maintenance employees	✓	✓

6. Conclusion

The research aimed to explore the factors affecting fleet performance in the Thabazimbi channel; identify critical success factors and adoption them in the study area, and finally to propose an improvement strategy. The literature review provided an opportunity to identify the critical success factors that have been adopted globally, factors that affect the performance of rolling stock and formulate a recommendation. The case study was selected as an appropriate research strategy for this research due to its ability to integrate multiple data sources into a single study. The questionnaire and operational data were selected as the current research information providers. The study found that critical success factors had been well adopted in the study area. Age-related failures, vandalism, financial resources and weather conditions have been identified as key factors affecting reliability. It was suggested that the company use benchmarking to develop, maintain and improve its current state of affairs. The company should invest in security to combat vandalism and identify non-value-added activities to reduce maintenance costs. The organization should consider implementing an overhaul program and replacing components with high failure rates to address age-related factors. Although the results showed that senior management was committed to improving reliability, the company still needs to develop an integrated asset management policy that adheres to international asset management standards such as ISO55000 and reduces maintenance costs.

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Biographies

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