The challenges affecting the reliability and maintainability of rolling stock operating in the Thabazimbi channel

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By

Avumile Bera

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SUPERVISOR: Dr Hannelie Nel

CO-SUPERVISOR: Bheki Makhanya

Declaration

I, Avumile Bera hereby declare that, apart from the acknowledged assistance, this mini-dissertation submitted by me for the degree of Master of Philosophy in engineering management at the University of Johannesburg (UJ) is entirely my work, and has not been submitted for a degree at another university or higher institution.

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Abstract

Rail transportation remains one of the cheapest and most effective modes of transportation in the Southern African Development Community. The proficiency and capability of the railway system, however, requires capital investment in infrastructure, transport system and, more importantly, rail infrastructure to support socio-economic growth and regional interlink across African nations. To accelerate socio-economic growth in the Southern African Development Community, there is a need for the African countries to work together. This is done with the intention of improving progress by minimising the cost of doing business through local integration and management.

Previous studies suggests that the heavy haul company experiences challenges of reliability and maintainability of its rolling stock, while trying to meet its business and customer objectives. This research aims to determine the challenges that affect the heavy haul company's rolling stock and identify critical success factors that can improve and optimize the reliability and maintainability of the rolling stock operating in the Thabazimbi channel, South Africa. The research utilized statistical data approaches and a questionnaire to answer the research questions and gain an in-depth understanding of the phenomena of the case study company.

The results revealed that the fleet was experiencing a decreasing failure rate, meaning the failures were emanating from the production or manufacturing design phase from the Original Equipment Manufacturer. The results and operational data strongly agreed that the heavy haul company railway infrastructure experiences theft and vandalism. The organisation did not have a modern reliability system or technology to detect failures before they occurred. Also the organisation did not adhere to its existing maintenance schedule, hence most of the failures were as a result of unplanned or unscheduled maintenance.

It is recommended that the heavy haul company focus on visual management, and people involvement who are responsible for the maintenance of the rolling stock operating in the Thabazimbi channel.

Furthermore the organisation should adopt a proactive approach to manage and implement asset management policy to optimise its reliability and maintainability of its rolling stock.

Table of Contents

Table of figures

Table of Tables

LIST OF ABBREVIATIONS

Acronym	Description
AFR	Sub-Saharan Africa Region
AMS	Asset Management System
BCM	Business Centred Maintenance
BM	Breakdown Maintenance
CM	Corrective Maintenance
DC	Direct Current
DRM	Deferred Reactive Maintenance
EAP	East Asia and Pacific Region
ECA	Europe and Central Asia Region
EM	Emergency Maintenance
EN	European Standard
FBM	Failure Based Maintenance
FMCG	Fast Moving Consumer Goods
FMEA	Failure mode effects and analysis
GDP	Gross Domestic Product
GFB	General Freight Business
IoT	Internet of Things
IRM	Immediate Reactive Maintenance
KM	Kilometre

Km/h	Kilometre per hour
LAC	Latin America Region
LCC	Life Cycle Cost
LIFEX	Life Extension
LTP	Long Term Programme
MDS	Market Demand Strategy
ME	Maintenance Excellence
MENA	Middle East and North Africa Region
MOR	Ministry of Railways of China
Mt	Million tons
MTBF	Mean Time Between Failures
MTTF	Mean Time To Failure
NATCOR	Natal Channel/corridor
OEM	Original Equipment Manufacturer
OTF	Operate to Failure
PHALA	PHALABORWA Channel
RAM	Reliability Availability Maintainability
RCM	Reliability Centred Maintenance
RIC	Russian Indian and Chinese
RM	Reactive Maintenance
ROI	Return on Investment

RTF	Run To Failure Maintenance
RTL	Residing Technical Life
SADC	Southern African Development Community
SAR	South Asia Region
SRM	Scheduled Reactive Maintenance
TBM	Time-Based Maintenance
TFR	Transnet Freight Rail
THABAZIMBI	Thabazimbi Channel
TPM	Total Productive Maintenance
TQM	Total Quality Management
USA	United States of America

1. CHAPTER ONE: INTRODUCTION

Moving freight by rail remains one of the major transportation modes in the present business world. Although railcars contrast negatively with road trucks and planes concerning flexibility, adaptability, and speed, the delivery costs are lower and the energy effectiveness is higher (Magadagela, Nel and Marnewick, 2017).

Heavy Haul Company is one of the biggest freight rail companies in the South African railway industry. It transports bulk and containerised freight along a 20 500km rail network, of which 1 500km comprises heavy haul export lines (Transnet, 2018).
Its network includes almost 4 000 km of branch lines. Heavy haul company's main business lines are the export coal line, the export iron ore line and the general freight business. The network and rail service provides strategic links between ports and production hubs and is connected with the railways of the Southern African Development Community (SADC) region, thus enabling trade with Africa (Transnet, 2018). Heavy Haul Company transports fourteen (14%) percent of South Africa's freight tonnage annually, operates 1050 trains a day and serves 450 customers (Transnet, 2018). Transports 250 million tonnes annually, and conveys 98 commodity groups over more than 4 000 origin-destination combinations (Transnet, 2018).

Railway freight transportation has been considered as a safe transportation mode and the increasing demand for it to transport goods and services for a country has drastically improved over the years. Thabazimbi channel operates with different assets which include 807 wagons and 234 locomotives. Thabazimbi Channel rail line is approximately 1874 Km consisting of double and single-track rail the, 777 Km double-track rail is electrified by 3 KV DC line operated by electric locomotives.

Diesel locomotives operate the single-line track rail. The Thabazimbi channel forms part of the five operating channels of the heavy haul company namely; Natcor, Phala, Coal and Cape channel, these channels were established to drive the organisation's operational objectives. In order to stay competitive and deliver on customer requirements.

Thabazimbi channel operates between 100 – 200 trains a day mainly focusing on Steel, Bulk cement, Coal, Lime and Grain commodities, amongst others (Transnet, 2018).

1.1 The International Railways

International railways can be grouped into five key areas, the greatest being the North American segment which has a joined course length of around 337 791km Bannikov, Dmitry, Sirina; Nina, Smolyaninov and Alexander (2018). The Russian, Indian and Chinese Railways (RIC) part has a joined course length of 268 652km and the European rail division 212 785km of consolidated course length Bannikov*, et al*., (2018). The two smallest divisions are the South American and Southern African Development Community (SADC) segments. The SADC division sits at a joined course length of 40 126km, which is commanded by South Africa's 22 051km. The North American and RIC areas represent 58 percent of the world's railroad courses, utilise 73 percent of the world's railroad workers, control 63 percent of the world's trains and record for 93 percent of the world's ton-kilometres (Havenga, 2015).

In the USA, railway systems, are organised by improving the way their systems are arranged to operate with the end goal that trains move from the starting point then into the next in the most efficient approach.

Diesel locomotive engines must meet the needs and requirements of reliability and availability of an organisation to meet the organisation’s maintenance strategy. Studies reveal that most diesel engine failures account for about 60 percent, and that China spends approximately 60 percent of its maintenance budget on diesel locomotive engine failures. Research shows that the majority of the failures are as a result of over/under maintenance (Zhang, 2012).

1.1.1 Sub-Saharan Africa Region (AFR)

Most of the railways in Africa were rigorously run-down because their reliability and rolling stock were poor.

They are requiring substantial rehabilitation of both infrastructure and rolling stock. They generally carry volumes at densities that are very low by world standards-what would be called branch line flows.

Transnet Freight Rail (TFR), Zimbabwe, Botswana, Swaziland and Zambian railways are amongst the railways in the region that are thriving to have reliable and continuously rehabilitating their infrastructure, reliability management and rolling stock. To support the neighbouring countries with commodities such as grain, petroleum and oil products, to enhance and improve food security and the economy of the Southern African Development Community (SADC) Amos and (Thompson, 2009).

1.1.2 East Asia and Pacific Region (EAP)

The Chinese railway framework (China rail) is managed under the Ministry of Railways of China (MOR). The Chinese railway network conveys 98 percent of the area's rail line traffic. It has 18 regional operational railways operating around 62,200 rout-km. MOR has found ways to improve the reliability of the railway system by contributing to a program that is required to cost over two hundred billion (Dhlamini, 2010). The project will increase rout-km to 100,000 km by 2020, increase electric traction from 31 percent of the current rail network to 50 percent of the system, and will expand double-track lines from 39 percent to 50 percent. Besides 7, 000 km of the new system will be devoted to passenger-only lines operating in ranges of 200-300kilometres per hour (km/h) speeds, hence improving reliability and rolling stock will open up existing lines for freight growth, that contribute 0.2 percent yearly into the Chinese Gross Domestic Product (GDP) Amos and Thompson (2009). Figure 1 shows the positive impact that MOR or Chinese railway system has and contributed into the country's GDP, through implementation and investing in the reliability and rolling stock of the railway system (Bloomberg, 2019).

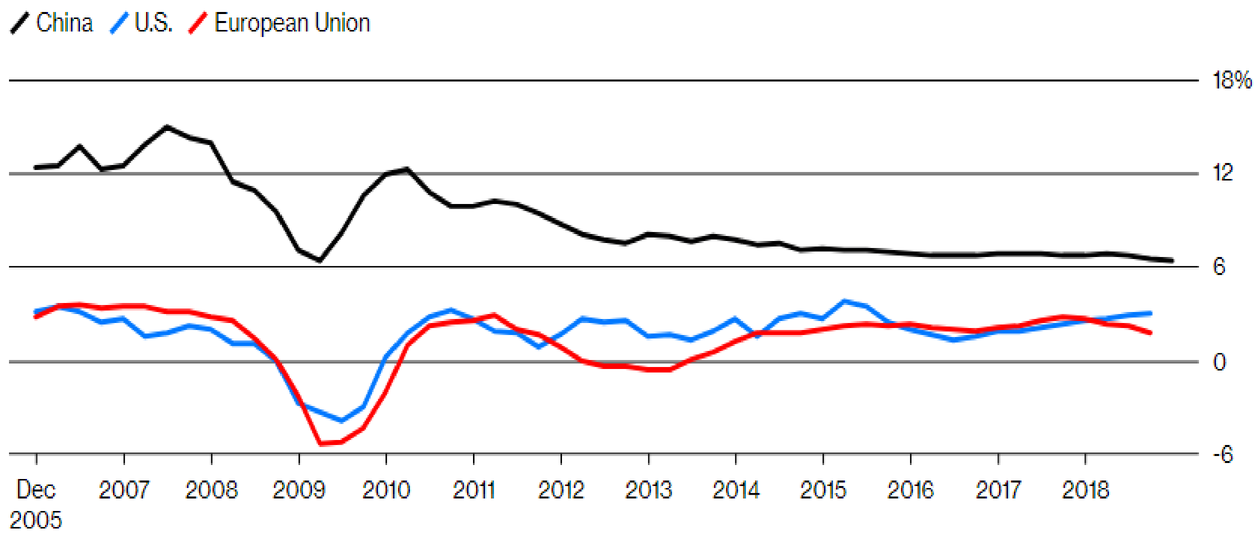

Figure 1 China Gross Domestic Product Growth (Bloomberg, 2019, p. 39)

1.1.3 Europe and Central Asia Region (ECA)

This district has the largest rail network reflecting the solid role that was allocated to railways in passenger and freight divisions when they were planned economies. In the decade 1996 to 2005, the rail network in the district declined in all respects possibly (by under 2 percent) Amos and (Thompson, 2009). Freight traffic in the area expanded in the decade by around 51 percent from the dimensions of 1996 (after a period in which traffic levels had been abandoned). The increases are not uniform over the district. The most grounded increase has been in Russia and Kazakhstan because of the resources boom. This means that in this region, the government or stakeholders do not have plans or programs to improve the reliability and railway infrastructure due to the unreliable infrastructure, funding and road transportation. Russian rail freight grew by 64 percent and overall total traffic by about 55 percent. This is because government instructed ministries of Transport and Economic Development to rehabilitate the state and reliability, infrastructure and rolling stock of the Russian railways to attract more customers and improve the country's railway system (Bloomberg, 2019).

1.1.4 Latin America Region (LAC)

The Latin American railways were most of the time operated by private companies. As a result, the railway infrastructure was left unattended, and that affected the reliability of the network and its rolling stock. Studies conducted by Makhanya (2016) further stresses that infrastructure left unattended to results, in dilapidation and distresses the asset Overall Equipment Efficiency (OEE), a measurement of Total Preventative Maintenance (TPM).Research conducted Makhanya (2016) further classifies the following two aspects that result in engineering product failures:

- The item is naturally unable, which implies the item will fail because of errors in the configuration and endure fundamentally at the inaccurate recurrence.
- Wear-out: a procedure making an item turned out to be weaker with age

However, privatisation of the Argentine railways was virtually complete by 1996, followed by Mexican railways, Bolivian railways, and Chilean Colombian railways in 1999. The current government of these states has established a 30-year program to rehabilitate the railway infrastructure and the network because the freight traffic in the region increased by around 80 percent over the decade, heavily concentrated in Brazil, Argentina and Mexico. Therefore according to Tsao (2010) this region is still facing the reliability, availability and maintainability of a reliable railway system.

1.1.5 The Middle East and North Africa Region (MENA)

The railways of the region change extensively in their qualities. Egyptian National Railways, for instance, is a main passenger railway (91 percent of the traffic is passenger). Over the ten years 1996-2005, Algeria, Egypt and Tunisia lost freight traffic, though freight traffic on the different railways developed by 30 percent and more Conradie, Fourie, Vlok and Treurnicht (2015). The biggest railway, Iran, gained up 40 percent more freight. There have been efficiency upgrades over the area because the government has set up Reliability Engineers to revive the railway infrastructure and its rolling stock.

Research by Makhanya (2016) further emphasises that the ability of a railway system to perform depends on the ability that its assets are well maintained and have a proper reliability management system. To be able to meet its customer demand and operational targets.

1.1.6 South Asia Region (SAR)

Indian Railways (IR) represents almost 98 percent of the majority of the rail cargo traffic in the location, and around 95 percent of the rail passenger traffic. With around 59 percent of its total traffic as freight traffic (Gandhare, *et al*., 2014). The legislature of India (and IR) has all the more as of late been thinking about the development of another and separate freight rail lines in the " Golden Quadrilateral" that interfaces Mumbai, Delhi, Kolkata and Chennai, to satisfy the increased freight demand and improve the system reliability and maintenance of rolling stock. The new lines will likewise improve efficiency freight operations, longer trains, and on-time arrival and departure of trains to increase customer satisfaction and quality. Research conducted by Seletlo (2018) also states that the need to increase rail transportation is of high importance because it also increases the global market share, and allows railway industry to be more flexible and reliable in their customers to deliver their goods and services on time.

1.2 The South African Railways

South African rail network comprises of two primary networks namely; the freight rail network and the passenger rail network. The two networks are owned by government and operated by state owned enterprises, namely Transnet Freight Rail (TFR) and Passenger Rail Agency of South Africa (PRASA). South Africa has a broad railway network which provides support to the road network to move a huge number of huge amounts of cargo everywhere throughout the nation. In any case, for a long time, the conditions of railway networks have been decaying as track maintenance was conceded due to an absence of funding. This has brought about poor railway lines.
Research done by Dailydka (2015) stresses that freight logistics play a pivotal role in a nation's economy and internationally, it is viewed as fundamental for national and

territorial financial advancement. Some developed nations like Canada, Germany and the USA are putting resources into freight system structures and expansions, while developing nations are utilising freight transportation as a method for accomplishing more prominent financial development and situating it as a focal angle in their monetary improvement designs (Dailydka, 2015).

1.3 Reliability in Railways

The reliability of an item is the probability that the item will perform a specific function under specified operational and environmental conditions at the end throughout a specified time. Reliability must devise certain criteria, and it depends on various factors, most of which are haphazard. It is difficult to measure reliability since there is no mechanism through which this may be done for precise apparatus (Bose, Ghosh, Mandal; Sau and Kunar, 2013). Operating locomotives on the railways normally leads to the natural oldness of the engines and other components and details that subsequently lead to increased failures. In order to prevent these failures and improve their reliability and maintainability, it is important to monitor their maintenance condition and deploy quality maintenance strategies on their technical maintenance plans and repairs (Liudvinavičius, 2014).

The respective reliabilities of the various components of complex diesel locomotives depends on the technology used for their production, the superiority and strength of materials used in their manufacturing, the settings or environment in which they operate (Bose, *et al.,* 2013). Insight of these considerations, the reliability of an asset is carefully related to many unforeseen dynamics.

The life cycle of a diesel locomotive or asset can be classified into three segments; the infant stage - where the failure rate gradually develops—useful life stage – where the failure rate remains steady. Wear out stage – where the failure rate accelerate. Within a population of diesel locomotives, there are subgroup systems with hidden defects that will fail when exposed to stress that would otherwise be benign to a good locomotive (Bose, *et al.,*2013). With the failure of the weak locomotives, the remaining population is more reliable, and the failure rate is known to decline.

Locomotives that pass the infant stage have a high probability of enduring the conditions exerted by the system and external forces (Bose, *et al.,* 2013). Reliability engineering plans offer a scope of options for developing maintenance capabilities. These can be utilised to expand maintenance and its application. Equipment history records are gotten and evaluated for the mean time between failures (MTBF) to be considered. The recurrence of emergency maintenance is recognised through the failure rate of the system which in turn will help with distinguishing the mean time between failures of the emergency maintenance activities; in this way, the lengthier the mean time between failures the more extended the number of emergency maintenance occurrences (Seletlo, 2018).

Reliability can be characterised as a strategy used to embrace what must be done to ensure that any physical asset, system or procedure continues to perform the manner in which it was planned to perform (Seletlo, 2018). Reliability bears incredible guidelines while deciding if a failure management policy is suitable by giving an ideal standard for deciding tedious tasks that should be considered out.

Systems suffer the effects of increased wear and age corrosion which causes low reliability and high operational costs. Occurring failures contribute to large breakdown costs, which implies that maintenance management as an indispensable part in manufacturing systems will be generally used to keep segments in great working condition to reduce failures and decrease high operational expenses (Seletlo, 2018).

Failure mode and effect analysis (FMEA) is a logical methodology utilised in dissecting looming failure methods of components for a specific system. It includes the documentation of failure modes, the potential outcomes or likely explanations and the significances related to risk. It very well may be utilised on both products and processes; this idea enables the capacity to recognise the most intense components and the probability of their failure mechanism, consequently determining the estimation of system limitations which should be observed (Seletlo, 2018).

1.4 Reliability Challenges in the Railway Industry

One of the challenges facing the improvement of reliability and rolling stock maintenance in the railway system is the scarcity of capital investment. This has been evident in countries like China, India and the SADC (Mbohwa, 2016). The railway system managers are continually left gauging the risks against the maintenance costs. As opposed to maintenance methodology choice in the manufacturing business, the maintenance of rolling stock additionally impacts passenger comfort, because preventative maintenance and corrective maintenance influence these three elements (safety, comfort and cost), railroad system administrators must build up a maintenance system that seeks to attempt an ideal situation. Given this, a technique that characterises a legitimate rolling stock maintenance methodology is incomparable to system managers (railway organisations), system safety supervisors (governments), and system users (Tsao, 2010).

The determination of a reasonable rolling stock maintenance system is complex. The system administrator needs to consider non-metric assessment factors (safety, quality) and metric assessment factors (maintenance cost, inventory cost, shortage cost) to choose a suitable methodology.

1.5 Reliability Engineering on Diesel Locomotives

Reliability engineering comprises of the systematic utilisation of time regarded engineering principles and systems throughout a product lifecycle and is in this manner a fundamental part of a decent product lifecycle program for managements (Swanepoel, 2018). The objective of reliability engineering is to assess the inherent reliability of an item or process and pinpoint potential areas for reliability improvement. Sensibly, all failure cannot be detected from a design phase, so another objective of reliability engineering is to recognise all the likelihood failures and after that distinguish fitting activities to mitigate the effects of those failures.

The reliability assessment of a product or process can incorporate various distinctive reliability analyses. Depending upon the period of the product lifecycle, particular kinds of analysis are appropriate (Mayoyo, 2015). As the reliability investigation is being performed, it is feasible to foresee the reliability impacts of configuration changes and rectifications. The different reliability analyses are altogether related, and inspect the reliability of the product or system from alternate points of view, to decide possible problems and help with analysing corrections and improvements.

Reliability engineering can help with applying great strategies and learning to avoid failures. It likewise assists with the identification and improvement of those failures and decides the methods for managing them (Mayoyo, 2015). Reliability engineers are in charge of distinguishing the strategies that can be utilised to break down reliability quality information (Mayoyo, 2015). Engineers are in charge of checking the availability and capability of the locomotives as indicated by the maintenance plan. They must apply reliability techniques that will guarantee that accessibility targets are met. Reliability engineers must be in a situation to identify failures and difficulties influencing rolling stock operating in the Thabazimbi channel (Mayoyo, 2015).

Reliability engineering is dependably observed as a need for the benefit of asset managers and business process owners. Maintenance management guarantees that there is a solid operation within the organisation that will re-establish the asset concerned back to its unique practical dimension to ensure it achieves its life expectancy (Mayoyo, 2015). According to research published by Mayoyo (2015) maintenance capabilities have assumed an imperative job in the development of innovation in a previous couple of years. The technique can likewise be utilised to unlock the economy of South Africa by making more opportunities for employment. Maintenance in France railways costs 15 percent to 70 percent of production costs attributable to their not maintaining their Locomotives.

Reliability engineering focuses on these items:

- To give the procedure that will resolve the failures that happen consistently
- To apply strategies for new design and analysis of reliability information

- To apply engineering information and specialist techniques
- To distinguish and correct symptoms of failures

1.6 Key Reliability Disciplines

The RAM analysis is a tool usually connected for the requirements of different ventures, railroad transport specifically. The aim of the Reliability Availability and Maintainability (RAM) analysis is to utilise operational data to perform out an evaluation of reliability with the requirements set out in the maintenance plan of the heavy haul company. These requirements concern explicit indicators of reliability, availability and maintainability.

The correctness of operational data plays a significant role in the RAM analysis. In this way, such information ought to be gathered by railroad transporters with specific seriousness and captured in exceptional database sheets. The information structure should provide for a description, as point by point as would be prudent, of the cause of failures, the period of their event and the extent of maintenance activities which have been attempted.

When forming and streamlining freight rail rolling stock diesel fleet, it is essential to appropriately asses the reliability of the presented rolling stock. Reliability decides the need for maintenance and specialised maintenance costs (Vaiciunas and Gelumbickas, 2015).

Reliability: The capacity of a device or system to perform out a required capacity under-expressed conditions for a predetermined timeframe. Also replicates the resistance from failure of a device or system (Szkoda and Kaczor, 2017). Covers the time to system failure (time-based capacity of failure rate or the Mean Time to Failure (MTTF).

Availability: Provides a clear indication of which subsystems are the main contributors to locomotive unavailability or the so-called “subsystem availability bad actors” (Szkoda and Kaczor, 2017).

All subsystems are availability constrainers; therefore, locomotive sub-system availabilities should be higher than the total diesel locomotive fleet size availability.

Maintainability: is the capability of an asset to be always in a good condition, or refurbished to a specified condition when maintenance is done, by workforce that has special skills using modern procedures. (Szkoda and Kaczor, 2017).

1.7 Importance of Reliability in Railway

There are various reasons why reliability is an essential item to an organisation some include:

Reputation: An organization's reputation is in all closely firmly identified with the reliability of its products. The more reliable an item is, the more probable the organization is to have a good reputation.

Warranty costs: If an item fails to perform out its capacity inside the warranty time frame, not just the replacement and repair costs will contrarily influence benefits, there might be negative client disappointment. Introducing reliability analysis is an essential advance in taking corrective action ultimately leads to an item that is increasingly reliable.

Cost analysis: Original equipment manufacturers (OEM) may take reliability information and consolidate it with other cost data to show the cost-effectiveness of their items. This life cycle cost investigation can demonstrate that despite the fact that the underlying expense of an item may be higher, the general lifetime cost is lower than that of a competitor's on the grounds that their item requires fewer repairs or less maintenance.

Customer requirements: Many clients in the present market demand that their providers have a compelling reliability program. These clients are aware of the advantages of reliability investigation from their own experiences.

1.8 Reasons for Reliability Engineering

For an organization to succeed in the present very focused and innovatively complex condition, it is important that it knows the reliability of its product and can control it so as to create products or services at an ultimate reliability level. This yields the minimum lifecycle cost for the client and limits the manufacturer's expenses of such a product without compromising the product's reliability and quality (Mbohwa, 2016).

Our increasing dependence on innovation necessitates that the products that make up our day by day live effectively work for the ideal or structured in the timeframe. It isn't adequate that a product works for time shorter than its main goal term, and yet there is no compelling reason to plan a product to work much past its planned life since this would force extra expenses on the manufacturer. In the present complex business markets operations are automated and reliant on the effective activity of those equipment's (for example reliability) and on the off chance that they fail, on their speedy restoration to work (for example maintainability) (Amos and Thompson, 2009).

Product failures have fluctuating impacts, running from those that reason minor annoyances, for example, the failure of a TV's remote control (which can turn into a significant irritation, if not a catastrophe, depending upon the football timetable of the day), to catastrophic failures including loss of life and property, for example, an aircraft accident. Reliability engineering resulted from the need to maintain a strategic distance from such disastrous occasions and, with them, the unnecessary loss of life and property. It is not amazing that Boeing was one of the primary business organisations to grasp and implement reliability engineering, the achievement of which can be found in the safety of the present commercial air travel (Bannikov, *et al.,* 2018).

1.9 Problem Statement

The railway sector is currently experiencing challenges with rail infrastructure, rolling stock and asset utilisation, while trying to lower the cost of moving freight reliably. Increased maintenance costs and unreliable operating rolling stock is a major challenge for the heavy haul company.

The heavy haul company is also faced with an increasing unplanned maintenance failures, resulting in loss of revenue and unsatisfied customers.

This operational Channel is struggling to meet its operational objectives due to the reliability challenges of the rolling stock operating in that area. According to the research conducted by Makhanya (2016), it was also identified that ageing of diesel locomotives, their maintenance process and allocation of resources as one of the challenges affecting the performance of rolling stock operating in the heavy haul company.

These findings are similar to those that were identified by Dibakoane (2013) who also identified the ageing of rolling stock and infrastructure as the main challenge affecting the performance of the Railway industry in South Africa. In a separate publication, Dibakoane (2013) also identified the training of key personnel, resource planning, and utilisation of rolling stock as one of the key areas affecting the reliability, maintenance and rolling stock of diesel locomotives. Other research studies have been conducted in the Sishen-Saldanha export iron ore line, and they revealed that the distance between the Saldanha line and the maintenance depots which is approximately 500-800 km as the major factor of poor reliability of the assets operating in that line (Keyno, 2014).

Research conducted by Seletlo (2018) further suggest that the diesel locomotives that are operating in the Phala channel their failures are mostly as a result of heavy haul company using a run to failure maintenance strategy, inadequate skills transfer from the OEM (Original Equipment Manufacturer) and inadequate maintenance schedules. The maintenance of rolling stock is dependent on two types of maintenance, corrective maintenance and preventative maintenance. Corrective maintenance activities are not planned; failures are repaired when they occur. Preventative maintenance seeks to retain the system or component in an operational state by preventing failures from occurring (Tsao, 2010).

The literature reviewed suggests that no studies have been conducted in the Thabazimbi Channel that focused on improving the reliability and maintainability of the rolling stock operating in the channel.
This existing gap in the literature provided a rationale for exploring the challenges and success factors that can be recommended to the case study company, specifically the diesel locomotives operating in the Thabazimbi channel.

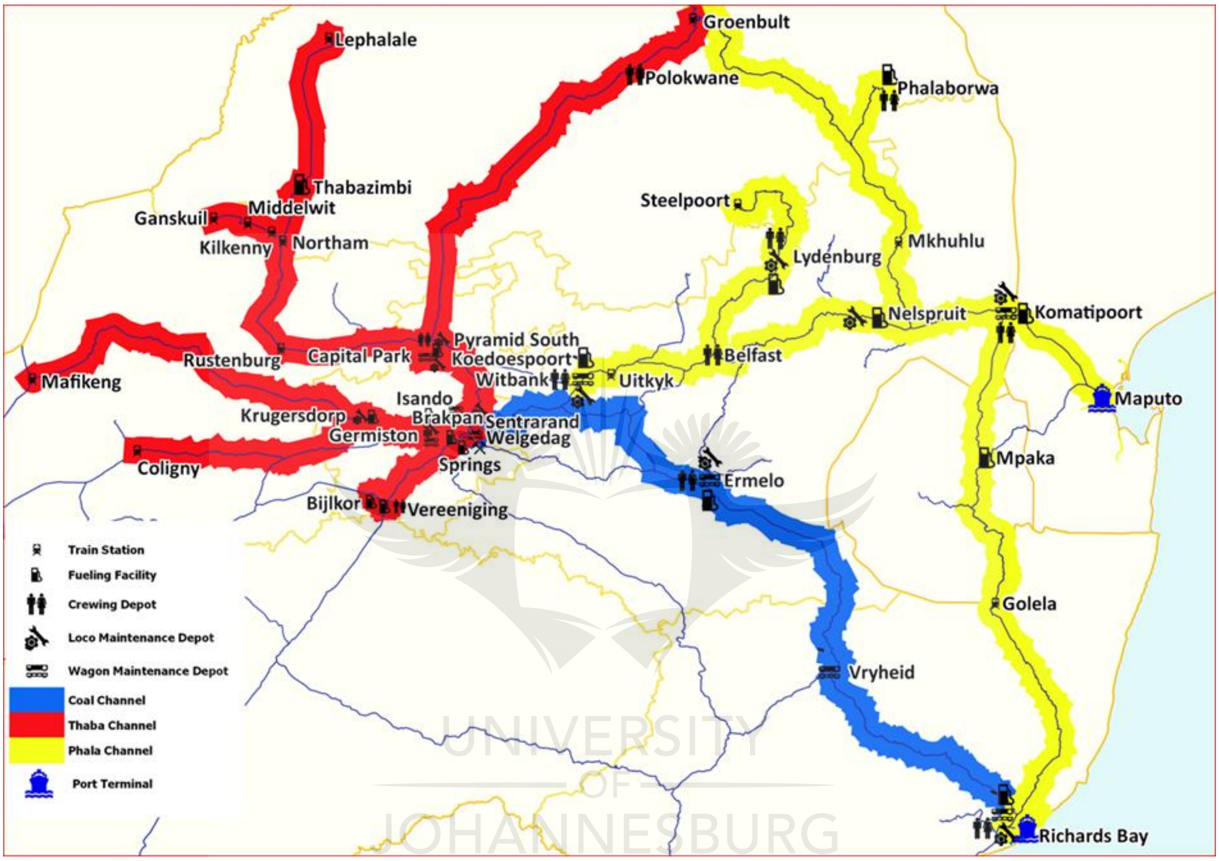

Figure 2 Thabazimbi Channel Network (Transnet, 2018, p. 5)

Thabazimbi channel operates with different assets which include (807 wagons and 234 locomotives). Thabazimbi Channel rail line is approximately 1874 km consisting of a double and single-track rail the, 777 Km double-track rail is electrified by 3 Kv DC line operated by electric locomotives. Diesel locomotives operate the single-line track rail is about 1097 km connecting the Natcor and Thabazimbi channels. 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 (Transnet, 2018).

1.10 Purpose of the Research

The primary objective of the research was to determine and explore the challenges affecting the reliability and maintainability of rolling stock operating in the Thabazimbi channel. It also sought to explore the success factors to improve the reliability of rolling stock. The research will focus on the diesel locomotives operating in the Thabazimbi channel.

1.11 Research Questions

a) What are the challenges affecting the reliability of rolling stock operating in the Thabazimbi channel?
b) What are the success factors to improve the reliability of rolling stock?
c) What strategies can be used by the heavy haul company to improve the reliability of rolling stock in the Thabazimbi channel?

1.12 Research Objectives

a) To determine the challenges affecting the reliability of rolling stock operating in the Thabazimbi channel.
b) To determine the success factors to improve the reliability of rolling stock.
c) To identify the strategy which can support the heavy haul company to improve the reliability of rolling stock in the Thabazimbi channel.

1.13 Assumptions

The main assumption of the research is that the research will receive support from the case study company. The results will also help the company to improve the reliability of rolling stock.

1.14 Limitations

This research will only collect the data about rolling stock operating in the Thabazimbi channel. It will exclude all other business units and operational channels of the case study company. It will only involve people who are working in the Thabazimbi channel.

1.15 Significance

This research will support the organisation to unlock the potential of rolling stock operating in the Thabazimbi channel. The research will also form the basis for researchers who want to advance about the rolling stock in reliability studies.

1.16 Report Layout

This research will comprise five Chapters. Chapter one characterises the foundation of the case study company, introduction, background and the research problem. Chapter two introduces the literature published and covered by other scholars addressing the objectives and the research questions in the field of reliability and maintainability processes, methods and practices that affect the reliability and availability of rolling stock. Chapter three is the research methodology that the researcher seeks to apply in this research to answer the research questions. Chapter four focuses on data introduction and discussion of results. The fifth chapter coordinates the literature, and the research findings conclude, recommends and suggests future work.

1.17 Ethical Considerations

The researcher upholds the need for privacy and confidentiality. It is for this reason that the respondents will be kept anonymous. The data extracted from the case study company will be used solely for this research. The research will be carried out with the consent of all those who will take part in it. Appendix (A.1) shows the ethical clearance certificate that the researcher obtained from the university to carry out the questionnaire.

1.18 Conclusion

This chapter highlights the problem that the heavy haul company is facing. It also highlights the background, research area and the reliability concepts that affect reliability and maintenance in the South African railway industry. Furthermore, it sets the tone of the importance of reliability management within railway organisations, and which success factors they should focus on, to improve the reliability of product and services. The following chapter will introduce the maintenance strategies that are applied by global companies, identify the challenges that affect reliability and the success factors that can help improve the rolling stock operating in the Thabazimbi channel.

2. CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Reliability plays a strategic foundation in the successful utilisation of rolling stock and its operation in heavy haul railway companies. Reliability is an essential element for the safe operation of any modern rolling stock and technological railway system of heavy haul companies in the freight rail business (Rossouw and Fröhling, 2019).

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 relating to system operation (Sillivant, 2015). According to Park, *et al.,* (2017) reliability is the capacity of a component and asset can perform out its expected function over a given time with no defined failure. According to Dibakoane (2013) reliability is the probability that equipment, asset or product will perform its intended function under designed conditions for a specific period.

Research conducted by Dibakoane (2013) further emphasises that reliability engineering is to develop the reliability requirements of a system, product and service for them to function at an acceptable optimal level. Therefore this means reliability can be linked with the design, manufacturing of raw material, strength and the external factors of a component or product. That can influence its performance when placed in an environment to perform its intended function during its total life cycle at a specified time (Abdullayev, *et al.,* 2017).

According to van Baaren, *et al* (2017) they view reliability as an integrated system that includes Life Cycle Cost (LCC), This approach minimises the cost of acquiring the rolling stock, maintenance cost and maximises the performance of the fleet from day one and is regarded as the highest priority in their reliability strategy management.

According to work published by Puntis and Walley (2009), they perceive reliability as being relying, on experience and maintaining good engineering practices to ensure that rail track, signalling, power supply systems and rolling stock provide a reliable train service. Furthermore, they elaborate that the success of this approach relies on measuring it regularly in terms of availability and reliability. Availability is the measure of the quantity of active and available fleet at any given time and is usually expressed as a percentage. Reliability is the measure of the number of delays to traffic above a specified control time limit (Puntis and Walley, 2009).

Research done by Tomo (2010) characterises reliability as the mean number of failures in a given time failure rate, or as a mean time between failures (MTBF) for repairable items, and mean time to failure (MTTF) for non-repairable items. This definition recognises the significance of things that that can be repaired and items that cannot be repaired; it gives a direction on the most proficient method to incorporate reliability with the two things.

Reliability of rolling stock and Locomotives operating in the Thabazimbi channel consist of equipment and parts which are repairable and non-repairable. The above descriptions of reliability are therefore best appropriate to define, determine and improve the challenges affecting the reliability of rolling stock operating in the Thabazimbi channel (O'Connor and Kleyner, 2012).

2.2 Factors Influencing Reliability and Rolling Stock

The diesel locomotives were identified as a major constraint of operations in the Thabazimbi channel. This research seeks to identify the factors affecting the performance of the assets. The research will focus on the 34D locomotives that operate in the Thabazimbi channel. The following section in table 1 provides a summary of the types of assets operating in the Thabazimbi channel:

Table 1 Thabazimbi Channel Operating Assets (Transnet, 2014, p. 14)

Channel	Commodity	Wagon Type	Locomotive Type
Thabazimbi	Petroleum	XPLJ	34D
	Soda Ash	FKMJ	34D
	Salt	CFR	34D
	Cement	XBLJ	34D
	Clinker	CR	34D
	Grain	FZ/FG	34D
	Chrome	CR	22E
	Coal	CFR	39D/7E/10E/22E
	Containers	SMLJ	7E
	Hexane	SXLJ	18E
	Flourspar	DGLJ	18E
	Citrus	SMLJ	7E/18E

The following section of the research will cover the factors that affect the performance of the fleet. Secondly identify the critical success factors that the heavy haul company might explore to improve the rolling stock. The literature that will be covered will give the researcher an in-depth understanding of the global maintenance strategies that are applied by international railway companies, and how they could benefit the heavy haul company.

From the literature covered, the factors that have an impact on the reliability of rolling stock and Locomotives operating in the Thabazimbi channel can be classified as shown in Figure 3:

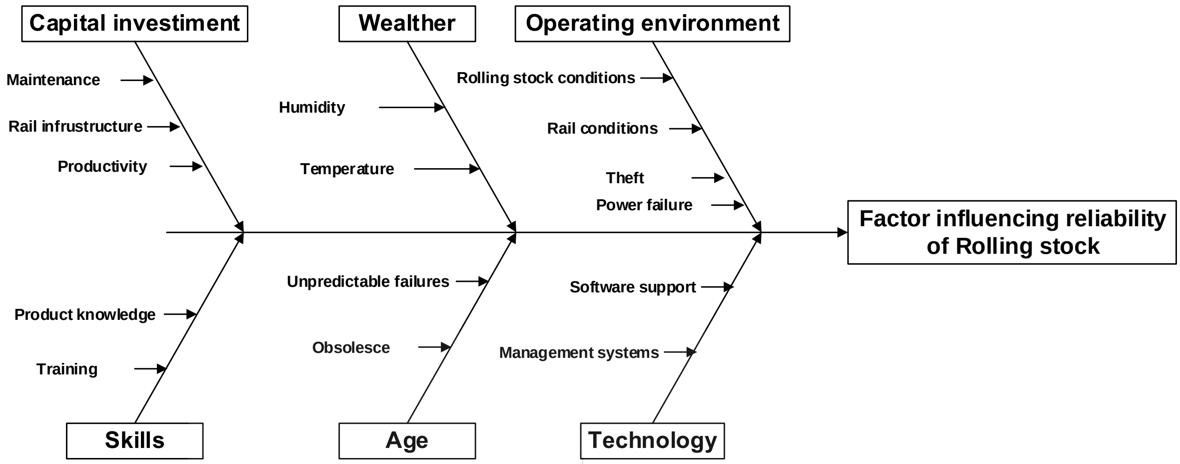

Figure 3: Factors influencing the Reliability of Rolling Stock

2.3 Factors that Influence Reliability and Rolling Stock in the Thabazimbi Channel

This research did not attempt to investigate all the variables illustrated in Figure 3. This research focused on the challenges that affect reliability and maintainability of rolling stock operating in the Thabazimbi Channel of heavy haul company. Furthermore, this research seeks to determine the success factors that can be applied in the South African railway industry, to improve the reliability and maintenance of rolling stock. Below the researcher elaborates more on the variables and components of the Locomotives and rolling stock system and subsystem, and the reliability measures used to measure a system's reliability, as well as the important maintenance strategies to improve the system reliability thereof.

2.3.1 Capital Investment

Railways can function for a considerable length of time without investment since railway rolling stock have long life expectancies. Without regular investment, the rolling stock can keep on running, however material and maintenance costs increase, and service quality and asset values decline. Over the longer term, the railway becomes uncompetitive and unsustainable. Over the past few years, Thabazimbi channel has experienced a lack of investments from the rehabilitation programmes that heavy haul company has embarked on, to improve the reliability and rolling stock that transports cargo volumes in the channel (Kuo and Zhu, 2012).

This has resulted in poor reliability and the rolling stock operating in the channel, which ultimately decreased the operational performance, poor customer satisfaction and reduced profits. There are, however, large capital investment programmes which are underway in an attempt to combat the problem of deteriorating reliability of assets and rolling stock operating in the Thabazimbi channel. Recently the Thabazimbi channel embarked on an improvement of the railway lines. The lines currently have an axle loading restriction of 20 tons per axle, being upgraded to 22 tons per axle to accommodate the new diesel locomotives to improve the efficiencies, customer satisfaction, safety, quality and the reliability of rolling stock.

2.3.2 Operating Environment

According to operational conditions refers to the climate changes, railway lines, and signalling that an asset operates within. These include dust, humidity and frost. These conditions are challenging factors during the successful operation of the rolling stock of any reliability asset in the railway industry. They also an imperative knowledge of the heavy haul companies when viewing reliability management and asset allocation and utilisation. They also need to be looked at when developing organisations short and long term reliability strategies (Crompton, *et al*., 2016).The environment in which an asset operates impacts its operational performance in a practical sense, infrastructures and their environments are inter-reliant.

The working conditions may incorporate environmental factors, for example, the geographical area where the asset or object is expected to work from, weather, temperature degrees and shock. Humidity and temperature play a vital role in the function and reliability of an item. For instance, High temperatures can cause rail tracks to expand and buckle and may lead to more regular repairs, speed restrictions, delays and disruption (Tomo, 2010).

2.3.3 Weather

Rail network systems have been structured and constructed utilising historical records of atmosphere and climate occasions (Conradie, et al., 2015). Presently with the 'Inconvenient truth' of environmental change, these projections are no longer a reliable indicator. Indeed, even what seem like unassuming changes in the normal temperature can mean vast and conceivably risky moves in atmosphere and climate (Bose, *et al*., 2013).

High temperatures can cause rail tracks to expand and clip and may prompt increasingly ordinary fixes, speed confinements, deferrals and interruption. Tempests can harm or store flotsam and jetsam on lines and at stations and floods or elevated tides can submerge them too. This is especially valid in underground passages, as observed in New York after Hurricane Sandy (Fourie and Zhuwaki, 2017). The rail business presently needs to get ready for an alternate climate future, and construct as needs be with a 'foresee and avert' philosophies that will take them forward with maintenance policies as opposed to backwards.

2.3.4 Age

There are numerous reasons behind the increased interest for better resource management in the railway industry, as the freight demand increases. At the point when organisations raise the significance of, risk, amount or cost of their corporate, critical or capital resources, they frequently observe a comparing rise to the management importance to maintain control and visibility of these assets (Fourie and Zhuwaki, 2017).

The overhaul company has experienced serious Maintenance budget cuts, over the past few years, this came as a result of reduced commodity prices, decreased mineral and mining demand from customers (Seshabela, 2018).

These budget cuts have compromised the maintenance of the rolling stock operating in the Thabazimbi channel; as a result, it affected the performance of the channel's tonnages from 18.7 Million tons (Mt) to 16.2 Mt (Transnet, 2018). Lack of resources, spares and inadequate training of fitters from the School of engineering to attend to the locomotive failures is still a challenge for the overhaul company in the Thabazimbi Channel.

2.3.5 Technology

According to Islam, Dewan, Zahurul; Jackson, Ross, Robinson and Mark (2015) they suggest that keeping assets for more than their life expectancy makes it difficult to fuse the new technology parts and control systems with the old asset original design. That, in turn, affects the performance of the asset, and no longer fulfil its intended function as reliability engineering stipulates (Islam, et al., 2015). The current heavy haul organisation locomotive fleet is common, of moderately high tare weight, implying that rail cargo trains can pull relatively lower net freight when compared with a vehicle with a lower tare weight. It is not unlikely to foresee that later on, towards two thousand and fifty Islam, *et al.,* (2015) a decrease in the tare weight of the trains will be accomplished, bringing about increased efficiency. By reducing tare weight, the net load to net weight proportion will be improved significantly to oblige both weight and volume parameters. It is perceived that a decrease in tare weight will be accomplished through the pattern toward light-weighting of the locomotive.

2.3.6 Skills and Training of Personnel

According to work done by Seletlo (2018) he mentioned that one of the challenges that his studies found is that the inadequate of resources and transfer of skills from the OEM's plays a crucial role in affecting the reliability of diesel locomotives.

Furthermore, Dibakoane (2013) also suggests that training and development of both diesel and electrical fitters is still a challenge that affects the reliability and performance of rolling stock in the railway industry. Research conducted by George-Williams and Patelli (2017) Suggests that in order to address this challenge the heavy haul company training department must adapt and transform their teaching material to be in line with the latest technology fitted on the rolling stock. To improve the reliability and performance of these assets, particularly where this research is focused on which is the Thabazimbi channel.

2.4 Asset Management

Asset Management is a concept intended to look at the locomotive and rolling stock total life span (Do, *et al*., 2016). It is trusted that through a greater realisation of the assets worth, studying the assets more adequately and perform the best ideal service and principles, will increase productivity through a more extended timeframe. Regularly utilised application areas are monetary, equipment maintenance and programming vendors and infrastructure. Financial, wherein the term must be viewed as best recognised, it is seen to get the best development and security for investment portfolio (Tomiyama, *et al*., 2018).

In equipment maintenance, the point is to improve the availability and reliability of the asset and its subsystem components. Maintenance has for quite a while been viewed as a pure cost driver and in this manner been getting a low financial rooftop. Asset management can here support raise the awareness and significance of the tied-up capital lastly in infrastructure where asset management is expected to help to depict their role in their total life cycle. Ageing of a locomotive and rolling stock has a major impact on the reliability of performance, and thus train service in the Thabazimbi channel. Ageing of assets is usually divided into three stages for the assets, reliable, degenerated and unreliable Asekun and Fourie (2015), see Figure 4: An effective maintenance strategy will minimize the aging process and thereby improving the performance of the asset over a longer period of time (Fredriksson and Larsson, 2012).

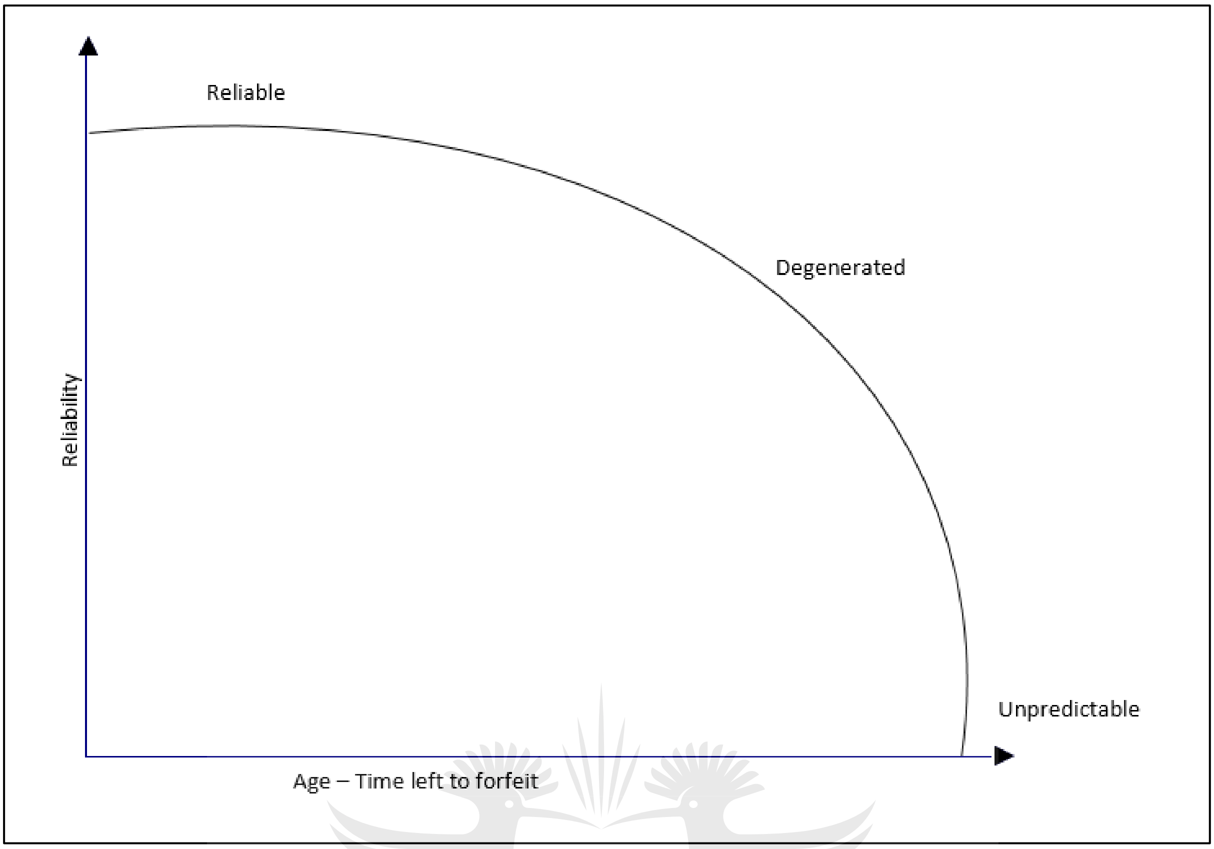

Figure 4 Reliability of an Asset vs Age (Fredriksson and Larsson, 2012, p. 189)

Figure 4 illustrates that an organisation should put in place an Asset management system that conforms to International Organisation for Standardization (ISO 55001), to take care of their asset base this could be achieved by the following:

2.4.1 Rail Infrastructure

The infrastructure should be well maintained, and capital investment programmes must be prioritised to rehabilitate the railway infrastructure at regular intervals. This will, in turn, increase and effectively improve the performance of the assets operating in the heavy haul company, in this case, the Thabazimbi Channel.

2.4.2 Operational Planning and Control

In order for the heavy haul company to achieve the objectives of implementing asset management all the stakeholders who are involved in the maintenance of assets need to be involved such departments will include rail network, operations, finance, engineering and maintenance. This will ensure that risks are mitigated, and the needs of the end-user of the asset are met. Overall during this phase, the risks and opportunities for the asset to perform its intended function will be realised.

2.4.3 Leadership and Commitment

Top management is regarded as the leaders of asset management to enable it to function well and optimise the performance of rolling stock in the railway industry. They align the organisation's maintenance strategy with that of asset management and provide resources to achieve the organisational goals and objectives to improve the reliability and efficiency of assets.

2.5 Maintenance

Maintenance gives a significant capability in every organisation, particularly in the railway business (Nur and Cahyo, 2018). Streamlining of maintenance function may fundamentally improve the overall equipment effectiveness of an asset, particularly in the Thabazimbi channel where diesel locomotives are their greatest asset for their operations. A well-overseen maintenance strategy may give a competitive advantage to the business (Nur and Cahyo, 2018). Many railway companies adopt maintenance as one of its vital accessories as opposed to seeing maintenance from a conventional viewpoint. Numerous organisations are struggling to be consistent in these processes, mainly because there are no reliability strategies in place, shortage of engineering skills and lack of funding. As indicated by the glossary of terms utilised in terotechnology maintenance can be characterised as the grouping of specialised and authoritative activities completed with the expectation to retain an asset to an adequate working standard. Dhlamini (2010) Characterizes maintenance as a combination of specialised, regulatory and administrative activities carried out during the lifecycle of an asset to re-establish it to a functional state.

Maintenance should in this manner be viewed as more than repairing equipment, it thinks about administrative ability, for example, engineering, the management and accounting factors.

The aim of maintenance is not just to repair items when they are due for repairs or when they are broken, yet additionally accomplish activities that counteract significant losses brought about by the breakdown of equipment (Ndlovu, 2017). Morden companies derive their maintenance goals from their asset management system policy and maintenance is seen as a significant support function in their organisation. It does as such by giving a solid and safe working condition of the railway infrastructure and rolling stock. A few maintenance methodologies exist in various companies, each developed in order to suit operational and business needs (Ndlovu, 2017).

According to Fredriksson and Larsson (2012), they describe maintenance as those tasks and activities that directly hold the best possible operation of an object or re-establish that activity when it is hindered by failure or some other variation from the norm. These tasks and activities incorporate removal and substitution of consumables, repair of failed stuff, lubricate, overhauling (incorporates renewal of consumables, for example, oil), and alignments. Different activities and assets are required to assist in maintenance.

The decision of an organisation to choosing a maintenance strategy has a direct impact on the performance, maintainability and reliability of an asset. Figure 5 summarises the types of maintenance strategies (Gandhare, *et al*., 2014).

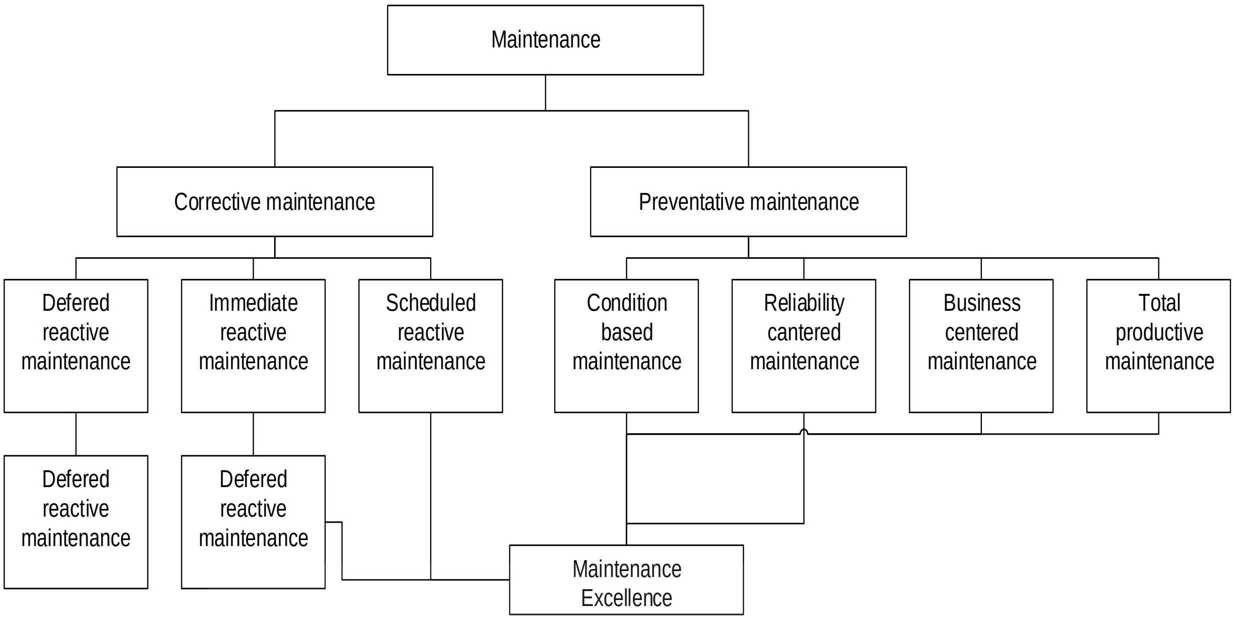

Figure 5 Maintenance Strategies (Hide, 2013, p. 3)

2.5.1 History of Maintenance

The industries, including the railway, did not have a high mechanical level before the Second World War, that is, the majority of the equipment was over-designed and simple. The implications of failure did not have a solid impact and the effect was disregarded (Fredriksson and Larsson, 2012). Because of this, the mechanical equipment was running until failure occurred, and when it did, it was either replaced or fixed. In this manner, the mind-set was: "fix it when it breaks". In the principal approach of maintenance, no moves were made to distinguish the onset of a failure neither to avoid failures, and this methodology can be depicted as reactive maintenance (Fredriksson and Larsson, 2012).

The Second World War turned things around, and everything changed drastically amid the war. This was because of the scarcity of manufacturing labour and an increasing request on production lines (Lidén, 2015). Accordingly, the automation expanded and the manufacturing plants changed to be progressively complex (Lidén, 2015).

To satisfy the developing need for war materials, client products and to remunerate to the workforce deficiencies, the innovation within manufacturing was compelled to grow more modernised (Lidén, 2015).

Cost, life span and accessibility were currently viewed as significant elements to accomplish the business targets and along these lines, maintenance was considered as a specialised way and turned into a task of the maintenance department. The equipment reliability was currently significant and production downtime turned into everyone's concern. The freshly discovered statue of maintenance enabled the maintenance department to create and implement periodic, planned and preventive maintenance programs (Lidén, 2015).

It was only in the 1970s that many concepts were introduced such as Total Productive Maintenance (TPM) and Reliability Centred Maintenance (RCM) (Flores-Colen and de Brito, 2017). The emphasis in today’s maintenance is, because of globalisation, to build an internal and external partnership among maintenance and different components in the supply chain network. This plays an important role in integrating the railway maintenance components system. Rolling stock is the most maintenance focused part of the railway system and in this manner, the most ineffective if maintenance is ignored. It is in this manner that, fundamental actions be taken for effective maintenance plan to improve rolling stock and its components.

Maintenance activities play an imperative role in railway infrastructure and its rolling stock to keep up with high levels of availability. Such activities are developed and depicted by the reliability specialists from the Original Equipment Manufacturers (OEM) which will be influenced by environmental conditions that the asset or rolling stock will be operating on. In this manner, it is vital to recognise suitable periods to maintain the rolling stock that will work under various situations to accomplish high Reliability. As indicated by the current practices, failure data analysis is considered as a supportive technique in recognising critical parts of a system and reliability analysis, which can play a significant role in deciding the suitable time frames for maintenance activities (Fredriksson and Larsson, 2012).

	First Generation	Second Generation	Third Generation	Fourth Generation
Years	1950 – 1960	1970 – 1980	1990 – 2000	2010 – 2020
Expectations	Downtime was a fact of life	Higher asset availability Defined asset life Lower maintenance costs	Higher plant reliability Equipment life extension Greater costs effectiveness Better product quality	Higher efficiency Longer equipment life Lean maintenance strategies Tighter cost control Zero tolerance safety
Methods	Fix it when it breaks Run to failure strategy	Scheduled repairs Systems for controlling work Big and slow computers Time or Cycle based strategy	Design for reliability Failure mode and effect analysis Condition monitoring Smaller faster computers	Design for maintainability Shorter equipment life cycle Business focused Performance monitoring

Figure 6 Maintenance Evolution (Hide, 2013, p. 2)

Figure 6 depicts the evolution of maintenance over the past years Hide (2013), this illustrates that maintenance is an integral part of any asset to enable it to be operational and perform its intended function over its life cycle.

2.5.2 Corrective Maintenance

Corrective Maintenance (CM) is meant to increase capability in every plant, system or component to limit unnecessary breakdowns and repairs, to have an efficient work environment. Corrective Maintenance (CM) occurrence is driven by work done that separates and ascertain a portion of faulty equipment to re-establish an acceptable operational condition (Olumuyiwa, 2014). CM is related to mechanical break downs, emergencies, corrective and regular repairs needed for the asset to function. If the equipment ceases to work then Corrective Maintenance (CM) can be applied immediately. Should the asset be unacceptable due to lack of maintenance, productivity will be compromised (Ndlovu, 2017).

2.5.2.1 Summary of Corrective sub maintenance Strategies

This section below provides a summary of the corrective maintenance sub maintenance strategy. These sub-strategies form part of maintenance approaches that can be adopted to mitigate the failures that this research sought to address on the locomotives that are utilized in the Thabazimbi channel. Table 2 below describes the acronym and the description of thereof.

Table 2 Corrective Maintenance Sub maintenance strategies (Do, et al., 2016, p. 102)

Strategy	Abbreviation	Description
Immediate reactive maintenance	IRM	Maintenance is done after an asset breaks down.
Scheduled reactive maintenance	SRM	Maintenance is scheduled and planned when an asset fails
Deferred reactive maintenance	DRM	Maintenance is delayed or postponed to a failure of an asset due to unavailability of resources and spares
Failure-based maintenance	FBM	Maintenance is done when one or more subsystems of an un-maintained asset have failed and observed thus after a breakdown.
Operate to failure	OTF	Maintenance is performed when an asset or equipment is failed.

2.5.3 Preventative Maintenance

Preventative Maintenance (PM) is aimed at limiting the likelihood of failure that might occur at the time of operating a piece of equipment. Preventative Maintenance (PM) is work done, continuously to avoid damaging the equipment and to decrease unnecessary interference that could require correction. Tomo (2010), suggest that PM includes a lot of managerial and specialised activities that is aimed at reducing the years of the asset to improve accessibility and reliability of the system.

Preventative Maintenance (PM) can turn out to be costly should it not be done adequately and proficiently. Preventative Maintenance done properly helps to mitigate equipment failures and deficiencies before they occur. Preventative Maintenance (PM) can be utilized for continuous unforeseen maintenance activities required by the organisation and improve the reliability of rolling stock

2.5.4 Reactive Maintenance

According to Sillivant (2015), reactive maintenance is the simplest method of maintenance because it is performed to restore a system to its intended functionality. He further highlights that this type of maintenance is more reactive and costly to a company because failures occur randomly and therefore are unpredictable. This literature review can be associated with the challenges that affect the reliability in the Thabazimbi channel, which this research seeks to identify and determine the impact they have on the operations of the heavy haul company.

Reactive maintenance (RM) is linked with the correction of unpredicted abnormalities and is quite often an emergency strategy, prompting to unavoidable additional expenses.

2.5.5 Reliability Centred Maintenance

The reliability-centred maintenance approach was built up in the 1970s, and reliability-centred maintenance was first tried on the Boeing 747 plane, with the intention to identify the planes engine’s system and the functional design of it and its reliability, and to what extent they expected to utilize it before failures can occur; it was during this period that numerous organisations started adopting this maintenance technique to improve their maintenance and reliability of their assets (Sillivant, 2015). Reliability centred maintenance is a preventive maintenance strategy which reliant on the user's high-reliability needs of an infrastructure and equipment’s design and services. RCM is another maintenance technique which emerges from the various maintenance theories of 20 years and increasingly been recognised, it is built on the equipment design features, operational function, failure mode and effects analysis.

It is also based on the purposes to maximise the reliability of equipment (Kong and Meng, 2011).

2.5.6 Predetermined Maintenance

Time-based Maintenance (TBM) technique is known as periodic-based maintenance it is a traditional maintenance system (Ahmad and Kamaruddin, 2012). In TBM, maintenance choices, for example, (preventive repair times/interims) are fixed based on failure time analyses. In basic terms, the maturing (anticipated lifetime), T of some equipment is measured based on failure time data or utilized based data (Ahmad and Kamaruddin, 2012). TBM assumes that the failure conduct of equipment is predictable. This assumption is dependent on the failure rate patterns, referred to as bathtub as illustrated in Figure 7.

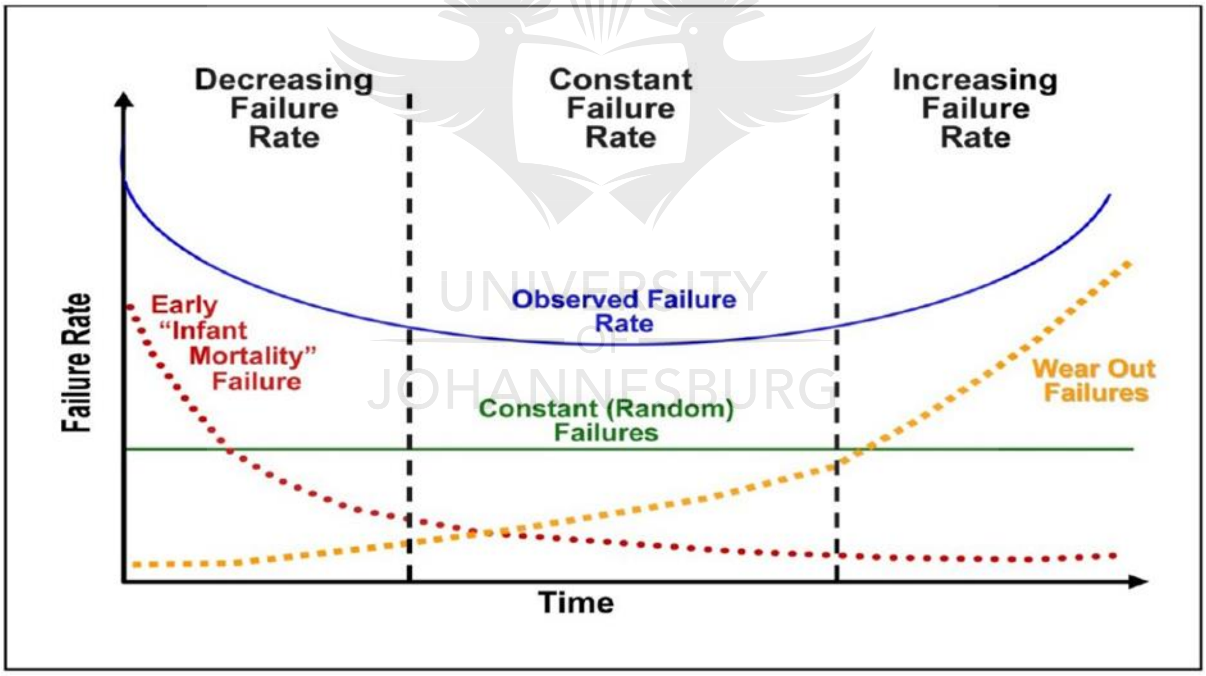

Figure 7 Bathtub curve (Hide, 2013, p. 1)

According to figure 7, failure rate patterns can be separated into three stages: infant stage, useful life, and wear-out. The TBM method expects that equipment experience decreasing failure rates from the early stage of its life in their life cycle (infant stage), followed by random failures during its (useful life). During the wear-out stage, the

equipment experiences an increasing failure rate as it is reaching the last stage of its design life expectancy (Ahmad and Kamaruddin, 2012).
The bathtub curve blue upper solid line on figure 6, represents the combination of a decreasing hazard of the early failure rate of the asset red dotted line and an increased hazard of wear-out failure yellow dotted line and lastly, the constant hazard of the random failure green lower solid line (Ahmad and Kamaruddin, 2012).

2.5.7 Condition-based Maintenance

Condition-based maintenance, otherwise called predictive support, is the most present-day and prominent support method discussed in the literature (Hameed, et al., 2009). CBM was adapted in 1975 altogether to maximise the effectiveness of PM decision making (Ahmad and Kamaruddin, 2012). As per Ahmad and Kamaruddin (2012) it is a support program that suggests maintenance activities (choices) in light of the data gathered through the condition monitoring process. In CBM, the lifetime (age) of the equipment is observed through its working condition, which can be estimated dependent on different checking parameters, for example, vibration, temperature, greasing up oil, contaminants, and noise levels. Monitoring is characterized as: 'An action which is expected to monitor the real condition of the asset'. As such, CM is an instrument used to determine the state of equipment in a system (Do, *et al*., 2016). Therefore CBM is required for better equipment health management and lower life cycle cost.

2.5.8 Total Productive Maintenance

Total Productive Maintenance (TPM) can be regarded as the medical science of machines and equipment (Jamkhaneh, *et al*., 2018). It involves new technology concepts for maintaining assets in the production plants and relatively in the heavy haul company equipment's. It is a method for continuously improving the effectiveness of production equipment, assets or manufacturing processes through the involvement of all people in the organisation (Jamkhaneh, et al., 2018). The focal point of this strategy is on practices and people as the fundamental pieces of Total Quality Management (TQM) (Pourjavad, *et al*., 2013). In addition, in certain nations, like

Germany, this strategy is, for the most part, observed as a way of thinking as opposed to a tactic. This maintenance methodology was created with the point of eliminating non-value adding activities resulting from equipment and machinery failures.
It enables the probability of uptime of an asset and process capacity. According to Deuse and Khazraei (2011) they believe that this strategy always produces great equipment efficiency, productivity or yield of complete modern equipment, such as locomotives.

2.5.9 Business Centered maintenance

This maintenance technique deals with recognising business goals that are translated based on the functions of maintenance (Deuse and Khazraei, 2011). The principle point of this maintenance strategy is to strengthen the share of maintenance profit. Its usage strategy requires a considerable measure of data including the production and design procedure of an asset (Deuse and Khazraei, 2011).

2.5.10 Maintenance Excellence

Maintenance excellence is the science of having optimal reliability equipment, whereby the reliability of the plant, asset or locomotive has least maintenance costs. According to Deuse and Khazraei (2011) maintenance excellence is whereby Reliability, Maintainability and Availability of an asset are at an utmost best, and the businesses are experiencing no maintenance obstacles. Furthermore, Shahin, *et al.,* (2018) explains maintenance excellence as the efficient manner in which an organisation implements, the correct maintenance strategies for its equipment and machinery at the right intervals, and thereby minimising the maintenance costs of the business.

2.6 Maintenance in Railways

The maintenance management of a railway system infrastructure plays a significant part in guaranteeing the reliability, accessibility and availability of rolling stock in the railway transport industry. In a strongly unpredictable transport business, the rail business is required to utilise new and creative maintenance strategies that will position heavy haul companies to be an affordable, and reliable mode of transport in the railway industry. This can be accomplished through performing maintenance procedures that prioritise the effective allocation of resources during budget planning. The use of reliability-based strategies to make sound informed business decisions in maintenance management, with an end goal to optimise reliability and maintainability of rolling stock, while maintaining efficiency and safety in the railway system (Fourie and Zhuwaki, 2017).

2.7 The Development of Different Maintenance Strategies

According to Winda Nur (2018), there are four phases in the maintenance development course of events. Those stages are:

- Maintenance as a ''necessary evil'' in the 1940s.
- Technical matter during the 1960s to 1970s
- Profit contributor phase in the 1980's to 1990s and,
- A vital partnership in mid-2000's up to this point

The stages mentioned above are the general evolution of the enterprise perspective in maintenance. However, Ramagaga (2018) suggests that today, the organisation's view maintenance as a critical component to meet customer and operational objectives. Some companies even consider maintenance strategies such as Life Extension (LifeX) and Long Term Programmes (LTP's) or Long Term Service Agreements (LTSA's), LifeX refers to a complete overhaul of an asset whereby the old design of the asset is replaced completely by a recent footprint or the critical components of the asset are replaced by the latest technology of the asset. The results of thereof increase the life expectancy of the asset or equipment. LTP's are complete maintenance packages that run for a certain period, they include consumables and spare parts supplies. They also include technical field assistance during the organisation's minor and major overhauls. These maintenance strategies are customised based on customer or organisation's specific maintenance needs.

The importance of maintenance has played a significant role in companies in recent years. As a result, the requirement made by the organisation to accomplish high standard of reliability and easy access of rolling stock adds value, as opposed to seeing it as an essential strain of costs that adds to the business profit (Olumuyiwa, 2014). The different techniques used for the upkeep of equipment or active system is managed accordingly to run the set planned capacity consistently (Olumuyiwa, 2014).

Maintenance can be considered as activities intended to restore an item, machine or equipment from failure mode and reviving it to a piece of equipment that will function to a condition whereby it can physical perform as required (Wakiru, *et al*., 2018). Maintenance is a need for most multicomponent infrastructures. However, its advantages are frequently linked with substantial expenses (George-Williams and Patelli, 2017). However, with the competent number of teams and a sustainable, cost-effective and innovative maintenance strategy optimal, feasible and reliable maintenance results are obtainable (George-Williams and Patelli, 2017).

2.8 Summary of Maintenance Strategies

Table 3 depicts the summary of the different maintenance strategies with their benefits and limitations. This section summarises the current literature on maintenance strategies that companies have adopted nowadays to improve and optimise their assets. This research objective was also aimed at exploring these strategies in order to identify the challenges that affect the reliability and maintainability of the Thabazimbi channel’s rolling stock.

Table 3 Summary of Maintenance Strategies (Mainkar and Rathod, 2017, p. 101)

	Description	**Benefits**	**Limitations**
Reactive	Fix or replace a device when it breaks	Suitable for non-critical and low-cost equipment	Potential safety hazards Increased costs due to unplanned maintenance and shutdowns
Preventive	Scheduling maintenance activities based on arbitrary time intervals	Reduces reactive maintenance Provides structure to maintenance actions	Does not eliminate unexpected equipment problems Wastes resources Large inventories
Predictive	Assesses the equipment's health through diagnostics testing and/or on-line monitoring	Predicts when a device is likely to fail Saves time and money	Does not always detect the root cause of a problem
Proactive	Uses the information provided through predictive methods to find and isolate the source of equipment problems	Prolong operating life of the equipment Minimises the risk of random failure	

2.9 Reliability Improvement

Reliability is the development of sound design, genuine choices, and the utilisation of parts and understanding components failure of the craft (Lewis, *et al*., 2014). Reliability of an asset depends on the design and development and in the manufacturing of the asset. Reliability improvement requires organisations to implement world-class practices such as continuous improvement or Lean six sigma in order to stay competitive in business.

2.9.1 Probability

Probability is typically characterised as the quantitative articulation that speaks to a rate to indicate the occasions that an occasion can be relied upon to happen in a complete number of preliminaries. Any occasion has a likelihood of the event, which can be in the scope of 0 – 1. A zero probability implies that equipment won't fail and one probability implies the equipment will positively fail (Swanepoel, 2018).

2.9.2 Adequate Performance

The performance demonstrates that particular criteria must be built up to illustrate what is viewed as adequate and acceptable performance. It can likewise be depicted as the required capacity of the object in the plant. Failure of a system might be a disaster or a total inability to work, or it might be brought about by an infringement of the required system purpose (Tomo, 2010). For instance, a locomotive may perform at below normal perimeter (below minimum requirement) even though it might at present be working.

2.9.3 Time

Time speaks to a measure against which the level of system performance can be associated. The time parameter must be known to decide the probability of the system to finish a given job or task as arranged. The way that reliability can be characterised as far as mean time between failures (MTBF) and mean time to failures (MTTF) defines time as a critical component in reliability engineering (Tomo, 2010).

2.10 Summary of Factors Affecting the Reliability of Rolling Stock

The section below summarises the global railway critical success factors that the literature reviewed revealed. As indicated in table 4 the first column mentions the factor that the research identified, the second column describes the author that the factor was sourced from lastly, the third column describes the country of which the author and the reviewed paper originates from. These factors similarly relate to the objectives of this research sought to identify and investigate. The literature reviewed in chapter two by the research team also identified these factors as challenges affecting the reliability and maintainability of rolling stock that operates in the Thabazimbi channel.

Table 4 Summary of challenges affecting the Reliability of Rolling Stock

Factor	**Description**	**Author**	**Country**
Integrated Asset management	The performance of the rolling stock is dependent on other systems like railway-track, supply chain and human resource management.	(Mainkar and Rathod, 2017) (Guo, *et al*., 2013) (Vlckova, *et al*., 2016)	India China Czech Republic
Asset condition	The asset condition, which is influenced by age, the operating environment and asset handling has a direct influence on the performance of the rolling stock.	(Jiang, *et al*., 2018) (Ouedraogo, *et al*., 2018) (Roccato, *et al*., 2018)	China & USA France Italy
Theft	The damage to the infrastructure and vandalism on the locomotives as a result of cable and battery theft also affect the performance of the fleet.	(Piroi, *et al*., 2014) (Yamamoto, *et al*., 2012) (Restel and Wolniewicz, 2017)	Romania & Austria Japan Poland
Weather	The changes in the weather condition also have an impact on the reliability of the asset to perform the intended function without failure.	(Seshabela, 2018) (Durand and Cozzarin, 2010) (Mayisela and Dorrell, 2019)	South Africa South Africa South Africa
Training	The skills and the ability of the maintainers, operators and managers determine the useful life of the asset like the locomotive.	(Roganov, *et al*., 2018) (Pathirathna Buddhika, *et al*., 2018)	Russia Sri Lanka Ukraine

Factor	Description	Author	Country
		(GOLYBENKO, *et al*., 2012) (CANG and TUAN, 2012)	Vietnam
Maintenance policies	The maintenance policies and activities should support the asset to perform its intended function by eliminating potential failures.	(Floyd, *et al*., 2010) (Asekun and Fourie, 2015) (Dibakoane, 2013)	USA South Africa South Africa
Funding	The organisation should allocate budget to support reliability programmes.	(Bloomberg, 2019) (Kałuza, 2016) (Naledi, 2018)	China Poland South Africa

2.11 Critical Success Factors for Improving Reliability

The following part of the research summarises the global critical success factors that can be adopted by the railway companies to improve the reliability and maintenance of their railway infrastructure and locomotives. As indicated in table 5 the first column mentions the improvement factor that the research identified, and the second column describes the author that the factor was sourced from lastly, the third column describes the country of which the author and the reviewed paper originates from. These factors similarly relate to the objectives of this research, sought to identify and investigate. The literature reviewed on chapter 2 by the research team also identified these factors as challenges affecting the reliability and maintainability of rolling stock that operates in the Thabazimbi channel.

Table 5 Critical Success Factors for Improving Reliability

Factor	Description	Author	Country
Organisational culture	Organisational culture determines how things are done within the organisation. Furthermore how the organisation treat its assets. Hence, reliability management should be embedded in the culture of the organisation.	(Ahmad and Kamaruddin, 2012) (Khorshidi, *et al*., 2015) (Yuan and Zhang, 2011)	Malaysia Australia China
Organisational policies	Reliability management needs to be integrated and reviewed in line with other company policies.	(Naledi, 2018) (Zhang, *et al*., 2011) (Hein, *et al*., 2017)	South Africa China Germany
Reliability programmes	The organisation should develop a reliability program as a continuous improvement strategy.	(Vujovic, *et al*., 2012) (Ghosh, *et al*., 2017) (Onwunta and Kahn, 2011)	Croatia India South Africa
Asset fleet management	The organisation should adopt a proven asset management strategy like ISO 55000 and PAS 55 to comply with the international best practice.	(Sillivant, 2015) (Apiwattananon, *et al*., 2010) (Li, et al., 2016)	USA Thailand China
Real-time monitoring	The organisation should invest in the use of technological devices and the internet, to assist the organisation in determining	(Koenen and Alma, 2016) (Rhein, *et al*., 2017) (Gebhard, 2011)	Netherlands Germany USA

Factor	Description	Author	Country
	locomotives reliability and fault finding.		
Training	The skills and the ability of the maintainers, operators and managers determine the useful life of the asset like the locomotive.	(Bannikov, *et al*., 2018) (Iwakami and Takino, 2014) (Yu, 2017)	Ukraine Japan China
Capital funding	The organisation should allocate and direct funding for short term and long term initiatives to support reliability programmes.	(Lewis, *et al*., 2014) (Vicente, 2012) (GEORGE, *et al*., 2018)	England Argentina South Africa

2.12 Conclusion

This chapter presented literature on factors that affect reliability, maintainability and availability of assets operating in the Thabazimbi channel and the impact of thereof. The major common challenge of these factors from the literature is the direct relationship between maintenance tactics applied in different industries and company competitiveness. Research illustrates that applying correct maintenance strategies and investing in rail infrastructure optimises the performance of a locomotive or asset in the railway industry. Furthermore, literature shows that consistent investing and upgrading of railway equipment and rolling stock optimises the reliability and performance of the assets operating in the railway companies.

For railway system maintenance tactics to be effective, the optimal maintenance strategy is achieved through stakeholder engagement, senior leadership, investment in maintenance strategies and technology. Will advance the organisation into a world-class operating Railway Company.

It is suggested by the literature that the knowledge of how the railway infrastructure deteriorates and the dependencies that exist amongst the locomotive components, contribute towards system thinking of maintenance engineers in choosing the most economical and effective maintenance methods. Chapter 3 will discuss the methodology of how to discover solutions to the research questions, research objectives and research problem stated in Chapter 1.

3. CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

Research is a methodical procedure for collecting analysing and translating data to build the researcher's knowledge and understanding of the investigation being undertaken (Walliman, 2011). Researchers have a distinct tendency to acquire information about a particular phenomenon or area under examination to gain knowledge, and research is an important part of the process. This research will adopt a mixed-method approach that is, qualitative and quantitative research techniques.

This chapter provides the systematic processes adopted to meet the research objectives of the current research. The topics of interest included in this section are research approach, research design, data collection methods, validity and reliability analysis to answer the research questions.

3.2 Research Approach

There are three basic research approaches provided: qualitative, quantitative and mixed methods in the literature. Qualitative research approach refers to the research which does not use numerical information to analyse the research questions. The qualitative research approach is dependent on text, sound, pictures and illustration as a source of information. This type of research approach is normally used to gain an in-depth understanding of the phenomena from people's experiences (Simons, 2009).

Quantitative research approach uses numbers as a source of information. It is mainly used in conjunction with experiments and surveys. Mixed methods are normally used with case study research method; hence it was selected as an appropriate research approach in the current research (Simons, 2009).

Research strategies incorporate deductive and inductive techniques. The deductive strategy begins by taking a look at the accessible data, develop a plan that is

dependent on the methods of reasoning, through the contentions, the hypotheses can be acknowledged or dismissed as a conclusion.
Inductive approach, as deliberated by Uma and Roger (2009) and Lacey and Luff (2009), is a hypothesis building approach rather than theory testing. This strategy starts by concentrating on the research goals and utilises research standards to create beliefs. This research embraced this technique as the favoured strategy for exploring the research objectives.

For the purpose of this research, the context of the current challenges within the heavy haul company, a case study design was selected. The heavy haul company, operational business unit, was selected as a case study. The Thabazimbi Channel rail line is approximately 1874 Km consisting of a double and single-track rail the, 777 Km double-track rail is electrified by 3 KV DC line operated by electric locomotives and about 1097 Km connecting the Natcor and Thabazimbi channels. 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

3.2.1. Mixed methods approach

The mixed-method approach is one which includes the collection and investigation of data, coordinating results and drawing conclusions utilising both qualitative and quantitative approaches in a single research.
The collection of data becomes increasingly proficient when utilising, both qualitative and quantitative research approaches (fielding, 2012).

The author fielding (2012), meaningful describe three different ways of linking the best qualitative and quantitative methodologies:

a) Integrating strategies for better estimation
b) Sequencing data for better examination
c) Merging findings for better outcomes

This research adopted the mixed method, because mixed methods integrates qualitative and quantitative research approaches to provide an inclusive and detailed understanding of the phenomenon and explains inconsistencies in the data (fielding, 2012). Also this research adopted the mixed methods strategy to increase the research team's confidence in the data collected and the findings thereof.

3.3 Research Design

The research design is the overall framework which provided the purpose of the study research method and the unit of analysis and the time horizon and required resources.

3.3.1 Purpose of inquiry

There are numerous research types to conduct research projects, in terms of addressing the research objectives these include: exploratory, cause and effect also known as causal and descriptive research (Sekaran and Bougie, 2012).

Exploratory research is embraced when very little information is known about the problem at hand, or no data is accessible on how comparable issues or research issues have been illuminated before (Walliman, 2011).

Cause and Effect research also called the causal research technique, is the approach used to clarify the connection among circumstances and logical results of factors. The procedure is sophisticated and enables the researcher to adopt a thorough list of causes impacting changes to different variables (fielding, 2012).

According to Walliman (2011), descriptive research is dependent on observations as a way of gathering data. It attempts to investigate scenarios in order to determine what the norm is. The current research used both exploratory and descriptive, the exploratory wanted to explore what is affecting the performance of the fleet operating in the Thabazimbi channel. The descriptive was how the research team will address the research problem.

3.3.2 Research Strategy

The following section of the research presents the method and methodology, adopted for this research to answer the research questions.
A research technique is a mixture of processes, procedures and systems, aimed to collect and scrutinise data to address the research question (Mafokosi, 2018). Research strategy include survey, experiments and case studies which be covered in the subsequent section of the research.

3.3.2.1 Survey

Surveys include gathering data, generally from genuinely enormous groups of individuals, by methods of questionnaires however different techniques, for example, interviews or telephoning may be utilised. The survey research was not suitable for this research because the aim of this was to study a single organisation (fielding, 2012)

3.3.2.2 Experiments

Experimental research attempts to separate and control each significant condition which decides the occasions explored and afterwards observes the impacts when the conditions are influenced (Uma and Roger, 2009). At its least complex, changes are made to an independent variable and the impacts are seen on a reliant variable – for example, cause and effect. Even though experiments should be possible to explore a specific occasion, they more often than not require a hypothesis (forecast) to be planned first to figure out what factors are to be tried and how they can be controlled and estimated (Walliman, 2011). This research did not use experiments because there were no variables that needed to be tested.

3.3.2.3 Case Study

Case study is an ideal approach when a comprehensive, in-depth examination is required (Yin, 2014). In a case study, the researcher gathers broad information on tasks and occurrences on which the examination is focused.

The data often incorporates observations, interviews, reports, and past records. In many occasions, the researcher may spend a lot of time on-site and collaborate more with the personnel working on the systems that the researcher is studying (Yin, 2014).

Another definition by Simons (2009) states that a case study is an in-depth investigation from numerous observations of the intricacy and uniqueness of a specific project, policy, organisation or system to create knowledge and additionally illuminate strategy improvement, proficient practice and common or community action. Yin (2009) characterises a case study as twofold: firstly, the extent of a case study is characterized, secondly, the specialised attributes are incorporated as a major aspect of the definition:

A case study is an observational request that:

a) Requires an investigation to determine the phenomenon and identify clear evidence (Yin, et al., 2015).
b) Deals with the theoretically distinct situation in which there will be many more variables of importance than data points , and as one outcome
c) relies on various sources of evidence, with data expecting to combine in a triangulation style, and as another outcome
d) Benefits from the earlier advancement of hypothetical suggestions to manage data collection and analysis (Yin, 2014).

The above-cited definitions all feature one similarity, which is to understand a phenomenon or instance. Yin (2014), suggest it is an escalated investigation of a single unit to understand a bigger class of comparative units. In the following section the advantages and disadvantages of case study research are outlined.

3.4 Case Study Research Strengths and Weaknesses

The strengths and weaknesses of case study research are summarised as follows from existing literature:

3.4.1 Strengths of a Case Study

a) A case study increases understanding of a particular issue (Sukdeo, 2012). It is a detailed analysis of a particular situation, group of people or set of documents, which can lead to a complete understanding of the aspect. The detail provides valuable insight into problem solving and evaluation.
b) The detailed observation in a case study provides an opportunity to obtain a holistic view of a specific issue (Simons, 2009). It provides the context of the specific issue with all the detail of how and why things happen.
c) A case study enables a researcher to obtain an in-depth understanding of a particular issue in the context of the organisation life (Marnewick, 2010). It provides insights into relationships within organisations which are difficult to access and are complex in structure.
d) A strength mentioned by Sukdeo (2012) is the type of knowledge that is acquired from case studies. An expertise domain knowledge and experience are the very heart expert activity when using a case study as a research methodology. It provides knowledge about the practical (domain-specific), which is more valuable than knowledge on the theoretical (general).

3.4.2 Weaknesses of a Case Study

A weakness of a case study is that consistently only small numbers of subjects can be studied because data collection methods are so work demanding, time-consuming, expensive, It is also often being criticised for being subject to researcher bias, the difficulties in analysing qualitative data rigorously, the lack of reproducibility and generalisation of the findings i.e. findings may not apply to other subjects or settings.

3.5 Sampling Methods

The two significant choices of sampling are probability and non-probability. The probability technique is shown as a method where each individual from the population has a known none zero probability of being chosen; as opposed to that, of non-probability technique that depends on personal or judgment selection (Simons, 2009). The research requirements, goals and resources accessible persuasive choice of which technique to utilise.

The sampling technique utilised in this research is that of non-probability purposive sampling. The participants were from the Thabazimbi channel locomotive department. These included fleet managers who are responsible for the maintenance of the locomotives, fitters who are responsible for fixing the faults reported by the operators of the locomotives, middle managers who are responsible for the formulation and reliability analysis of the locomotives. A population of fifty-one participants were requested to participate in the questionnaire.

The researcher chose to use a non-probability sampling procedure for the choice of the participants. The criteria for choosing the unit of analysis was as per the following:

a) The participants need to have access to a computer and emails
b) The participants need to have a minimum of twelve months working with the locomotives.
c) The participants need to be familiar with the rolling stock maintenance management system
d) The participant needs to be employed for at least twelve months in the heavy haul company
e) The participants are required to be willing to participate in answering the questionnaire.

3.6 Data Collection and Interpretation

Data is a portion of the values of subjects concerning qualitative or quantitative variables. As indicated by Sreejesh, *et al.,* (2014) there are two kinds of data, primary and secondary data. Scholars like Uma and Roger (2009) describes secondary data as records gathered from different sources for different purposes as opposed to those of the research at hand. Primary data are direct insights gathered by the specialist through surveys and trials for the exceptional research project.

This research used a field report from the heavy haul company Asset management system database to gather primary data. Secondary data gathered from existing literature sources including the University of Johannesburg database, Emerald insight, IEEE Xplore, Google Scholar, Heavy haul company systems and locomotive field reports to fulfil the research objectives. Figure 8 depicts the summary of the data collection process that this research followed to answer the research questions.

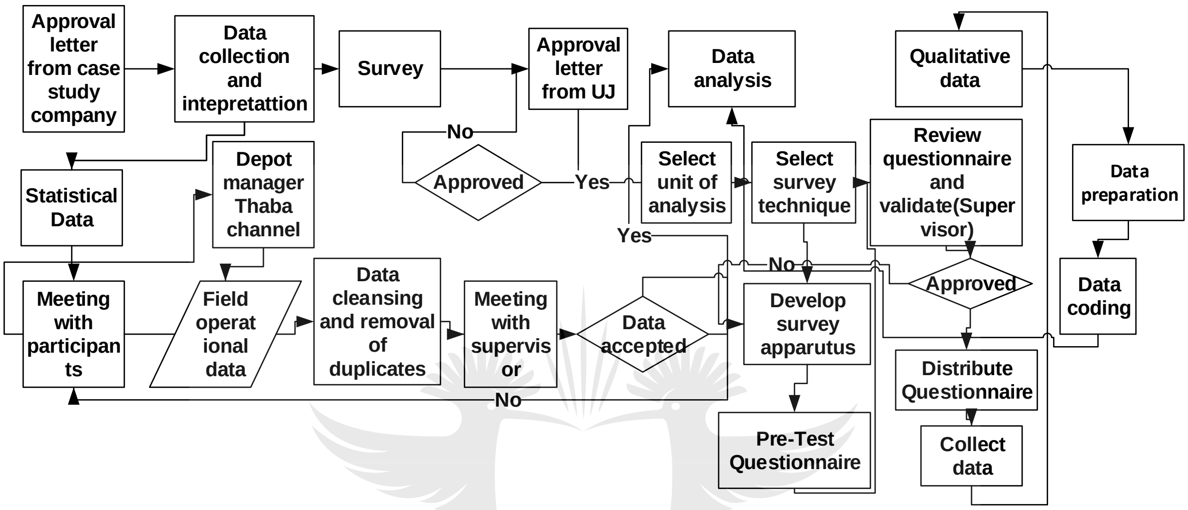

Figure 8 Data Collection Process Flow

3.7 Questionnaire Design

The research used the survey monkey as the platform to prepare and distribute the survey questionnaire. The survey link was distributed using the e-mail to the respondents who had the computer with e-mail in the case study company. Appendix (A.2) contains a list of the considerable number of questions contained in the survey. The data acquired from the survey was validated using the literature review.

For validating the factors and effect that were acquired from literature review table 6 illustrates and seek to explore the challenges that affect the reliability and maintainability of rolling stock operating in the Thabazimbi channel, a questionnaire was distributed to the selected participants who are actively interacting with the diesel locomotives. The questionnaire included a biographical section, a Likert scale section and the last section included open-ended questions.

3.7.1 Question one: What are the challenges affecting the reliability of rolling Stock in the Thabazimbi channel?

In this section, the researcher opted for primary data, obtained from the database of the heavy haul company asset management system, and followed the below process to answer this research question.

Data preparation	Data cleansing	Data coding	Interpretation and Reporting

Figure 9 Data Collection Process

Step 1**: Preparation** The researcher obtained approval from the heavy haul company to be able to conduct the research and access data from their Asset management system.

Step 2 **Data Cleansing**: In this progression, the data required to respond to the exploration questions was recognized, and the information was isolated to analyse the locomotive's data further. Microsoft Excel was instrumental in recognising duplication and gathering of the locomotive failures information from the raw data.

Step 3 **Data Coding**: In this stage, the researcher gathered the literature review factors affecting the performance of the fleet and coded them with the causes.

Step 4 **Reporting**: Used the qualitative research to identify the factors affecting the performance of the locomotives from the field reports
Report on the findings

Figure 10 outlines the detail process adopted to collect data for the research:

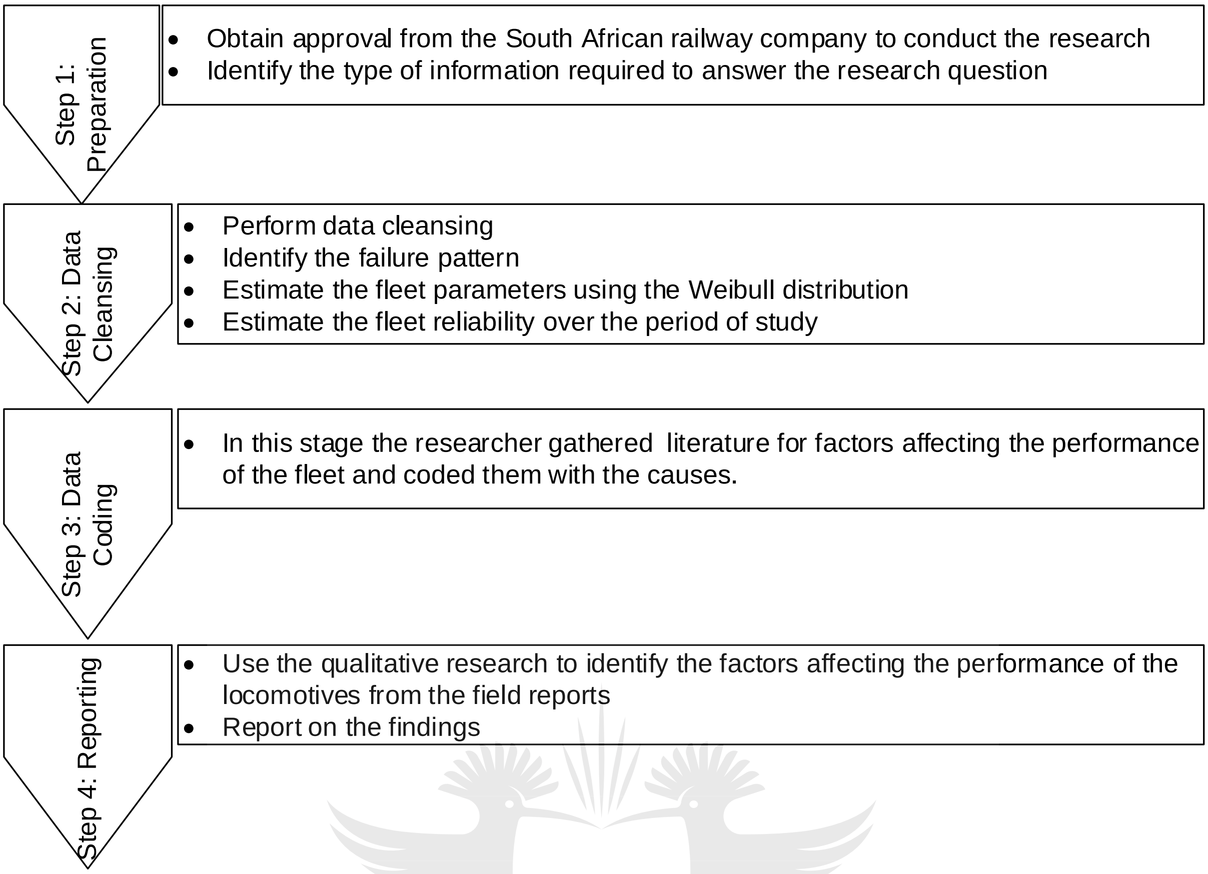

Figure 10 Data Collection Steps

3.7.2 Question two: What are the success factors to improve the reliability of rolling stock operating in the Thabazimbi channel?

In this section, the researcher opted the application of the triangulation technique, as discussed by (fielding, 2012). Figure 11 illustrates the data sources that the researcher consulted to answer this research question. The process mentioned in figure 8 was also applied in this section.

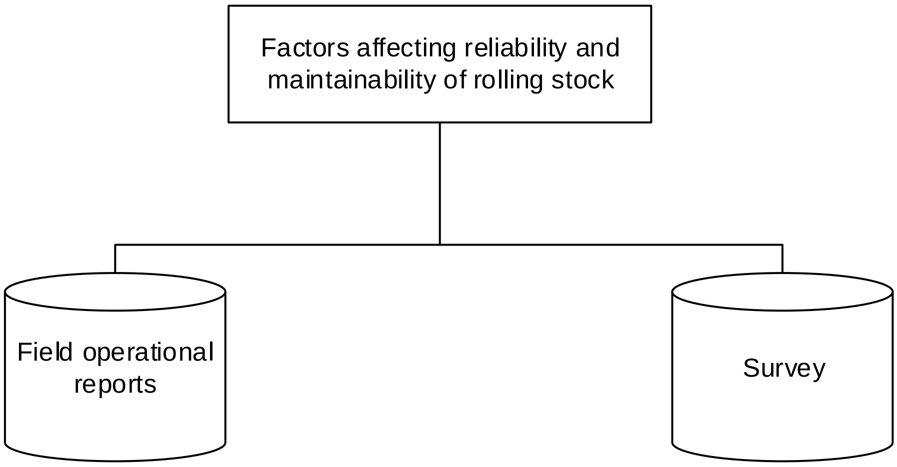

Figure 11 Triangulation Data Technique

Field operational reports: the main purpose of collecting the operational field data was to determine the trend and failure rate of the locomotives. The Pareto Chart gave the ability to rank (from the most noteworthy to the lowest) Failures as indicated by the number of recorded defects. The Pareto analysis is one of the most used quality tools across businesses to highlight the areas of improvement, and directing organisations resources in the right direction (He, 2011). He (2011) suggests that the Pareto analysis should be applied in relation to the fishbone diagram, which is beyond the extent of this research.

Survey: Survey is the collection of data attained by asking individuals questions either in person, on paper, phone calls or online. The literature in this research necessitated that the research employed a self-managed online survey provided by Survey Monkey. The method defined by Uma and Roger (2009) which entails the procedure and the preparation of an online survey. Figure12 illustrates the process followed to implement the survey.

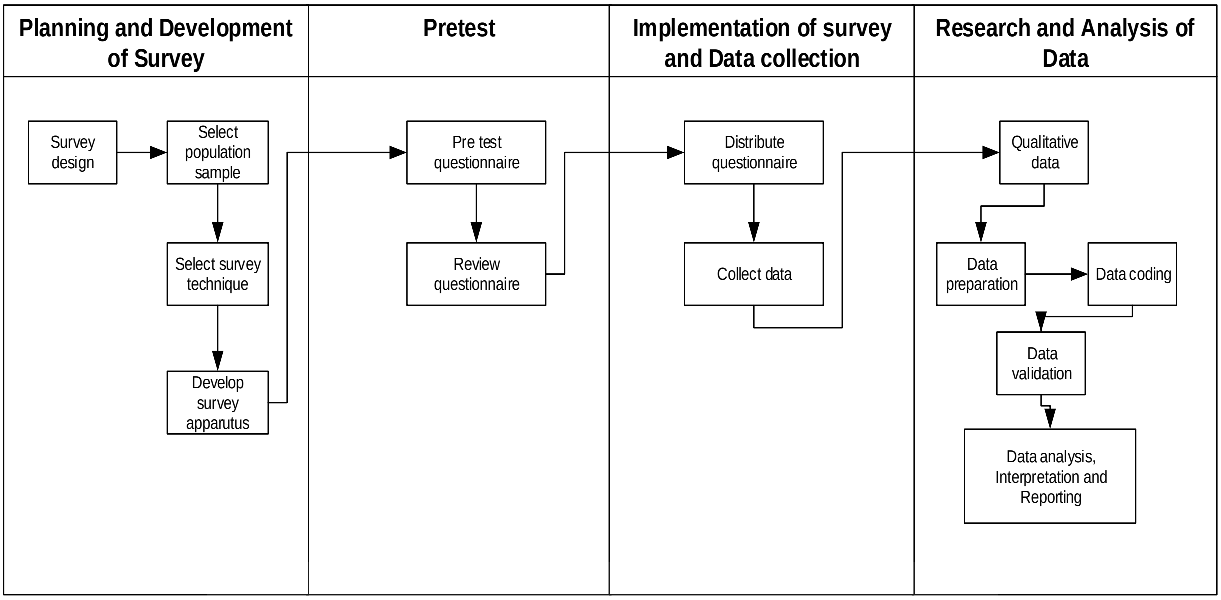

Figure 12 Survey Process Flow

The research used an online survey, because of its adaptability of design and increased response rate. Uma and Roger (2009) recommend that the adequate responses for the online survey are between 25% - 30% given every one of the difficulties related to the method. The survey gave knowledge of what the operator's think about the organisation's maintenance practices.

The examination comprised of two segments; the first part or area contained demographic questions, and the second part of the research contained the sub-research questions. The reason for demographics was to create an understanding of the participant's background about their work experience and exposure to maintenance policies of the Thabazimbi channel. The participants were requested to rate the sub-questions using the Likert scale items from strongly agreed, agree, neutral, disagree and strongly disagreeing with the statements presented to them and include their remarks toward the end of the survey.

3.7.3 Question three: What strategies can be used by the heavy haul company to improve the reliability of rolling stock in the Thabazimbi channel?

One of the sources adopted by the researcher to address this research question was the outcome or the responses from the survey.
The literature that has been covered on this research attempted to identify the relationships between various maintenance themes that the comments from the survey have revealed (Lacey and Luff, 2009). Practically there are two key methodologies of analysing qualitative data: the deductive approach and the inductive approach. Deductive approaches include using a structure or prearranged framework to analyse data. Then again, the inductive approach includes exploring data with little or no predetermined theory, structure or framework and utilises the actual data itself to develop the structure of analysis.

This research opted for the deductive approach whereby predetermined the operational field reports were analysed to get a deeper understanding and a structure in order to make sense of them (Lacey and Luff, 2009). The qualitative data approach played a pivotal role in assessing the participant's responses, as shown in Figure 13.

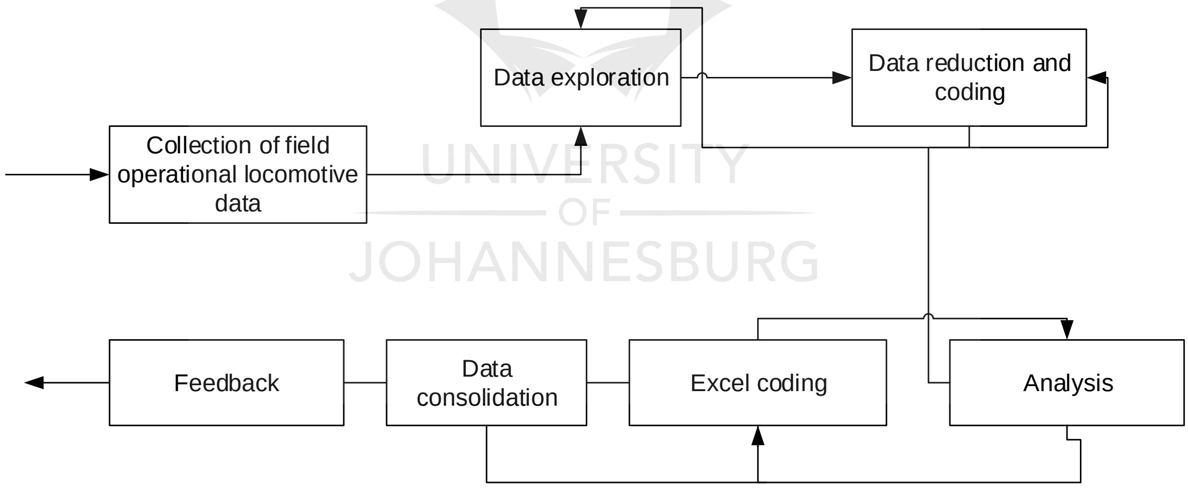

Figure 13 Qualitative Data Process Adopted

Qualitative data analysis is an iterative procedure of investigating and translating non-numeric data to increase a more insightful understanding of the phenomenon (Uma and Roger, 2009). Figure 13 shows the collaboration process implemented in analysing texts from participants comments. The incorporated step by step process performed while analysing the participant's responses included:

Field Data Collection: suggests to the accepting of data through Survey Monkey and developing topics during the data analysis process.

Data Exploration: This refers to the interpretation and rearranging the information obtained from the Survey to gain more insight relating to the research objectives.

Data Reduction: This section of qualitative data analysis includes coding and arrangement of codes for better identification of developing themes and new thoughts (Makhanya, 2016). Coding is the process of choosing significances from the content, which conforms to the research goals. Codes are words or articulations representing the verbal information, and they are vital in fulfilling a purpose. The code structure can be inductive, start list techniques or incorporated methodology.

For the purpose and objectives of this research, the researcher pursued the **Start list Methods**, which incorporates:

a) Preliminary arranging structure
b) Deductive in nature
c) Initial codes are drawn from the literature review or researcher's ability

Analysis: This part of the research presents the analysis of the text from the participant's responses.

Data coding and data consolidation: In this section, the objective was to reduce variation and streamline the data using excel software according to the themes. The data is graphically presented according to the topics covered in the literature and for ease of reporting.

The recommendations from the participant's comments, responses and experience with the locomotives operating in the Thabazimbi channel; all provided the context to address the research questions for this research and come to conclusions.

3.8 Reliability and Validity

Different authors describe reliability in different ways. In this research, reliability suggests the ability to deliver the same results repeatedly, utilising similar instruments and procedures in similar environmental settings (Marnewick, 2013). Reliability is sensitive to factors like the condition of the observer, participant errors, and preference of role players (Makhanya, 2016). Validity is characterised by Walliman (2011), as the capability of the tools or methods to produce the desired results.

This research adopted the well-established practices in the field of engineering and collected data from a trustworthy database. The reliability of the Likert scale was affirmed by using Cronbach's alpha, which is an efficient approach to deal with how well the tools applied and the legitimacy of the questions in the Likert scale supplement each other to measure the concept of interest Tavakol and Dennick (2011), recommend that the Cronbach's alpha of under 0.60 is unsuitable, yet anything from 0.7 and upward is adequate to make a knowledgeable conclusion.

In this research, the Maintenance Manager and fleet owner assumed the role of being specialists to pass judgment on the validity of the research questionnaire.

3.9 Limitations

Data gathered to address the research questions was just restricted to the locomotives and operators working on the Thabazimbi channel line. The results of the research are just restricted to the Thabazimbi channel; they exclude other different business operating channels. The recommendations and conclusions of the research are limited to the data provided to the project team.

3.10 Conclusion

The chapter outlined the description of the mind map that helped the researcher to achieve the research questions. The research approaches adopted in this research were derived from the existing literature.

The study also adopted the exploratory approach to intensely understand the causes that affect the reliability and rolling stock operating on the Thabazimbi channel. This chapter also embarked on a detailed process which explained how data was collected for this research. The next chapter presents findings and the results of the field report adopted from the heavy haul company Asset Management System (AMS).

4. CHAPTER FOUR: DATA COLLECTION, ANALYSIS and RESULTS

4.1 Introduction

A case study approach was followed for this research. The Thabazimbi operational channel experiences a challenge of executing efficient train service and minimising rolling stock downtime and increasing throughput. There is pressure for Thabazimbi channel to reduce the overall inefficiencies of rolling stock and increase availability, reliability and safety of the fleet. Therefore

The main objective of this research was to examine the challenges that affect the reliability and maintainability of rolling stock operating in the Thabazimbi channel. Also, assist the heavy haul company in optimising reliability and maintenance of its rolling stock. The research findings presented in this chapter will assist in giving meaningful input of the performance of the fleet and the challenges that the Thabazimbi channel is faced with. The setup of this research was to achieve the research objectives which are: (1) to determine the challenges affecting the reliability of rolling stock in the Thabazimbi channel. (2) to determine the success factors to improve the reliability of rolling stock. (3) to identify the strategies which can support the heavy haul company to improve the reliability of rolling stock in the Thabazimbi channel. The research was conducted through utilising primary and secondary data collection method which included a survey for the analysis of the results and it is presented in this chapter.

4.2 Operational Data Analysis

This part of the research presents historical data obtained from the heavy haul company asset management system database. This section of the chapter presents the trend and frequency of the failure rate of 34 D class locomotives operating in the Thabazimbi channel, for twelve months. The fleet size comprises of Two hundred and nineteen (219) locomotives.

4.2.1 Fleet Size and Failures throughout observation

The table below presents the statistics of the failures that occurred on the locomotives that were in operation during the period of observation. The research team adopted the following steps in order to generate the calculations below:

Step 1: The team identified the period of observation (Aug-2018 to July 2019).

Step 2: Identified units in the form of (hours, days and months), but this research adopted the monthly superposition.

Step 3: Determined the total number of events in each superposition: this included identification of duplicates and removing them.

Step 4: Identified the number of locomotives and failures per unit.

Step 5: Identified the type of statistical distribution model (Goodness of fit test) which best fit the data using the P- values a p-value less than 0,05 is statistically significant and a p-value higher than 0,05 is not statistically significant and Anderson – Darling number (AD*) from Minitab 17.

Step 6: Analysed the text from the field report to identify the cause of failure. This included linking the themes identified from the literature with the reported defects using the predetermined codes this was done with the use of Minitab 17 statistical software.

Table 6 Fleet Size and Failures throughout observation

Trend dates	Frequency of failures (monthly)	Fleet size	Failure/Fleet size	Cumulative failures
Aug-18	149	219	0.680	0.680
Sep-18	145	219	0.662	1.342
Oct-18	163	219	0.744	2.087
Nov-18	185	219	0.845	2.932
Dec-18	131	219	0.598	3.530
Jan-19	142	219	0.648	4.178
Feb-19	159	219	0.726	4.904
Mar-19	191	219	0.872	5.776
Apr-19	151	219	0.689	6.466
May-19	165	219	0.753	7.219
Jun-19	139	219	0.635	7.854
Jul-19	129	219	0.589	8.443

Table 6 illustrates the failure rate of the Thabazimbi channel locomotives that were observed throughout investigation. Column one represents the months that the locomotives were observed for the research. Column two represents the trend analysis of the locomotive failures occurred over eleven months of observation, and column two illustrates that the locomotive failures are not distributed normally as they start with a high value of 149 and a mean value of 154, the table also indicates that the failure is declining with time which also supports that the failures fall in the decreasing failure rate stage (infant stage) of the bathtub (figure 7) covered in the literature.

The following section of the research presents the model that this research adopted to analyse and fulfil the objectives of this research.

4.2.2 Goodness of fit Test

This section investigated the statistical model which best suit the data distribution model using the Anderson-Darling number (AD) and P values. The results in table 7 provide the ability of which distribution model best suit the data of failing assets. The exponential distribution had the highest AD value of 4.309, which indicated that the distribution was not the best suitable distribution model for this research data. The smallest extreme value distribution also had the second-highest AD number of 0, 60.

However, Rao and Mohsin (2018), maintain that the Weibull and Gamma distributions are the most used distribution models to analyse the failures for assets like locomotives. Therefore Weibull and Gamma were the best two model distribution with P values of > than 0,005 (0,228 and 0,250) and AD values of (0,471 and 0,264). The researcher's data Skewness was 0.700, a Mean of 154 and a Median of 150 which means that this research's data was not normally distributed. The Weibull distribution had the AD number of 0,471. Hence, the current research used the Weibull distribution for further analysis.

Table 7 Goodness of fit test

Distribution	**AD***	**P values**
Normal	0,301	0,524
Box cox Transformation	0,148	0,950
Lognormal	0,220	0,785
3 - Parameter Lognormal	0,170	0,341
Exponential	4,309	<*0,003
2 - Parameter Exponential	0,457	>0,250
Weibull	**0,471**	**>0,228**
3 - Parameter Weibull	0,305	>0,500
Smallest Extreme value	0,600	0,102
Largest Extreme value	0,171	>0,250
Gamma	**0,264**	**>0,250**
3 - Parameter Gamma	0,234	0,626
Logistic	0,267	>0,250
Loglogistics	0,212	>0,250
3 - Parameter Loglogistic	0,168	0,361

4.2.3 Hazard Plot Weibull Analysis

This portion of the research presents the failure pattern of the locomotive fleet to determine the shape of the failure rate against time. Figure 14 shows the hazard plot of the failure spread per day over twelve months. The research team used days as the unit measure instead of months to plot figure 14, for the benefif of visibility and quality of the graph. Furthermore beyond 184 days there was no trend or changes hence the graph ends at 180 days.

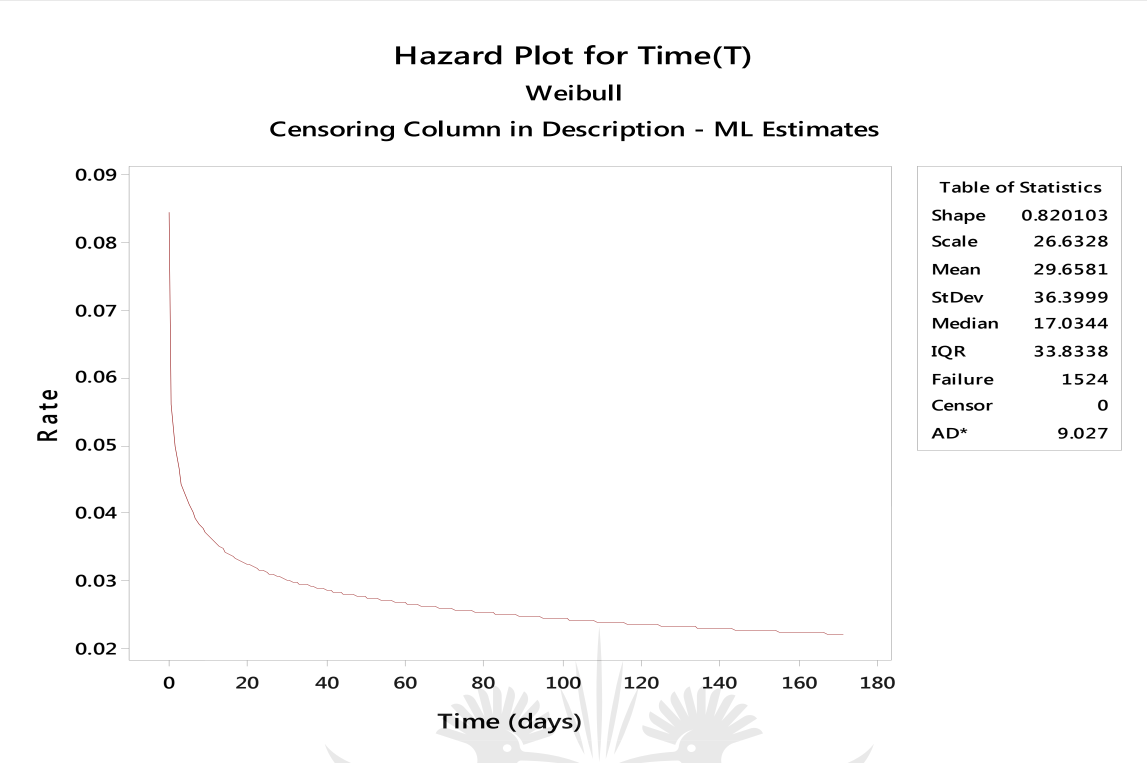

Figure 14 Hazard Plot

- **Shape or β**: The concept of β is to analyse data sets with or without failures.

When β < 1 represent early failures in the bathtub curve these are caused by material defects design blunders at the time asembly or production. β = 1 falls within random/constant rapid failure rates which are generally caused by, stress exceeding strenght. β > 1 indicates that the failures fall under wear out stage of the bathtub curve, due to fatigue or depletion of material.

The shape parameter plays an important role in describing the condition of an asset, in the statistical model (bathtub curve). The fleet under scrutiny has an actual existence shape parameter of 0.820, which implies that the failures are going down with time and that the failures fall under the infant stage of the bathtub curve with random occurring failures.

- **Scale or η**: Figure 14 illustrates the scale parameter of 26.63 per day of the Thabazimbi channel locomotives under examination.

- **Mean, Standard Deviation**: The fleet has an expected 29.65 errors or approximately 30 failures per day with the standard deviation of 36.39, this means that the variation of the failures is spread out wide over time.

- **Interquartile Range (IQR)**: This is the procedure of distributing data into four equivalent groups and subtract the first quarter to the last quarter (third quartile – first quartile). The interquartile range is essential in categorising the data abnormalities. This research did not implement the strategy of utilising the interquartile range since all data gathered for this research was incorporated in the analysis.

The following section of the research presents the Pareto chart that classifies the ranking of the locomotive failures by ranking them from the highest to the lowest.

4.2.4 Pareto Chart of Locomotive Failures

Figure 15 consolidates the locomotive failures according to their poor reliability train service disruption from highest to lowest.

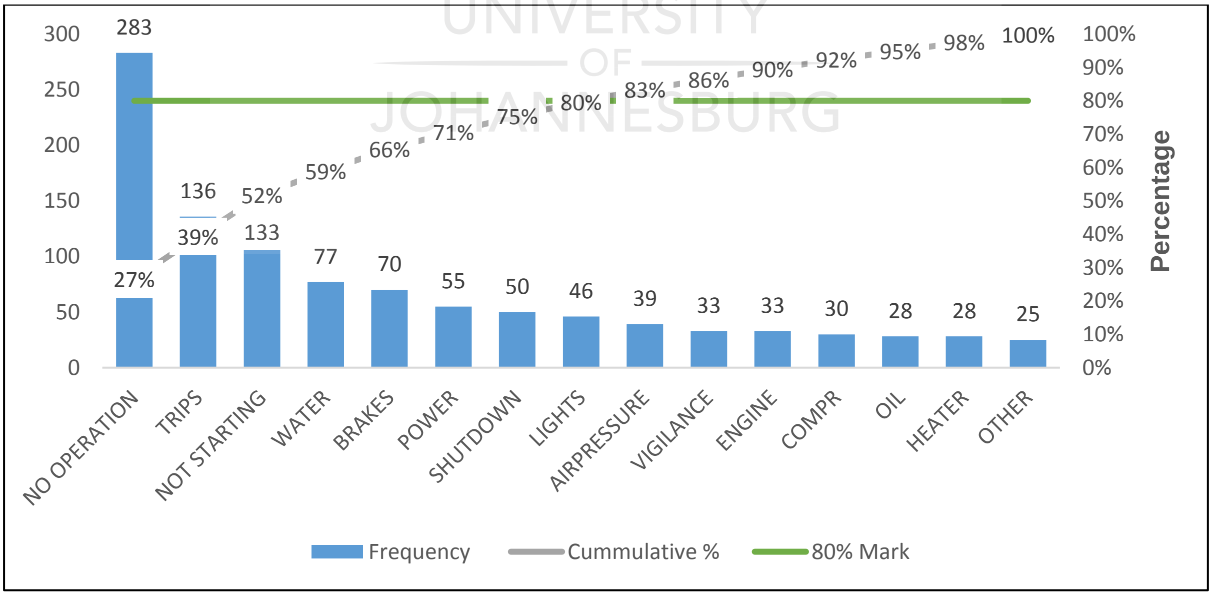

Figure 15 Pareto Chart

The chart indicates that the top twenty percent of the locomotive defects cause eighty percent of the poor reliability of 34D locomotives operating in the Thabazimbi channel. The top twenty percent included no operation (which means the driver could not determine what the problem was), locomotive trips, locomotive not starting, water leaks, brakes, power and loco shutdown.

The bottom eighty percent of the locomotive defects, causing twenty percent of the poor reliability of 34D locomotives included lights, air pressure, vigilance, engine, compressor, oil, heater and others.

The next section of the research presents the cause and effect diagram of the locomotive failures. The detailed information regarding the cause and effect diagram analysis is shown on Appendix (A.3).

4.2.6 Factors affecting the fleet reliability from the document review

The following figure presents the causes and elements of the factors affecting fleet reliability obtained from the field operational report. It further illustrates the percentage that each cause contributed to each factor. These factors were identified in the literature, and the percentages were generated through the use of microsoft excel. The researcher is presenting the fishbone diagram not in a classic use of the six M's factors.

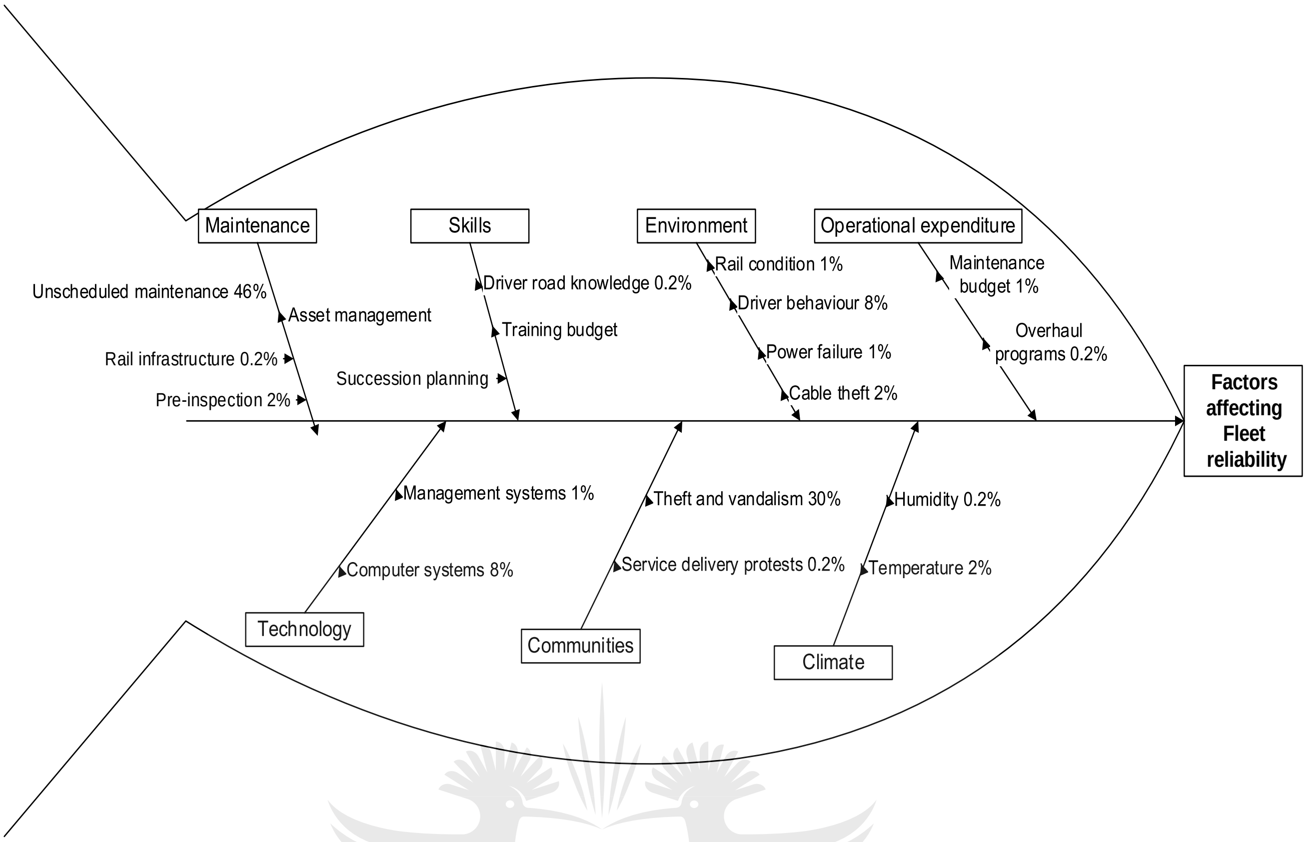

Figure 16 Fish Bone Diagram

Figure 16 illustrates the cause and effect of quantitative analysis from the operational data reports. This included linking the themes identified from the literature with the reported issues using the predetermined codes, the percentages shown in figure 16 were generated using Minitab 17 statistical software. The operational data had a total number of 1524 lines of defects analysed, of which figure 16 shows that unscheduled maintenance of the fleet constituted 46% from the operational data analysed. This means that the majority of the train service in the Thabazimbi channel was affected by maintenance. Followed by theft and vandalism with a contribution of 30%, this could be caused by lack of security, increased informal settlements next to the railway lines and socio-economic challenges. Driver behaviour and computer systems contributed 8% to the poor reliability and fleet performance operating in the Thabazimbi Channel.

4.3 Survey Data Analysis

This part of the research presents the results of the survey. The researcher invited fifty-one participants to respond to the survey questionnaire, but thirty-eight participants responded, which is 75% response rate, which is a good acceptable response rate according to (Saldivar, 2012). The survey was distributed to all participants with access to emails, and are working within the maintenance department of the Thabazimbi channel locomotives. The participants included maintenance managers, maintenance planners, Artisans, Technicians and Executive managers. The participants were selected on the basis that:

- They worked in the Thabazimbi channel for five and more years
- They have been working with diesel locomotives, and
- They worked on the maintenance department of locomotives.

The first portion of the questionnaire requested the participants their level of experience within the organisation and their number of years working with the 34 D class locomotives operating in the Thabazimbi channel. In the second portion, participants rated the Likert scale items which included the factors and challenges identified from the literature. Lastly the questionnaire requested the participants to recommend strategies for improvement and consideration.

4.3.1 Section A: Biography

4.3.1.1 Level of Experience in the Organisation

Table 8 below illustrates the results of the participants that participated on the online survey under the biography section. The results are interpreted below the table.

Table 8 Level of Experience in the Organisation

Answer choice	Frequency	Related percentage	Cumulative percentage
1-5 years	9	24%	24%
6-10 years	17	45%	68%

Answer choice	Frequency	Related percentage	Cumulative percentage
11-20 years	8	21%	89%
20 and above	4	11%	100%
Total	**38**	**100%**	

Out of the fifty-one participants that the survey had aimed at, thirty eight participants responded and had between 6-10 years of work experience. They contributed 45% of the respondents on the survey, meaning they were well experienced and matured participants to answer the questionnaire. Secondly, the majority, which is the youth working on the Thabazimbi channel contributed 24 % on the survey questionnaire, meaning they were eager and willing to participate in the survey. The adult and seasoned group of workers 20 and above accounted for only twenty percent of the number of participants.

4.3.1.2 Educational levels

Table 9 Educational Levels

Answer choice	Frequency	Related percentage	Cumulative percentage
Secondary school qualification	0	0%	0%
Matric qualification	6	16%	16%
Three year degree	14	37%	53%
Four year degree (BSc hons, B tech etc.	15	39%	92%
Master's degree	3	8%	100%
PhD or equivalent	0	0%	100%
Total	**38**	**100%**	

In this section of the research table 9 presents the results of the educational qualifications of the participants that took part in the online survey. Out of fifty-one, thirty-eight participants responded to the questionnaire relating to qualifications. The results indicate that 37% of the participants had matric and a four-year degree, which means that their experience plus their level of education was relevant and added meaningful insight to the research topic and questionnaire.

4.3.2 Section B: Research Questions

The researcher developed two sections of the questionnaire, which included the factors and challenges that affect fleet reliability. The participants rated the two themes of the questionnaire using a five-level Likert scale. The two themes were aimed at determining what can be done to improve the reliability and maintainability of the diesel locomotives operating in the Thabazimbi channel.

Furthermore, the participants were requested to give their input on strategies that could be considered for management to implement in order to improve reliability on the fleet. The Cronbach's alpha provided the capability to quantify the internal consistency of the Likert scale items.

4.3.2.1 Critical success factors for improving reliability

This section of the research provided the participants with the critical success factors gathered from the literature, of which they were requested to rate them on a five-level Likert scale. The following table presents the results and analysis of the items that were included in the success factors from the results of the online survey.

Table 10 Critical Success Factors Results

Item	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Weighted average
	1	2	3	4	5	
An overall culture shift is required for an organisation to fully understand the big picture when it comes to asset reliability	0% 0	2.7% 1	14% 5	35% 13	49% 18	4.30
The role of maintenance and reliability in operations in policy plays a crucial role in asset management	2.7% 1	2.7% 1	8% 3	35% 13	51% 19	4.30

Item	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Weighted average
	1	2	3	4	5	
A reliability programme provides an appropriate means of monitoring the effectiveness of a maintenance programme	2.7% 1	2.7% 1	11% 4	41% 15	43% 16	4.19
Senior management has linked rolling stock maintenance to the business strategy and scorecard	0% 0	5% 2	22% 8	41% 15	32% 12	4.00
The organisation uses modern technology to identify locomotive faults	2.7% 1	8.% 3	24% 9	41% 15	24% 9	3.76
There is regular staff training on the locomotive maintenance and fault finding	0% 0	11% 4	19% 7	41% 15	30% 11	3.89
The organisation invests funding to rehabilitate its rail infrastructure and rolling stock	2.7% 1	5% 2	16% 6	41% 15	35% 13	4.00

Table 10 shows that out of fifty-one participants that were targeted to rate the items per factor, only thirty-eight responded. The majority (51%) strongly agreed that the role of maintenance and reliability policies in locomotive operations plays a crucial role in a railway organisation. The Likert scale of the items in Table 10 had an internal consistency of Cronbach's alpha of 0.8222, suggesting that the items were closely related to each other as a group.

The other (49%) participants felt that an overall culture shift is required for an organisation to fully understand the big picture when it comes to asset reliability. Which means that if reliability culture is embedded in organisation reliability can be improved.

The other group of (43%) suggested that a reliability programme can provide an appropriate means of monitoring the effectiveness of a maintenance programme.
Lastly (35%) of the participants strongly agreed that capital funding is also an important aspect for any organisation in order to meet its business and customer obligations.

4.3.2.2 Challenges that affect reliability

This section of the research provided the participants with the challenges that affect reliability collected from the literature, of which they were requested to rate them on a five-level Likert scale. The following table presents the results and analysis of the items that were included on the challenges affecting reliability from the results of the online survey.

Table 11 Challenges that affect reliability results

Item	**Strongly disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly agree**	**Weighted average**
	1	**2**	**3**	**4**	**5**	
Heavy haul company has integrated asset management policy	0% 0	6% 2	18% 6	47% 16	29% 10	4.00
Heavy haul company has an ageing fleet	0% 0	3% 1	11% 4	49% 17	37% 13	4.20
Global railway companies experience theft and vandalism on their rail infrastructure	0% 0	9% 3	20% 7	17% 6	54% 19	4.17
Adverse weather conditions contribute negatively on fleet performance	0% 0	9% 2	18% 6	38% 13	38% 13	4.09
There is regular staff training on the locomotive maintenance and fault finding	0% 0	9% 3	26% 9	41% 14	24% 8	3.79

Item	**Strongly disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly agree**	**Weighted average**
	1	**2**	**3**	**4**	**5**	
The maintenance policies are consistent with the organisation strategy	0% 0	11% 4	31% 11	23% 8	34% 12	3.80
Senior management has allocated maintenance budget for the fleet of locomotives	0% 0	0% 0	23% 8	43% 15	34% 12	4.11

This section of the research shows that out of fifty-one participants that the online survey targeted only thirty-eight responded on the theft challenges. The table above reveals that (54%) of the participants strongly agree that theft and vandalism has a huge impact on the railway infrastructure. This means that many of global railway companies including the heavy haul company, will continue spending more funds on maintenance, security, reliability programmes and rail infrastructure, in order to minimise this challenge and to meet its customer requirements.

The second thirty-eight majority of the participants who constitutes of (49%) felt that ageing of the fleet for heavy haul company is also a major concern, which means that asset management policy which talks about asset care and management is not being fully implemented to mitigate this challenge. Another group which contributed to (38%) suggested that adverse weather conditions contribute negatively to fleet performance. This is as a result of nature of which railway companies do not have control of, but can only put contingency funds to address the challenge whenever it arises. A further (43%) of the participants agreed that funding is also an important aspect for any organisation in order to meet its business and customer obligations. Lastly, forty-one (41%) felt that training and development of personnel is not a major challenge for the heavy haul company.

4.3.2.3 Strategies for Consideration

This section of the research requested the participants to recommend strategies for consideration. The top five strategies that were aligned with the survey questionnaire and the research objectives were:

- The organisation needs to invest heavily on the maintenance of assets and infrastructure.
- The fleet should be maintained as per maintenance schedule.
- Personnel need regular training on locomotive maintenance.
- More security guard personnel should be employed to prevent vandalism and theft of the rolling stock.
- Business needs should inform a well-orchestrated and integrated approach to the acquisition and deployment of the fleet for operational readiness.

4.4 Pattern Matching

This section of the research compares the results from the survey and operational data. Analysis of the data from operational reports (failures) suggests that unscheduled maintenance and locomotive pre-inspection were the major contributing factors on the locomotive failures. Table 12 summarises the similarities and differences from the operational data and the online survey, this concept is referred to as pattern-matching. According to Almutairi, Gardner and McCarthy (2014) pattern matching is a technique used to analyse and synthesising the multiple findings obtained from a case study research.

Table 12 Pattern matching of the Operational data and Questionnaire results

Factor	Online Survey	Operational Data
Theft	Seventy-one percent (71%) of the online survey participants suggested that theft and vandalism were a major contributing factor on railway infrastructure companies. This meant that the reliability of the fleet is impacted due to theft and vandalism.	The operational data also showed that 30% of the failures were due to theft and vandalism.

Factor	Online Survey	Operational Data
Asset condition	The analysis from the online respondents suggests that the fleet operating in the Thabazimbi channel, its failures are occurring in the infant mortality stage of the bathtub curve. During the infant mortality stage, the asset experiences a decreasing failure rate.	The operational data also illustrated different results as there were no failures caused by poor asset condition.
Maintenance Policies	Eighty-six percent (86%) of the participants suggested that the organisations' maintenance policies were in line with the overall business strategy. Secondly, they suggested that maintenance played a crucial role in operations, which does not match what the field operational results revealed	The operational data showed that reliability was improving with time because the failure rate was decreasing.
Weather	Seventy-six percent (76%) of the online survey participants strongly agreed that adverse weather conditions affect train operations. Which does not complement the results from the operational data.	The operational data revealed contrary results of climate condition failures with (2%) of contribution as opposed to the online results.
Integrated Asset management	The participants suggested that the organisational maintenance policies are aligned with asset management reliability programmes.	The results from the operational data also proved that integrated asset management was well managed and implemented because the reliability of the fleet was improving with time.
Training	The survey results revealed that training is not an issue. This was observed as a similarity	The operational data results did not reveal any failures that were caused by lack of training.
Funding	The participants suggested that the organisation must invest in new locomotives for the future and components for the current fleet in order to prevent delays when the current fleet needs maintenance.	The operational data showed that most failures occurred as a result of unscheduled maintenance.

Table 12 identified the differences and similarities between the operational field data and the survey results. Analysis from the operational data reveals that the fleet failure rate is at the infant mortality stage.

During this phase, the assets are experiencing a decreasing failure rate. Also, the operational data analysis revealed that 46% percent of the failures were as a result of unscheduled maintenance. However, although the participants suggested that training was not an issue and that maintenance policies were aligned with the organisation strategy, and reliability was improving with time, this was observed as a similarity. Secondly, the researcher observed that although the training and policies were in line and followed, the failing points were as a result of unscheduled or unplanned maintenance.

4.5 Conclusion

This chapter revealed the findings from the field operational data, and the online survey questionnaire results. The operational data was collected from two hundred and nineteen (219) locomotive for eleven (11) months. The failure rate calculations in Table 6 provided an understanding to find a relationship between the failures of locomotives over time. The Goodness of fit test results proved that Weibull and Gamma distributions models were the only ones that could interpret the healthiness of the locomotive failures.

The Pareto Chart provided the capability to display the top twenty percent of the locomotive failures that cause eighty percent of the poor reliability of 34D locomotives operating in the Thabazimbi channel. The top twenty percent included no operation (which means the driver could not determine what the problem was), locomotive trips, locomotive not starting, water leaks, brakes, power and loco shutdown. The bottom eighty percent of the locomotive failures causing twenty percent of the poor reliability of 34D locomotives included lights, air pressure, vigilance, engine, compressor, oil, heater and others.

The survey results included the demographics, level of experience and educational qualifications of the participants. Likert scale was adopted for the participants to rate the items of the factors and challenges that affect the fleet. Also, the survey results revealed the strategies for consideration that the heavy haul company can adopt and implement to improve the reliability and maintainability of its rolling stock. Fifty-one 51 participants were invited only thirty-seven (37) participated in the survey. The survey results revealed that seventy-one percent (71%) of the participants suggested that theft and vandalism are the major contributing factors that affect the reliability of the Railway Company's infrastructure and rolling stock.

5. CHAPTER FIVE: DISCUSSION, RECOMMENDATIONS AND CONCLUSION

5.1 Introduction

This research was undertaken within the Thabazimbi channel environment. The research was triggered by work done by previous researchers on the railway companies citing issues, relating to locomotive maintenance and rolling stock challenges operating in the Thabazimbi Channel. Previous researchers highlighted a whole range of factors that affect railway organisations, such as maintenance policies, lack of personnel training and operational expenditure on locomotive maintenance (Dibakoane, 2013).

The literature gathered from previous researchers demonstrated that there is still a huge gap in the implementation and management of rolling stock maintenance policies in railway organisations. The research focused on the 34D class diesel locomotives operating in the Thabazimbi channel.

Literature obtained from previously published work played an important role in constructing the research questions and constructing the research methodology and data collection method and analysis. The research utilised both qualitative and quantitative approaches in acquiring data and seeking answers to the research questions.

This chapter's focus is to outline and link the literature covered in chapter 2, the research methodology, and the results from the operational data analysis and the findings from the online survey to address the research questions. The first part of the chapter is the discussion of the findings and the second part is the recommendations, conclusion and future work.

5.2 Discussion

The research focused on three primary objectives namely; (1) determining the challenges that affect reliability of rolling stock operating in the Thabazimbi channel,

(2) determining the success factors to improving the reliability of rolling stock, (3) identifying maintenance strategies that can support the heavy haul company to improve the reliability of its rolling stock operating in the Thabazimbi channel.

5.2.1 Challenges affecting the reliability of rolling stock.

Reliability is the probability that a piece of equipment, asset or machinery will carry out its planned function under specified environment for a specific duration. Reliability plays a pivotal role in the successful operation of rolling stock and its operation in heavy haul railway companies. The results of the online survey revealed that one of the challenges facing reliability improvement and rolling stock maintenance in the heavy haul company was vandalism and theft of railway infrastructure. These results and findings are supported by research conducted by (Ramuhulu and Chiranga, 2018).

5.2.2 Critical success factors to improve the reliability of rolling stock.

The second research objective was to determine the critical success factors that can improve the reliability and maintainability of rolling stock operating in the Thabazimbi channel. The literature presented this research with success factors such as improved organisational culture, improved reliability programmes and regular training on locomotive maintenance personnel. According to Vujovic,*et al*., (2012) an organisation should develop the reliability program as a continuous improvement strategy, in order to yield benefits of healthy and productive fleet performance. The operational data results indicated that majority of the locomotive failures occurred because of unplanned maintenance.

5.2.3 Strategies for improvement to optimise reliability

The literature provided several well-established reliability improvement strategies. The strategies include Total quality management (TQM), Lean six sigma and Total Productive Maintenance (TPM).

The strategies integrate the business objectives from employee involvement, visual management and supplier networks (business processes, organisation infrastructure and corporate governance) as key performance indicators to drive reliability improvement.

This research made use of operational field data and online survey technique to identify success factors to optimise and improve the reliability and maintainability of the organisation's assets that operate in the Thabazimbi operational area.

The results indicated that the organisation did not have any technique or strategy employed to detect failures of locomotive early or before they occurred. This was evident from the results of the operational data where most failures were as a result of unplanned maintenance.

5.3 Recommendations

Reliability has been characterized as the probability that an object will achieve its intended function under specified conditions for a particular timeframe, and that quality can be characterized as how the receiver of a product or service recognizes the product or service before purchasing, upon delivery and after the delivery and use (Rao, *et al*., 2011).

- The heavy haul company should consider integrating its existing maintenance strategy with Total Productive Maintenance (TPM) and Business Centred Maintenance (BCM) strategy in order to maximise and optimise its asset condition, availability and maintenance.
- The heavy haul railway company should consider investing in modern security systems such as drones (a flying robot that can be remotely controlled) to strengthen security in their operational hotspot areas.
- The organisation should involve all stakeholders when implementing reliability and maintenance programs during the acquisition of new assets and locomotives.

- The researcher also recommends that the heavy haul company should integrate maintenance plans, volumes increase with the assets utilisation in order to avoid mismatch during the assets maintenance overhaul schedules.
- Original Equipment Manufacturers (OEM) should form part of transferring the skills of maintaining the assets to the heavy haul maintenance personnel.
- Invest in modern railway infrastructures, such as signalling and train controlling equipment; this will add more value to freight rail transportation and will unlock more job opportunities.

5.4 Research Challenges and Limitations

- The research only collected the data about rolling stock operating in the Thabazimbi channel. It excluded all other business units and operational channels of the case study company. It only involved people who are working in the Thabazimbi channel.
- The research team was limited only to the operational field data (11 month period) and survey results to analyse and meet the research objectives. With these constraints, the researcher and the project team could not be able to quantify the monetary value of the factors that harm the Thabazimbi fleet performance.
- The research cannot be generalised across other operational channels of the heavy haul company.
- There is a lack of literature covered on this topic in the Southern African Development Community (SADC), the majority is covered in the European railway industry, and therefore the recommendations and results of the publications may vary in South Africa due to climate changes and other natural causes.

5.5 Conclusions

This research explored the reliability and maintenance of the rolling stock operating in the Thabazimbi channel. This research utilised statistical methods and questionnaires for data collection to address the research questions and attain an in-depth knowledge of the topic. The source of data collection was the database of the heavy haul company for the locomotives operating in the Thabazimbi channel.

The results revealed that the fleet was experiencing a decreasing failure rate, which means reliability was improving with time. Participants from the survey results and operational data strongly agreed that the heavy haul company railway infrastructure experiences theft and vandalism. The organisation did not have a modern reliability system or technology to detect failures before they occurred. Also, the organisation did not adhere to its existing maintenance schedule; hence most of the failures were as a result of unplanned or unscheduled maintenance.

The heavy haul company should focus on visual management, and people involved in maintenance of the rolling stock operating in the Thabazimbi channel. Furthermore, the organisation should adopt a proactive tactic to manage and implement asset management policy.

5.5.1 Recommendations for Future Work

- Integration of Total Quality Management System (TQMS) into the existing maintenance strategies.
- Secondly, further research can be carried out to investigate how asset management policy can be utilised to optimise the reliability of locomotives and lower maintenance cost while satisfying the business objectives.
- Top executive management perception to reactive maintenance strategies.

6. References

Abdullayev, S. et al., 2017. OPTIMUM DISTRIBUTION OF REPAIRS IN TS-8 OF ELECTRIC LOCOMOTIVES VL80C BETWEEN REPAIR DEPOTS IN THE REPUBLIC OF KAZAKHSTAN. *TRANSPORT PROBLEMS,* 12(2), pp. 1-20.

Acharya, A. S., Prakash, A., Saxena, P. & Nigam, A., 2013. Sampling: Why and How of it?. *Indian Journal of Medical Specialities,* 4(2), pp. 330-333.

Ahmad, R. & Kamaruddin, S., 2012. An overview of time-based and condition-based maintenance in industrial application. *Computers & Industrial Engineering,* Volume 63, pp. 135-149.

Almutairi, A. F., Gardner, G. E. & McCarthy, A., 2014. *Practical guidance for the use of a pattern-matching technique in case-study research: A case presentation,* Brisbane: Copyright 2013 Wiley Publishing Asia Pty Ltd.

Amos, P. & Thompson, L., 2009. *Railways in Development: Global Round-Up Transport Note No. TRN-36,* WASHINGTON, DC: THE WORLD BANK, WASHINGTON, DC.

Apiwattananon, A. et al., 2010. *Reliability Index Forecast by Fuzzy Principle.* Bangkok, IEEE.

Asekun, O. & Fourie, C., 2015. Selection of a Decision Model for Rolling Stock Maintenance Scheduling. *South African Journal of Industrial Engineering,* 26(1), pp. 135-149.

Bannikov, D., Sirina, N. & Smolyaninov, A., 2018. MODEL OF THE MAINTENANCE AND REPAIR SYSTEM IN SERVICE MAINTENANCE MANAGEMENT. *TRANSPORT PROBLEMS,* 13(3), pp. 5-7.

Bloomberg, 2019. *China's Latest Official GDP Report,* Texas: www.bloomberg.com.

Bose, D. et al., 2013. Measurement and Evaluation of Reliability, Availability and Maintainability of a Diesel Locomotive Engine. *International Journal of Engineering Research and Technology.,* 6(4), pp. 515-534.

Bouikidis, S. R. C. D., 2018. Focusing on the Fundamentals: A Simplistic Differentiation Between Qualitative and Quantitative Research. *Nephrology Nursing Journal,* 45(2), pp. 200-212.

CANG, V. T. & TUAN, D. D., 2012. *Reliability Based Calculation of Repairing Interval of Locomotive Wheel Axles.* Hochiminh city, Hanoi, 2012 9th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD 2012).

Celik, F. H. C. .. A. S. .. O. N., 2018. Maintenance Error Detection Procedure and A Case Study of Failure Analysis Locomotive Diesel Engine Bearings. *TECHNICAL ARTICLE,* 18(10), pp. 356-363.

Conradie, Fourie, Vlok & Treurnicht, 2015. QUANTIFYING SYSTEM RELIABILITY IN RAIL TRANSPORTATION IN AN AGEING FLEET ENVIRONMENT. *South African Journal of Industrial Engineering,* 26(2), pp. 128-142.

Crompton, R., Fessehaie, J., Kaziboni, L. & Zengeni, T., 2016. *Railway Locomotives and Transnet: A Case Study,* Johannesburg: University of Johannesburg.

Dailydka, V., 2015. RESEARCH OF IMPACT OF THE LOADING ON ENDURANCE OF THE FREIGHT LOCOMOTIVE ENGINES. *TRANSPORT PROBLEMS,* 10(4), pp. 45-57.

Deuse, J. & Khazraei, K., 2011. A strategic standpoint on maintenance taxonomy. *Journal of Facilities Management,* 9(2), pp. 96-113.

Dhlamini, 2010. *Operational Risk Analysis for the Management of Railway Infrastructure Maintenance,* Johannesburg: University of Johannesburg.

Dibakoane, 2013. *Challenges affecting the reliability of Diesel locomotives within the south african railway industry,* Johannesburg: University of Johannesburg.

Do, P., Voisin, A., Levrat, E. & Iung, B., 2016. *A proactive condition-based maintenance strategy with both perfect and imperfect maintenance actions,* Vandoeuvre: Lorraine University.

Drost, E. A., 2011. Validity and Reliability in Social Science Research. *Education Research and Perspective,* 38(1), pp. 105-123.

Durand, J. J. & Cozzarin, P., 2010. *Code of Practice & Safety Related Items List (SRIL) in Railway Industry.* Johannesburg, IEEE.

Farghaly1, 2., 2018. Comparing and Contrasting Quantitative and Qualitative Research Approaches in Education: The Peculiar Situation of Medical Education. *Education in Medicine Journal.,* 10(1), pp. 3-11.

Ferreira, L. L. et al., 2017. *A Pilot for Proactive Maintenance in Industry 4.0.* Portugal, IEEE.

fielding, N. G., 2012. Triangulation and Mixed Methods Designs: Data Integration with New Research Technologies. *Journal of Mixed Methods Research,* 6(2), pp. 124-136.

Flores-Colen, I. & de Brito, J., 2017. A SYSTEMATIC APPROACH FOR MAINTENANCE BUDGETING OF BUILDINGS FAÇADES BASED ON PREDICTIVE AND PREVENTIVE STRATEGIES. *1, 2 DECivil-IST, Technical University of Lisbon,Rovisco Pais, 1049-001, Lisbon, Portugal,* 1(1), pp. 1-47.

Floyd, H. L. et al., 2010. *MAINTENANCE STRATEGIES FOR A NEW ERA IN ELECTRICAL SAFETY.* Wilmington Pass Christian, Houston Cassatt , IEEE.

Fourie, C. & Zhuwaki, N., 2017. A modelling Framework for Railway Infrastructure Reliability Analysis. *South African Journal of Industrial Engineering ,* 28(4), pp. 151-152.

Fourie, C. & Zhuwaki, N., 2017. A MODELLING FRAMEWORK FOR RAILWAY INFRASTRUCTURE RELIABILITY ANALYSIS. *South African Journal of Industrial Engineering,* 28(4), pp. 150-160.

Fredriksson, G. & Larsson, H., 2012. *An analysis of maintenance strategies and development of a model for strategy formulation.* Göteborg, CHALMERS UNIVERSITY OF TECHNOLOGY.

Gandhare, S. N., Madankar, T. A. & Ikhar, D. R., 2014. *Re-Scheduling Of Maintenance Tasks for Diesel Locomotive (ZDM) Maintenance Work Using FMEA Technique- An Industrial Engineering Approach for Saving the Resources.* Nagpur, IOSR Journal of Mechanical and Civil Engineering.

Gebhard, J. R., 2011. *Engine Fleet Reliability Data Management Optimization.* Indianapolis, IEEE.

GEORGE, T., MOKOENA, R. & RUST, F., 2018. *A REVIEW ON THE CURRENT CONDITION OF RAIL INFRASTRUCTURE IN SOUTH AFRICA.* Pretoria, Annual Southern African Transport Conference (SATC 2018).

George-Williams, H. & Patelli, E., 2017. Maintenance Strategy Optimization for Complex Power Systems Susceptible to Maintenance Delays and Operational Dynamics. *IEEE TRANSACTIONS ON RELIABILITY,* 66(4), pp. 1309-1310.

Ghosh, S. K., Nanda, A. & Dey, S., 2017. *Reliability Aware Real Time Scheduling Strategies for Heterogeneous Embedded Systems.* Kharagpur West Bengal, IEEE.

GOLYBENKO, A. et al., 2012. PERSPECTIVE METHOD TO GUARANTEE THE RELIABILITY FOR THE ROLLING STOCK OF THE RAILWAY. *TRANSPORT PROBLEMS,* 7(4), pp. 34-38.

Guo, S., Rong, Z., Yao, J. & Wang, H., 2013. *Reliability Modeling and Assigning Method for HXD Electric Locomotive.* Beijing, International Conference on Quality, Reliability, Risk, Maintenance, and Safety Engineering (QR2MSE).

Gutierrez1, J. D. C. •. D. M., 2016. Using Qualitative, Quantitative, and Mixed Methods Research to Promote Family Therapy with Adolescents in Residential Settings. *Contemp Fam Ther,* 31(23), pp. 52-61.

Hameed, Z. et al., 2009. Condtion monitoring and fault detection of wind turbines and related algorithms: A review.. *Renewable and Sustainable Energy Review,* 13(1), pp. 1-39.

Havenga, 2015. *The state of logistics in South Africa.* Stellenboch, research gate.

Hein, V. et al., 2017. *Differences in Reliability Effects for Thick Copper and Thick Aluminium Metallizations.* Hannover, IEEE.

He, Z., 2011. *Pareto-optimality is a Criterion Uniting Efficiency and Justice.* Carrollton, IEEE.

Hide, M., 2013. *Fourth Generation Maintenance.* [Online]
[Accessed 18 October 2019].

Islam, D. M. Z., Jackson, . R. & Robinson, M., 2015. European freight rolling stock fleet size in 2050 in light of the Transport White Paper 2011. *Journal of Rail Transport Planning & Management,* 5(1), pp. 197-198.

Iwakami, T. & Takino, T., 2014. *Education for the engineers of traction power supply division in East Japan Railway Company.* Tokyo, IEEE.

Jamkhaneh, H. B. et al., 2018. Impacts of computerized maintenance management system and relevant supportive organizational factors on total productive maintenance. *Benchmarking: An International Journal,* 25(7), pp. 2230-2247.

Jiang, J. et al., 2018. *Fault vibration features of heavy-haul locomotive with tooth root crack in gear transmissions.* Chengdu, Southwest Jiaotong University.

Kałuza, A., 2016. General statistics of diesel engines' idle time Shunting locomotives in industrial sidings in Poland 2009. . .2013. *Transportation Research Part D,* 1(49), pp. 82-93.

Keyno, R. v. d. M. &. M., 2014. *"Differences and Similarities: Learning from Heavy Haul in Cold and Heat ," in proceedings of the Interbational Heavy Haul Association Specialist Technical Session: Railroading in Extreme Conditions. Calgary Canada:.* Canada, International Heavy Haul Association.

Khorshidi, H. A., Ibrahim, M. Y. & Gunawan, I., 2015. *Reliability centered maintenance using System Dynamics Approach.* Churchill, IEEE.

Koenen, D. & Alma, R., 2016. *How asset management can boost the competitiveness of renewable energy.* s.l., SCADA.

Kong, Z.-j. & Meng, Y.-x., 2011. *Research on Probability Reliability-Centered Maintenance Model Based on Requirement-Oriented Maintenance.* Tianjin, IEEE.

Kuo, W. & Zhu, X., 2012. Relations and Generalizations of Importance Measures in Reliability. *IEEE TRANSACTIONS ON RELIABILITY,* 61(3), pp. 659-660.

Lacey , A. & Luff, D., 2009. *Qualitative Research Analysis.,* Sheffield and Boston : The NIHR RDS for the East Midlands /Yorkshire & the Humber Informatics Collaboratory for the Social Sciences (ICOSS) The University of Sheffield .

Lewis, R. W., Maddison, S. & Stewart, E. J. C., 2014. *An extensible framework architecture for wireless condition monitoring applications for railway rolling stock.* Birmingham, University of Birmingham IEEE.

Lidén, T., 2015. Railway infrastructure maintenance - a survey of planning problems and conducted research. *Transportation Research Procedia,* 10(1), p. 574 – 583.

Liudvinavičius, L. P. L. S. L. L., 2014. Evaluation of the operational reliability and forecasting of the operating life of the power train of the freight diesel locomotive fleet. *Maintenance and Reliability,* 16(1), pp. 73-79.

Li, Z., Yang, Y. & Shi, L., 2016. *Continuous Improvement Actions: Moderating Effects of the Consciousness of Employees.* Haerbin, IEEE.

Mafokosi, K. R., 2018. *The causes of project failure in railway infrastructure projects,* Johannesburg: University of Johannesburg.

Magadagela, K., Nel, H. & Marnewick, A., 2017. *Identification of Delay Factors that Affect High Dwell Times of Freight Trains.* Johannesburg, IEEE.

Mainkar, M. S. & Rathod, R. K., 2017. *Maintenance Management System. Effective tool to progress and reach Total Productive Maintenance & Six sigma Business Development Strateg ies..* Kothrud,, The Automotive Research Association of India,.

Makhanya, B., 2016. *Sustainability Optimisation for Transnet Freight Rail Electric Locomotives Operating on the Natal Corridor (NATCOR),* Johannesburg: University of Johannesburg.

Marnewick, A., 2010. *The Effect of Requirements Engineering on the Success of System Implementation: A Comparative Case Study,* Johannesburg: University of Johannesburg.

Marnewick, A., 2013. *A socio-technical view of the requirements engineering process,* Johannesburg: University of Johannesburg.

Mayisela, M. & Dorrell, D. G., 2019. *Application of Reliability-Centred Maintenance for DC Traction Motors - A Review.* Bloemfontein, SAUPEC.

Mayoyo, A. R., 2015. *Factors that cause engine failure on diesel locomotives,* johannesburg: University of johannesburg.

Mbohwa, C., 2016. OPERATING A RAILWAY SYSTEM WITHIN A CHALLENGING ENVIRONMENT:ECONOMIC HISTORY AND EXPERIENCES OF ZIMBABWE'S NATIONAL RAILWAYS. *Journal of Transport and Supply Chain Management,* pp. 26-30.

Mbohwa, C., 2016. OPERATING A RAILWAY SYSTEM WITHIN A CHALLENGING ENVIRONMENT:ECONOMIC HISTORY AND EXPERIENCES OF ZIMBABWE'S NATIONAL RAILWAYS. *Thesis,* pp. 26-30.

Mmbengwa, M., 2016. *Evaluating the level of project management maturity within a transport company and its effect on Market Demand Strategy,* Johannesburg: University of Johannesburg.

Naledi, T. E., 2018. *Exploring the causes of pre-mature failures of water pipeline system in South Africa,* Johannesburg: University of Johannesburg.

Ndlovu, L., 2017. *A review on effective maintenance strategies and management for optimising equipment systems ,* Johannesburg: University of Johannesburg.

Nur, W. & Cahyo, 2018. *A Proposed Model for Aligning Maintenance Strategy to Business Strategies in Engineering Asset Management.* Sleman, Yogyakarta, Indonesia, Islamic University of Indonesia,.

Onwunta, O. & Kahn, M., 2011. *ENERGY EFFICIENCY AND RELIABILITY IMPROVEMENT STRATEGIES IN INDUSTRIAL ELECTRIC MOTOR-DRIVEN SYSTEMS (EMDS).* Cape Town, 8th Conference on the Industrial amd Commercial Use of Energy.

Ouedraogo, K. A. et al., 2018. Toward an Application Guide for Safety Integrity Level Allocation in Railway Systems. *Society for Risk Analysis,* 38(8), pp. 1634-1636.

Park, S. C., Kim, Y. J. & Won, J. U., 2017. Application of IoT for the Maintaining Rolling Stocks. *QUALITY INNOVATION PROSPERITY,* 21(2), pp. 71-73.

Pathirathna Buddhika, K. A., Malinga Rathnayake, R. M. D. & Fernando, G. D., 2018. *Use of thermal imaging technology for locomotive maintenance in Sri Lanka Railways.* Colombo, IEEE.

Piroi, I., Spunei, E., Muscai, C. & Piroi, F., 2014. *Diagnosis Charts for Regular Inversion Failures of an Automatic Block Signal Installation.* Reşiţa & Vienna, Eftimie Murgu" University of Reşiţa, UEMR & Vienna University of Technology.

Pourjavad, E., Shirouyehzad, H. & Shahin, A., 2013. Selecting maintenance strategy in mining industry by analytic network processes and TOPSIS. *International Journal of Industrial & Systems Engineering,* 15(2), pp. 171-192.

Puntis & Walley, 2009. *The use of reliabilty techniques on traction and rolling stock.* London, Proc Instn Mech Engrs.

Ramagaga, T., 2018. *Critical success factors for the implementation of reliability centered maintennace,* Johannesburg: University of Johannesburg.

Ramuhulu, M. & Chiranga, N., 2018. AN INVESTIGATION INTO THE CAUSES OF FAILURES IN RAILWAY INFRASTRUCTURE AT TRANSNET FREIGHT RAIL – A CASE OF THE STEEL AND CEMENT BUSINESS UNIT. *International Journal of Sustainable Development & World Policy,* 7(1), pp. 8-26.

Rao, A. et al., 2011. *Total Quality Management.* Six ed. New York, Chichister, Brisbane, Toronto and Singapore: John Wiley & Sons.

Rao, K. V. & Mohsin, M., 2018. *Estimation of Weibull Distribution Parameters and Wind Power Density for Wind Farm Site at Akalat Jaisalmer in Rajasthan.* Pradesh and Rajasthan, IEEE.

Restel, F. & Wolniewicz, L., 2017. *Tramway Reliability and Safety Influencing Factors.* Poland, 10th International Scientific Conference Transbaltica 2017: Transportation Science and Technology.

REZVANIZANIANI, et al., 2009. Reliability Analysis of the Rolling Stock Industry: A Case Study. *International Journal of Performability Engineering,* 5(2), pp. 167-175.

Rhein, A., Balzer, G. & Renz, P., 2017. *Reliability-based improvement of life-cycl maintenance and replacement strategies in transmission systems using ant colony optimization.* Darmstadt, IEEE.

Roccato, P. et al., 2018. *Pantograph-to-OHL Arc: Conducted Effects in DC Railway Supply System.* Torino, IEEE.

Roganov, V., Roganova, E. & Glebova, T., 2018. *Requirements for Optical-Hardware-Software Systems for Modeling Three-Dimensional Visually Observable Space for Training Simulators for Locomotives.* Penza, the Federation of Russia, Penza State Technological University University of Architecture and Construction.

Rossiter, J. R., 2011. Marketing measurement revolution: The C- OAR- SE method and why it must replace psychometrics.. *European Journal of Marketing,* 45(11/12), pp. 1561-1588.

Rossouw, C. & Fröhling, R., 2019. *Fault diagnosis in railway vehicle suspensions.* Narvik, IHHA.

Runeson, P. & Host, M., 2009. Guidlines for conducting and reporting case study research in software engineering. *Emperical Software Engineering ,* 14(2), pp. 131-164.

Saldivar, M. G., 2012. *A primer on Survey Response Rate,* Florida: Florida State University Learning Systems Institute.

Sekaran, U. & Bougie, R., 2012. *Research Methods for Business.* Fifth ed. Sussex: John Wiley & Sons .

Seletlo, 2018. *The reliability of 43D locomotives on the Phalaborwa to richardsbay corridor,* Johannesburg: University of Johannesburg.

Seshabela, P., 2018. *Evaluating the effectiveness of rolling stock maintenanace strategies in South African raiway service,* Johannesburg: University of Johannesburg.

Shahin, A., Kianfar, K. & Aminsabouri, N., 2018. Developing a Decision Making Grid for determining proactive maintenance tactics. *Journal of Manufacturing Technology Management,* 29(8), pp. pp. 1296-1315.

Shodhganga, 2018. *Basic concepts of reliability.* [Online]
Available at: http://www.shodhgangainflibnet.ac.za
[Accessed Thursday March 2019].

Sillivant, D., 2015. *Reliability Centered Maintenance Cost Modeling: Lost Opportunity.* Alabama, IEEE.

Simons, H., 2009. *Case Study Research in Practice.* London Los Angeles: SAGE Publications.

Solutions, L. R., 2018. *How to build your ISO 55001 Asset Management System ,* Johannesburg: Enterprise Asset Management.

Sreejesh, S., Anusree, M. R. & Mohapatra, S., 2014. *Business Research Methods: An Applied Orientation.* London: Springer.

Sukdeo, N., 2012. *The role of Total Quality Management System (TQM) practices on improving Organisational Performance in manufacturing and service organisations,* Johannesburg: University of Johannesburg.

Swanepoel, R., 2018. *Reliability Management – Lecture 2,* Johannesburg: University of Johannesburg.

Szkoda, M. & Kaczor, G., 2017. RAMS ANALYSIS OF RAILWAY VEHICLES LIFECYCLE. *Journal of KONBiN.*

Tavakol, M. & Dennick, R., 2011. Making sense of Cronbach's alpha. *International journal of Medical Education,* Volume 2, pp. 45-55.

Tomiyama, T. et al., 2018. Railway Rolling-Stock-Assignment-Scheduling Algorithmfor Minimizing Inspection Cost. *IAENG International Journal of Applied Mathematics,* 48(2), pp. 1992-9978.

Tomo, Z. Z. S., 2010. *Improving the reliability of a Chemical plant,* Johannesburg: University of Johannesburg.

Transnet, 2014. *MDS Booklet,* Johannesburg: Mikateko.

Transnet, 2018. *Engagement with Employees.* Johannesburg, Mikateko publishers.

Transnet, 2018. *MDS Booklet,* Johannesburg: Mikateko.

Tsao, Y.-H. C. a. H.-L., 2010. Rolling stock maintenance strategy selection, spares parts' estimation, and replacements' interval calculation. *Production Economics,* 8(10), pp. 404-412.

Uma, S. & Roger, B., 2009. *Research Methods for Business: A Skill Building Approach.* United Kingdom: John Wiley and Son.

Vaiciunas, G. & Gelumbickas, G., 2015. *Diesel Trains Reliabilty Diversity Research.* Transbaltica, Elsevier.

Valis, Z. &. P., 2014. Failure prediction of diesel engine based on occurrence of selected wear particles in oil. *Engineering Failure Analysis,* 56(11), pp. 501-511.

van Baaren, R., Wijns, W. & Smulders, T., 2017. *Reliability and Maintainability as Key Driver for Rolling Stock Acquisition.* Netherlands, IEEE.

Vicente, F., 2012. *ASSESSING THE COST OF UNRELIABILITY IN GAS PLANT TO HAVE A SUSTAINABLE OPERATION.* Neuquén, IEEE.

Vlckova, V., Lostakova, H. & Bartova, K., 2016. *DECIDING BETWEEN RAILWAY AND ROAD TRANSPORT OF DANGEROUS ITEMS WITH RESPECT TO THE LEVEL OF CUSTOMER SERVICES.* Pardubice, International Multidisciplinary Scientific Conference on Social Sciences & Arts SGEM.

Vujovic, A., Krivokapic, Z., Jovanovic, J. & Lifvergren, S., 2012. *TOTAL QUALITY MANAGEMENT AND SIX SIGMA.* Rijeka, Published by InTech.

Wakiru, J., Pintelon, L., Muchiri, P. & Chemweno, P., 2018. *Maintenance optimization: Application of remanufacturing and repair strategies.* Copenhagen, ScienceDirect.

Walliman, N., 2011. *Research Methods: The Basics.* 1st ed. London: Routledge.

Westerman, M. A., 2006. What counts as ‘‘good’’ quantitative research and what can we say about when to use quantitative and/or qualitative methods?. *New Ideas in Psychology,* 24(14), pp. 263-274.

Xin Li 1, *., 2018. Quantitative Research on Product Form Based on Kansei Engineering. *Journal of Engineering Science and Technology Review,* 11(1), pp. 84-89.

Yamamoto, T., Takemori, F. & Itakura, R., 2012. *Development of Stair Locomotive Wheelchair with Adjustable Wheelbase.* Akita, SICE Annual Conference 2012.

Yi, L. & Yun, Z., 2018. Reliability Modeling and Maintenance Policy Optimization for Deteriorating System Under Random Shock. *J. Shanghai Jiao Tong Univ. (Sci.),* 23(6), pp. 791-797.

Yin, R. K., 2014. *Case Study Research Design and Methods.* 5th ed. Thousand Oaks: CA: SAGE Publications.

Yin, R., Merriam, S. & Stake, R., 2015. Three Approaches to Case Study Methods in Education: Yin, Merriam, and Stake. *The qualitative report,* 20(2), pp. 134-152.

Yuan, D. & Zhang, C., 2011. *Evaluation Strategy for Software Reliability based on ANFIS.* Beijing, IEEE.

Yuan, F. Q., 2016. *Overall Reliability Index Development for Railway Infrastructure and Rolling Stock with Case Study.* Tromsø,, 1Department of Engineering and Safety, University of Tromsø, Tromsø, Norway.

Yu, K., 2017. *China Railway Technology Efficiency Measurement and Optimization Path Analysis.* Beijing, IEEE.

Z, H. &. S., 2013. *Global Benchmarking of South Africa's Freight Rail Syste- A macroeconomic View.,* Stellenbosch.: University of Stellenbosch.

Zhang, G., 2012. Reliability Modeling and Maintenance Optimization of the Diesel System in Locomotives. *Maintenance and Reliability,* 14(4), pp. 302-311.

Zhang, X., Xie, L., Hu, Z. & Qiu, Z., 2011. *The Strategy Research of Maintenance and Replacement under Multi-Constraint.* Shenyang, IEEE.

Appendix A

A.1. Ethics Approval Clearance Certificate

RETHINK. REINVENT. UNIVERSITY OF JOHANNESBURG

Ethics Approval Clearance Certificate

The ethics approval application submitted by

Name of Researcher	Avumile Bara
Name of Organization	University of Johannesburg
Name of Faculty	Faculty of Engineering and the Built Environment
Name of Principal Investigator	Dr. Hannelie Nel
Name of the Research Project	The challenges affecting the reliability and maintainability of rolling stock operating in the Thaba channel

Has been

- [x] APPROVED without the need for any modification by the Ethic Committee.
- [ ] APPROVED in principle but requires modification / additional information as indicated below in the comments section by the Committee.
- [ ] NOT APPROVED and requires modification / additional information as indicated below in the comments section by the Committee. Resubmission is required before approval can be granted.
- [ ] DISAPPROVED without the possibility for resubmission – the information indicated below in the comments section by the Committee highlights the reasons for this decision.

UNIVERSITY OF JOHANNESBURG

Signature (Chair of the FEBE FEPC) | December 11, 2019 Date of FEBE FEPC meeting

A.2. Questionnaire Design

Section A: Biography

Please answer the following questions by selecting the category relevant to you.

Demographic Data	
1. What is your level of experience?	a. 1-5 years ☐ b. 6-10 years ☐ c. 11-20 years ☐ d. 20 and above ☐
2. How long have you worked with 34 class diesel locomotives operating in the Thaba channel?	a. Less than 12 months ☐ b. 1-5 years ☐ c. 6-10 years ☐ d. 11-15 years ☐ e. 16-20 years ☐ f. 20 ≥years ☐

Section B: Research questions

This section seeks to determine what can be done to improve the reliability and maintainability of the diesel locomotives operating in the Thaba channel.

We have identified the following factors from literature that are known as success factors from global research.

1 = SD - Strongly disagree   3 = N - Neutral   5. SA – Strongly agree
2 = D - Disagree   4 = A – Agree

Critical success factors for improving reliability

Factor	Question	SD	D	N	A	SA
Organisational culture	Overall culture shift is required for an organization to fully understand the big picture when it comes to asset reliability					
Organisational policies	The role of maintenance and reliability in operations in policy plays a crucial role in asset management					
Reliability programmes	A reliability programme provides an appropriate means of monitoring the effectiveness of a maintenance programme					
Asset fleet management	Senior management has linked rolling stock maintenance to the business strategy and score card					
Real time monitoring	The organisation uses modern technology to identify locomotive faults					
Training	There is regular staff training on the locomotive maintenance and fault finding					
Capital funding	The organisation invests funding to rehabilitate its rail infrastructure and rolling stock					

We have identified the following challenges from literature that are known as success factors from global research.

1 = SD - Strongly disagree
2 = D - Disagree
3 = N - Neutral
4 = A – Agree
5. SA – Strongly agree

Challenges affecting reliability in the Thaba channel

Challenge	Question	SD	D	N	A	SA
Integrated Asset management	Heavy haul company has integrated asset management policy					
Asset condition	Heavy haul company has an ageing fleet					
Theft	Global railway companies experience theft and vandalism on their rail infrastructure					
Climate	Adverse weather conditions contribute negatively on fleet performance					
Training	There is regular staff training on the locomotive maintenance and fault finding					

Challenge	Question	SD	D	N	A	SA
Maintenance policies	The maintenance policies are consistent with the organisation strategy					
Funding	Senior management has allocated maintenance budget for the fleet of locomotives					

3. Please recommend strategies for consideration

A.3. Cause and Effect Diagram

Cause and Effect table for factors that affect the performance of the fleet.

Factor	**Cause**	**Counts**	**Percentage**	**Cumulative**
Maintenance	Unscheduled maintenance	855	46%	46%
	Productivity	23	1%	47%
	Loco inspection	0	7%	55%
	Rail infrastructure	0	0%	55%
	Asset management	0	0%	55%
Climate changes	Temperature	25	1%	56%
	Humidity	0	0%	56%
Operating environment	Rail conditions	3	0%	56%
	Driver behaviour	140	8%	64%
	power failure	25	1%	65%
	Cable theft	28	1%	67%
	Loco condition	421	23%	89%
Communities	Community unrests	5	0%	89%
	Theft and vandalism	38	2%	91%
Skills and Training	Driver road knowledge	3	0%	92%
	Training budget	0	0%	92%
	Succession planning	0	0%	92%
Technology	Computers systems	145	8%	99%
	Management system	10	1%	100%