



UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

*Investigating the impact of Railway Signalling Performance on Railway Operations &
Performance in South Africa*

Student Name: Pranell Naidoo

(Student number: 2613921)

School of Mechanical, Aeronautical and Industrial Engineering
University of the Witwatersrand
Johannesburg, South Africa.

Supervisor: Dr. Bernadette Sunjka

A Research Project submitted to the Faculty of Engineering and the Built Environment,
University of the Witwatersrand, in fulfilment of the requirements for the degree of
Master of Science in Engineering.

Johannesburg 2024

DECLARATION

I, Pranell Naidoo, declare that this research is my own unaided work. It is being submitted for the degree of Master of Science to the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

A handwritten signature in black ink, appearing to read 'Pranell Naidoo', is positioned above a horizontal line.

Pranell Naidoo

2 September 2024

ABSTRACT

The South African railway was once an attractive and thriving industry, serving as a catalyst for socio-economic growth and opportunities (George, Mokoena and Rust, 2018). However, in the past decade, the South African freight rail service has become uncompetitive, unreliable, and ineffectively integrated to other modes of freight transportation (The World Bank, 2023).

Railway signalling systems are a vital component of the rail network as it ensures that trains travel safely and the rail network is operating at optimal capacity (Zhang *et al.*, 2021). This research focuses on investigating the critical factors contributing to poor railway signalling performance in South Africa, and the impact that these risk factors have on the performance of railway operations, safety and the organization.

A critical literature review revealed a gap in the knowledge and understanding of the systemic factors contributing to poor signalling performance. In the effort to close this literature gap, a holistic approach was adopted to develop a conceptual framework which presented factors identified from literature which affects the performance of railway signalling systems. This research adopted a qualitative research approach to achieve the objectives of this research. Semi-structured interviews were conducted with railway signalling and operations professionals. Thematic analysis was used to identify emergent themes from the collected data.

The findings identified several factors contributing to poor signalling performance, some of the major identified factors were theft and vandalism, loss of critical skills, lack of investment and budget, managerial issues, ageing infrastructure, inadequate maintenance, human factors, etc. The research findings concluded by outlining the recommendations for future research to address theft and vandalism through collaborative strategies and initiatives, obtaining investments through public-private partnerships, addressing the skills shortage through effective skills retention programs, upgrading the freight rail signalling systems, optimizing the maintenance philosophy, and expanding the research into the passenger rail network to improve railway signalling systems in South Africa.

ACKNOWLEDGEMENTS

This research report is dedicated to my beautiful daughter, Jesslyn Naidoo. You are my source of inspiration and my biggest blessing. I hope that this achievement inspires you

to pursue your own dreams. I am eternally grateful to call you, *my* daughter.

I love you endlessly.

I extend my heartfelt appreciation to my husband, Caylin John Naidoo, you are my pillar of strength. Your patience, understanding and support had sustained me through the challenges of this journey. I am endlessly grateful for your love, encouragement and presence in *my* life.

My extraordinary parents, Devan and Nalini Reddy, you both have been a source of strength, motivation and light in my life. Your love, sacrifices, support and encouragement has shaped me into the person that I am today. I am eternally grateful and blessed to call you both *my* parents.

To my family, thank you for your continuous support and encouragement.

Dr. Bernadette Sunjka, thank you for your guidance and invaluable feedback throughout this research process.

TABLE OF CONTENTS

DECLARATION	ii
ABSTRACT	iii
ACKNOWLEDGEMENTS.....	iv
TABLE OF CONTENTS	v
LIST OF FIGURES.....	x
LIST OF TABLES	xi
LIST OF ABBREVIATIONS	xii
CHAPTER 1	1
1. INTRODUCTION.....	1
1.1. Research Background	1
1.2. Research Context	5
1.3. Problem Statement	6
1.4. Research Question	6
1.5. Research Objectives	6
1.6. Summary of Research Method	7
1.7. Delimitations and Assumptions	8
1.8. Outline of Chapters	8
CHAPTER 2	10
2. LITERATURE REVIEW	10
2.1. South African Railway Transportation.....	10
2.1.1. South African Freight Rail Network	11
2.2. Railways - A system of systems	13
2.3. Railway Systems.....	15
2.4. Railway Operations	18

2.4.1. Service Design & Evaluation	18
2.4.2. Interface Management	19
2.4.3. Train Scheduling.....	19
2.5. Rail Network Infrastructure	20
2.5.1. Railway Signalling.....	21
2.5.2. Permanent Way	22
2.5.3. Electrical System	22
2.5.4. Telecommunication	23
2.6. Railway Signalling.....	24
2.6.1. Railway Signalling Basic Elements	25
2.7. Railway Signalling Performance	28
2.8. Railway Reliability, Availability, Maintainability & Safety (RAMS).....	30
2.8.1. Reliability	31
2.8.2. Availability.....	32
2.8.3. Maintainability	33
2.8.4. Safety	34
2.9. Factors Affecting Signalling Performance in Railways	34
2.10. Conceptual Framework.....	38
2.10.1. Signalling Performance	39
2.10.2. Systemic Factors	40
2.10.3. Organizational Factors	41
2.10.4. Organizational and Operational Performance.....	42
2.10.5. Technological Factors.....	42
2.10.6. Signalling Maintenance Practices.....	43
2.10.7. Human Factors	44

2.10.8. Environmental and External Factors	44
2.10.9. Risk Management	44
CHAPTER 3	46
3. RESEARCH METHODS	46
3.1. Research Design	46
3.2. Instrumentation	47
3.3. Sampling	48
3.4. Data Collection	49
3.5. Research Interview Context	52
3.5.1. Section A: Demographics	52
3.5.2. Section B: Railway Signalling Performance	52
3.5.3. Section C: Risk to the Organization	52
3.5.4. Section D: Next Steps/ Closing the gap	53
3.6. Data Analysis	53
3.7. Validity and Reliability	55
3.8. Ethical Considerations	57
CHAPTER 4	58
4. ANALYSIS & FINDINGS	58
4.1. Participants' profiles	58
4.2. Thematic Analysis	59
4.2.1. Codes	59
4.2.2. Themes	61
4.3. The current railway signalling Performance in South Africa	63
4.3.1. Theme 1: Signalling Performance	63
4.4. The factors contributing to poor railway signalling performance	63

4.4.1. Theme 2: Socio-Economic Climate	64
4.4.2. Theme 3: Inadequate Resources	65
4.4.3. Theme 4: Investment	67
4.4.4. Theme 5: Management.....	67
4.4.5. Theme 6: Ageing Infrastructure	69
4.4.6. Theme 7: Procurement	70
4.4.7. Theme 8: Structure	70
4.4.8. Theme 9: Human Factors	71
4.4.9. Theme 10: Maintenance	73
4.4.10. Theme 11: Impact of other disciplines and external factors	73
4.5. The impact of the critical risk factors on railway operations, safety, and organizational performance.....	75
4.5.1. Theme 12: Risks of Poor Signalling Performance	76
4.6. The next steps to address the critical factors contributing to poor signalling performance	77
4.6.1. Theme 13: Strategic Solutions.....	77
4.6.2. Theme 14: Upgrading Signalling Systems.....	78
4.7. The impact of the risk factors on railway operations, safety, and organizational performance	80
CHAPTER 5	86
5. DISCUSSION	86
CHAPTER 6	93
6. CONCLUSION AND RECOMMENDATIONS	93
6.1. Recommendations for Future Research.....	94
REFERENCES.....	96
APPENDIX A: Participant Information Sheet	108

APPENDIX B: Consent Form	109
APPENDIX C: Interview Questions.....	110
Section A: Demographics.....	110
Section B: Railway Signalling Performance	110
Section C: Risk to the Organization.....	110
Section D: Next Steps / Closing the Gap	110
APPENDIX D: Detailed Codes generated through Thematic Analysis	111
APPENDIX E: Interview Transcripts	113

LIST OF FIGURES

Figure 1: Corridor Operating Model.....	2
Figure 2: Freight Rail Volume Target vs Actual Performance between 2016/17 to 2022/23	4
Figure 3: Transnet Freight Rail Network	12
Figure 4: Functional Interdependence of the Railway System	17
Figure 5: The planning Cycle	19
Figure 6: Train rescheduling due to the detection of conflicting operations	20
Figure 7: Structure of railway infrastructure.....	21
Figure 8: Signal Aspects	26
Figure 9: Principle of speed information using signals.....	26
Figure 10: General Principle of Track Circuits	27
Figure 11: Signal Interlocking.....	28
Figure 12: Reliability Bathtub Curve.....	32
Figure 13: Relationship between System Reliability, Maintainability & Availability.....	32
Figure 14: Maintenance Strategies	33
Figure 15: Conceptual Framework for Investigating the impact of Railway Signalling Performance on Railway Operations & Performance in South Africa	38
Figure 16: Inputs and Outputs of rail infrastructure performance.....	40
Figure 17 Development Processes for the Interview Questions	51
Figure 18: Frequency of occurrence of main codes from the data collected	60
Figure 19: Codes and Themes for the factors contributing to poor signalling performance	61

LIST OF TABLES

Table 1: Research Participants profiles 59

Table 2: Categorization of themes 62

Table 3: The impact of the risk factors on railway operations, safety, and organizational
performance 85

LIST OF ABBREVIATIONS

SOC	State-Owned Company
TFR	Transnet Freight Rail
Ltd	Limited
GDP	Gross Domestic Product
SADC	South African Development Committee
Natcor	Natal Corridor
RAMS	Railway reliability, availability, maintainability, and safety
PRASA	Passenger Rail Agency of South Africa
Km	Kilometre
kV	kilovolt
AC	Alternating Current
DC	Direct Current
SAR&H	South African Railways and Harbours administration
SATS	South African Transport Services
PMI	Project Management Institute
TCO	Train Control Officer
CTC	Centralized Traffic Control
OHTE	Overhead Traction Equipment
ICT	Information and Communication Technology
SCS	Supply Chain Services
TAS	Train Authorization Systems
KPT	Key Performance Themes
KPI	Key Performance Indicators
ETR	Estimate Time to Repair
IM	Infrastructure Managers
RPM	Routine Preventative Maintenance
PM	Predictive Maintenance

OEM	Original Equipment Manufacturer
PPM	Public Procurement Management
VSP	Voluntary Severance Package
INCOSE	International Council on Systems Engineering
SLA	Service Level Agreements

CHAPTER 1

1. INTRODUCTION

1.1. Research Background

The global economy is largely dependent on effective, reliable, and efficient transportation of freight (Capineri et al., 2006.). In the South African economy, freight transportation is crucial, especially for attracting investments and creating jobs (Western Cape Mobility Department, 2023). Large volumes of freight are transported via railways, ports, and pipelines, with the State-Owned Company (SOC), Transnet, being the custodian, operator, and owner for these freight transportation infrastructure networks in South Africa (Department of Public Enterprises, 2023).

Transnet SOC Limited (Ltd) plays a pivotal role in the South African economy and aims to maintain and develop a reliable freight system that not only retains its global competitiveness but also ensures customer satisfaction and fosters continuous, sustainable economic, social, and environmental outcomes, and diversification within the country (Transnet SOC Ltd, 2022; Department of Public Enterprises, 2023).

Transnet Freight Rail (TFR) is Transnet's largest Operating Division, with the primary goal of providing railway transportation of various commodities for the local and export markets (Transnet Freight Rail, 2019). One of the key factors influencing the South African economy is TFR's performance, which oversees the fostering of the country's economy's competitiveness, improvement, and progression by offering efficient and cost-effective rail services that satisfy customer demand (Transnet, 2012).



Figure 1: Corridor Operating Model (Transnet Freight Rail, 2021)

There are 9 major commodities transported by TFR which contributes to 80% of Transnet's revenue and 42.9% toward the Gross Domestic Product (GDP) of South Africa (Derby and Dlamini, 2021). This evidence shows that effective, reliable, and efficient railway transportation is essential because TFR, and notably freight rail transportation, is essential for the continued expansion and development of the South African economy.

The rail network is split into 6 corridors, each transporting various commodities across the country for local and international customers (Transnet Freight Rail, 2022):

- North Corridor which is a diverse mixture of line types and capacity, which transports coal, chrome, ferrochrome, and cement.
- The Ore Corridor, a heavy haul line capable of carrying 30 tons per axle, is instrumental in transporting iron ore. Spanning 861 kilometres of track, this remarkable line ranks as the second longest heavy haul line globally (Kuys, 2011).
- North-East Corridor which transports 14% of freight volumes and has transportation links from South Africa to the neighboring South African Development Committee (SADC) countries. The North-East corridor transports a high amount of General Freight Business, such as magnetite, chrome, ferrochrome, and rock phosphate.

- Cape Corridor which consists of lines from key mining areas in the Northern Cape to the ports of Gqeberha and Ngqura. Commodities such as manganese, iron ore, automotive, agriculture, cement, lime, and grain are transported in this corridor.
- Natal Corridor (Natcor) deals with bulk freight from the Port of Durban and pipelines, linking Durban to the economic hub of Gauteng through an extensive rail network. Commodities passing through this link are containers, automotive, grain, fuel, coal, and chrome.
- Central Corridor transported 24 million tons of freight passing through its line in 2021, it links operations throughout the rail network. High revenue freight such as chrome, coal, iron ore and manganese, as well as time-sensitive trade of containers to the automotive industry supporting the manufacturing industry are transporting via the central corridor.

The functioning of a society and economy critically depends on essential infrastructure networks, encompassing transportation and power (Bešinović, 2020). The railway is a remarkable invention aimed at connecting areas and regions for the transportation of goods and people over long distances. With the current global problems, railway systems are vital to many countries around the world as it aids in economic growth, it is energy efficient, and has low emissions, whilst having the transportation capabilities of hauling large volumes of passengers and freight across long distances (The World Bank, 2023). In South Africa, the freight rail service is uncompetitive, unreliable, and ineffectively integrated to the other different modes of transportation, which causes the existing and potential customers to look for alternative modes of transportation for their freight (The World Bank, 2023).

This research focuses on the freight rail network. TFR is the custodian for the freight rail network, and one of the largest railway operators in Africa, responsible for transporting freight across South Africa and its neighboring countries (van Rensburg, 2022).

Over the past 6 years, TFR has been facing significant challenges such as bad weather (heavy rain, flooding, wind, etc.), technical failures, theft and vandalism, poor maintenance, etc., which affects the performance of its rail network infrastructure (Paton, 2023). This results in a decline in railway capacity, availability, reliability, and

safety. Disruptions and incidents to the rail network infrastructure result in disruptions or delays to train services or even temporary line closures which could halt train movement (Bešinović, 2020). The published TFR 2022 annual performance report reflected a 5% decline in rail volume performance, in the 2021/2022 financial year the volumes railed was 172.7 million tons compared with 2020/2021 financial year which railed volumes of 181.3 million tons (Transnet Freight Rail, 2021, 2022). Figure 2 below illustrates the performance of the target rail volumes versus the actual railed volumes from the financial year 2016/2017 to 2022/2023.

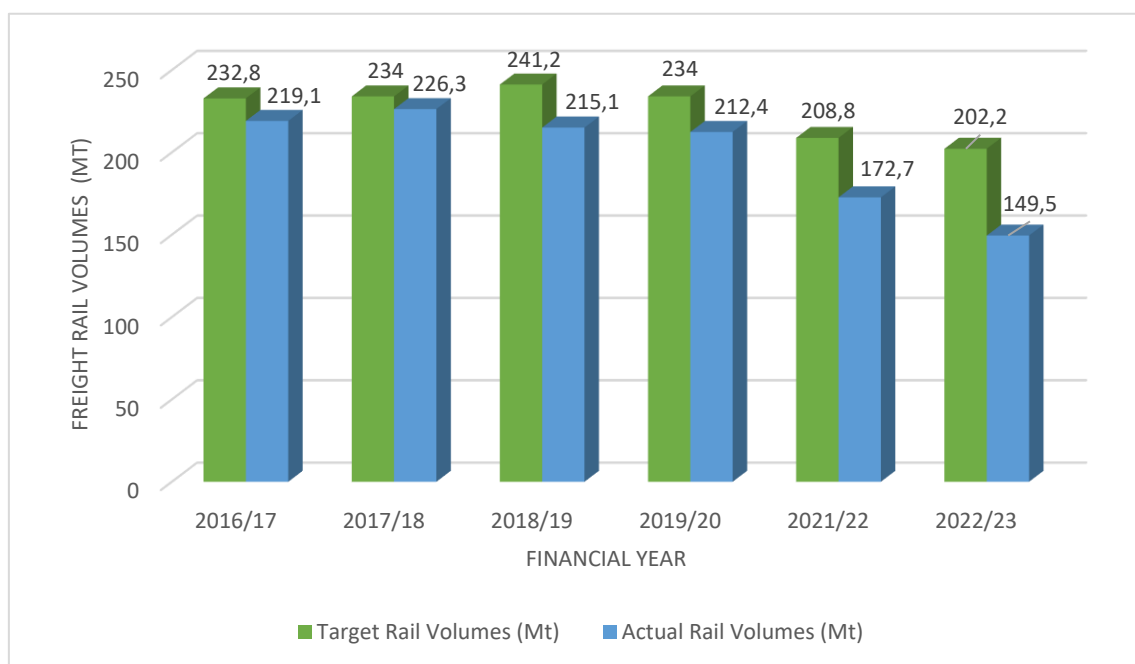


Figure 2: Freight Rail Volume Target vs Actual Performance between 2016/17 to 2022/23 (Transnet Freight Rail, 2017, 2018, 2019, 2020, 2021, 2022, 2023c)

As the demand of freight transportation increases and with the current state of the rail network infrastructure, the system experiences heightened levels of congestion and under performance, leading to increased interdependence and operational complexity (George, Mokoena and Rust, 2018; Bešinović, 2020). These challenges have taken a toll on TFRs reputation and their ability to satisfy their customers' needs which has led to their customers looking at alternative modes of transportation to meet their demands and targets. Due to the underperformance of TFRs railway systems, more customers have opted to transport their freight via road, which has sparked a boost in investment for road infrastructure and road transportation vehicles (Bouraima *et al.*, 2023). This has

caused a significant downturn for TFRs railed volume targets and profits. The increase in road traffic has a much larger effect on the South African economy, environment, and society. The higher road traffic has caused an increase in road accidents, increase in carbon dioxide emissions, higher transportation costs, and congested roads (Bouraima *et al.*, 2023).

1.2. Research Context

To ensure that trains travel safely, and the rail network is operating at full capacity, railway signalling systems play a vital role in the rail network (Zhang *et al.*, 2021). The objective of railway signalling is to prevent conflicting train movements and ensure that trains move safely and efficiently (Mhlongo, 2021). It is vital that railway signalling systems are reliable, fail-safe, and interoperable to ensure safe and efficient train movement, increase railway capacity, and improve safety and train operations (Krmac and Djordjević, 2017). Additionally, signalling systems are critical because they have a direct influence on the railway system's overall effectiveness, operation, availability, efficiency, and safety (Morant *et al.*, 2012).

The freight logistic system is one of immense importance to the South African economy. According to Havenga and Simpson (2018), the freight logistic system plays a microeconomic role in the success of business development in many countries. With the railways being a large entity made up of many interdependent and interoperable systems. By looking into the factors that affect railway signalling performance it is a step closer to improving signalling performance which in turn would aid in the improvement of the overall performance of the freight rail network. With the rail network performance improving, rail transportation would once again become a more attractive and lucrative option for customers, thus enabling a shift from road-to-rail, which would improve the freight logistic industry as well as the socio-economic state of South Africa.

1.3. Problem Statement

The railway system is a system of systems thus there are numerous factors that contribute to its poor performance, the disturbances, or failures in any of these systems will contribute to a decline in operational performance (Lidén and Joborn, 2017). One of the key contributing factors to these challenges is poor signalling performance, which affects the safe and efficient movement of trains throughout the network. Performance in signalling has an impact on both railway operations and performance, as well as the overall performance of the organization. Despite the critical role that signalling systems play in TFRs operations and organizational performance, there is a lack of understanding of the systemic factors causing poor signalling performance as well as the risks associated with its effects on railway operations, safety, and organizational performance. These factors need further investigating.

1.4. Research Question

The research aims to answer the critical research question below:

What are the critical factors contributing to poor signalling performance which is impacting railway operations and organizational performance in South Africa?

1.5. Research Objectives

This study intends to investigate and identify the factors that lead to poor railway signalling performance to enhance the reliability, availability, maintainability, and safety of the rail network infrastructure in South Africa. This study can help railway management, signalling specialists, and researchers to have a better understanding of the challenges and complexities affecting signalling performance, and this can aid better decision making, planning, and strategies for improvement.

The objectives of this research are to:

1. Identify the key systemic factors contributing to poor signalling performance.

2. Assess the risk factors of poor signalling performance and evaluate the impact on railway operations and safety, and organizational performance.
3. Develop recommendations for addressing the critical factors that contribute to poor signalling performance to improve railway operations and organizational performance.

1.6. Summary of Research Method

This research aims at investigating the critical factors affecting the performance of railway signalling systems in South Africa, which subsequently impacts the performance of railway operations and the organization. Due to the limitations in present research with regards to this phenomenon being investigation, the nature of this research is complex and exploratory and therefore a qualitative research approach is suitable for this study (Golafshani, 2003; Creswell, 2009).

The critical literature review is designed to develop a deeper understanding of the railway signalling environment, the factors that negatively impact its performance, and the impact that these factors have on railway operations, safety, and organizational performance. Critical concepts from the literature review contributed to the development of a conceptual framework.

The formulation of the semi-structured interview questions for this study incorporated the Rose-Wengraf model. The analysis of the collected data used thematic analysis, which is a qualitative analysis technique used to detect patterns and themes in data to achieve a deeper understanding and significance of the data collected and, as a result, gain more understanding of the research question and objectives (Liamputtong, 2009). The themes identified through this process is presented in the analysis and findings of this study.

All aspects of the research were carried out in accordance with the ethical guidelines stipulated by the University of Witwatersrand Human Research Ethics Committee (non-medical). The ethics clearance number for this research is MIAEC 070/23.

1.7. Delimitations and Assumptions

- Due to the time constraints for this research, this study was limited to the freight rail operator (Transnet) in South Africa.
- The researcher was aware that the railway signalling and operations experts and professionals for the freight operator are at various locations across the country. Therefore, the researcher would be unable to conduct face to face interviews with all the selected participants. To ensure an equitable and easily accessible interview process, the researcher opted for virtual interviews on Microsoft Teams.
- The challenges facing railway signalling systems are unique to the country and the type of system installed in that country. Many first world countries use modern and advanced signalling systems together with state-of-the-art trains, which differs from the signalling systems used in South Africa and Africa. Therefore, there are limitations to the available literature on South African signalling systems, particularly the systemic factors affecting signalling performance.

1.8. Outline of Chapters

- | | |
|-----------|---|
| Chapter 1 | Introduction to this research with the research background and problem statement, and presenting the research question, research objectives and context for this research. |
| Chapter 2 | Literature review relevant to the railway industry, signalling systems, the factors affecting signalling performance, and then leading into the conceptual framework for this research. |
| Chapter 3 | Outlines the research methodology used for this research |

- Chapter 4 Presents the analysis of the collected data and the results obtained from the analysis
- Chapter 5 Discussion on the outcome of this research. Addresses the research question, research objectives and the analysis and results of the information obtained.
- Chapter 6 Concludes the research and highlights the recommendations for future research.

CHAPTER 2

2. LITERATURE REVIEW

The literature review covers topics related to railway transportation with specific focus on railway signalling performance and the factors that impact signalling performance. This aims to provide a foundation for the research question and objectives. The review begins by introducing railway transportation, highlighting the importance of railways as a mode of transportation and their role in facilitating economic development. It then delves into the details of railway systems, railway operations and rail network infrastructure, providing a brief overview of the various components that make up the railway network.

The review then narrows its focus to railway signalling, exploring the role of signalling in ensuring safe and efficient railway operations. It examines the different elements of the signalling systems used in railways, and then moves on to railway signalling performance. The review also covers railway reliability, availability, maintainability, and safety (RAMS), which are critical factors in ensuring railway performance. Finally, the literature review focuses on the factors that impact signalling performance in railways.

2.1. South African Railway Transportation

A study conducted by Oumarou (2015) showed that among the nations in the African continent, South Africa stands out with its most established and successful rail transportation network. South Africa has one of the most developed and established rail transportation networks on the African continent.

The current South African rail network is a product of more than a century of development to produce a large rail network infrastructure (Coutsoukis, 2004). The South African Railways currently transport passengers and freight (George, Mokoena and Rust, 2018; Bouraima *et al.*, 2023). The South African government owns two major and dominant national rail operators. One of them is Transnet SOC Ltd, responsible for transporting freight, while the other is the Passenger Rail Agency of South Africa

(PRASA), which focuses on transporting people (George, Mokoena and Rust, 2018). According to the statistics provided by Department of Transport (2023), PRASA currently possesses 2280 kilometres (Km) of track within the South African rail network, additionally PRASA utilizes an extensive network of 22000 km of track which is owned and operated by Transnet.

In the year 2010, a new rail operator, Gautrain, entered the private sector rail space in the Gauteng province for transportation of passengers (*National Rail Policy: Draft White Paper*, 2017). The monumental Gautrain project required an investment of approximately ZAR 25 billion to construct this high technology rail network, which is the first high-speed mass transit rail network in South Africa as well as the African continent and has an 80-kilometre-long rail network adhering to the standard track gauge (Schilling, 2013; Thomas, 2013; Railway Technology, 2020).

The South African Railway was once a booming and thriving industry, however in recent years the condition of the rail network infrastructure, particularly the state-owned networks operated by TFR and PRASA, has undergone significant deterioration (George, Mokoena and Rust, 2018). This research focuses on the freight rail network in South Africa.

2.1.1. South African Freight Rail Network

The South African government oversaw the regulation of the freight rail network until the establishment of TFR on April 1, 1990, at that point, TFR transitioned into a profit-oriented operating division under Transnet SOC Ltd (Pienaar, 2010). TFR is the custodian of the freight rail network in South Africa and plays an essential and significant role in the economy. TFR is responsible for generating 80% of Transnet's revenue which in turn contributes 42.9% to the country's GDP (Department of Transport, 2017; Derby and Dlamini, 2021). TFR owns over 55 000km of track in sub-Saharan Africa (Transnet, 2016), of which approximately 31 000km of track is located in South Africa (Transnet Freight Rail, 2022). TFR's Cape gauge network enabled strategic links between the freight rail network, ports, and transportation service providers of all six neighboring countries (Transnet Freight Rail, 2023), which in turn links eleven African countries to the South African freight rail network (Bouraima *et al.*, 2023).

The South African freight rail network is composed of two heavy haul lines, the coal line (26 tons per axle) and the iron ore line (30 tons per axle), with constitute 1500km of track, and 3928km of track being branch lines which serves as feeders into the main lines (Transnet Freight Rail, 2022). In the past, the South African heavy haul lines held a commanding position at the forefront of the global market, however, in recent years, their standing has waned, with the iron ore line now ranked third and the coal line ranked fifth in their respective international markets (Department of Transport, 2023).

There is a total of 7998km of track in areas which are electrified with overhead traction currents of either 25 kilovolt (kV) Alternating Current (AC), 50kV AC, or 3kV Direct Current (DC), as well as 2146 stations which are signalled (Transnet Freight Rail, 2022).

Figure 3 illustrates a map of TFR's network.



Figure 3: Transnet Freight Rail Network (Transnet Freight Rail, 2022)

As a result of the failure to effectively strategize freight transportation and see the benefits and long-term potential in freight rail transportation, the investment in the freight rail infrastructure declined after the first two decades of the inception of the network. Road transportation was prioritized as it was an attractive option due to its flexibility and cost (Havenga, Simpson and De Bod, 2014). Today, 33 years since the inception of Transnet, the freight market is deregulated and monopolized by TFR, who

heavily depends on government investment and funding for infrastructure development and maintenance. There have been occasional positive spikes in the rail industry, however, the overall trend for the freight railway infrastructure condition has been on a downward trajectory (Department of Transport, 2023). This decline is attributed to the government's preference for investing in road infrastructure over rail for freight transportation, which has resulted in a lack of adequate resources for the development and maintenance of the rail network (Oumarou, 2015). Consequently, roads have become unsafe, traffic congestion has surged, and the costs of required road maintenance have become unsustainable, contributing to the counterproductive effects on the economy (Bullock, 2009).

In the year 2012, the rail network saw a resurgence with Transnet introducing its Market Demand Strategy (MDS) which was seven-year investment of ZAR 336 billion for the expansion of the rail, ports and pipeline networks (Prins, 2015), however it is a long road to recover the rail network after years of underinvestment. The lack of investment in the rail industry has caused catastrophic problems as the infrastructure development has been neglected and the infrastructure is aging and deteriorating. The unreliable and unavailable network has resulted in the railway customers choosing road transportation over rail transportation (Mathabatha, 2015), the poor performance of the rail network negatively impacts the railway organization.

The performance of the freight rail network does not only impact the railway organizations, the freight rail system fits into a larger logistic chain system. The freight rail system is an element or sub-system in the transportation chain of the pit-to-port process (Leech, 2012).

2.2. Railways - A system of systems

Railway Systems are not just a mere amalgamation of a railway track and railway vehicle. Railway systems are complex and sophisticated as there are many interlocking components that form an intricate "system of systems". The railway network has several different technologies, systems, and processes working together to achieve and deliver

the objective and purpose of the rail system, which creates challenges and complexity unique to the railway system (Morant *et al.*, 2013).

The Oxford English dictionary defines a system as “a set of things working together as parts of a mechanism or an interconnecting network; a complex whole” (Oxford English Dictionary, 2023). The handbook for the International Council on Systems Engineering (INCOSE) describes a system as the combination of man-made artifacts to perform a desired function in a specific environment (INCOSE, 2015). Whilst Clayton *et al.* (2009) states that a system “is a combination of interacting elements organized to achieve one or more stated purposes”.

Using these definitions and descriptions, and for context of this research the purpose of TFRs railway system is to transport freight safely, reliably, and efficiently to their customers. The proper functioning and performance of individual contributing systems do not guarantee the functionality and performance of the entire rail network (Morant *et al.*, 2013), and it is therefore vital to adopt a holistic perspective while considering the railway system. The interoperability of systems is important to achieve the overall purpose of the entire system. According to Clayton *et al.* (2009) the interactions and connections that a system has with its various stakeholders, departments, with other systems, and the environment, are what give it its complexity, and it is broader than just the technical element. Umiliacchi *et al.* (2019) further reiterates this by saying complex systems should be addressed using a whole-system approach in order to (i) understand the design and requirements of a system, as well as the environment the system operates in, (ii) understand the interaction, connections and interdependencies of a system, (iii) assess the impact an individual system’s performance, change, or modification has on other interconnecting systems or the overall system, and (iv) understand the impact new solutions and technology has on the business.

A study by Ghaleb and Abdullah (2021) investigates the relationship between transportation projects complexity and project performance and success, this relationship is relatable and applies to the railway system. The Project Management Institute (PMI) identifies system performance as one of the three dimensions of complexity, and therefore this study emphasizes the importance of applying a

systematic and holistic approach to achieve optimal system performance (PMI, 2014; Ghaleb and Abdullah, 2021).

In order to answer the research question, it is necessary to understand how signalling systems fit into railway systems and rail infrastructure, to establish relationships and interactions, and to be able to identify systemic factors causing challenges to signalling performance.

2.3. Railway Systems

A well operating railway system is one that achieves on time and reliable train services while maintaining low train operational cost and high business opportunity (Ferreira, 1997). On time freight arrivals and low transit times are of profound importance to the customer, and therefore disruptions to train services need to be investigated in order to improve customer satisfaction, retain customers and attract new businesses (Ferreira, 1997). Due to the interconnected nature of the railway system, when any component is underperforming or presents degradation, the overall performance of the rail system is affected (Al-Douri et al., 2016).

Railway systems inherently possess significant complexity, as the primary objective of delivering efficient train operations aligned with customer demands involves a sequence of intricate actions. These actions, when executed, form a cohesive process aimed at fulfilling freight rail objectives. Therefore, in railway systems, a fundamental bifurcation emerges, dividing the system into two core domains: Railway Operational Planning (dynamic resources) and Rail Network Infrastructure (static resources) (Marinov *et al.*, 2013). These domains, together shaping the system, drive the holistic performance of the system as a whole (Stenström, 2014). The intricate relationship between Railway Operational Planning and Infrastructure are characterized by a profound interdependence and interoperability (Marinov *et al.*, 2013), necessitating a comprehensive understanding of their combined dynamics.

The South African freight rail industry enforces a multifaceted approach to bolster profitability and accountability (Transnet Freight Rail, 2024). This approach includes the

implementation of adopting an organizational structure with 'vertical' functional separation, where various operational units, namely rail operation planning and rail network infrastructure, are broken down further into various internal business units to cater to specific market segments (Transnet Freight Rail, 2024). This vertical organizational structure mirrors similar strategies employed in the freight rail sector of many countries in the United Kingdom, Sweden, Australia, and Germany, (Ferreira, 1997). A study by (Oumarou, 2015) found this approach beneficial and further highlights that the vertically integrated business model is dominant in the private sector of the United States of America, and many countries in Asia, North Africa, and Europe. The vertically integrated business model is advantageous as a single entity controls the business operations which allows for optimal coordination between railway operations and infrastructure, however there are drawbacks particularly if this monopolized entity is underperforming (Oumarou, 2015). The concept of autonomous infrastructure management, planning, and ownership is gaining prominence, underlining a parallel pursuit of enhanced accountability and profitability in both contexts.

According to Umiliacchi et al. (2019) it is important to include all factors of the system, thus these can be further broken down into subsystems, elements, departments, technology, processes, and people who interact with each other to perform a specific objective. These include operational (dynamic) disciplines such as rolling stock, train operations, safety, management, business corridors, customers and stakeholders (Baek and Lee, 2017), and infrastructure (static) subsystems which typically include your engineering disciplines such as Track infrastructure, Signalling Systems, Condition Monitoring Systems, Electrical Power distribution (Overhead Track Equipment and Substations), Telecommunication networks, maintenance management, technology management, and projects (Marinov *et al.*, 2013; Stenström, 2014; Baek and Lee, 2017; Mhlongo, 2021). Railway Operations and infrastructure are complex systems made up of many components, subsystems, departments, processes, and people, and the performance of each component and subsystem impacts the performance of that entire system and the organizational performance (Marinov *et al.*, 2013). This is further emphasized by Mhlongo (2021), who states that the seamless operations of train services require reliable and good performing rail infrastructure.

Due to the interconnected nature of the railway system, decisions in one operational planning aspect will inherently affect the rail network infrastructure, and vice versa. A study by Ferreira (1997), outlines the linkages and the interdependent relationship between the dynamic and static resources and functions of the rail system, this is shown in figure 4 below. An interconnected example is when considering a business decision to increasing the tonnages railed by potentially adding longer trains or heavier trains, there are a number of factors and disciplines that should be considered for example: (i) upgrading the track infrastructure by either extending the loop lines and sidings, or doubling the relevant tracks, or increasing crossing loops, (ii) track design standards such as the axle-loads and train speeds, (iii) railway signalling design to manage the capacity for example, the signalling train authorization technology, distances between signals, or bidirectional train movement, or simultaneous entry of trains at crossing loops, etc. (iv) track condition and maintenance strategies which effects the rolling stock performance and maintenance, or (v) the overhead electrical traction capacity and electrified areas, and etc., (Ferreira, 1997). In this similar fashion, this is how the performance of the signalling systems affect the performance of the train operations, as a delay in one function has a ripple effect causing delays in multiple other interconnected disciplines. Figure 4 below illustrates the interconnections and the interdependence of systems and elements within a railway system.

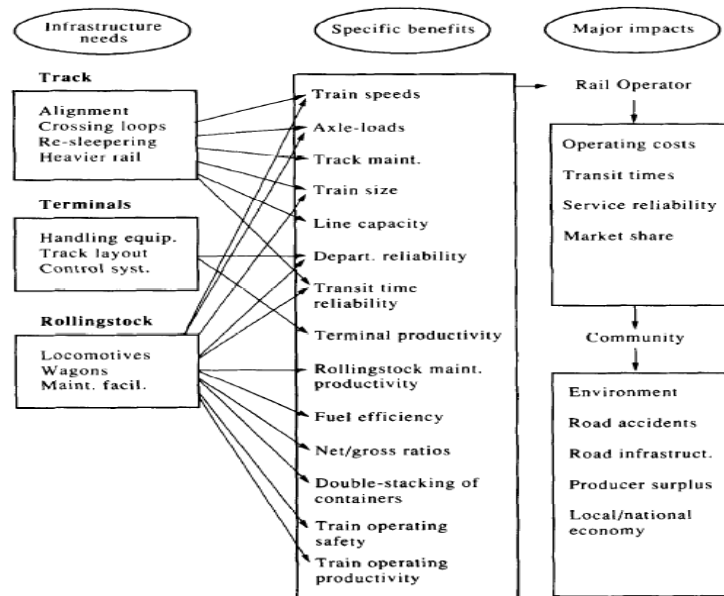


Figure 4: Functional Interdependence of the Railway System (Ferreira, 1997)

Given the scope of this study, the primary emphasis of the rail network infrastructure will be on Railway Signalling. To comprehend the implications of signalling performance, a high-level, overarching exploration of railway operations and infrastructure will also be undertaken.

2.4. Railway Operations

To achieve the research objective of evaluating the impact that Railway Signalling has on operations and safety, it is essential to firstly understand the role of railway operations and its interconnectivity with the rail network infrastructure. This section highlights the South African freight rail operations, involving the planning and coordination of the dynamic or moveable resources of the railway system, such as rolling stock, train planning, and train scheduling (Marinov *et al.*, 2013).

At high-level Railway operations encompass the activities and processes involved in managing and executing the movement of trains, ensuring the safe and efficient transportation of freight. A study by Mhlongo (2021), highlights that South Africa train service interruptions are typically due to infrastructure failures caused by technical faults, theft and vandalism, and the inability to execute planned or scheduled maintenance.

The South African rail freight is controlled and coordinated via Planning & Operations Command Centre, which serves as the nerve centre for pivotal operational and maintenance decisions, wielding control over network access through strategic planning and precise execution oversight (Transnet, 2023). A high level description of the core operational functionality is provided below.

2.4.1. Service Design & Evaluation

The first step in the freight rail planning cycle aims at grasping the customers' requirements, ensuring comprehensive oversight to align the freight rail volumes with available resource capacity (Transnet, 2023). This involves evaluating the customer requirements and designing based on the available operational resources and factoring

in the capacity of the network in order to meet customer expectations (Ferreira, 1997). Service design and evaluation also involves long term planning of operational and infrastructure capacity. The figure below illustrates an overview of the planning cycle and factors considered to develop a train plan.

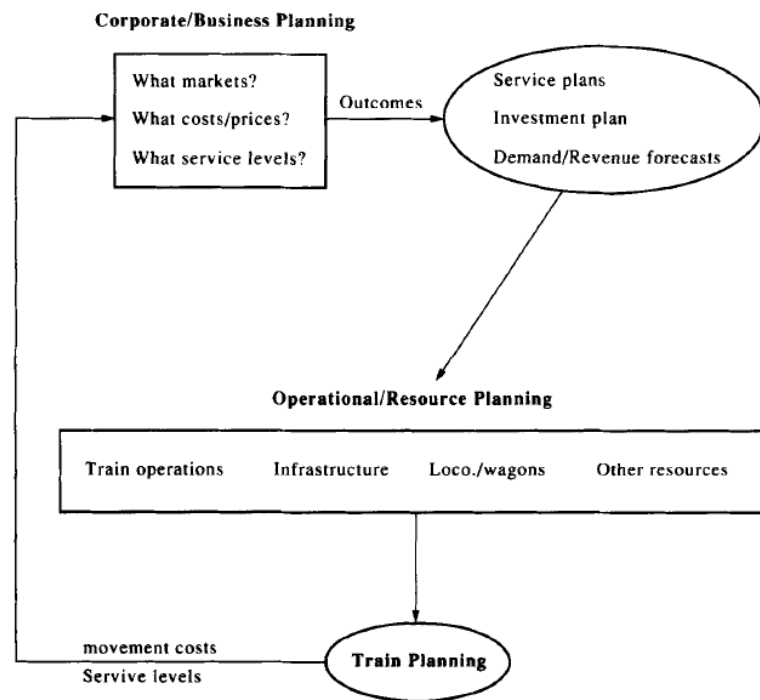


Figure 5: The planning Cycle(Ferreira, 1997)

2.4.2. Interface Management

The core function of interface management revolves around orchestrating seamless interchanges across the rail network infrastructure, strategizing and overseeing external interfaces with entities like PRASA, and overseeing the interdependencies between TFR and other stakeholders, and fostering the uninterrupted operation of the rail network (Transnet, 2023).

2.4.3. Train Scheduling

Train Scheduling involves planning, developing and executing a holistic integrated train schedule through assessing and refining train services through continuous evaluation and optimization (Ferreira, 1997). Train scheduling is a significant responsibility of the Train Control Officer (TCO), as the TCO needs to continually oversee the flow of train

traffic on the Visual Display Unit (VDU) and predict, detect and address any potential train traffic issues or conflicts proactively to ensure minimal disruptions to the train service (Marinov *et al.*, 2013). The diagram below illustrates train rescheduling due to the detection of an issue or conflict with the current train schedule.

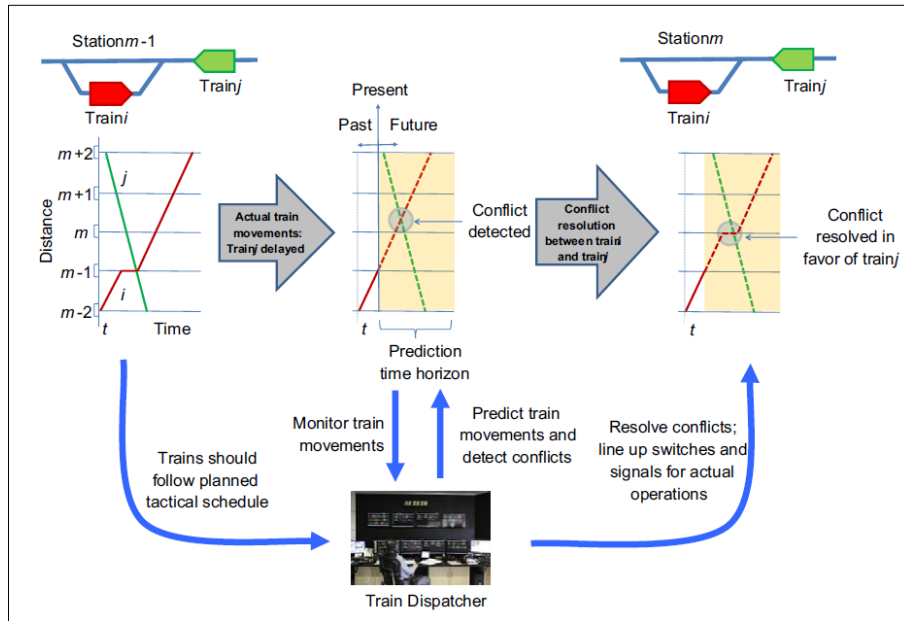


Figure 6: Train rescheduling due to the detection of conflicting operations (Marinov *et al.*, 2013)

Some of the other department responsibilities include converting the customer order into a comprehensive Operations Plan, upholding secure train planning methodologies, strategizing network maintenance planning and occupations, and ensuring compliance to the train plan (Transnet, 2023).

2.5. Rail Network Infrastructure

This section focuses on the intricate array of elements and components that compose the rail networks physical and technological domain, in order to establish a high-level scope of the rail network infrastructure and how railway signalling fits in. A brief overview of the physical or static systems that are vital to facilitate the safe and efficient of train movements will be explored. The static resources establish the inherent capacity of rail infrastructure components, categorizable based on their configurations and technical designs (Marinov *et al.*, 2013). The Commission Of The European Communities (1970), under the regulation 2598/1970, classifies a range of systems, elements and

components under rail infrastructure, these range from engineering structures (bridges, culverts, tunnels, etc.), track (substructure) and track bed (cuttings, culverts, embankments, drainage channels, trenches, etc.), level crossings; track superstructure (rails, fasteners, sleepers, ballast, etc.), railway access and service roads buildings electrical power distribution, telecommunications, safety, and railway signalling. There are many factors that compose the rail network infrastructure, however there are primary systems which are instrumental in actually allowing safe train movement and these are railway signalling, electrical power systems, communication systems, and permanent way (Zhuwaki, 2017; Mhlongo, 2021). Figure 7 below shows the railway infrastructure elements and demonstrates the integration of signalling within the rail network infrastructure. A brief description of the elements of the rail network infrastructure is also provided.

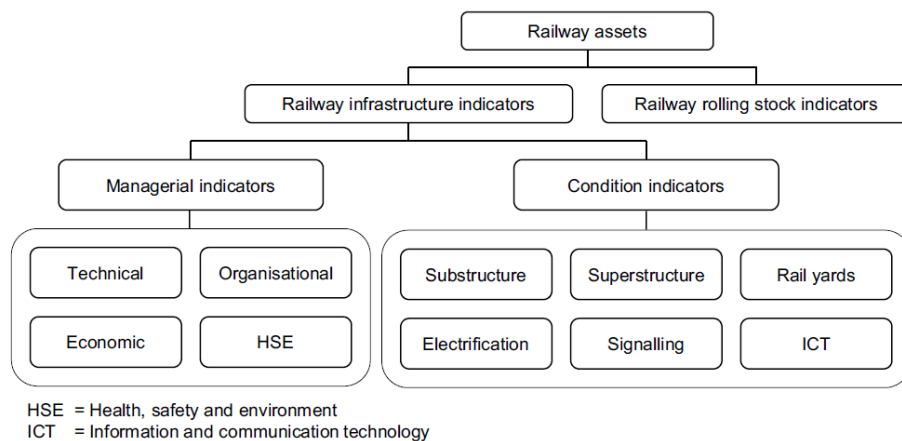


Figure 7: Structure of railway infrastructure (Stenström, Parida and Galar, 2012)

2.5.1. Railway Signalling

Railway Signalling, the focus of this research, is simply the sentinel of train operations. Signalling systems are complex and meticulously designed with high safety standards to ensure the safe and efficient movement of trains along the railway tracks (Estevan, 2015; Zhuwaki, 2017). Signalling is a system of systems, and as previously highlighted in section 1.3., the purpose of signalling is to safely authorize train movement by preventing conflicts, increase the railway capacity, maintain the integrity of rail

operations, and ensure optimal operational efficiency (Krmac and Djordjević, 2017; Mhlongo, 2021). Railway signalling will be discussed in more detail in section 2.6.

2.5.2. Permanent Way

Permanent Way also known as Perway, is an essential part of the rail network infrastructure as it is the actual foundation upon which trains travel on. Perway is a safety critical and heterogeneous system which is made up of components which are critical to rail network infrastructure performance, as any defective component could result in shutdown of the track section, speed restrictions, derailments or other safety incidents (Sedghi *et al.*, 2021). Perway comprises of a (i) superstructure which constitutes of railway tracks, sleepers, block joints, fasteners and rail pads, and (ii) substructure which constitutes of ballast and the sub ballast layers, as well as the formation layers (Zhuwaki, 2017). In terms of the relationship between perway and signalling, the railway tracks serve as a medium for the track vacancy detection systems, block joints which are insulated rail joints are used for isolating track circuits, and the points machine are located in the track turnouts (Pachl, 2020). Therefore, the condition of the perway assets is of importance to both train operations and signalling system performance.

2.5.3. Electrical System

The electrical system is made up of subsystems such as Overhead Traction Equipment (OHE) and substations (Zhuwaki, 2017). OHE, often referred to as catenary systems, consist of overhead wires that provide the electrical power needed to propel trains, the rolling stock's pantograph makes contact with the overhead electrical contact wire on the electrified railway tracks (Ding *et al.*, 2014). The substations are connected to the main power grid and aims to step down the high-voltage electricity from the grid and distribute stable and consistent electrical power to the rail network electrified areas (Zhuwaki, 2017). Electricity is distributed and supplied to the OHE, and the signalling relay rooms or equipment rooms via the electrical transmission lines. This is the interaction or the interface between the electrical power systems and the signalling systems. Due to the critical nature of signalling systems, it is dependent on an uninterrupted and stable supply of electrical power to ensure real-time communication

and safe train control and authorization (Estevan, 2015). The cleanliness of the electrical power supply is also equally important, as it is vital that signalling systems received a clean power input due to the sensitive nature of the electronic signalling components (Estevan, 2015)

2.5.4. Telecommunication

Telecommunication systems also referred to as Information and Communication Technology (ICT) in many studies, play an integral role in interoperability of the railways (Rail Communications, 2023). The purpose of telecommunication systems in the South African freight rail infrastructure is to (i) provide communication infrastructure for the signalling systems, condition monitoring systems, electrical substations, and radio networks, and (ii) establish and maintain a transmission network for voice and data services (Transnet Freight Rail, 2023a). The telecommunication infrastructure network is a vital to the signalling as it relies on real-time communication.

According to Al-Douri et al. (2016), the railway infrastructure covers vast stretches of land, involves numerous stakeholders, and is susceptible to weather fluctuations. Moreover, its intricate nature, characterized by a multitude of technical and physical components, contributes to its inherent complexity and maintenance challenges. Failures and deterioration within systems such as rolling stock, perway, signalling systems and electrical systems carry consequences beyond their own operational performance, these issues extend their impact to interconnected systems, leading to a cascade of effects that compromise both individual and collective system efficiencies (Lidén and Joborn, 2017). The repercussions ripple through interdependent components, thereby not only disrupting the immediate system but also propagating adverse effects across the broader rail network infrastructure.

Numerous studies emphasize the importance of maintenance and the direct correlation between maintenance and system performance. Therefore, maintenance procedures of signalling systems will be covered in detail in section 2.8.3. As the focus of this study is railway signalling, the next section will provide a detailed description of the purpose and components of railway signalling.

2.6. Railway Signalling

Railway Signalling systems, also known as Train Authorization Systems (TAS) in South Africa, is a vital system in the seamless and safe operation of the rail network. The aim of railway signalling is to provide safe and efficient movements of trains, and to increase rail capacity (Mhlongo, 2021). Train authorization systems are mandated to ensure the safe movement of trains (Estevan, 2015). Zhang et al. (2021) adds that signalling systems are critical for the safe operation of trains; it prevents conflicting train movements and ensures that trains maintain a minimum and safe headway on the tracks. According to Krmac and Djordjević (2017), an optimal signalling system should increase capacity of the rail network, improve safety of train operations, ensure effective train movement, improve interoperability, and be energy efficient. Morant et al. (2012) emphasise that signalling systems are critical components of railway traffic management, monitoring, and protection, and further highlights that the performance of signalling systems directly influence the entire performance of the rail system. Ibnazia (2022) further states that in order to achieve the requirements of the signalling system, it is vital that the signalling system is designed with highest safety level being the main requirement. From the research it is evident that railway signalling systems need to be fail-safe as it is a vital component of the railways, as it is directly linked to the operation, availability, efficiency, performance and safety of the rail network.

To achieve the purpose and requirements of the signalling system described above, railway signalling, similar to the rail network, is also system of systems, with each system having its own goal and objective (Estevan, 2015). A system of systems encompasses systems that constitute of independent systems pursuing its own individual objective and goal, yet the individual system is also interdependent to the entire system, that when operating as a whole, delivers a distinctive purpose or function (Baldwin, Sauser and Cloutier, 2015). This characteristic classifies railway signalling as one of the most complex systems in the rail network (Ibnazia, 2022). Therefore, due to the complexity, an individual system or subsystem of signalling should not be considered in isolation when looking at the system performance (Mhlongo, 2021).

2.6.1. Railway Signalling Basic Elements

The South African signalling systems are a decade behind the first world countries, the systems use older or outdated technology, commonly referred to as legacy systems. The main infrastructure components of railway signalling systems are points, signals, track detection systems, interlocking, remote-control systems, and signalling power systems (Ramuhulu and Chiranga, 2018). This subsection provides a brief description of the main components and subsystems which form part of the signalling system.

2.6.1.1. Points:

Point machines are positioned in railway turnouts and allow the train to travel from a particular track to another (Pachl, 2020). Points can be mechanical, electrical, or electro-hydraulic machines which allow for the switching from one track to another (Mhlongo, 2021). The points machine has three main circuits or subsystems which can be classified as the switching, detection and locking system. The points switching is the movement or switching of the points between the straight position and the turnout position, this position is dependent on which route that the Train Control Officer (TCO) operates for train movement. Once the points have switched to the correct position, that position must be detected and then locked in that position (Ibnazia, 2022). As safety is one of the most critical factors of signalling, the operated route will only be allowed if the points are detected and locked in a desired position.

2.6.1.2. Signals:

Signals serves as visual communication to the train driver about the route that lies ahead (Pachl, 2020). Signals can be colour light multi-aspect or single aspect signals (Ramuhulu and Chiranga, 2018), and the aspects displayed on the signals will instruct the driver about how to control the train. The colour aspects red, yellow, or green provides information to the driver about how to drive the train. Figure 8 indicates the meaning of the signal aspects, and figure 9 graphically shows how the train driver needs to adjust the train based on the visual information provided by the signals.

Aspect	Symbol	Meaning
		Proceed and next signal is displaying a proceed aspect and there are no turnouts in the route or overlap ahead
		Proceed and be prepared to stop at next signal unless it displaying a proceed aspect and this aspect also indicates that the driver must expect to deviate from straight route or overlap ahead over a low speed point set
		Danger and the driver must stop in front of the signal
		Indicates the driver Right Routes or Left Routes as per the route indicator

Figure 8: Signal Aspects (Ibnazia, 2022)

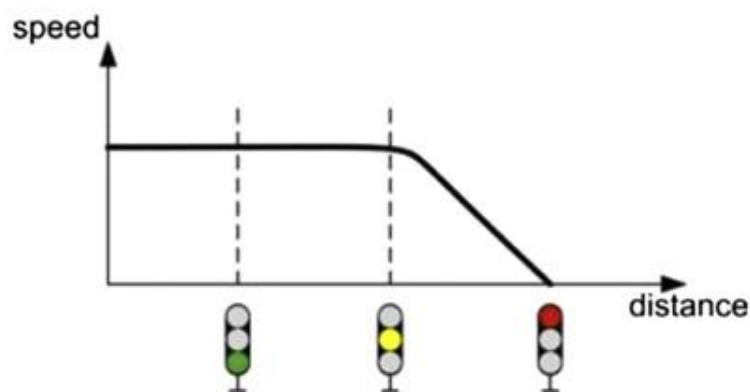


Figure 9: Principle of speed information using signals (Franklin, Nemtanu and Teixeira, 2013)

2.6.1.3. Track Vacancy detection System:

Like the name suggests, this system detects the presence of a train or rail vehicle on the railway track. The objective is to determine if that section of track is vacant before allowing another train access into that section (Pachl, 2020). There are 2 common types of systems used which are axle counters or track circuits (Morant *et al.*, 2012). A track circuit is a portion of track that is isolated from the rest of the track either by an insulated block joint (Ibnazia, 2022), or isolated electrically (jointless). Track Circuits is essentially an electrical circuit which used the rail tracks as a medium for current to flow through between the track's transmitter and receiver unit (Simons, 2019). A train on that track

length causes a disruption to the flow of current, based on the principles of track circuits, any disruption to the flow of current indicates that the track is occupied (Ibnazia, 2022). Figure 10 below illustrates the general principle of track circuits. Axle counters detect the presence of trains on a track section by counting the number of axles of the rolling stock vehicle on the track (Simons, 2019). Axle counter wheel sensors are placed at the start and end of a track section, as a train enters the track section, the sensor starts to count the number of axles entering and the sensor at the end counts the number of axles exiting the section, the completeness of the train or the vacancy of the track is determined by evaluating the axle counter sensors (Mhlongo, 2021; Ibnazia, 2022).

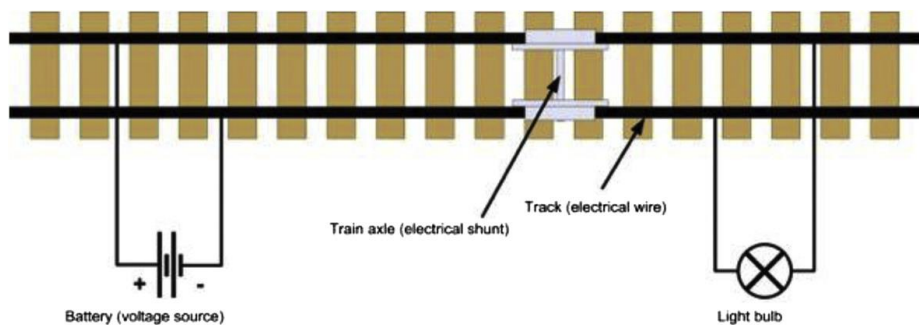


Figure 10: General Principle of Track Circuits (Franklin, Nemtanu and Teixeira, 2013)

2.6.1.4. Interlocking System:

The Interlocking system is the brain of the signalling systems (Mhlongo, 2021). The interlocking ensures that all the relevant signalling elements for a specific train route are interlocked or connected and locked in a specific state to prevent conflicting train movements and ensure the safe passage of trains (Ibnazia, 2022). The interlocking system is the interface between the remote-control system and the track side equipment, namely the points, signals, and track vacancy detection elements (Mukwena, 2018). The types of interlocking systems have evolved over the decades, the four main developments of interlocking system revolve around mechanical, relay, hybrid (relay and electronic), and computer-based or electronic interlocking systems (Huang, 2020; Ibnazia, 2022). In South Africa, different areas of the country use different types of interlocking systems. Different types of the relay-based interlocking systems are installed at majority of the signalled stations, this technology is outdated, which is approximately 40-50 years old, and almost obsolete, whilst the other areas in the country use a hybrid type of interlocking or electronic interlocking, which is

approximately 10-20 years old. The relay interlocking systems are old and the outdated technology contributes to high failure rates. Many first world countries make use of advanced railway signalling and interlocking systems such as European Rail Traffic Management System or Automatic train control system, which are all-digital computer and GPS-based systems used to identify the exact location of the train and the interlocking processor calculates the authorization procedures for the trains in route (Estevan, 2015; Huang, 2020). These systems eliminate the need for extensive copper cabling and trackside equipment which reduces the vulnerability of the system to theft and vandalism.

Figure 11 illustrates a simple example of two train routes whereby the trackside signals and its associated tracks being interlocked to prevent conflicting train movements.

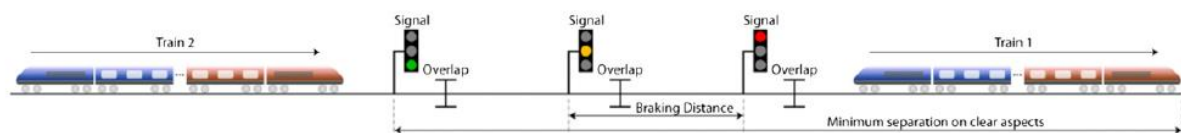


Figure 11: Signal Interlocking (Marinov et al., 2013)

2.6.1.5. Remote-Control System:

Remote-control systems enable a Train Control Officer (TCO) from a Centralized Traffic Control (CTC) headquarters to control the signalling elements at the field stations (Ibnazia, 2022). Through the remote-control system, the TCO is able to monitor the status of the field signalling equipment and based on their train plan and schedule information they are able to authorize trains into the desired routes (Mhlongo, 2021).

2.7. Railway Signalling Performance

According to the Department of Environmental Affairs (2023), with the railway transportation being more cost effective and environmentally friendly, coupled with the highly congested and deteriorating road network infrastructure in South Africa, there are Government proposals and plans to implement the shift of freight from road to rail.

For the railway transportation system to cater for the increase of rail traffic density, the increase in capacity and to its existing customers, there is a need to improve the performance of the railways, especially the performance of the railway signalling systems. Stenström, Parida and Galar (2012), highlighted the significance of establishing proficient and streamlined train operation and maintenance procedures to support the increase in capacity stemming from the transition from road to rail, moreover, emphasizing the necessity for systematic measurement and monitoring of these endeavours.

Railway Signalling systems are complex as it is also a system of systems, but the complexity further broadens as it needs to inter-operate with to the rest of the railway infrastructure, the interrelations and an unclear system overview makes performance evaluation of signalling systems difficult (Morant *et al.*, 2016). As the railways are continuously evolving, there is a necessity to monitor and measure the repercussions of disruptions on the network and to track the evolution of system performance (Bešinović, 2020). Signalling performance cannot be based only on the technical performance of the individual components and subsystems, as the objective of railway signalling is to ensure the safe movement of trains, therefore performance must be looked at holistically (Morant *et al.*, 2016). Signalling Performance affects the entire performance of the rail network (Morant *et al.*, 2016). According to Krmac and Djordjević (2017), developing Key Performance Themes (KPT) which act as indicators used to report on the status of aspects regarded as crucial to a system's success need to be sustainable and relevant to the business, the system environment, and to the stakeholders. It is important that the railway organization and each infrastructure discipline has effective and relevant performance indicators that assist Infrastructure Managers (IM) to make effective decisions regarding the status of their infrastructure asset, and these should be benchmarked to industry standards (Stenström, Parida and Galar, 2012). Ensuring economical measurements and monitoring of technical assets is vital to improve the performance of signalling systems, and for the organization to calculate their return on investment (Stenström, Parida and Galar, 2012). Traditional methods to evaluate railway signalling performance would be to use Key Performance Indicators (KPI) such as Estimate Time to Repair (ETR), or failure occurrence frequency, but these metrics

have low value to the customers who are more concerned with the final performance in terms of railway reliability and availability (Jidayi, 2015). Stenström et al. (2015) outlines that it is common to equate the performance rate based on the delay of train service due to the equipment or technology down time. Jidayi (2015), Stenström, Parida and Galar (2012), Morant (2014), and many other papers, emphasized the importance of maintenance in their study and further elaborated the importance of using a KPI for maintenance as a factor contributing to signalling performance. George, Mokoena and Rust (2018) also added that when monitoring performance and looking at options to improve performance, it is also imperative to look at the safety and reliability that a system has on train operations.

Bešinović (2020) elaborates on the difficulty of quantitatively interpreting the impact of an infrastructure failure (singular or multiple) on the entire rail network performance. It is also difficult to precisely quantify the impact of a singular incident due to the interconnectedness of the rail network. This problem brings about the need for the evolution of performance indicators and the break away from the traditional methods of measuring performance, and also emphasizes the need for resilient railway system performance (Bešinović, 2020).

Morant et al. (2013) sums up the above mentioned aspects by expressing that Reliability, Availability, Maintainability, and Safety (RAMS) is a vital part of railway signalling performance because it helps to guarantee that the signalling system is designed, implemented, tested, commissioned, and operating safely and reliably.

2.8. Railway Reliability, Availability, Maintainability & Safety (RAMS)

RAMS is an essential aspect in Railway Signalling Performance, and it will be useful to evaluate the risks posed to signalling performance in terms of RAMS of the railway. The RAMS of signalling systems has a ripple effect on the safety and availability of the entire rail network and organizational performance (Morant *et al.*, 2013). According to Jidayi (2015), RAMS is also an effective technique for decision making as it defines a level of certainty in terms of operational performance of a system.

2.8.1. Reliability

Reliability is the likelihood of the signalling system to execute an expected function over a specific timeframe under certain conditions (EN50126-1 *Railway Applications - The Specification and Demonstration of Reliability, Availability Maintainability and Safety (RAMS)*, 2017). The safety of the railway personnel, train operators, train drivers and train crew depend on the ability of the signalling system to perform correctly as per the requirements of the system. To understand the concept of reliability and its role in signalling performance, the bathtub curve is shown in figure 12. The bathtub curve is a visual representation commonly used in reliability engineering which illustrates the failure rates of a system or asset over its lifecycle (Jidayi, 2015; Mhlongo, 2021). This is useful conceptual tool to IMs and engineers as this assist with effective maintenance planning or strategies for system upgrade or component replacement (Makhuvele, 2016). The curve demonstrates three phases of a system lifecycle (Jidayi, 2015; Makhuvele, 2016; Mhlongo, 2021):

- (i) Infant Mortality: the system is expected to have a high failure rate at the beginning of its lifecycle due to various reasons such as manufacturing, installation, equipment, or even design issues or defects, etc.
- (ii) Normal Period: Failure rate of a system is more stable or constant in this phase as most of the start-up issues or teething problems have been dealt with. It can be said that the system is performing as per expectation, random issues are expected, however a normal routine can be established to maintain the system.
- (iii) Wear-out: at this phase of the system lifecycle, high failure rates should be expected nearing the end of the system lifecycle, and the IMs should plan accordingly.

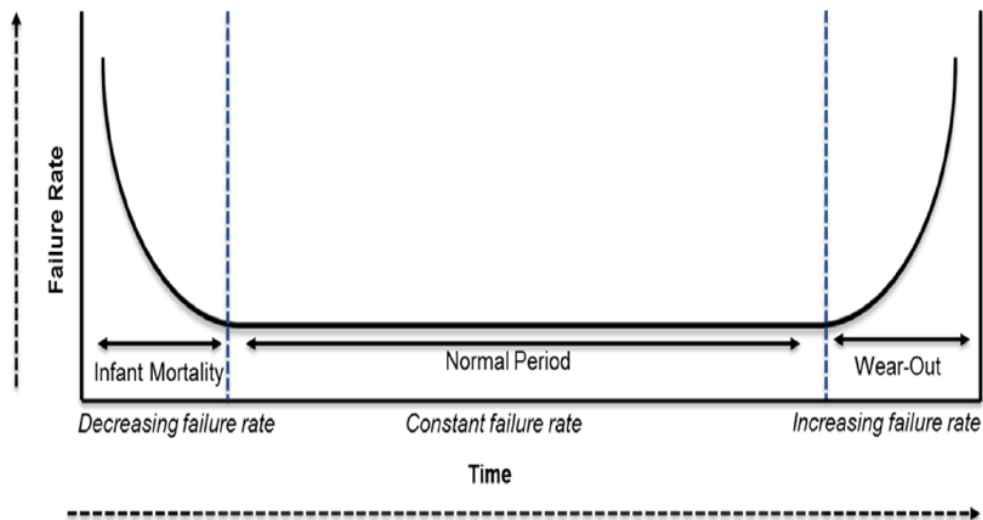


Figure 12: Reliability Bathtub Curve(Makhuvele, 2016; Mhlongo, 2021)

2.8.2. Availability

Availability is the “ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided”(EN50126-1 *Railway Applications - The Specification and Demonstration of Reliability, Availability Maintainability and Safety (RAMS)*, 2017). This is the percentage or the amount of time that the signalling system is available for operational use. The three concepts Reliability, Availability and Maintainability are interconnected and directly impact each other. Figure 13 below shows the relationship between the three concepts.

Reliability	Maintainability	Availability
Constant	Decreases	Decreases
Constant	Increases	Increases
Increases	Constant	Increases
Decreases	Constant	Decreases

Figure 13: Relationship between System Reliability, Maintainability & Availability (Jidayi, 2015)

2.8.3. Maintainability

Maintainability is the likelihood that signalling systems can undergo maintenance activities using the appropriate resources at a specific timeframe or frequency (EN50126-1 *Railway Applications - The Specification and Demonstration of Reliability, Availability Maintainability and Safety (RAMS)*, 2017).

Maintenance activities is commonly described as encompassing all essential activities required to guarantee the proper functioning of a system, and these activities and their frequencies are generally determined by the supplier or manufacturer of the system or asset (Jidayi, 2015; M. Pour and Rasmussen, 2017). Apart from the manufacturer's recommendations, there are other railway factors that need be considered when developing maintenance strategies and these are the density of traffic, the types of rolling stock vehicles and the loading of the wagons, environmental conditions, climate changes, theft, and vandalism, etc. (Jidayi, 2015). A well-maintained system decreases the chances of system failures, ensures the seamless operation of signalling systems, and thus ensures a constant or well performing system. Maintenance strategies for signalling systems can be classified as Routine Preventative Maintenance (RPM), Predictive Maintenance (PM) and Corrective Maintenance (Jidayi, 2015). Figure 14 below illustrates a schema of the commonly used maintenance strategies for railway signalling systems, a brief overview of the strategies is also discussed below.

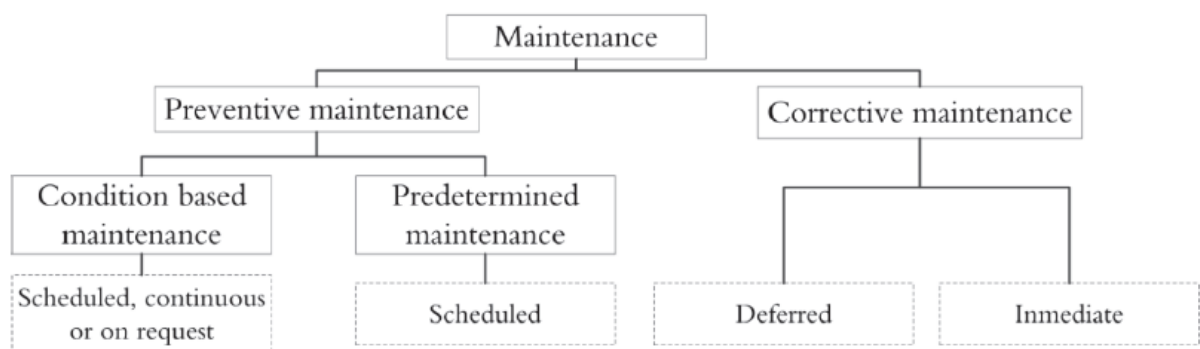


Figure 14: Maintenance Strategies (Morant, 2014)

- (i) Routine Preventative Maintenance (RPM): like the name suggests, this is maintenance done at predetermined frequencies or intervals. Jidayi (2015) adds that RPM can also be based on the condition of the asset. The aim of

RPM is to proactively avert the onset of failures or diminish the likelihood of their occurrence (Morant, 2014).

- (ii) **Corrective Maintenance:** like the name suggests, this type of maintenance is executed to correct or fix a problem. Corrective maintenance is carrying out the necessary actions due to the identification of a fault or failure in the system, depending on the severity or the impact of the incident, the corrective maintenance can be immediately upon occurrence or at a later stage (Jidayi, 2015). The aim of corrective maintenance is to restore the product to a condition whereby it can effectively fulfil its intended function (Morant, 2014).
- (iii) **Predictive Maintenance (PM):** involves the continuous monitoring of a system's characteristics, conditions, and behaviour over a period of time. This data can be collected and analysed to formulate a maintenance approach that anticipates or predicts potential failures or incidents. This contributes to the enhancement of the preventative maintenance strategy, ensuring proactive measures are taken to mitigate the impact of impending issues (Makhuvele, 2016).

2.8.4. Safety

Safety is the most crucial element for railway signalling systems. For system to be safe it implies that it cannot cause harm, injuries or fatalities to human life, and for the system throughout its lifecycle to prevent damage or destruction to the infrastructure, assets, and the environment (Jidayi, 2015).

An essential aspect of this study is identifying characteristics that have a negative effect on the reliability, availability, maintainability, and safety of signalling systems, as well as their performance.

2.9. Factors Affecting Signalling Performance in Railways

According to Umiliacchi et al. (2019) significant emerging properties can be discovered when a system is explored beyond its individual parts and looked from a whole system

perspective. A whole system approach considers the system's operational environment, system elements, and the interactions and relationships of the elements with one another and with the entire system (Umiliacchi *et al.*, 2019). By understanding the factors that affect signalling performance it is a step closer to improving the system and making changes that can yield a sustainable and resilient system (Krmac and Djordjević, 2017). In order to identify factors that affect railway signalling performance, and to look at the factors beyond that of technical failures, a whole system approach will be adopted.

There are not many studies looking into the factors specifically affecting signalling performance, therefore studies related to signalling reliability challenges were also considered as reliability is one of the performance factors, and also due to the holistic approach factors affecting rail infrastructure performance which were relevant to signalling was also explored. The investigation into the factors that affect railway signalling performance creates awareness of the underlying problems which aids decision making and strategies to improve the condition of the railways.

The evolution of railway signalling was directly linked to the evolution of the railways (Estevan, 2015). According to Havenga, Simpson and De Bod (2014), the South African Railways and Harbours administration (SAR&H) has invested in rail infrastructure development only during the first twenty years of ownership, without considering future planning, expansion and rail sustainability. Hutchings (2017) added that the lack of investment in rail infrastructure by SAR&H has led to a generation gap in the development and advancement of South African railways. The investment in freight rail infrastructure declined in the mid-1980s (Havenga, 2012), and picked up again in the year 2012, when Transnet announced its seven year investment of ZAR 336 billion in their Market Demand Strategy (MDS), which was an initiative to expand the Transnet's port, pipelines and rail infrastructure (Prins, 2015). During this period of curtailed investment in the railway infrastructure, investment in road infrastructure was subsequently prioritized, and this has resulted in the South African freight rail network's signalling infrastructure and technology being decades behind many first world countries.

Oumarou (2015) looked at the rail infrastructure in Africa and highlighted that the current condition of the rail infrastructure in many African countries is poor, although South African railways are in a better condition the infrastructure is deteriorating and this is largely due to the lack of investment and poor organizational management. Owusu-Manu et al. (2021) looked at assessing the behavioural factors affecting rail infrastructure investments for Ghana. This study also elaborated about poor organizational management and further emphasized that it directly impacts the system performance which is unattractive to potential investors. Studies by Rangarajan et al., (2013) and Ghaleb and Abdulla (2021) investigated the cause of poor organizational performance and unsuccessful construction projects and emphasized that poor stakeholder engagement and ineffective stakeholder communication increase the complexity of the system and decrease success of system performance, and thus these human behavioural factors are important in system performance.

Signalling system performance is constrained by its interconnections to the rail network, such as power systems, communication networks, as well as the organization it resides in, the interoperability challenge is another factor affecting signalling performance (Oumarou, 2015). Lidén and Joborn (2017) also highlight the importance of all railway systems being interoperable as a disruption in one system will impact another system and consequently impact the performance of the entire network. Lidén and Joborn (2017) further emphasized that effective and frequent maintenance is crucial due to the dependencies of the system and for the dependability of the system, the research paper also highlighted the problems experienced with maintenance and that is firstly maintenance can be costly and organizations budgets are usually limited, and secondly maintenance planning is difficult to coordinate as many organizations tend to prioritise train traffic over the scheduling of maintenance.

Luiz (2010) investigated the challenges experienced by India's rail infrastructure and has related it to Africa and has outlined some of the key factors affecting performance is poor management, low capacity or poor retention of technical skills, and underutilization of technical workers, engineers and managers.

Mhlongo (2021) looked at challenges affecting the reliability of signalling performance and has reiterated the factors mentioned above and has added to the list with factors such as design flaws due to cost constraints; high technical failures due to ageing/fatigued infrastructure, obsolete technology, poor maintenance strategies and policies, and manufacturing defects; organizational factors such as rigidity in the organizational structure, policies, quality and investment strategies; operational factors such as inadequate training, skills shortage, human error, etc.; environmental factors such as bad weather, vegetation, etc.; and external factors such as power outages, theft, vandalism, looting, etc.

Estevan (2015) conducted a study of the Swedish Railway which investigated the causes of signalling failures which led to corrective maintenance or emergency work being required. The study revealed that these factors were signalling design flaws; ageing infrastructure, mechanical failures due to overused, fatigued or overstressed signalling equipment; inadequate maintenance; failures in electrical departments power systems causing power outages to the signalling network; environmental issues such as high temperatures, snow, wind, flooding, vegetation, etc.; and external factors such as issues with the rolling stock, safety related incidents caused by other railway stakeholders and departments, third party interferences, etc. (Estevan, 2015).

Finally, Bouraima et al. (2023) looked at the challenges affecting railways and projects in Africa and the theory is relevant to signalling performance. The study revealed the two major problems being technical failures and poor organizational and project management. Another factor raised by Bouraima et al. (2023) which differs from that of the other papers was that many organizations conduct inadequate risk evaluation, risk assessments, feasibility studies, and cost-benefit analysis for new projects and new technology, coupled with poor management leads to a major downfall in the infrastructure and the organization. According to the Railway Safety Management Standard (2008) the appropriate risk management is crucial to provide the required safety standards of railways as the process allows for the identification of technical, operational, social, and environmental risks, the assessment of these risks, the ability to identify and implement control measures, and to monitor the control measures. Other

factors that Bouraima et al. (2023) had outlined were organizational corruption, poor stakeholder integration, environmental factors, power outages, and poor knowledge sharing.

2.10. Conceptual Framework

The purpose of this section is to identify concepts from the critical literature review and integrate these concepts to develop a conceptual framework which would serve as a roadmap or structure for this study’s research question and objectives. Figure 15 illustrates a visual representation of the conceptual framework for this research.

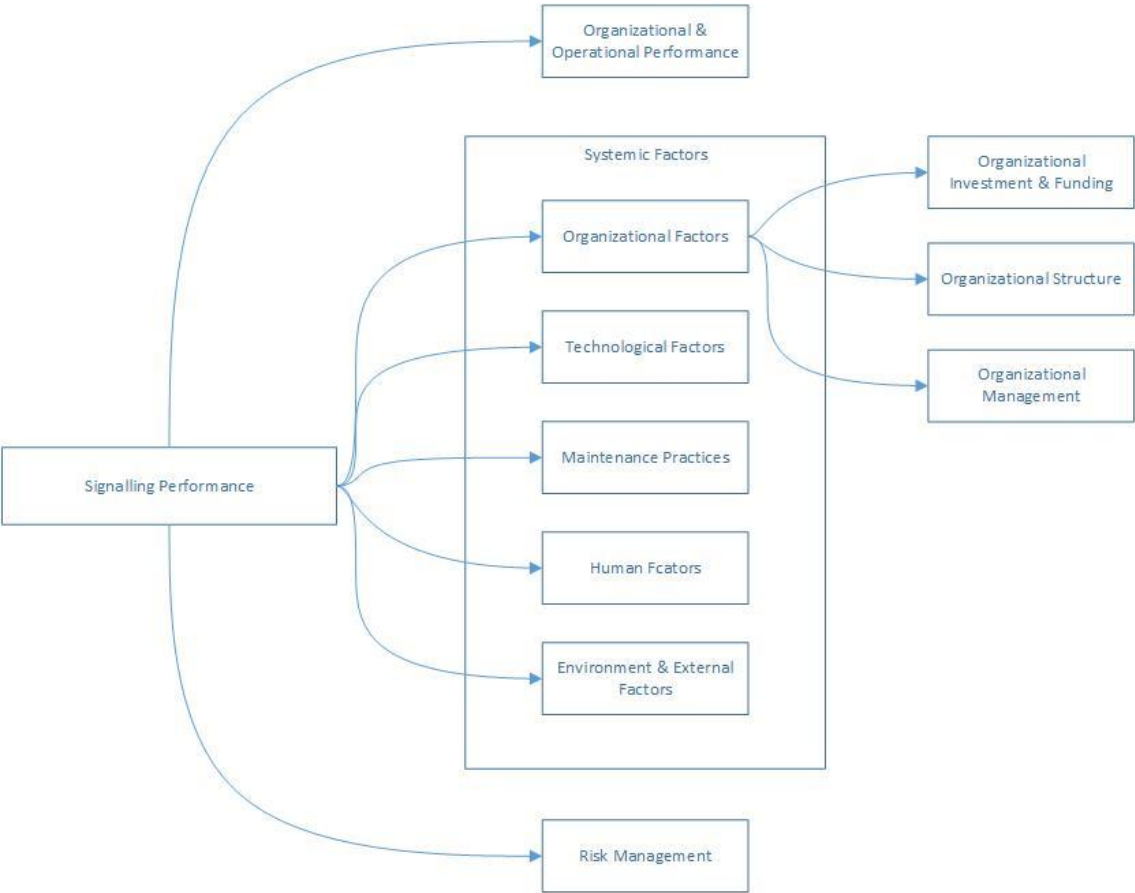


Figure 15: Conceptual Framework for Investigating the impact of Railway Signalling Performance on Railway Operations & Performance in South Africa

2.10.1. Signalling Performance

Signalling Performance is a fundamental concept to train operations as the system ensures efficient, safe and reliable train movements, and it is a vital concept to this research which aims to answer the critical research question:

“What are the critical factors contributing to poor signalling performance which is impacting railway operations and organizational performance in South Africa?” (p 6)

Performance measures are used as tools to support the need for improvement, upgrades and investments for signalling systems, other disciplines, and elements of the railway system (Jidayi, 2015). Using only the technical data of a systems performance does not accurately validate the signalling performance as it has financial, operational and safety implications on the entire railway system (Stenström, Parida and Galar, 2012; Jidayi, 2015). Signalling performance, in the context of this research, evaluates the signalling systems infrastructure’s ability to ensure safe train movements, transmit accurate information among its subsystems, and be resilient to operational conditions. RAMS is a popular technique in many railway organizations, especially in European countries, to evaluate performance and assist IMs in decision making (Morant, 2014; Jidayi, 2015). RAMS coupled to other operational performance indicators such as train cancellations, train minute delays, train on time arrivals or punctuality, train capacity, the frequency of a failure or the time to repair a failure, are effective indicators to assist IMs in decision making in order to develop and upgrade the signalling infrastructure (Stenström, Parida and Galar, 2012).

Railway signalling systems cover a large area of the land and by simply monitoring, measuring and collecting data, this could generate an abundance of raw data, however this could be an insignificant paper exercise if the data is not analysed, validated and processed into valuable information which can be used by the relevant stakeholders to make informed decisions to improve performance (Stenström, Parida and Galar, 2012; Stenström *et al.*, 2015). The figure 16 below shows the input and output factors which are used for many of the rail network infrastructure system performance, as well as for signalling performance. The factors relating to the technical aspect and the design of the system such as reliability and the system maintenance are input factors and this have a

direct influence on some of the operational output factors such as train delays, network availability, train cancellations, etc. (Stenström *et al.*, 2015).

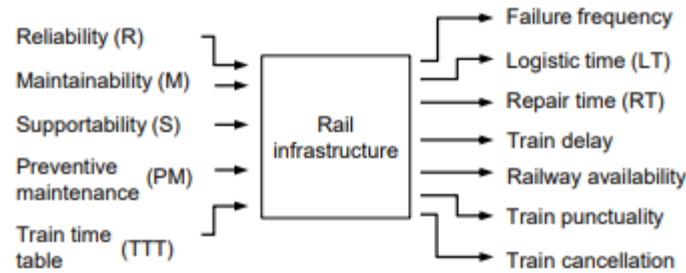


Figure 16: Inputs and Outputs of rail infrastructure performance (Stenström *et al.*, 2015)

2.10.2. Systemic Factors

In section 2.2 in the literature review, the railway system and the signalling systems were classified as a “system of systems”. Railway signalling system has different technologies, stakeholders, departments, systems, processes, people, environments, etc. interacting and connecting to perform the goal and objective of a system (Clayton *et al.*, 2009). Thus, the factors affecting signalling performance are beyond the technical and infrastructure challenges, and a holistic approach will be used to achieve the first objective of the research, which is to:

“Identify the key systemic factors contributing to poor signalling performance.” (p 6)

Through the development of the literature and identifying factors affecting signalling performance in section 2.9, the studies showed that the concept of systemic factors can be grouped or classified into organizational factors, technological factors, maintenance practices, operational factors, human factors, environmental and external factors (Oumarou, 2015; Umiliacchi *et al.*, 2019; Mhlongo, 2021; Bouraima *et al.*, 2023). These concepts will be explored to identify the systemic factors and its impact on railway signalling performance.

2.10.3. Organizational Factors

The concept of organizational factors ties into the concept of looking into the factors affecting signalling performance from a holistic standpoint. The organizational factors deal with the organizations ability to navigate the challenges hindering signalling system performance. This section looks into concepts such as organizational investments and funding, organizational structure, and the impact of poor signalling performance on the organizational and operational performance.

2.10.3.1. Organizational Investments and Funding

The South African freight railway transportation system is owned by the Government and relies heavily on Government funding and investment. The freight rail network has suffered due to decades of underinvestment in the rail infrastructure. With road infrastructure investment being prioritized over railway infrastructure investment, the underlying failure to understand and adapt to a shift from road to rail will cause the rail network infrastructure to constantly experience challenges (Havenga, 2012; Havenga, Simpson and De Bod, 2014).

George, Mokoena and Rust (2018) investigated the condition of the South African rail infrastructure and emphasized that the underinvestment in rail resulted in obsolete rail infrastructure and technology, ineffective methods and strategies to predict failures and optimize operational performance, high maintenance costs, and a network vulnerable to theft and vandalism. The underinvestment directly impacts the railway and signalling performance which in turn impacts the operational and organizational performance.

2.10.3.2. Organizational Structure

TFR is a division of Transnet, with Transnet SOC Ltd reporting to the Government's Department of Public Enterprises (Department of Public Enterprises, 2023). As discussed in section 2.3, the organizational structure of TFR follows a vertical separation organizational structure. This type of structure has advantages such as autonomous control and has proved to be a profitable structure for many countries (Ferreira, 1997). Oumarou (2015), identified that this organizational structure is disadvantageous for underperforming and monopolized entities, and this is the case of the South African

freight rail organization. Owusu-Manu et al. (2021) identified poor organizational structure as a factor impacting system performance.

2.10.3.3. Organizational Management

Poor organizational management is a concept identified by many studies as a factor contributing to poor rail infrastructure and organizational performance (Luiz, 2010; Oumarou, 2015; Mhlongo, 2021; Bouraima *et al.*, 2023). The poor management of people, resources, projects, processes and procedures contribute to poor system performance.

2.10.4. Organizational and Operational Performance

The concept of poor organizational performance links to a study by Clayton et al., 2009, which investigates using the “whole-system paradigm” to improve or evolve the state of the United Kingdom’s railways. This is one of the factors which add to the complexity of signalling systems, as the system is interdependent to the whole system that it integrates into, and technical factors are not the only challenges hindering optimal performance of the organization.

Signalling system performance has a direct impact on operational performance which in turn directly impacts the organizational performance. Signalling incidents and poor system performance hinders operational performance, resulting in potential train delays affecting transit times, train schedule disruptions causing train cancellations which affect service reliability, safety incidents, manual train authorizations leading to unsafe train operations and safety incidents due to human error, etc. (Ferreira, 1997; Mhlongo, 2021). The poor signalling performance impacts trains efficiency and reliability which results in poor customer satisfaction, causing customers to look for alternative transportation options, which impacts the financial revenue, reputation, and the overall performance of the organization.

2.10.5. Technological Factors

This concept deals with technical and technology failures of the signalling system. The signalling infrastructure is ageing and deteriorating, most of the equipment and technology installed are obsolete or nearing the end of its lifecycle, and inadequate

maintenance is resulting in a high number of technical failures in the signalling system (George, Mokoena and Rust, 2018; Ramuhulu and Chiranga, 2018; Mhlongo, 2021). The high theft and vandalism experienced in South Africa also increases the technical and technology failures (George, Mokoena and Rust, 2018). Technical failures result in the system being unavailable and unreliable and decreases the safe operation of train movement, which negatively impacts the performance of the system.

2.10.6. Signalling Maintenance Practices

Signalling Maintenance is an important concept and factor in railway signalling systems as it ensures that the assets and infrastructure are properly serviced or maintained to ensure proper operation and functionality. Maintenance activities involves the coordination of administrative, technical and operational activities to ensure effective maintenance is executed to meet the customers demand (Morant, 2014).

Signalling systems, similar to the rail network infrastructure, covers a large area of land and are made up of many elements with various lifespans and lifecycles, which makes managing and maintaining the entire signalling system a difficult task (Morant *et al.*, 2012). Maintaining the signalling infrastructure is expensive, particularly due to the ageing and degrading components. This allocation consumes the majority of the signalling budget (Lidén and Joborn, 2017). With cost constraints and investment issues experienced by the freight rail organization, adequate and efficient maintenance activities are decreasing. To add to the complexity, the coordination required between train operations and scheduling maintenance activities is often challenging as it is commonly treated as separate planning entities in many railway organizations (Lidén and Joborn, 2017).

According to Wu (2020), effective RPM practices has many benefits to the system performance such as preventing or decreasing the frequency of corrective maintenance, decreasing the ETR in the event of a failure which in turn also reduces the associated overtime costs, increasing the asset or system lifecycle, and increases the safety and reliability of the network. However, with inadequate maintenance activities being performed and the asset nearing the end of its lifecycle, these benefits aren't fully reaped by the signalling system.

2.10.7. Human Factors

The concept of human factors is identified through applying a holistic approach to investigating factors contributing to poor signalling performance. A study by Clayton et al. (2009) identified that poor communication and collaboration between stakeholders plays a significant role in the poor performance of systems or projects. Inadequate training and continuous development, human error, failure to retain the relevant technical skills and qualified personnel within the organization or the country, and ineffective knowledge sharing are all human factors which add risk to the performance of the signalling system and the overall performance of the organization.

2.10.8. Environmental and External Factors

The environmental and external factors also play a role in the performance of the rail infrastructure system. Climatic factors such as heavy rain, flooding, and extreme temperatures can cause signalling equipment failures (Mhlongo, 2021; Bouraima *et al.*, 2023).

External factors such as disruptions from other engineering disciplines such as electrical or telecommunications can cause disruptions to the signalling system. As discussed in section 2.1 TFR also shares a portion of its rail network with PRASA, with TFR and PRASA sharing the responsibility of maintenance, cost of repair and upgrade in those areas. This interface between TFR and PRASA causes challenges as the PRASA areas are subjected to high theft and vandalism which affects the operations of the signalling systems.

2.10.9. Risk Management

The concept of risk management was identified as a vital factor to ensure safety standards for the railways (Railway Safety Management Standard, 2008). The concept of Risk underpins the second research objective of this study, which is to:

“Assess the risk factors of poor signalling performance and evaluate the impact on railway operations and safety, and organizational performance.” (p 7)

Poor signalling performance poses risks such a safety, operational, financial, environmental, etc. This study will identify the factors contributing to poor signalling

performance and assess those risks on railway operations, safety, and organizational performance. The inadequate assessment of risks and the failure to implement mitigation measures is a downfall of system performance in the railways(Bouraima *et al.*, 2023).

CHAPTER 3

3. RESEARCH METHODS

3.1. Research Design

This chapter highlights the research design and methodology that was adopted for this study to answer the research question and objectives. According to Mehrad and Zangeneh (2019), with the proliferation of scientific and social science research inquiry, there is significant emphasis for researchers to adopt the appropriate research methodology or approaches in their scientific research, with substantial prominence on two types of research design methodologies being quantitative and qualitative. Creswell (2009), elaborated that research can be conducted using three design methodologies, namely quantitative, qualitative, and mixed methods, which is a combination of quantitative and qualitative methodologies. A study by Howe and Eisenhart (1990) elaborates that the debates for the implementation of quantitative or qualitative research design has been around for many decades and emphasizes the importance of following the standards and logical best practices framework when selecting the appropriate research methodology.

Quantitative research focuses on numerical or measurable information, and is experimental in nature (Creswell, 2009; Golafshani, 2003). Quantitative research design concentrates on investigating the relationship or interconnections between an independent or predictor variable and its dependent outcome and requires a large sample population size to accurately evaluate and represent the relationship being researched (Cresswell, 2007; Mehrad and Zangeneh, 2019).

While in contrast, Qualitative research is exploratory and focuses on understanding the complexity of a problem or situation within its natural environment (Creswell, 2009; Golafshani, 2003). Qualitative research involves understanding and interpreting the phenomena from those who have experienced it or have a deep knowledge about the problem or situation (McMillan, 2009). Qualitative research is also adopted for real world phenomena which are difficult to quantify (Mehrad and Zangeneh, 2019).

Qualitative research focuses on understanding the human standpoint, experience, beliefs and opinions (Hammarberg, Kirkman and de Lacey, 2016). Therefore, qualitative research design has been adopted for this study.

The objective of this research is to identify the key systemic factors contributing to poor signalling performance, assess of risk factors of poor signalling performance, and to recommend ways to improve railway signalling performance which will thus improve railway operations, safety, and organizational performance. The selection of a qualitative research strategy of inquiry involves the consideration of the research question, the research objectives and the nature of phenomenon being investigated (Creswell, 2009). (Creswell, 2009) presented five qualitative strategies of inquiry for qualitative research which are narrative research, phenomenological, ethnographic, grounded theory, and case study. The phenomenological method enables the researcher to investigate the participates lived experiences and in-depth insight of a phenomenon (Creswell, 2009). Therefore, the phenomenological method or approach is most appropriate and was therefore adopted for this qualitative research design.

3.2. Instrumentation

For qualitative research there are many types of instrumentation that can be used to collect information such as observation, surveys, documentation analysis, interviews, focus groups, etc. (Creswell, 2009). As mentioned above, the phenomenological study method will be used. As the phenomenological method aims to study human experiences, views and perceptions of a phenomena, interviews have proven a valuable instrument to obtain the necessary data from participants (Leedy and Ormrod, 2016). An interview entails the researcher (the interviewer) asking the participant (the interviewee) questions to acquire data on the experiences and opinions of the participants regarding a particular phenomenon (Whiting, 2008). Interviews can be structured, semi-structured, or unstructured (Whiting, 2008). Unstructured interviews or small group workshops are aimed at discussing and exploring the participants attitude, beliefs and norms, semi-structured interviews elicit opinions, experiences and

explore perspectives from subject matter experts on a specific topic, and structured interviews in-depth personal perspectives following a set or rigid process (Hammarberg, Kirkman and de Lacey, 2016). Semi-structured interviews ensure a degree of standardization whereby all participants are asked the same pre-determined questions and subsequent questions can be prompted based on the responses of the participants (Dearnley, 2005). This loose structure facilitates flexibility and adaptability that allows for elicitation of in-depth and rich data (de Trigueros and Sandoval, 2017). Therefore, semi-structured interviews were used to collect data as it allows for the identification of key systemic factors contributing to poor signalling performance, the assessment of risk factors, and the development of recommendations for improving railway operations and organizational performance.

3.3. Sampling

In this study, the chosen sampling approach is purposive sampling. Purposive sampling is a non-probability sampling technique whereby participants are selected according to characteristics or criteria linked to the research objectives (Tongco, 2007; Rai and Thapa, 2015). In this case, the criteria for selecting participants are those who have the relevant expertise, knowledge, and experience, and they can communicate their knowledge and experience related to the studies research question and research objectives (Tongco, 2007).

Purposive sampling involves the researcher's discernment in selecting a research population that can offer rich, substantial, and valuable data for the study (Rai and Thapa, 2015). Purposive sampling allows for careful selection of participants, and the experts selected for this study were signalling managers, signalling engineers, signalling specialists, operations managers, and technical/rail network managers with a signalling background, that can provide rich, meaningful, and data. The criteria for these participants is to firstly hold a managerial position and secondly have more than five years of experience in railway signalling and/or railway operations. Participants were also available and willing to take part in this study.

The sample size for this research is limited as there is a relatively small population of individuals with the relevant signalling experience and expertise. However as mentioned, this study follows the phenomenological study method, and Creswell (2009) highlighted that the phenomenological method involves obtaining data from a small number of participants through lengthy and meaningful engagement. This is reiterated by Leedy and Ormrod (2016) who state that phenomenological study requires a small group of carefully selected experienced individuals, typically 5-25 individuals, who can provide rich data through intense and long interviews. A smaller sample size is not necessarily a limitation as it is often used in qualitative research studies as the focus is eliciting in-depth insight about a specific problem or situation (Dworkin, 2012). Dworkin (2012) further recommends that a guide for a sample size is about 5-50 individuals for qualitative research, however the sample size would be determined based on the point of data saturation, which occurs when no new information is being obtained from additional participants. Therefore, for the objective of this study and considering the limitations, a sample size of 5-10 participants will be used for this research.

3.4. Data Collection

Rowley (2002) and Ranney et al. (2015) highlighted the importance for a researcher to develop a clear, impartial, and adaptable data collection strategy or protocol. An essential component of qualitative research data collection is (1) having a well-developed data collection process, (2) effectively identifying the sample population, and (3) efficiently collecting the information from the sample population (Ranney *et al.*, 2015). Whilst (Rowley, 2002), outlines three data collection guidelines such as (1) having an overview of the research, (2) determining and arranging the procedures to obtain the pertinent information from the relevant sources, and (3) formulating appropriate interview questions for the study. The researcher adopted data collection strategies from Ranney et al. (2015), Rowley (2002), and Wengraf (2001), and developed and followed the data collection steps discussed below for this study:

Step 1: Identification and selection of participants- The potential participants were identified, analyzed, and chosen according to their knowledge, proficiency, and experience related to the research objectives (Ranney *et al.*, 2015; Leedy and Ormrod, 2016). A participant list was created, and a table illustrating the participant profiles is included in section 4.1.

Step 2: Invitation to participants- According to data collection protocol outlined by Rowley (2002), the researcher should make the field arrangements to collect the information needed from their source. An invitation in the form of an email was sent to the selected participants. This invitation included a participant information sheet (Appendix A) which outlined the information on the study's goals and objectives, described how the interviews will be conducted, and requested the participants for permission to participate. If they were willing to participate the individual could accept the invitation and complete a consent form (Appendix B) that was also attached to the invitation.

Step 3: Preparation of the semi-structured interviews- The interview questions (Appendix C) for this research was pre-determined and designed to be open-ended. The Rose-Wengraf model was incorporated into the preparation of the semi-structured interviews. The Rose-Wengraf model has several stages of iterative processes. The start of the model emphasizes the importance of developing a conceptual framework, which is centralized around the research question and objectives, this then gives rise to theoretical propositions which will be used for developing and refining interview questions (Wengraf, 2001). In order to develop a conceptual framework, a comprehensive and well-structured literature review had to first be developed which formed the basis for the conceptual framework. The literature was then reviewed to develop a conceptual framework of identified themes and concepts related to the research question and objectives; this was used to develop initial interview questions. As mentioned, the Rose-Wengraf model is an iterative process. The initial interview questions were thoroughly examined to identify and iron out any practical problems that could arise, the interview questions were revised and reviewed by revisiting the earlier stages of the development of the interview questions (Wengraf, 2001). The

diagram below illustrates the above-mentioned processes regarding the development of the interview questions for this research.

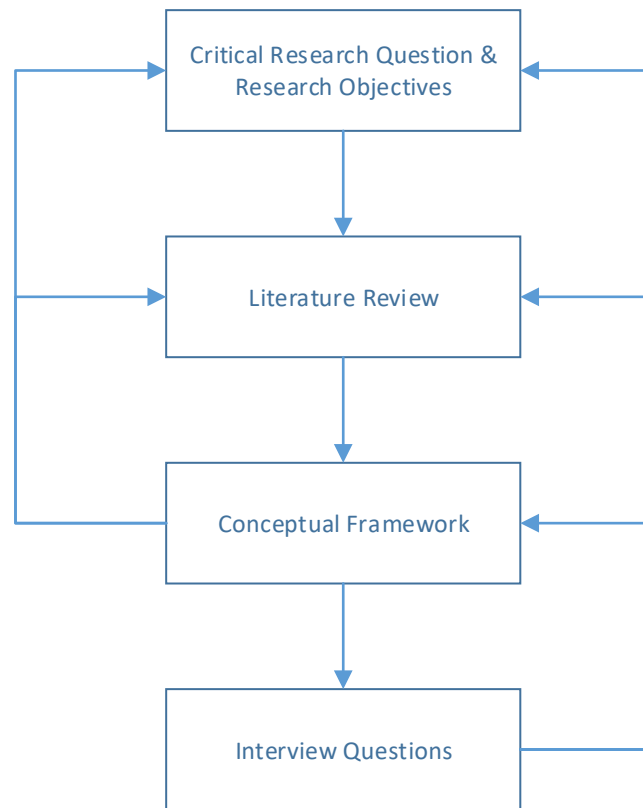


Figure 17 Development Processes for the Interview Questions

Step 4: Conduct the Interviews- In accordance with the sample criteria discussed in section 3.3 and the widespread nature of the rail network, the participants were scattered at various locations throughout the country, the interviews were conducted virtually on Microsoft Teams. In opting for virtual interviews additionally ensures and equitable and easily accessible interview process for the participants involved. All the interviews were recorded via Microsoft Teams with the transcription feature activated. The researcher made additional notes for follow-up questions and as an additional back-up to the recording and transcription.

Step 5: Transcription Review and Checking- The transcription for each interview was reviewed and edited according to the recording to ensure accuracy. The participants were sent their interview transcription through email for them to examine and review the transcription to confirm that it accurately represents the interview.

3.5. Research Interview Context

The aim of this section is to develop an understanding of the context of the research interviews which will aid in the understanding of the analysis of the data. As outlined in section 3.4, the semi-structured interview questions were constructed using the Rose-Wengraf model, which uses the research conceptual framework as the nucleus for the development of the interview questions (Wengraf, 2001). Following the methodology of the Rose-Wengraf model, the semi-structured interviews in Appendix C has four sections which were designed to achieve the following outcomes:

3.5.1. Section A: Demographics

The purpose of this section was to obtain the basic information from the participant to establish a basic participant profile. This was their name, surname, their job title, and the number of years of experience in railway signalling and/or operations.

3.5.2. Section B: Railway Signalling Performance

This section had a total of 10 questions. The aim of this section was to elicit the factors contributing to poor railway signalling performance. The questions were designed to firstly obtain an understanding of the current state of the signalling equipment and the existing performance of the system. Secondly it focused on eliciting all the factors such as organizational factors, systemic factors, external factors, environmental factors, and human factors that contribute to poor signalling performance. As the interview is semi-structure, this allowed the researcher to prompt for more information and get clarity on certain challenges outlined by the participants.

3.5.3. Section C: Risk to the Organization

The purpose of section C was to understand the risks of poor signalling performance on the organization. The risk factors identified as factors contributing to poor signalling performance in section B was further analyzed to identify the impact, in terms of low, medium of high impact, that these factors have on railway operations, safety, and the organization.

3.5.4. Section D: Next Steps/ Closing the gap

One of the objectives of this research is to develop recommendations to address the critical factors contributing to poor signalling performance. This section of the interview aimed at looking at the recommendations that the participants will propose to improve signalling performance. By obtaining this input from the experts who are working in the railway signalling field on a daily basis, it helps the researcher obtain a richer understanding of the feelings and challenges from the perspective of the participant. By asking the participants their opinions about the changes they would like to see happen, this helps the researcher with developing recommendations to meet this objective of the research.

3.6. Data Analysis

Data analysis aims at understanding and contextualizing the data that has been collected (Ranney *et al.*, 2015). The collected data from the participant interviews was analyzed using Thematic Analysis. Thematic Analysis is a commonly used qualitative research analysis technique that aims to methodically detect and analyze patterns and themes in the data to obtain greater insight and essential meaning of the data collected and, as a result, gain more understanding of the research question (Liamputtong, 2009). Braun and Clarke (2012) have designed a six-phase approach to using Thematic Analysis, which was adopted for this research because the method is accessible and flexible, which enables the data to be analysed in various ways, allowing the researcher to identify meaningful relationships to the research question and objectives. The six-phase approach to Thematic Analysis is discussed below:

Phase 1: Familiarizing yourself with the data

In this phase the researcher started by listening to the recording of each interview and reviewing and editing the transcription generated through Microsoft Teams for that interview. It is vital that the transcriptions follow an appropriate format to allow for effective data analysis of the collected content (Ranney *et al.*, 2015). Once the transcriptions were accurately updated, the interview transcripts were then read

multiple times until the content was well understood by the researcher, high level notes were made throughout this phase of the process to highlight key concepts and interpretation of the data (Braun and Clarke, 2012). This point was also emphasized by (Creswell, 2007;Creswell, 2009) who highlights the importance of reading through the data to gain deeper understanding and interpretation of the data.

Phase 2: Generating initial codes

Braun and Clarke (2012) classify this phase as the starting point of the data analysis, and the study by Liamputtong (2009) confirms this statement. Coding is a way to interpret data which involves identifying meaningful words, phrases, sentences or any units of text from the dataset and labelling them with a code or descriptive name relevant to the research (Braun and Clarke, 2012). To generate the codes, the researcher made use of a qualitative data analysis software called NVIVO. The researcher opted for the use of data analysis software over manual coding, and therefore it was vital that sufficient time and accuracy went into reviewing and formatting the interview transcriptions to allow for better interpretation and analysis of the data. The NVIVO data analysis software helped facilitate the data analysis as it was easily accessible and allowed for the management and organization of the many codes that were initially generated (Ranney *et al.*, 2015).

Phase 3: Searching for themes

The initial generated codes were further analysed, merged and refined to generate detailed codes, the detailed codes were then further analysed, categorized, and generated into themes at this step. Searching for themes does not mean discovering themes from the data. It is the process of actively generating or creating themes through the interpretation and analysis of the data (Braun and Clarke, 2012). The process of developing themes challenges the researcher to find commonality or links amongst codes of data to establish a category or theme (Ranney *et al.*, 2015). The emerged themes were based on a semantic approach which is what the content of the data literally means, and a latent approach which is to uncover the underlying meaning or assumptions of the data. Codes with similar patterns will be clustered and organized into similar groups, themes can then be derived based on the similarities, patterns,

relationships or overall meaning that emerge from the data (Braun and Clarke, 2012). An Affinity Diagram is a tool that would be used for this phase of the analysis to help organize or classify data to help construct themes.

Phase 4: Reviewing potential themes

In this phase the generated themes were reviewed and refined against the coded information, the dataset as a whole, and the research question and objectives (Braun and Clarke, 2012). By reviewing the potential themes, new themes may emerge, redundant themes may be discarded, or themes may be split or merged into new themes (Caulfield, 2022).

Phase 5: Defining and naming themes

Once the themes are finalized in phase four, each of the themes were named and the uniqueness of each theme can be defined (Caulfield, 2022). Themes must be clearly defined with a purpose and scope, themes should be related and build on each other, and most importantly depict a clear story of the data (Braun and Clarke, 2012).

Phase 6: Producing the report

This final phase of Thematic Analysis allows for synthesizing the findings from the analysis into a coherent report. The report entails a detailed and logical structure outlining the results and findings of the analysis and the themes that emerged from the data, which is presented in the next chapter. To supplement this, the impact of the risk factors of poor signalling performance were tabulated.

3.7. Validity and Reliability

In qualitative research, the validity and reliability of the research is the process of ensuring rigor, trustworthiness, and quality of the research (Golafshani, 2003). The following methods will be used to ensure the validity and reliability of this research:

- a) Triangulation- According to Leedy and Ormrod (2016) and Ranney et al. (2015), researchers collect different forms of data associated to the same research with the aim to identify any discrepancies in the data and improve the trustworthiness

of the data. To ensure the credibility and reliability of the data collected is through interviewing multiple sources, the interviews were recorded, the transcription feature on Microsoft teams was activated, the researcher reviewed and verified the audio recording to the transcription, and the researcher also made notes throughout the interview to supplement the transcription and recording.

- b) The interview sample population size included 10 research participants with a background in railway signalling or railway operations and with a minimum of five years of experience in a managerial position. This criteria enables the researcher to select from a range of managers, specialists, engineers, and senior engineers who were able to provide rich data in order to increase the reliability and validity of this study.
- c) Reflexivity- According to Leedy and Ormrod (2016) good researchers are able to identify their biasness and actively try to reduce or mitigate their biasness having influence over their study. Through self-awareness or self-examination of one's opinions, assumptions, or biasedness, it would prevent the researcher from influencing the participants through leading, agreeing or negating the participants responses, or introducing the own opinions or prejudices into discussions which could influence the outcome (Ranney *et al.*, 2015). Throughout the interview process, the researcher will keep a reflexive journal during the data collection process to note down any thoughts, observations, assumptions, or biasness that may arise. Through this self-reflection process, the researcher biasness could be reduced and mitigated.
- d) Transcription Review and Verification – The participants of the interview have been sent the transcript of their interview to review, check, and verify the correctness of the data that was captured. This transcription review and verification process with the participants will increase the dependability and validity of the data that was analyzed.

3.8. Ethical Considerations

To conduct interviews with the railway experts and professionals in the freight rail industry, consent was required, and a letter of clearance was obtained from TFR to conduct research with their employees. As this research required data collection through the form of interviews with human participants, the researcher obtained ethical clearance from the University of Witwatersrand Human Research Ethics Committee (non-medical). The ethics clearance number for this research is MIAEC 070/23.

As per the Ethical guidelines, the research participants received a Participant Information Sheet (Appendix A) whereby they were informed that their participation is completely voluntary, and they are free to withdraw from the research at any time. The participant information sheet also outlined that their participation is strictly confidential, and that the information they have provided will be stored securely to ensure that the researcher maintains the anonymity and confidentiality of the participant. The researcher requested the consent of the participant before the interviews were scheduled and again confirmed their consent before the interviews were conducted, the participant consent form can be found in Appendix B.

CHAPTER 4

4. ANALYSIS & FINDINGS

The purpose of this chapter is to present the analysis and findings attained from the qualitative data collected from the research participants experiences and perspectives for this research. This chapter includes a high-level analysis of the participant profiles, followed by the thematic analysis that highlights the codes generated and then discusses the themes that have emerged from the data collected. The emerged themes are discussed and supplemented with a narrative description of the participants responses.

4.1. Participants' profiles

There were 10 research participants that were selected according to the Sampling criteria outlined in section 3.3, all participants had vast knowledge of the railway industry specifically in railway signalling and railway operations. Based on the vast knowledge of the 10 research participants and the data collected, the researcher was certain that saturation was achieved in this process. The table below illustrates a high-level profile of the research participants as well as the number of years of experience that each possesses.

<i>Pseudo Name</i>	<i>Employment Area</i>	<i>Position</i>	<i>Years of experience</i>
Participant 1	Railway Signalling	Specialist	8.5
Participant 2	Railway Signalling	Engineer	9.5
Participant 3	Railway Signalling	Engineer	5.5
Participant 4	Railway Signalling	Senior Engineer	9.5
Participant 5	Railway Signalling	Engineer	7.5
Participant 6	Railway Signalling	Engineer	8.5
Participant 7	Railway Signalling	Engineer	5.5
Participant 8	Railway Signalling	Manager	44.5

<i>Pseudo Name</i>	<i>Employment Area</i>	<i>Position</i>	<i>Years of experience</i>
Participant 9	Railway Operations	Senior Manager	35
Participant 10	Railway Signalling	Senior Engineer	8.5

Table 1: Research Participants profiles

4.2. Thematic Analysis

Semi-structured interviews were conducted with the research participants mentioned in section 4.1, all the interviews were recorded and then transcribed. As outlined in section 3.6, thematic analysis was used to analyze the data collected for this research. The transcribed interviews (Appendix E) were used to conduct the thematic analysis, and the themes and findings will be discussed in this section.

4.2.1. Codes

As outlined in phase 2 of the thematic analysis process of “Generating initial codes” in section 3.6, the transcribed participant interview data set was analyzed, and codes were identified and generated. The detailed codes that were generated can be viewed in Appendix D. Figure 18 illustrates the 46 main or refined codes generated coupled with its frequency of occurrence among the participants. The high-level analysis of some of the collected data containing the main or refined codes can be found in Appendix E. The codes represent factors, challenges or focus areas that the participants related to the objectives of this research.

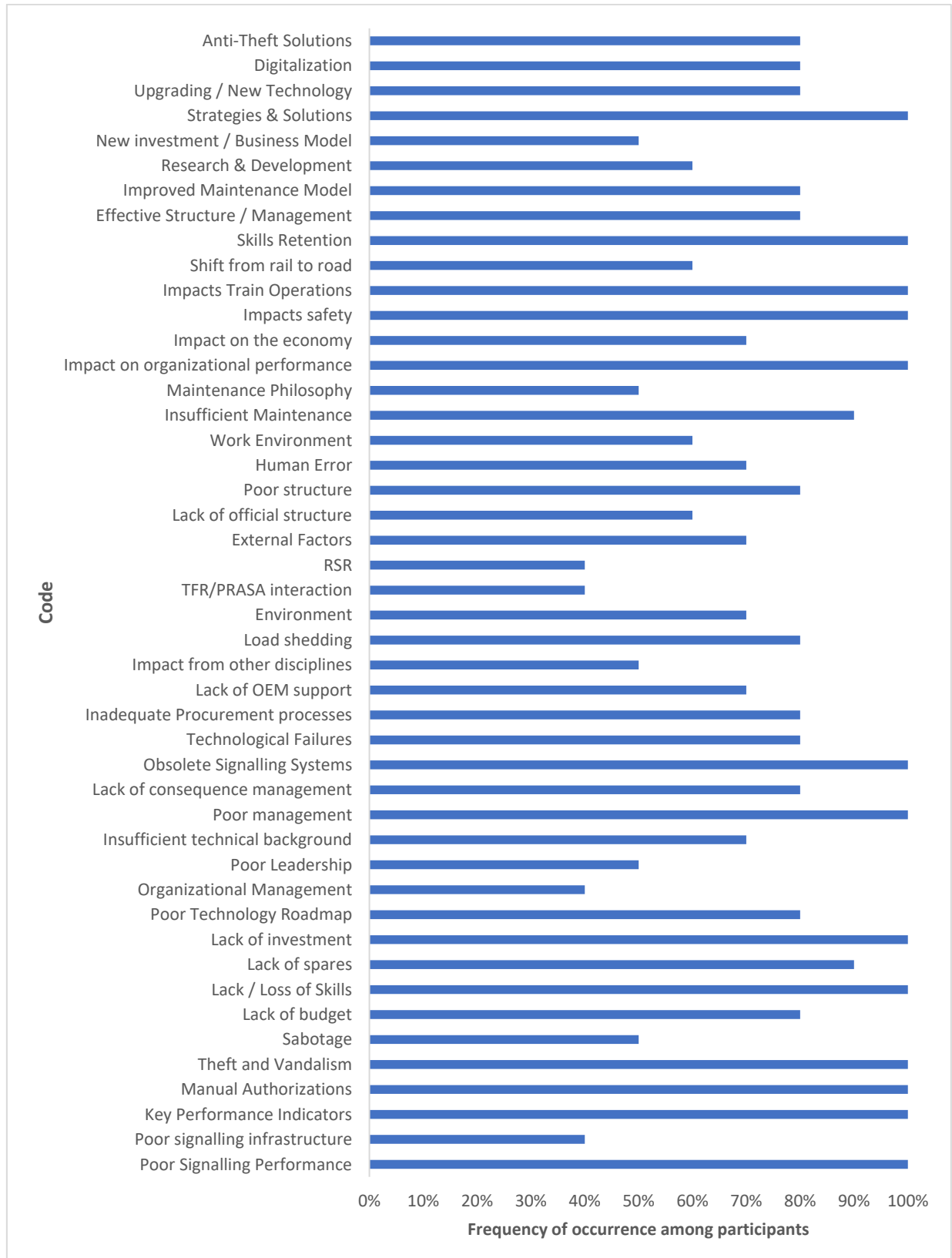


Figure 18: Frequency of occurrence of main codes from the data collected

4.2.2. Themes

The codes in Figure 18 were then categorized into similar groups to uncover the emergent themes. Figure 19 below is an affinity diagram which illustrates the main codes mapped and clustered to the emergent themes. The 46 main codes were grouped to develop 14 main themes.

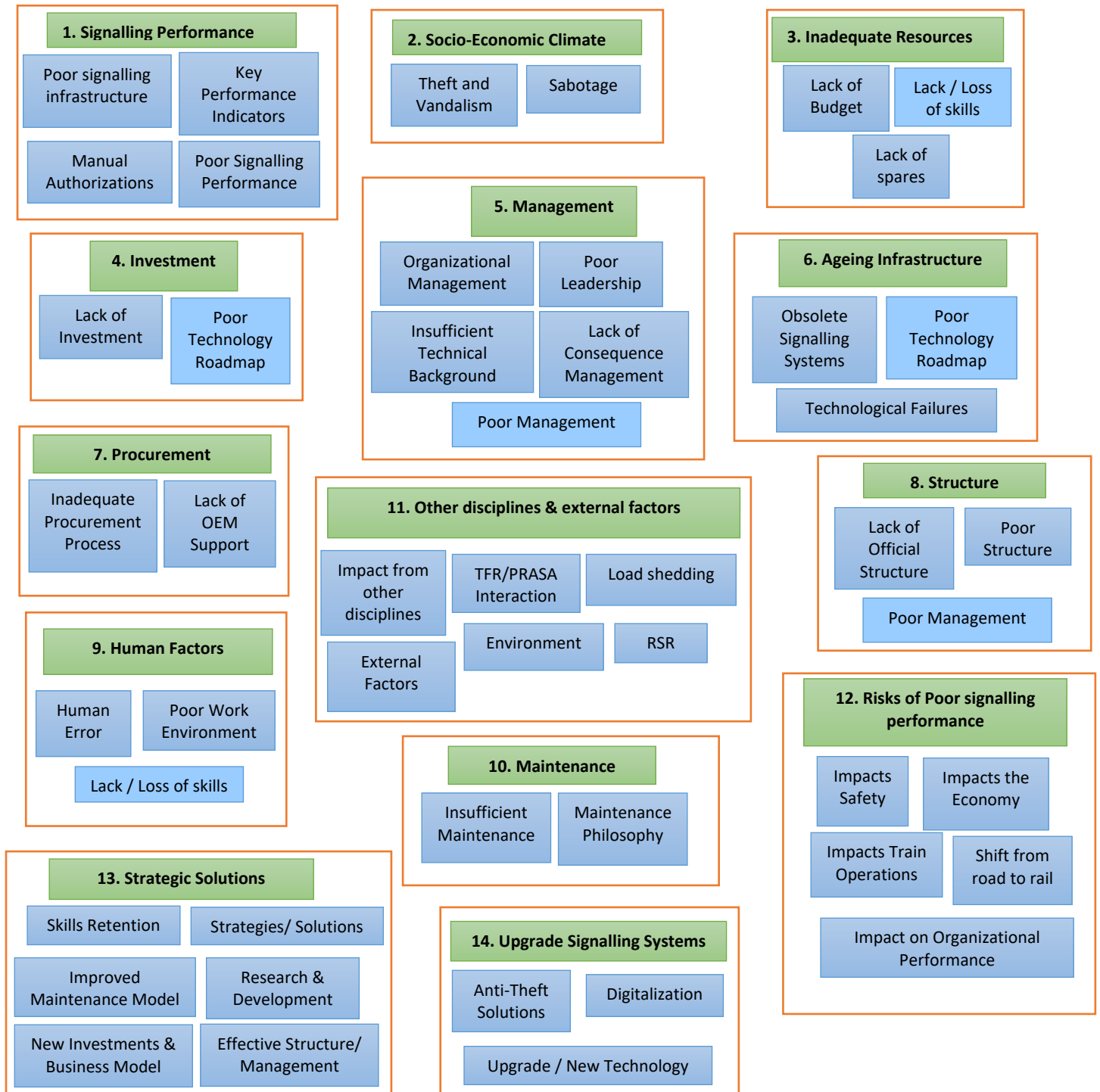


Figure 19: Codes and Themes for the factors contributing to poor signalling performance

Following phases 3, 4 and 5 of the thematic analysis process outlined in section 3.6, there was a total of 14 themes which had emerged through the data analysis process. The final generated themes were reviewed against the detailed coded data (Appendix D), the research question and the research objectives. In line with the research question and objectives of this study, the themes are categorized into the following categories:

- The current signalling Performance in South Africa
- The factors contributing to poor signalling performance
- The risks and impact of these factors on railway operations, safety, and organizational performance
- The next steps to address the critical factors contributing to poor signalling performance

<i>Theme</i>	<i>Category</i>
<i>1. Signalling Performance</i>	The current signalling Performance in South Africa
<i>2. Socio-Economic Climate</i> <i>3. Inadequate Resources</i> <i>4. Investment</i> <i>5. Management</i> <i>6. Ageing Infrastructure</i> <i>7. Procurement</i> <i>8. Structure</i> <i>9. Human Factors</i> <i>10. Maintenance</i> <i>11. Impact of other disciplines and external factors</i>	The factors contributing to poor signalling performance
<i>12. Risks of poor signalling performance</i>	The risks and impact of these factors on railway operations, safety, and organizational performance
<i>13. Strategic Solutions</i> <i>14. Upgrading Signalling Systems</i>	The next steps to address the critical factors contributing to poor signalling performance

Table 2: Categorization of themes

4.3. The current railway signalling Performance in South Africa

Interview questions one to four of section B, were generated to understand and obtain a description of the actual state of the railway signalling infrastructure, the current signalling performance of South Africa, and to establish the KPIs used to measure signalling performance.

4.3.1. Theme 1: Signalling Performance

The participants unanimously agree that the current condition of the signalling infrastructure and the current signalling performance is very poor. Since the participants have joined the railway organization at their different starting dates, they have all seen significant decline in the signalling performance. As signalling performance is the core of this research, a few narratives from the interviews are used to emphasize the participants perspective about the current state.

Participant 8 has been working in railway signalling for over 40 years and has described the signalling system as, *“performance of the signalling system is dismal, it is not compliant, it is not performing at all, it is failing rapidly.”*

According to participant 10, *“the signalling system is quite a dire state, and it is heavily underutilized especially looking at where it was previously versus the current capacity that we are experiencing.”* The underutilized signalling infrastructure is largely due to the poor state or condition of the infrastructure, and this is causing the railway capacity to be affected.

Participant 9 has been working in railway operations for over 30 years and has further reiterated, *“The current state is very poor, and the performance is also very poor, more than 80% of the railway signalling system countrywide is dysfunctional.”*

4.4. The factors contributing to poor railway signalling performance

The interview questions number 5 to 10 of section B focused on identifying the various factors that contribute to poor signalling performance. There are 10 main themes that

were consistent among the responses of the participants, and their narratives are discussed below.

4.4.1. Theme 2: Socio-Economic Climate

All 10 participants emphasized the challenging socio-economic conditions of South Africa and the severe impact the railway organizations are suffering due to this. The railways span thousands of kilometers of infrastructure throughout the country, with portions of the rail network running through high theft areas and locations, which makes the infrastructure vulnerable to extreme theft and vandalism.

Participant 10 elaborated that, *“the socio-economic climate of the country and the high unemployment rate means people are desperate to survive.”* Therefore, people are resorting to theft in order to support their families and make a living. *“One of the challenges with the railway network is there are so many kilometres of infrastructure it is impossible to safeguard and protect all of it just because the sheer size of it.”*

Participant 1 has stated that, *“when I started my career in 2015... my focus was projects, maintaining and upkeeping of the signalling systems... since 2019 specifically, we’ve been challenged with theft and vandalism... I can say the current state, in some places there’s no signalling systems left, and if I look at the trend, maybe in the next few years, there’s going to be nothing left for my area of control. So, it’s deteriorated to the state where it’s not functioning because everything is stolen.”*

According to participant 8 *“theft and vandalism play a very big role in South Africa. Whatever technology you put on the on the railway line, you need to always ensure that the components are secured. It’s not something that can be stolen easily and, as a result, we sometimes install equipment that isn’t so efficient just so it doesn’t get stolen.”*

Participant 3 reiterated this by sharing that *“sometimes we have to install equipment that is not as efficient, simply because they don’t get stolen as much...in our signalling systems, where newer, much more efficient, lithium ion batteries or other solutions are available, we cannot install it because those batteries get stolen and so then for that reason, we opt for the cheaper batteries.”*

Participant 9 concludes their argument by stating that *“Anything that looks like metal, that can be sold to a scrap dealer, is stolen.”*

Participants 1, 2, 3, 5 and 8 (50% of the participants) highlighted that the signalling power supplies are subjected to high theft and vandalism, which creates a huge problem for train movement. Participant 8 also added that *“...we also get power from our backup systems which are battery backup systems or solar systems, however the solar systems are inevitably prone to theft, even our batteries as well. We've had a lot of relay rooms broken into...our batteries have also been stolen.”*

Furthermore, participants 1, 2, 8 and 9 (40% of the participants) also asserted that sabotage is also a factor affecting the performance of the signalling systems, and they suggest that this could be a strategy to enable more freight to be transported by road instead of the railways.

4.4.2. Theme 3: Inadequate Resources

All 10 participants highlighted that the signalling resources available are inadequate and lacking, and this is another major contributor to poor signalling performance. The resources the participants discussed were skills, budget, and spares, and these are discussed as subthemes below.

a) Skills

Participant 9 emphasized that *“there is a dire shortage of scarce skills”*, and further elaborated that signalling is a *“specialized and scarce skill”*. All participants emphasized that signalling has lost a lot of highly skilled employees, which has put a lot of strain on the existing signalling workforce. Participant 7, 8 and 9 (30% of the participants) conveyed that the loss of skills is largely due to the *“Voluntary Severance Packages (VSP)”* that was offered to the freight rail employees in the year 2020. The participants have also added that in their experience, the loss of skills has been due to the *“lack of incentives by the organization”, “poor skills retention”, “lack of talent management”, “poor training and development”, “people immigrating”, “normal attrition”,* etc. Participant 5 voiced that *“we do not have the adequate skills to perform tasks, this is because of a lack of resources.”* The participants conclude that the skilled employees

leave without transferring their knowledge, and there is a lack of training and development. This leads to inadequately skilled people occupying roles in which they are not qualified for and unable to fulfill the requirements of that job.

Apart from the participants arguing that signalling skills is a scarce skill, and that the loss of this scarce skill is negatively affecting the state of the signalling systems in the country, the participants have also highlighted that there are other skills across the board which is also lacking within the railway industry, such as *“effective managerial and leadership skills”, “good project managers”, “influential leaders”, “skilled procurement personnel”,* etc., and emphasized that the lack of these essential skills within the industry is negatively impacting the railway performance.

b) Budget

80% of the participants have shared their experience of how the lack of budget has negatively affected the performance of signalling. Participant 1 has expressed, *“we get a fraction of the required operating expenditure...it is not sufficient for us to maintain what is left. With the high theft and vandalism that we are experiencing, the funding available for daily tasks such as maintenance, has to be used for repairs.”* With the current state of the infrastructure and the problems experienced, participant 2 has added that, *“we don’t have funds to upgrade the systems, it is costly.”* Participant 3 further reiterates this by sharing that, *“the restrictions on capital available is quite big and the signalling systems are extremely expensive, and I don't think we are financially at a point where we can necessarily afford the upgrade of these systems.”*

c) Spares

90% of the participants have voiced that the unavailability of spares is affecting the performance of the signalling systems. Participant 4 stated, *“the lack of spares leads to not having the system available all the time and that impacts the operation of trains directly.”* Participant 10 indicated that *“because the systems are obsolete, they are no longer supported by the Original Equipment Manufacturers (OEM), so there are limitations on the spares.”*

4.4.3. Theme 4: Investment

The lack of investment in signalling infrastructure and the upkeep of signalling systems was a predominant concept raised by all the research participants. The participants had raised that the lack of investment created a large gap in the development of the railways and in turn has a cascading effect resulting in other issues or factors affecting railway signalling performance.

Six of the 10 participants highlighted a catch-22 situation when it comes to investments within the railway organization. Participant 10 shared that *“you need to make money in order to obtain investment for the infrastructure upgrades... if the infrastructure is not performing, you won’t have the investment to upgrade the infrastructure as needed.”* Participant 2 also added that *“organizational investments are prioritized to the corridors or sections with high generating revenue, so you need to make money to get money... which puts the corridors with lower freight volumes in a bigger problem”*. Participant 3 stated that *“the lack of investment has a very high impact on the system...without investment, we cannot move forward, the less we invest, the more signalling systems becomes unavailable.”*

4.4.4. Theme 5: Management

Throughout question 5 to 10 of the interview, all 10 participants shared their experience, at various points of the interview, of managerial issues which has influenced the current situation and the overall signalling performance. The participants shared their experience and perspective with regards to management and leadership which is discussed below.

Five of the 10 participants voiced their perspective of the importance of having management that has a combination of good leadership skills, good managerial skills and has an adequate railway signalling technical background, which is lacking according to their observation. There are *“constant leadership changes”* with people appointed in managerial positions when they *“do not have good managerial skills”*, they have an *“inability to lead”* and they have a *“lack of technical background”* which leads to ineffective and *“poor decision making”* and the implementation of *“poor solutions”* and

“poor strategies”. The participants have expressed that when a managerial role is occupied by an individual with an insufficient technical background, this creates a barrier and communication deficit between the manager and the workforce as there is a lack of understanding of the intricacies of the operational and engineering tasks.

Four of the 10 participants shared their experiences of poor management with regards to people management and process and policy management. Participant 1 highlights that when a *“manager fails to effectively lead and manage their teams...it basically starts to sink the ship,”* and has further elaborated that the failure to effectively manage their teams also leads to high overtime expenditure, ineffective maintenance, and poor resource management. With participant 5 adding that *“management is failing to sort the procurement process,”* a similar view was also shared by participants 6 and 7 where that they feel that the managerial support and effective management intervention is lacking. The participants also indicate that they feel that there is poor management of maintenance policies, procurement policies and procedures, recruitment policies, as well as resources. Participant 4 added that *“with management of equipment...not having spares available on time or not having enough funds and skills available for maintenance is also another managerial issue.”*

Participant 9 has identified a deficiency in the strategic planning of management and the lack of long-term vision for the signalling systems on the coal line, by stating, *“it is a lack of management foresight, currently it's a lack of funding because we are broke, but 20 years ago, I wouldn't say it was a lack of funding... railway signalling equipment, historically has got a 30-year life expectancy the coal line as a case in point, built in 1976, it's now 47 years old, it is gone beyond its life expectancy, by 2006 it should have been all fully replaced with the current signalling equipment that the international market might have been using.”* The lack of strategic long-term planning shows that the failure to effectively anticipate and plan for future upgrades and future challenges and the inability to adapt timeously is a contributor to the backlog of obsolete railway signalling infrastructure.

Participant 3 expressed their experience regarding consequence management, *“consequence management is where improvement is needed, there's not always*

consequences for the actions of people when something negative happens.” Participants 1 and 5 shared similar views with regards to *“holding people accountable for their performance”* and there *“should be accountability across the board.”* The participants highlighted that the lack of consequences and accountability for poor decisions or actions across the board is contributing to the decline of not only signalling performance but the organization as well. With participant 2 further reiterating the lack of consequence management by stating that *“the technicians are not incentivized or motivated to repair a fault in five minutes or even within an hour, because trains can be manually authorized... so they end up taking their time to get overtime...because no one is following up.”* These participants highlighted the importance of accountability and ensuring that management encounters and enforces appropriate repercussions for poor or inadequate performance.

4.4.5. Theme 6: Ageing Infrastructure

All 10 participants have expressed that majority of the signalling systems are old and obsolete. Participant 10 summed up the factor as *“a lot of the systems were installed between 1950 to 1980. So, they're all over 50 years, which is kind of over the lifespan of a signalling system, they have reached end of life and obsolescence.”* Participant 9 reiterated this based on their experience on the coal heavy haul line, *“The coal line was built in 1976, the track circuits, relays, relay rooms, interlocking, etc., dates back to 1976, its 47 years old, the manufacturers of the equipment doesn't even exist anymore.”* Participants 1, 2, 3, 6 and 7 have referred to the signalling systems consisting of *“older technology”* or *“legacy systems”*, and due to the age of the infrastructure there is a *“lack of support of the OEM”*, and the *“lack of spares”*, and therefore the signalling systems experience *“more failures”* or a high rate of *“technological failures.”*

Six of the 10 participants have also highlighted the poor signalling technology roadmap as one of the many contributing factors to the current obsolete and ageing infrastructure. Participant 1 added about the technology roadmap, *“we don't have a proper technology road map... I know it exists, but I personally have not seen where we need to be and by what timeline... it's not existent to me and I am the end user...there is a lack of alignment and communication.”*

4.4.6. Theme 7: Procurement

Eight of the 10 participants have agreed that in their experience the procurement processes have major impact on the performance of the signalling systems. Four of the participants have expressed great concerns with the governance and regulation of the procurement processes, as well the management of the procurement process, which causes a lengthy procurement process. Participant 3 stated that *“the Public Procurement Management (PPM) Act, influences how we are allowed to procure... It is putting quite a lot of restrictions in place to have access to quick spares and even though there are management ways to implement that, I think that is not being done to the level that it should be to support signalling systems.”* Participant 8 reiterated this by stating that *“the other thing that's lacking is the procurement of specialized equipment and the procurement policies in the company are throttling the performance of signalling.”*

Participants 5, 6, 7 and 8 also shared that the procurement process uses a *“one size fits all”* policy, whereby a lot of the procurement rules and regulations are the same across the board for all railway disciplines and departments. Participant 8 further stated that *“all departments are not the same and our equipment is very different because we've got specialized equipment, signalling is specialized equipment, so you cannot have the same procurement rules.”* The participants also voiced that a restrictive procurement process, makes procurement of the simplest and basic component and equipment extremely difficult.

All eight participants agree that the procurement process is flawed and the *“long lead time”* is *“crippling the signalling system,”* and causing a *“lack of spares.”* Participant 6 shared that *“with contracts ending and not being renewed in time, the OEM or the contractors will stop their services which affects the system and your customers as well.”*

4.4.7. Theme 8: Structure

Eight of the 10 participants have discussed issues relating to the organizational structure and hierarchy framework and have highlighted the challenges in their experience that negatively impacts signalling performance.

Five participants have shared that the lack of an official structure results in constant leadership changes which causes instability, uncertainty, and the lack of accountability within their departments. Participant 6 added that *“with the constant changes in leadership, top leadership specifically, the instability and uncertainty is felt by our teams...people seek stability and therefore leave to find that.”*

Participant 5 also added that, *“there are so many open vacancies from those that took the VSPs or left the company for some other reason, with a lack of an official structure and no new appointments, our signalling team is overworked and overwhelmed, we are not recognized for our skills and our contribution, therefore they tend to leave whenever they get an opportunity.”* A similar sentiment was also shared by participant 9 who stated that *“...talent management is a huge factor, we need to look after skills development in signalling.”*

Four participants have discussed their perspective of the top-down approach of the organizational structure, whereby the decisions, plans and strategies are made by the top-level or higher management without communicating and aligning with the employees at the lower levels of the structure. The lower levels then also fail to understand the implications of their actions as there is little or no alignment within the structure.

Another concern raised by the participants is with the way the structure is formed with a separation of the signalling technical teams at the depot and the central signalling support structures for the country. Participant 1 stated that, *“if I need technical support or advise, I will not get that from my structure, I have to maybe go to our supporting function, which isn’t also ideal because there is a lack of alignment and communication...we all are talking different languages.”*

4.4.8. Theme 9: Human Factors

Question 7 of Section B of the interview focused on the human factors affecting signalling performance. The factors that emerged from the participants were human factors relating to human error, the signalling work environment, and the loss of skills.

With the signalling systems being unavailable, the TCO at the CTC then reverts to abnormally working for authorizing train movement which is manually authorizing trains through the network. Participant 8 states that *“with the state of signalling systems we have today, we have a high number of manual authorizations which bypasses the signalling systems, so bringing in this human factor increases the risks of incidents happening.”*

Participant 5 stated that, *“with the high number of manual authorizations, the TCO and even the train driver gets frustrated and fatigued. One manual authorization between the TCO and the train driver can take up to five minutes and there is a high number done per day, this increases the chances of mistakes and human error.”*

Participant 9 shares insight about the implications of manual authorizations on the TCO, *“the TCO signs on to abnormal working and signs off to abnormal working... the TCOs are overworked and demotivated... when the TCO makes an error, they are dismissed... previously, the machine protected the human, now the human needs to protect the machine...their productivity levels have dropped.”* Participant 10 reiterate this by stating that *“when you are more reliant on humans who are prone to human error, you introduce fatigue both in the person authorizing the movement as well as the train driver, which poses safety risk.”* This creates an unhappy and highly stressed work environment, which is a contributing factor to employees leaving the organization.

Apart from the TCOs and train drivers experiencing abnormal working conditions, seven of the 10 participants discussed that due to the loss of skills in signalling, those that are left are overworked and unhappy. The participants reiterated the lack of skills transfer and those that left the organization did not share their knowledge which creates a huge skills gap, thus those signalling personnel that are left behind are struggling to fill the void and provide the correct signalling expertise to the rail network. The participants explained their frustration and voiced that they are overworked, not incentivized, and under a lot of pressure to perform or fill many roles and functions within signalling.

4.4.9. Theme 10: Maintenance

Nine of the 10 participants have identified maintenance factors as a challenge contributing to poor signalling performance.

According to participants 1, 6 and 8, RPM is planned for but not always conducted as per the plan due to the high number of signalling technical faults and incidents, the incidents have to be prioritized over the maintenance. Participant 9 stated, *“maintenance is being done to a standard, but they're not getting to all of the maintenance within their allotted time frames because there are so many breakdowns, breakdowns cost the company money and the company needs the income.”* Participant 1 shared a similar view by saying, *“our teams are mainly redirected to look at or to address the incidents related to cable theft. The theft and vandalism are so high in our area, there isn't enough time to actually get to the maintenance.”*

According to three out of the 10 participants, the maintenance philosophy is reactive and not predictive or proactive, which isn't ideal for the current state of the signalling equipment. Participant 7 stated that, *“Routine preventative maintenance for each signalling equipment is determined by the supplier...there isn't a document outlining a maintenance philosophy which allows for the adjustment of the maintenance frequency depending on the usage or state of that specific equipment, if such a document exists then I have not yet seen it.”* Participant 1 elaborated that *“a set of points may be thrown 50 times a day versus another set of points which may be thrown five times a day in a quieter area...the maintenance frequency for both these points machines are the same, yet they are not used in the same way... I am not in a position to change the frequency.”*

Participants have also raised concerns that maintenance may be executed, but the maintenance of the equipment is not being inspected nor is the quality of maintenance being recorded and this is due to the signalling teams losing their skilled personnel, being understaffed and not at their full capacity.

4.4.10. Theme 11: Impact of other disciplines and external factors

The purpose of question 8 of Section B of the interview was designed to elicit the external factors that negatively impacts railway signalling performance from the

participants. The main factors discussed in this theme include loadshedding, the impact from electrical and perway systems, the interaction between TFR and PRASA, and environmental conditions.

80% of the participants identified load shedding as an external factor contributing to poor signalling performance. Participant 9 stated that *“the phenomenon of load shedding is like 15 years old. 20 years ago, you had your primary and secondary power supply and load shedding was an unheard-of concept. These days they steal the main power cable, then you are left with the secondary supply which is now subjected to theft and vandalism, and to exacerbate that outcome Eskom or the municipality switches off the power, so everything comes to a standstill...the points are in fact clamped because of the frequency of load shedding...we clamped them knowing that the power could fail at any time and that the trains would stand.”* Participants 2, 4 and 5 have highlighted that loadshedding and other electrical power failures put a lot of strain on the signalling backup power supply which ultimately reduced the lifespan of the batteries and signalling power equipment and increase the technical failures and railway incidents.

Eight out of the 10 participants have identified the Electrical and Perway disciplines causing impact to the signalling systems which effectively impacts signalling performance. Some participants have agreed that the impact from the other technical disciplines may vary depending on the severity of the failure. Participant 1 added that *“due to the high theft and vandalism of the signalling batteries, we do not have a backup power supply in some of our stations, therefore if there is no power supply to our relay rooms from electrical, then we have stations that are out at once... I do believe there's a lot of faults on their network and we only seeing this now because we don't have backup present.”*

Participant 8 has shared that *“we have a huge issue with the electrical supply and backup power systems for our equipment, we get drop downs from the overhead traction equipment (OHTE), which we termed “dirty power” because it is not a clean and dedicated signalling power supply...the harmonics present in the “dirty power” supply causes damage to our signalling equipment and reduces the lifespan of the equipment.”*

Participants have identified Perway issues such as rail breaks, poor drainage and culvert maintenance, and failures with their crossings, which impact signalling systems. Participant 1 further added that *“due to electrical power failures and Perway infrastructure failures some of our points are clamped for a specific position...due to it being clamped for long periods of time, we have found that this reduced the lifespan of some of the components in the points machine”*

Three of the 10 participants discussed the interaction and interface between TFR and PRASA's signalling systems. Participant 4 stated that *“PRASA and Transnet has a lot of Service Level Agreements (SLAs) as PRASA and Transnet share some of the rail network.”* Participant 3 has also shared an incident that *“a motor vehicle accident occurred in the metro area where there was quite a lot of damage to the signalling equipment, but the outside signalling equipment belongs to PRASA, while the relay room belongs to Transnet, and getting that reinstated was quite a challenge, as we need to align budgets, resources, etc. between us and PRASA, so I think that plays a significant role.”*

Six of the 10 participants have highlighted environmental issues such as extreme heat, heavy winds, heavy rains, flooding, and rust, negatively impacts the signalling systems. Participant 10 shared that *“we recently experienced flooding in Durban, where the system was completely underwater and therefore not available. The system couldn't be repaired in most stations due to the technology being obsolete and we don't have the necessary skills to be able to do it.”* Due to this, the signalling systems in this area needed to be replaced with newer electronic interlocking by the OEM. Participant 8 has shared that *“in the coastal areas...due to heavy rains, we have had wash aways which exposes our signalling cables and pushes over the rust factor within the coastal environment.”*

4.5. The impact of the critical risk factors on railway operations, safety, and organizational performance

Section C of the interview focused on identifying the risks to the organization due to poor signalling performance. The theme risk of poor signalling performance discusses

the risks and impact of the critical factors on railway operations, safety, and organizational performance.

4.5.1. Theme 12: Risks of Poor Signalling Performance

All participants unanimously agreed that poor signalling performance has a negative impact on railway operations, safety, and organizational performance. The participants have highlighted the risks and implications as a result of poor signalling performance, which is discussed below.

Participant 9 stated that, *“poor signalling performance has got a huge impact on the safe running of trains. For every ton we move, we make money, basically the performance of the organization is based or determined by the performance of railway operations. So, if you have got poor signalling performance it has got an impact on the operator. But it's also got a major impact on the organization as a whole and a good example is our last year's volumes where we delivered in the vicinity of 150-million-tons, which was actually the lowest in recorded history.”*

Participant 3 shared that, *“signalling performance affects railway operations quite significantly. First of all, the throughput of the line is significantly impacted, and you are losing quite a lot of train slots with manual authorizations... and it is increasing our transit time quite significantly as well... the number of trains and the number of tonnages we can haul is significantly reduced... and then in terms of safety, whenever there are manual authorizations, you always introduce a safety risk as well.”* All participants shared similar sentiments that when signalling performance is reduced, the capacity of the network is reduced which thus lowers the volumes which ultimately affects the revenue of the organization.

Participant 10 stated that *“manual authorizations introduce safety risks, there is the risk of somebody making a mistake resulting in a train collision, resulting in a derailment.”*

Participant 5 shared that *“poor signalling performance can introduce safety risks such as near misses, collisions, derailments, injuries and fatalities.”* With participant 6 adding that *“railway incidents can cause damage to infrastructure which is very costly to the company.”*

Participant 8 further reiterated that *“when a train derails, it's huge financial loss in terms of the damaged equipment and to replace or reinstate the line, because the line is closed for example four days, you've lost four days of generated income. It's a loss of income for Transnet and for the customer because the customer's commodity is not being delivered and there's a backlog and that costs them money... It is not only money and time and expense, but also our relationship with that customer...because that customer will rather move to the road and away from us, we risk losing a customer base.”*

Six of the 10 participants discussed that trains transport the commodities from the mines to the port and an under performance of the train services causes challenges with these customers, which results in them looking at other modes of transportation for their freight. Participants have also raised that this further impacts the South African economy. Participant 4 shared *“for example if coal or fuel or agricultural commodities are not delivered on time, it impacts people's livelihood, the welfare of the people and the entire economy is impacted.”*

4.6. The next steps to address the critical factors contributing to poor signalling performance

Section D of the interview aimed at getting the participants perspective as to changes, recommendations, and next steps that they would suggest based on their experience and expertise that could improve the condition of the railway signalling system and thus improve the current performance. A high-level analysis of the participants narratives will be discussed in this section.

4.6.1. Theme 13: Strategic Solutions

The participants have suggested that the railway organization strategically plan their solutions to improve the signalling performance in South Africa.

Seven out of the 10 participants have discussed the need for more investment to make improvements to the signalling systems. Participant 3 started by stating that *“key investments are also very important, and we've got two let's say three lines in this*

country which brings in quite a lot of revenue, being the manganese line which they are investing quite a lot of money at the moment, and the coal line as well as the iron ore line. So, I mean the iron ore line is a very good example where newer technology has been installed and the performance on that line is significantly better than on the other lines. So, these lines are sort of your revenue generating lines and so I think investment is quite important in these areas to increase your freight volumes in these key areas before you know just investing here and there and not really having an impact."

All participants unanimously agreed that the railway organization should develop a sound skills retention or talent management program and an environment suited to productivity, growth and success. Participant 10 shared that, *"I think the biggest thing is the development of the knowledge pool... if you have a substantial knowledge pool you create an environment where you are able to develop solutions that are more appropriate to the specific environment... if you have that knowledge pool and the resource availability with the necessary skills and knowledge you can then have systems that are appropriate to our environment and can be used in our environment to increase capacity... and it doesn't take huge amounts of money to improve that knowledge pool and having necessary knowledge transfers..."* Participant 8 discussed improving the organizational structure to accommodate talent management by adding that *"the organizational structure would need to look after their talent, in other words, talent management is a huge factor because signalling is only sort of used in Transnet and rail companies throughout the world. It's not very common so one has to look after your skills development in those areas."*

The participants have also discussed the idea of having an inhouse Research and development team to come up with immediate and long term solutions to improve signalling performance.

4.6.2. Theme 14: Upgrading Signalling Systems

On the technical side of strategic solutions, eight of the 10 participants have raised that the railway needs to decrease theft and vandalism and develop innovative anti-theft solutions. These anti-theft solutions will be a form of upgrade for the signalling systems to ensure that it is more available and reliable. Participant 8 started with, *"one of the*

technologies we need to adopt is to remove all of the copper communication due to high theft and vandalism... For example, moving to optic fibre, but when we move to optic fibre, we also have to upgrade our systems to be able to work on optic fibre..." Participant 2 also reiterated the solution of de-coppering of signalling cables and further added that *"we need high tech security systems... drones, cameras, monitoring systems, and quick response teams."* With participant 10 adding that *"we need to have a strong security presence and also strong security reaction and security patrolling... we need a response if an alarm is triggered, there needs to be a set like response time of 20 minutes or 30 minutes and then you can design the technologies that are then appropriate to that response time. So, security presence I think is important."*

All participants have touched on upgrading the existing signalling systems to newer electronic systems or moving toward digitalization of the signalling systems. Participant 8 suggested that *"we need to think of systems being used by other countries... whereby we will start running trains with GPS location instead of track circuit, and use in-cab signalling, etc... with in-cab signalling we can move away from so much of copper."* Participant 2 added that *"new technologies can always benefit the system and eliminate the high risk commodity of copper cables. Anything that you can decentralize and reduced the number of components, can reduce theft and vandalism, and this is always a must."* Participant 9 has also added that *"incorporating new technology can provide quicker turnaround times between faults and also the availability of spares for newer technology versus old obsolete stuff."*

Participants 1, 3, 5, 6 and 7 have discussed using new technology to improve the maintenance philosophy. Participant 3 suggested that *"there's a lot of opportunity to implement technology such as IOT sensors to move to a more predictable maintenance instead of a time based periodic maintenance... there are other technologies such as blockchain which can very accurately capture information regarding maintenance in a ledger that cannot be manipulated or changed, so a combination of those two could improve Signalling performance quite significantly when looking at maintenance."*

4.7. The impact of the risk factors on railway operations, safety, and organizational performance

The critical factors contributing to poor signalling performance, which were identified by the research participants, together with its risks and hazards and impact on railway operations, safety and organizational performance are tabulated in this section. This is in line with the research objective to assess the risk factors of poor signalling performance and evaluate the impact. The impact has been evaluated using the Low, Medium, and High rating risk priority (Transnet, 2017), all ratings are based on the participants experience and are dependent on the severity of the incident or situation, whereby:

- Low impact- Low chance of occurrence, having no or negligible or insignificant effect on train operations, safety, and the organization. Little or negligible financial implications (<R999 999)
- Medium- minor or noticeable impact, with a financial implication between the range of one million rand to 9.9 million rand. The safety incidents could result in minor injuries, where no or minor medical attention is needed with no downtime.
- High impact- major or significant impact to train operations, safety, and the organization, with financial implications of > 10 million rand. The safety incidents could result in major injuries or even fatalities.

Risk Factor	No. of Participants that identified the factor (out of 10)	Hazard (Causes/ Leads to...)	Impact on Operations	Impact on Safety	Impact on the Organization
1. Theft and Vandalism	10	• Unavailable and unreliable signalling network • Maintenance is neglected • High technical failures • High budget expenditure • Train delays • Train cancellations • Abnormal working • Loss of volume & revenue • Overworked employees	10/10 participants stated it has HIGH impact on Operations	10/10 participants stated it has HIGH impact on Safety	10/10 participants stated it has HIGH impact on the Organization

Risk Factor	No. of Participants that identified the factor (out of 10)	Hazard (Causes/ Leads to...)	Impact on Operations	Impact on Safety	Impact on the Organization
		- Human Error - Safety Incidents - Loss of customers			
2. Lack of Skilled Personnel/ Poor skills retention	10	- Overworked employees - Incorrect or inadequate execution of work - Rework - Long lead times - Technical Failures - Poor job satisfaction - Loss of existing employees - Human Error - Safety Incidents - Loss of customers	10/10 participants stated it has HIGH impact on Operations	10/10 participants stated it has HIGH impact on Safety	10/10 participants stated it has HIGH impact on the Organization
3. Lack of Investment	10	- Lack of upgrades - Ageing infrastructure - Insufficient maintenance - Demotivated employees - Loss of skilled employees - Poor working environment - Loss of customers	10/10 participants stated it has HIGH impact on Operations	10/10 participants stated it has HIGH impact on Safety	10/10 participants stated it has HIGH impact on the Organization
4. Poor Management/ Leadership/consequences	10	- Unorganized and underperforming teams - High overtime expenditure - Overworked employees - Inefficient standard operating procedures and processes - Demotivated employees - Ineffective management of resources - Higher chance of human error - Loss of skilled employees - Poor skills retention and talent management - Lack of skills transfer	10/10 participants stated it has HIGH impact on Operations	10/10 participants stated it has HIGH impact on Safety	10/10 participants stated it has HIGH impact on the Organization

Risk Factor	No. of Participants that identified the factor (out of 10)	Hazard (Causes/ Leads to...)	Impact on Operations	Impact on Safety	Impact on the Organization
		- Poor training and development - Human Error - Safety Incidents			
5. Obsolete & Ageing Infrastructure/ Technological failures	10	- High technical failures - Lack of spares - Lack of skilled employees with the knowledge of the obsolete systems - Lack of OEM support - Unavailable and unreliable signalling network - Train delays - Train cancellations - Human Error - Safety Incidents - Loss of customers	10/10 participants stated it has HIGH impact on Operations	10/10 participants stated it has HIGH impact on Safety	10/10 participants stated it has HIGH impact on the Organization
6. Lack of Spares/Contracts/ OEM Support	9	- Unavailable and unreliable signalling network - Insufficient Maintenance - High technical failures - High budget expenditure - Train delays - Train cancellations - Abnormal working - Loss of volume & revenue - Low Morale	9/9 participants stated it has HIGH impact on Operations	9/9 participants stated it has HIGH impact on Safety	9/9 participants stated it has HIGH impact on the Organization
7. Insufficient Maintenance & Maintenance Procedures	9	- Unavailable and unreliable signalling network - Maintenance is neglected - High technical failures - High budget expenditure - Train delays - Train cancellations - Abnormal working - Loss of volume & revenue - Human Error - Safety Incidents	9/9 participants stated it has HIGH impact on Operations	9/9 participants stated it has HIGH impact on Safety	9/9 participants stated it has HIGH impact on the Organization

Risk Factor	No. of Participants that identified the factor (out of 10)	Hazard (Causes/ Leads to...)	Impact on Operations	Impact on Safety	Impact on the Organization
8. Inadequate procurement processes & procedures	8	• Loss of customers • High technical failures • Lack of spare • Lack of OEM support • Unavailable and unreliable signalling network • Insufficient maintenance • Demotivated employees • Loss of operating expenditure	8/8 participants stated it has HIGH impact on Operations	8/8 participants stated it has HIGH impact on Safety	8/8 participants stated it has HIGH impact on the Organization
9. Inadequate organizational structure	8	• Unfilled vacancies • Lack of alignment • Poor Management • Poor communication • Working in silos • Lack of accountability • Underperforming teams and departments • Overworked employees • Higher chance of human error • Demotivated employees • Loss of skilled employees	8/8 participants stated it has HIGH impact on Operations	8/8 participants stated it has HIGH impact on Safety	8/8 participants stated it has HIGH impact on the Organization
10. Load shedding	8	• Unavailable and unreliable signalling network • Reduction in lifespan of signalling systems • Insufficient Maintenance • High technical failures • High budget expenditure • Train delays • Train cancellations • Abnormal working • Loss of volume & revenue • Demotivated employees • Human Error	8/8 participants stated it has HIGH impact on Operations	8/8 participants stated it has HIGH impact on Safety	8/8 participants stated it has HIGH impact on the Organization

Risk Factor	No. of Participants that identified the factor (out of 10)	Hazard (Causes/ Leads to...)	Impact on Operations	Impact on Safety	Impact on the Organization
		- Safety Incidents - Loss of customers			
11. Interaction with Perway & Electrical	8	- Unavailable and unreliable signalling network - Train delays - Train cancellations - Abnormal working - Loss of volume & revenue	4/8 participants stated it has HIGH impact on Operations. 1/8 stated its MED to HIGH. 1/8 stated its MEDIUM impact. 1/8 stated its LOW impact. While 1/8 participant stated it may have an impact that VARIES depending on the severity of the failure mode	3/8 participants stated it has HIGH impact on Safety. 1/8 stated its MED to HIGH. 1/8 stated its LOW impact While 3/8 participants stated it may it may have an impact that VARIES depending on the severity of the failure mode	4/8 participants stated it has HIGH impact on the Organization 1/8 stated its MED to HIGH. 1/8 stated its MEDIUM impact. 1/8 stated its LOW impact While 1/8 participant stated it may have an impact that VARIES depending on the severity of the failure mode
12. Lack of Funding	7	- Lack of upgrades - Ageing infrastructure - Insufficient maintenance - Demotivated employees - Loss of skilled employees	7/7 participants stated it has HIGH impact on Operations	7/7 participants stated it has HIGH impact on Safety	7/7 participants stated it has HIGH impact on the Organization
13. Human Factors	7	- Safety Incidents such as train collisions, near misses, derailments, injuries and fatalities - Damage to infrastructure - High budget expenditure - Train delays - Train cancellations - Loss of volume & revenue - Loss of jobs - Low morale/poor working environment - Loss of customers	5/7 participants stated it has HIGH impact on Operations. While 2/7 participants stated it has a MEDIUM impact.	7/7 participants stated it has HIGH impact on Safety. While 1/7 participant stated it has a MEDIUM impact.	7/7 participants stated it has HIGH impact on the Organization While 1/7 participant stated it has a MEDIUM impact.

Risk Factor	No. of Participants that identified the factor (out of 10)	Hazard (Causes/ Leads to...)	Impact on Operations	Impact on Safety	Impact on the Organization
14. Environmental Conditions	6	- Unavailable and unreliable signalling network - Damage to infrastructure - High technical failures - High budget expenditure - Train delays - Train cancellations - Abnormal working - Loss of volume & revenue	4/6 participants stated it has HIGH impact on Operations. While 2/6 participants stated it has a MEDIUM impact.	3/6 participants stated it has HIGH impact on Safety. 2/6 stated it has a MEDIUM impact. While 1/6 participant stated it has a LOW impact	3/6 participants stated it has HIGH impact on the Organization 1/6 stated it has a MED to HIGH impact 1/6 stated it has a MEDIUM impact. While 1/6 stated it has a LOW impact
15. Poor working environment/low morale/Demotivated employees	5	- Human error - Safety incidents - Loss of skilled employees - Lack of knowledge transfer - Low productivity	3/5 participants stated it has HIGH impact on Operations. While 2/5 participants stated it may have a MEDIUM impact depending on the severity of the situation	3/5 participants stated it has HIGH impact on Safety. 1/5 stated it has MEDIUM pact. While 1/5 stated it may have a LOW impact depending on the severity of the situation	3/5 participants stated it has HIGH impact on the Organization 1/5 stated it has MEDIUM pact. While 1/5 stated it may have a LOW impact depending on the severity of the situation
16. TFR/Prasa Interaction	3	- Unavailable and unreliable signalling network - Insufficient maintenance - High budget expenditure - Train delays - Train cancellations - Abnormal working - Loss of volume & revenue	2/3 participants stated it has HIGH impact on Operations. While 1/3 participant stated it may have a MEDIUM impact depending on the severity of the situation	1/3 participants stated it has HIGH impact on Safety. While 2/3 participants stated it may have a LOW to MEDIUM impact depending on the severity of the situation	3/3 participants stated it has MEDIUM impact on the Organization depending on the severity of the situation

Table 3: The impact of the risk factors on railway operations, safety, and organizational performance

CHAPTER 5

5. DISCUSSION

This research aimed at identifying the critical factors affecting the performance of railway signalling systems in South Africa, which subsequently impacts the performance of railway operations and the organization in its entirety. A critical literature review was designed around the research question and research objectives in order to develop a comprehensive understanding of the railway signalling environment in South Africa. The literature was used as a basis for the development of a conceptual framework which was then used to develop the research interview questions. Semi-structured interviews were conducted for this research with railway signalling and railway operations experts and professionals in order to identify the factors contributing to poor signalling performance to determine if these factors refute or supports the factors identified from literature.

This research provides an in-depth understanding of the factors contributing to poor signalling performance, and has addressed the following objectives:

1. Identify the key systemic factors contributing to poor signalling performance.
2. Assess the risk factors of poor signalling performance and evaluate the impact on railway operations and safety, and organizational performance.
3. Develop recommendations for addressing the critical factors that contribute to poor signalling performance to improve railway operations and organizational performance.

The critical literature review aimed at developing context of the South African freight rail system, looking deeper into signalling systems and its performance, then finally leading into the factors affecting railway signalling performance. The limitations and gaps in literature emerged when investigating the factors affecting railway signalling performance as not many studies covered this aspect of railway signalling, particularly in the South African context. As outlined by Morant et al. (2016), due to the complex nature and the interoperability of the railway system, signalling performance has a

ripple effect on the entire performance of the railway system. Therefore, a holistic approach had to be adopted to explore the relevant literature for signalling reliability challenges coupled to factors influencing the performance of railway infrastructure systems, which in turn was used to form the basis for the development of a conceptual framework of factors influencing the performance of railway signalling systems. The critical literature review and the conceptual framework has outlined that poor signalling performance negatively impacts railway operations and the railway organization as a whole, which in turn impacts the freight industry and the South African economy.

The conceptual framework (figure 15) was developed from concepts which emerged from the literature on the factors contributing to poor railway signalling performance and the risks associated with the poor railway signalling performance. The development of a conceptual framework was a pivotal part of this research as it established the foundation for the investigation of poor railway signalling performance. Following the Rose-Wengraf model, an interview question development process (figure 17) was established which incorporated the conceptual framework, the research questions, and the research objectives to develop the final interview questions for this research (Wengraf, 2001).

Through the observational domain, the collected data through the research interviews validated the concepts presented in the literature review and conceptual framework with regards to poor signalling performance. This was expected and also supports the significance of this study in investigating the factors contributing to poor signalling performance and its impact on railway operations and organizational performance in South Africa. The literature painted a picture of the decline of railway signalling infrastructure and performance in South Africa, and despite this being unfortunate, the evidence collected through the observational realm fully supports that the current state of signalling performance is indeed poor and declining drastically. The evidence obtained through the observational realm helped create a deeper insight of the impact that the declining signalling performance has on multiple aspects such as railway

operations, other railway disciplines, the employees within the organizations, the organization, as well as the country.

The research participants have expressed their views as to the significance that signalling systems play in the rail network and have further emphasized the factors that contribute to poor signalling performance. It is clear from the participants responses which was outlined in the themes in the analysis and findings that poor signalling performance is a systemic problem and has been a buildup of years of issues and challenges that the railway environment has faced. Factors posing risk to the signalling performance, or the “risk factors of poor signalling performance”, have been identified in the literature review and have been further identified or reiterated by the research participants, and the impact or hazards of these risk factors have been discussed in detail in table 3 in section 4.7.

To answer the research question, meet the research objectives, and to support the literature review, a total of 14 themes that emerged from the data analysis of the data collected through the semi-structured interviews with the research participants. Themes are developed through commonality of the coded data which can be grouped and merged (Ranney *et al.*, 2015). Although each theme discusses its own concept relating to signalling performance, it was evident from the results obtained from the literature review as well as the research participants that there are further commonalities amongst the themes as specific concepts or issues thread into or impact concepts discussed in another theme.

Section 4.4 of the analysis and results, highlights 10 themes that emerged from this study which addresses the factors contributing to poor railway signalling performance. Theft and vandalism were the most dominant theme that emerged from the study. This is coherent with the literature as theft, vandalism, and sabotage is a leading contributor to the freight rails inability to perform as per its capacity and the expectation of its freight rail customers. South Africa has been experiencing socio-economic challenges,

such as high rates of unemployment, high cost of living, increased poverty, and social disparity, since the global recession in the late 2000's, and the socio-economic climate has been severely exacerbated to date due to the COVID-19 pandemic (World Bank Group, 2023; Development Bank of Southern Africa, 2024). The study also shows that the signalling department moreover the rail industry can put measures in place to safeguard the signalling infrastructure from theft and vandalism, however the problem cannot be resolved in isolation as theft and vandalism is a national systemic problem needing the collaboration and intervention of the public sector, private sector, the community, the Government, investors, etc.

The theme of inadequate resources, which addresses resources such as skills, budget, and spares, has been identified in this study as another major contributing factor to poor railway signalling performance. With the current socio-economic climate of South Africa coupled with the declining railway industry, it is increasingly difficult to retain skilled employees in the railway industry, more so the country. It is evident from this study that South Africans with critical skills emigrate due to the socio-economic issues, inadequate service delivery, power crisis, politics, looting, poorly run state owned enterprises, lack of career growth and opportunities, etc. Moreover, the impact of poorly managed organizations results in many skilled employees leaving the organization without transferring their skills, which creates a larger skills shortage gap, and over worked and unhappy employees within the railway industry. This severely impacts the remaining employees, as the signalling and train control employees are overworked due to insufficient manpower which causes frustrated, overworked, and demotivated employees. This creates an environment prone to human error. Employees often overextend themselves to meet daily expectations, and when they fall short, it becomes difficult to disconnect, leading them to bring work into their home environment, this pattern contributes to burnout, reduced productivity, poor sleep and deteriorating mental health. (Barik and Yadav, 2023). Maswabi and Qing (2017) adds that for an organization to successfully meet their objectives and targets, it is crucial that its human resources are motivated to produce and execute their expected daily requirements. They further argue that a high-performing organization largely depends on motivated

employees, a positive work environment and the ability of its workforce. South Africa has over 70% of its youth not having jobs, yet there is an increasingly growing number of vacancies in engineering, science, financial and business sectors, medical sector, media, digital market, information technology, trade, etc., with a lack of skilled South Africans to fill those vacancies (Davey, 2023; Fraser, 2023).

The theme of investment revealed that the lack of finances is critical as it has a ripple effect on the other critical factors affecting poor signalling performance that was raised by the research participants. The impact of a lack of finances and investment in the railway signalling department and the organization, results in:

- The inability to successfully maintain and upgrade the signalling infrastructure, which causes ageing and obsolete infrastructure leading to the lack of spares. The obsolete signalling equipment is further deteriorated with the extreme loadshedding the nation is experiencing, increasing the number of technical failures and incidents.
- The inability to create opportunities for employee's career growth, training, and development programs, which results in a loss of skilled employees.
- The inability to develop and execute effective solutions to combat theft and vandalism.
- The inability to secure future investors as investors don't want to invest in an underperforming organization.
- Human factors such as unhappy and demotivated employees and managers.

The managerial issues within the railway industry have proven to have an effect in the way the signalling discipline performs. The theme of management revealed dissatisfaction among the research participants. The study showed that the lack of a stable and effective management force, strategic planning, long-term vision, effective decision making, constant leadership changes, effective managerial processes, and a lack of consequence management and project management, not only created an overall absence of inspirational guidance but has caused significant harm to the current

signalling infrastructure. The failure to effectively and timeously plan for routine work, upgrades, and challenges through the development of effective strategies, procedures and processes, an adequate technology roadmap, efficient maintenance, and effective resource allocation has contributed to the current poor state of the signalling systems. The emerged theme of management from the observational realm is fully supported by literature with several studies revealing that poor organizational management, departmental management and project management plays a large role in the underperformance of an organization and its failure to meet the goals, objectives, and targets (Luiz, 2010; Oumarou, 2015; Mhlongo, 2021; Bouraima *et al.*, 2023). Furthermore, the research has revealed that inadequate management has links to other critical factors or themes that were identified, such as the railway procurement processes, issues with the organizational structure, and has a significant implication on human factors which affects the signalling resources and retention of employees.

In line with the research objective to assess the risk factors of poor signalling performance and evaluate the impact, section 4.5 of the analysis and results, addresses the impact that the risk factors have on railway operations, safety, and organizational performance. Table 3 illustrated the findings for this objective which validates the literature for this study.

The study outlined the next steps to address the critical factors contributing to poor signalling performance in section 4.6. The Department of Transport (2017a) drafted the white paper of national rail policy of South Africa, which outlines a few high-level options to address theft and vandalism, managerial aspects, and investment. However, there is a gap in literature with regards to detailed strategies and effective plans to be implemented for the improvement of both the freight rail and signalling systems. Investment in signalling infrastructure, implementing solid anti-theft and vandalism solutions, upgrading the signalling systems to newer technology, and prioritizing career development and skills retention, revealed to be highly favored recommendations and solutions from this study to improve the signalling performance.

To summarize, findings of this study has answered the research question and the research objectives. The literature explored and documented for this study and the results obtained supports and validates the phenomena investigated in this study. The links and evidence formed between the literature review (Chapter 2) and the Analysis and Findings (Chapter 4) regarding the factors contributing to poor signalling performance and its impact on railway operations, safety and the organizational performance have been clearly revealed. This is critical for the study's reliability and validity.

CHAPTER 6

6. CONCLUSION AND RECOMMENDATIONS

This research was motivated by the current declining railway signalling performance in South Africa and the lack of understanding of the systemic factors causing poor signalling performance as well as the risks associated with its effects on railway operations, safety, and organizational performance. The South African freight logistic network and the economy relies heavily on the freight rail network, with signalling systems being critical to the rail network as it is responsible for the safe travel of trains and enhancing the capacity of the rail network to meet the customer demand. Therefore, this research aimed at investigating the critical factors contributing to poor signalling performance in South Africa and its impact on railway operations, safety and organizational performance.

For this study, the qualitative research methodology was adopted for the researcher to not only investigate the factors contributing to poor signalling performance, but the study takes this further by assessing the risk factors of poor signalling performance, and to recommend ways to improve railway signalling performance which will thus improve railway operations and organizational performance.

The literature review showed that the factors directly affecting railway signalling performance are not fully explored and documented, which further motivated the need for this research. As the rail network is a complex and interoperable system, a holistic approach was adopted whereby the rail infrastructure performance and reliability challenges relevant to the literature on railway signalling challenges were extracted in order to develop a conceptual framework for this study.

Using a holistic approach to developing a conceptual framework to identify the factors affecting signalling performance created a deeper understanding of the systemic issues affecting the system. Through thematic analysis of the data obtained from the research participants, several key findings and themes have emerged, whereby the

interconnected nature of the factors and issues were demonstrated together with the impact on the rail network. The concepts identified through the literature review were validated and verified through the analysis and findings for this study.

The findings and results for this study has answered the research question and met the research objectives. Furthermore, the results have also revealed that the critical factors impacting signalling performance extend beyond the railway and has socio-economic implications in South Africa. This emphasizes the need for the prioritization of future work to start reforming the South African railway signalling systems to a more reliable and sustainable rail network.

6.1. Recommendations for Future Research

This study revealed various routes for potential research exploring some of concepts and findings which have emerged through this research, which could significantly improve the state of the signalling and rail infrastructure in South Africa.

- Theft and vandalism were a prominent factor which emerged from this study. Anti-theft and vandalism strategies or collaborative strategies and initiatives with the community, public sector and private sector should be investigated with the aim of combatting this socio-economic crisis.
- Future work exploring public-private partnerships to influence private sector investment, resources and expertise in upgrading and maintaining signalling systems, and development of sustainable funding models and protocols that can be implemented to ensure short-term and long-term investment for the signalling and railway systems.
- Detailed investigations and solutions into the skills shortage challenges in the railway industry should be looked into. Solutions of effective and efficient skills retention, training and development, and career succession plans and strategies would not only benefit the rail industry but also aid the country's unemployment crisis.

- Feasibility studies, and research and development into the upgrading of the signalling systems to the appropriate modern signalling systems, and digitalization and data-driven decision making of signalling maintenance and managerial processes, that are compatible to the challenges unique to South Africa's socio-economic climate and environment.
- Investigation into a digital approach to develop an optimal maintenance philosophy that allows for flexibility for scheduling, monitoring and controlling maintenance activities, including the alignment of the evolving needs of the asset to ensure maintenance is dynamic and effective.
- Assessing the performance of Condition Assessment Systems and its impact on the performance of the overall railway signalling system and railway operations and investigating methods to improve the signalling performance.
- Due to the time limitations for this study, only the South African freight rail network was investigated. Future studies should expand to the South African passenger rail, both public and private sectors, to get a broader and holistic view of the performance of the signalling systems in the country.

REFERENCES

- Al-Douri, Y.K., Tretten, P. and Karim, R. (2016) 'Improvement of railway performance: a study of Swedish railway infrastructure', *Journal of Modern Transportation*, 24(1), pp. 22–37. Available at: <https://doi.org/10.1007/s40534-015-0092-0>.
- Baek, Y.-G. and Lee, J.C. (2017) 'Railway Systems Development Based on the Concept of Systems Engineering and Safety: A Case Study of Railway Industry Practices', *The International Journal of Engineering and Science (IJES)*, 6(10), pp. 18–29. Available at: <https://doi.org/10.9790/1813-0610021829>.
- Baldwin, W.C., Sauser, B. and Cloutier, R. (2015) 'Simulation approaches for system of systems: Events-based versus agent based modeling', in *Procedia Computer Science*. Elsevier, pp. 363–372. Available at: <https://doi.org/10.1016/j.procs.2015.03.032>.
- Barik, S. and Yadav, J. (2023) 'Is Overwork Culture a New Normal? Rethinking from Psychological Detachment Perspective', *International Journal of Life science and Pharma Research*, (4), pp. 21–31. Available at: <https://doi.org/10.22376/ijlpr.2023.13.4.SP6.L21-31>.
- Bešinović, N. (2020) 'Resilience in railway transport systems: a literature review and research agenda', *Transport Reviews*, 40(4), pp. 457–478. Available at: <https://doi.org/10.1080/01441647.2020.1728419>.
- Bouraima, M.B. *et al.* (2023) 'Africa's railway renaissance and sustainability: Current knowledge, challenges, and prospects', *Journal of Transport Geography*. Elsevier Ltd. Available at: <https://doi.org/10.1016/j.jtrangeo.2022.103487>.
- Braun, V. and Clarke, V. (2012) 'Thematic analysis.', in *APA handbook of research methods in psychology, Vol 2: Research designs: Quantitative, qualitative, neuropsychological, and biological*. American Psychological Association, pp. 57–71. Available at: <https://doi.org/10.1037/13620-004>.
- Bullock, R. (2009) *Off Track: Sub-Saharan African Railways*. Available at: www.worldbank.org.

Capineri, C., Leinbach, T.R. and Gips, D. (2006) *Freight Transport, Seamlessness, and Competitive Advantage in the Global Economy*.

Caulfield, J. (2022) *How to Do Thematic Analysis | Step-by-Step Guide & Examples*, Scribbr. Available at: <https://www.scribbr.com/methodology/thematic-analysis/> (Accessed: 29 April 2023).

Clayton, R.J. *et al.* (2009) 'Applying Systems Engineering to Optimise the Operation and Maintenance of Railway Vehicles throughout the Value Chain', in *7th Annual Conference on Systems Engineering Research 2009 (CSER 2009)*.

Coutsoukis, P. (2004) *South Africa Railroads, Countries of the World*.

Cresswell, J.W. (2007) 'Qualitative Inquiry and Research Design: Choosing among five approaches'.

Creswell, J.W. (2009) *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches (3rd Edition)*. 3rd edn.

Davey, D. (2023) 'Addressing the skills shortage in SA will reduce youth unemployment', *Mail & Guardian*, 18 April. Available at: <https://mg.co.za/partner-content/2023-04-18-addressing-the-skills-shortage-in-sa-will-reduce-youth-unemployment/> (Accessed: 26 January 2024).

Dearnley, C. (2005) 'A reflection on the use of semi-structured interviews', *Nurse Researcher* 2005, 13(1), p. 19.

Department of Environmental Affairs (2023) *Freight shift from road to rail THE SOCIO-ECONOMIC IMPACT OF A MODAL SHIFT OF FREIGHT FROM ROAD TO RAIL TO ACHIEVE MAXIMUM GREENHOUSE GAS MITIGATION IN THE TRANSPORT SECTOR*. Available at: https://www.dffe.gov.za/sites/default/files/docs/publications/freightshift_roadtorail.pdf (Accessed: 29 August 2023).

Department of Public Enterprises (2023) *Transnet, Department of Public Enterprises*.

Department of Transport (2017) *National Rail Policy*.

Department of Transport (2023) *Rail*. Available at: <https://www.transport.gov.za/rail> (Accessed: 31 July 2023).

Derby, P. and Dlamini, N. (2021) *Annual Results Announcement 2021*. Johannesburg.

Development Bank of Southern Africa (2024) *Socio-economic factors that challenge SA's education system*. Available at: <https://www.dbsa.org/article/socio-economic-factors-challenge-sas-education-system#:~:text=While%20South%20Africa%20is%20rich,affect%20their%20quality%20of%20life>. (Accessed: 26 January 2024).

Ding, T. et al. (2014) *Study on Friction and Wear Properties of Pantograph Strip/Copper Contact Wire for High-Speed Train*, *The Open Mechanical Engineering Journal*.

Dworkin, S.L. (2012) 'Sample size policy for qualitative studies using in-depth interviews', *Archives of Sexual Behavior*. Springer Science and Business Media, LLC, pp. 1319–1320. Available at: <https://doi.org/10.1007/s10508-012-0016-6>.

EN50126-1 Railway Applications - The Specification and Demonstration of Reliability, Availability Maintainability and Safety (RAMS) (2017).

Estevan, A.M. (2015) *Dependability and Safety Evaluation of Railway Signalling Systems Based on Field Data*.

Ferreira, L. (1997) 'PLANNING AUSTRALIAN FREIGHT RAIL OPERATIONS: AN OVERVIEW', 31(4), pp. 335–348.

Franklin, F., Nemtanu, F. and Teixeira, P.F. (2013) 'Rail infrastructure, ITS and access charges', *Research in Transportation Economics*, 41(1), pp. 31–42. Available at: <https://doi.org/10.1016/j.retrec.2012.10.004>.

Fraser, L. (2023) 'South Africa's critical skills crisis – companies are desperate', *BusinessTech*, 2 September. Available at: <https://businesstech.co.za/news/business/714092/south-africas-critical-skills-crisis-companies-are-desperate/> (Accessed: 26 January 2024).

George, T.B., Mokoena, R. and Rust, F.C. (2018) *A REVIEW ON THE CURRENT CONDITION OF RAIL INFRASTRUCTURE IN SOUTH AFRICA*. Available at: www.jukwaa.net.

Ghaleb, H. and Abdullah, A.A. (2021) 'A Conceptual Framework for Impact of Project Complexity on Success of Railway Construction Projects: The Moderating Role of Effective Communications to All Stakeholders', *The Journal of Management Theory and Practice (JMTP)*, 2(1), pp. 62–69. Available at: <https://doi.org/10.37231/jmtp.2021.2.1.85>.

Golafshani, N. (2003) 'Understanding Reliability and Validity in Qualitative Research', *The Qualitative Report*, 8(4), pp. 597–607. Available at: <http://www.nova.edu/ssss/QR/QR8-4/golafshani.pdf> (Accessed: 29 April 2023).

Hammarberg, K., Kirkman, M. and de Lacey, S. (2016) 'Qualitative research methods: When to use them and how to judge them', *Human Reproduction*, 31(3), pp. 498–501. Available at: <https://doi.org/10.1093/humrep/dev334>.

Havenga, J.H. (2012) 'Rail renaissance based on strategic market segmentation principles', *Southern African Business Review*, 16.

Havenga, J.H. and Simpson, Z.P. (2018) 'Freight logistics' contribution to sustainability: Systemic measurement facilitates behavioural change', *Transportation Research Part D: Transport and Environment*, 58, pp. 320–331. Available at: <https://doi.org/10.1016/j.trd.2016.08.035>.

Havenga, J.H., Simpson, Z.P. and De Bod, A. (2014) 'South Africa's freight rail reform: A demand-driven perspective', *Journal of Transport and Supply Chain Management*, 8(1). Available at: <https://doi.org/10.4102/jtscm.v8i1.153>.

Howe, K. and Eisenhart, M. (1990) 'Standards for Qualitative (And Quantitative) Research: A Prolegomenon', *American Educational Research Association*, 19(4), pp. 2–9. Available at: <https://www.jstor.org/stable/1176381> (Accessed: 27 December 2023).

Huang, L. (2020) 'The Past, Present and Future of Railway Interlocking System', in *2020 IEEE 5th International Conference on Intelligent Transportation Engineering, ICITE 2020*.

Institute of Electrical and Electronics Engineers Inc., pp. 170–174. Available at: <https://doi.org/10.1109/ICITE50838.2020.9231438>.

Hutchings, J. (2017) *Systemic Factors in the investigation of South African Railway Occurrences*.

Ibnazia, M. (2022) *Investigation On The Algorithm Efficiency Of Generating The Interlocking Control Table Using The Compositional Approach*. University of the Witwatersrand.

INCOSE (2015) *INCOSE Systems Engineering Handbook*. Fourth.

Jidayi, Y.M. (2015) *RELIABILITY IMPROVEMENT OF RAILWAY INFRASTRUCTURE*. Available at: <https://scholar.sun.ac.za>.

Krmac, E. and Djordjević, B. (2017) 'An evaluation of train control information systems for sustainable railway using the analytic hierarchy process (AHP) model', *European Transport Research Review*, 9(3). Available at: <https://doi.org/10.1007/s12544-017-0253-9>.

Kuys, W. (2011) *Heavy Haul Operations in South Africa IHHA 2011 Calgary, Canada*.

Leech, J. (2012) *Optimising your bulk minerals export chain, aurecon*. Available at: <https://www.aurecongroup.com/insights/optimising-your-bulk-minerals-export-chain> (Accessed: 6 August 2023).

Leedy, P.D. and Ormrod, J.E. (2016) *Practical research : planning and design*.

Liamputtong, P. (2009) 'Qualitative data analysis: Conceptual and practical considerations', *Health Promotion Journal of Australia*, 20(2), pp. 133–139. Available at: <https://doi.org/10.1071/he09133>.

Lidén, T. and Joborn, M. (2017) 'An optimization model for integrated planning of railway traffic and network maintenance', *Transportation Research Part C: Emerging Technologies*, 74, pp. 327–347. Available at: <https://doi.org/10.1016/j.trc.2016.11.016>.

Luiz, J. (2010) 'Infrastructure investment and its performance in Africa over the course of the twentieth century', *International Journal of Social Economics*, 37(7), pp. 512–536. Available at: <https://doi.org/10.1108/03068291011055450>.

M. Pour, S. and Rasmussen, K.M. (2017) *Towards Signalling Maintenance Scheduling for European Railway Traffic Management System*. APA. Available at: www.bane.dk.

Makhuvele, A. (2016) *Application of integrated logistics support: A South African railway case study*. University of Johannesburg. Available at: <https://ujcontent.uj.ac.za/esploro/outputs/graduate/Application-of-integrated-logistics-support/9910737007691> (Accessed: 30 August 2023).

Marinov, M. *et al.* (2013) 'Railway operations, time-tabling and control', *Research in Transportation Economics*, 41(1), pp. 59–75. Available at: <https://doi.org/10.1016/j.retrec.2012.10.003>.

Maswabi, O.K. and Qing, Y. (2017) 'Risk Analysis of Operating an Organization with Demotivated Employees', in W. Aimin (ed.) *Proceedings of the 14th International Conference on Innovation & Management*. Wuhan: Wuhan University of Technology Press, pp. 760–764.

Mathabatha, D. (2015) *Rail transport and the economic competitiveness of South Africa: Timeous delivery of goods and demurrage*.

McMillan, W.J. (2009) *Finding a Method to Analyze Qualitative Data: Using a Study of Conceptual Learning*, *Journal of Dental Education*.

Mehrad, A. and Zangeneh, M.T. (2019) 'Comparison between Qualitative and Quantitative Research Approaches: Social Sciences', *International Journal For Research In Educational Studies*, 5(7). Available at: <https://orcid.org/0000-0003-4364-5709>.

Mhlongo, N.G. (2021) *Improving the reliability of railway signalling systems*. University of Johannesburg.

Morant, A. *et al.* (2012) *Improvement of configuration management in railway signalling system*. Available at: <https://www.researchgate.net/publication/236120392>.

Morant, A. *et al.* (2013) 'Dependability improvement through configuration management--A study of railway signalling systems', *Article in International Journal of COMADEM* [Preprint]. Available at: <https://www.researchgate.net/publication/260096249>.

Morant, A. (2014) *Dependability and Maintenance Analysis of Railway Signalling Systems*. Luleå University of Technology.

Morant, A. *et al.* (2016) 'Safety and availability evaluation of railway operation based on the state of signalling systems', *Journal of Rail and Rapid Transit*, 231(2).

Mukwena, M. (2018) *Analysis of factors undermining the reliability of railway track in South Africa*.

National Rail Policy: Draft White Paper (2017).

Oumarou, A. (2015) *Rail Infrastructure in Africa*. Available at: www.afdb.org.

Owusu-Manu, D.-G. *et al.* (2021) 'Assessing the Policy Provisions and Institutional Behavioral Factors Influencing Rail Infrastructure Financing in Developing Countries', *Journal of Infrastructure Systems*, 27(2). Available at: [https://doi.org/10.1061/\(asce\)is.1943-555x.0000610](https://doi.org/10.1061/(asce)is.1943-555x.0000610).

Oxford English Dictionary (2023) *Definition of system*, *Oxford English Dictionary*. Available at: https://www.google.com/search?rlz=1C1GCEU_enZA963ZA963&sxsrf=APwXEdcKrZqXrxxfUjip5NoYikqIOZcBQw:1680943308260&q=system&si=AMnBZoFgv3j24YeLEV-qyfUcM2ZM-ydkWjJ2-qwmNk2fpoq7acsNUq-6aUCVGzDApL6lL8qYKe9GxX32GUMzkDNenc9wf_OQoQ%3D%3D&expnd=1&sa=X&ved=2ahUKEwie4J (Accessed: 29 April 2023).

Pachl, I.J. (2020) *Railway Signalling Principles*. CC BY-NC-ND 4.0 Licence.

Paton, C. (2023) *Ramaphosa 'directs Transnet' to sort out logistics crisis*, *news24*. Available at: <https://www.news24.com/fin24/companies/ramaphosa-directs-transnet-to-sort-out-logistics-crisis-20230328> (Accessed: 29 April 2023).

Pienaar, W.J. (2010) 'RAILWAY CORPORATE GOVERNANCE IN A FREE-FUNCTIONING FREIGHT TRANSPORT MARKET: A SOUTH AFRICAN POSITION', *Corporate Ownership & Control*, 7(3), pp. 448–453.

PMI (2014) *Navigating Complexity: A Practice Guide*. Pennsylvania, USA: PMI. Available at: <https://www.pmi.org/pmbok-guide-standards/practice-guides/complexity> (Accessed: 30 July 2023).

Prins, E. (2015) *Transnet Market Demand Strategy, Parliamentary Monitoring Group*. Available at: <https://pmg.org.za/committee-meeting/21066/> (Accessed: 31 August 2023).

Rai, N. and Thapa, B. (2015) *A STUDY ON PURPOSIVE SAMPLING METHOD IN RESEARCH*. Kathmandu. Available at: https://d1wqtxts1xzle7.cloudfront.net/48403395/A_Study_on_Purposive_Sampling_Method_in_Research-libre.pdf?1472466369=&response-content-disposition=inline%3B+filename%3DA_STUDY_ON_PURPOSIVE_SAMPLING_METHOD_I_N.pdf&Expires=1703882734&Signature=Fp~IXFJEzDWmM1nlqDnR~K-T-n~cRlFVTA8saNW3pR3ZrohKTGHiNmVGWszguvVmLEgv6NrC3-U3uVyUs0UunnU14BpZeaHVO3zc9tADmCWzV0CdHI9Cmnulzzn4ew2mUCPKVIX~Hwq9YIFvZrDhqyTeMjRWW82Q8dUPnRcWokUJT4Fbq-u7OJXuYmRHzzTsTWt1cne0R4DyC2jnwGfzSVFScnZ5Sxh6cBQ0YrpBggiOLlcfNSpcMY5wn~71aapWWMTHXzm7rhDuPbSkhM0h4tLmh~blqebn9eAjP2DeEJQM7PP~KPH7tdVvOE3BDkqehy27ltwbaPRflWcyih4w__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA (Accessed: 29 December 2023).

Rail Communications (2023) *Rail Communications (RT)*, ETSI. Available at: <https://www.etsi.org/technologies/rail-communications> (Accessed: 19 August 2023).

RAILWAY SAFETY MANAGEMENT STANDARD (2008). Harare. Available at: <http://www.sararail.org>.

Railway Technology (2020) *Gautrain Rapid Rail Link*. Available at: <https://www.railway-technology.com/projects/gautrain/> (Accessed: 29 July 2023).

Ramuhulu, M. and 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. Available at: <https://doi.org/10.18488/journal.26.2018.71.8.26>.

Rangarajan, K. *et al.* (2013) 'The role of stakeholder engagement in the development of sustainable rail infrastructure systems', *Research in Transportation Business and Management*, 7, pp. 106–113. Available at: <https://doi.org/10.1016/j.rtbm.2013.03.007>.

Ranney, M.L. *et al.* (2015) 'Interview-based Qualitative Research in Emergency Care Part II: Data Collection, Analysis and Results Reporting', *Academic Emergency Medicine*. Blackwell Publishing Inc., pp. 1103–1112. Available at: <https://doi.org/10.1111/acem.12735>.

van Rensburg, J. (2022) *South Africa Transnet Freight Rail, International Trade Administration*. Available at: <https://www.trade.gov/market-intelligence/south-africa-transnet-freight-rail#:~:text=TFR%20is%20the%20largest%20freight%20rail%20transport%20operator%20in%20Africa>. (Accessed: 29 April 2023).

Rowley, J. (2002) *Using case studies in research: MRN, Management Research News*.

Schilling, D.R. (2013) *Gautrain: Building Africa's First High Tech World-Class Railway System, Industry Tap*.

Sedghi, M. *et al.* (2021) 'A taxonomy of railway track maintenance planning and scheduling: A review and research trends', *Reliability Engineering and System Safety*. Elsevier Ltd. Available at: <https://doi.org/10.1016/j.ress.2021.107827>.

Simons, R.J. (2019) *The influence of railway signalling characteristics on resilience*.

Stenström, C. (2014) 'Operation and Maintenance Performance of Rail Infrastructure Model and Methods', in.

Stenström, C. *et al.* (2015) 'Development of an integrity index for benchmarking and monitoring rail infrastructure: Application of composite indicators', *International*

Journal of Rail Transportation, 3(2), pp. 61–80. Available at: <https://doi.org/10.1080/23248378.2015.1015220>.

Stenström, C., Parida, A. and Galar, D. (2012) 'Performance Indicators of Railway Infrastructure', *International Journal of Railway Technology*, 1(3), pp. 1–18. Available at: <https://doi.org/10.4203/ijrt.1.3.1>.

The Commission Of The European Communities (1970) 'REGULATION (EEC) No 2598/70 OF THE COMMISSION'. THE COMMISSION OF THE EUROPEAN COMMUNITIES.

The World Bank (2023) *Railways*, *The World Bank*. Available at: <https://www.worldbank.org/en/topic/transport/brief/railways> (Accessed: 25 July 2023).

Thomas, D.P. (2013) 'The Gautrain project in South Africa: a cautionary tale', *Journal of Contemporary African Studies*, 31(1), pp. 77–94. Available at: <https://doi.org/10.1080/02589001.2013.747292>.

Tongco, M.D.C. (2007) 'Purposive Sampling as a tool for informant selection', *Ethnobotany Research & Applications*, 5, pp. 147–158.

Transnet (2012) *Transnet 2012*. Available at: <https://www.transnet.net/BusinessWithUs/MDS/External%20Magazine%20-%20Final.pdf> (Accessed: 29 April 2023).

Transnet (2016) *Rail Development Plan*. Johannesburg.

Transnet (2017) *Risk management within Transnet Transnet's top risks for 2017*. Available at: <https://www.transnet.net/InvestorRelations/Transnet%20Online%20Integrated%20Report%202017/downloads/opportunities-and-risks.pdf> (Accessed: 11 December 2023).

Transnet (2023) *Planning & Operations Command Centre*, *Transnet*. Available at: <https://www.transnetfreight-trail-tfr.net/NCC/Pages/Overview.aspx> (Accessed: 13 August 2023).

Transnet Freight Rail (2019) *Transnet Freight Rail Performance Report 2019*, Transnet. Available at: <https://www.transnet.net/InvestorRelations/AR2019/Freight%20Rail.pdf> (Accessed: 28 April 2023).

Transnet Freight Rail (2021) *Transnet Freight Rail Performance Report 2021*. Available at: <https://www.transnet.net/InvestorRelations/AR2021/Transnet%20Freight%20Rail.pdf> (Accessed: 30 July 2023).

Transnet Freight Rail (2022) *Transnet Freight Rail Performance Report 2022*, Transnet. Available at: <https://www.transnet.net/InvestorRelations/AR2022/Freight%20Rail%202022.pdf> (Accessed: 29 April 2023).

Transnet Freight Rail (2023a) *Telecoms*, Transnet. Available at: <https://www.transnetfreightrail-tfr.net/Rail%20Network/Pages/Telecoms-.aspx> (Accessed: 19 August 2023).

Transnet Freight Rail (2023b) *International Business (IB) Overview*, Transnet. Available at: <https://www.transnetfreightrail-tfr.net/BU/IB/Pages/Overview.aspx> (Accessed: 31 July 2023).

Transnet Freight Rail (2024) *Transnet Freight Rail Overview*, Transnet. Available at: <https://www.transnet.net/Divisions/Pages/FreightRail.aspx> (Accessed: 23 February 2024).

Transnet SOC Ltd (2022) *Information Statement*. Johannesburg, South Africa.

de Trigueros, R. and Sandoval, J.F.H. (2017) *Qualitative and Quantitative Research Instruments: Research Tools*. Available at: <https://www.researchgate.net/publication/323014697>.

Umiliacchi, S. *et al.* (2019) 'Enterprise architecture within railway systems engineering', *IET Intelligent Transport Systems*, 13(10), pp. 1461–1467. Available at: <https://doi.org/10.1049/iet-its.2018.5062>.

Wengraf, T. (2001) *Qualitative Research Interviewing*. Thousand Oaks: SAGE Publications.

Western Cape Mobility Department (2023) *Growing the economy with freight, Western Cape Government*.

Whiting, L.S. (2008) 'Semi-structured interviews: Guidance for novice researchers', *Nursing Standard*, 22(23), pp. 35–40.

World Bank Group (2023) *The World Bank in South Africa, The World Bank*. Available at: <https://www.worldbank.org/en/country/southafrica/overview> (Accessed: 26 January 2024).

Wu, W. (2020) *What is Preventive Maintenance? Types, Benefits, Cost, and Examples, Coast*. Available at: <https://coastapp.com/blog/preventive-maintenance/xamples> (Accessed: 2 September 2023).

Zhang, A. *et al.* (2021) 'Functional Safety of Railway Signaling Systems: Performance Requirements and Evaluation Methods', in *Proceedings of the 31st European Safety and Reliability Conference (ESREL 2021)*. Singapore: Research Publishing Services, pp. 3192–3198. Available at: https://doi.org/10.3850/978-981-18-2016-8_743-cd.

Zhuwaki, N.T. (2017) *Application of reliability analysis for performance assessments in railway infrastructure asset management*. Available at: <https://scholar.sun.ac.za>.

APPENDIX A: Participant Information Sheet



Dear Sir/Madam

My name is Pranell Naidoo, and I am a part time MSc Systems Engineering student in the school of Mechanical, Industrial and Aeronautical Engineering at the University of Witwatersrand, under the supervision of Dr Bernadette Sunjka. As part of my studies, I have to undertake a research project, and I am Investigating the impact of Railway Signalling Performance on Railway Operations & Performance in South Africa. The aim of this research is to identify the critical factors contributing to poor Signalling performance and assess the risk factors of poor signalling performance and evaluate the impact on railway operations and safety, and organizational performance.

Your knowledge and experience would contribute significantly to this study. I would like to formally invite you to participate in an online interview on Microsoft Teams which will take around 90 minutes. With your permission, I would also like to audio record the interview using the record function on Microsoft Teams. This recording and interview transcriptions will be securely stored on OneDrive Cloud Data Storage and only I will have access to the interview data.

Participation in this study is voluntary, and you may withdraw at any time. Anonymity and confidentiality of information provided will be strictly maintained and respected.

The results of the study will form part of my MSc research report which will be available online through the university library website and may also be reported in academic papers and at conferences. A summary of the report will be made available to you on request.

Please contact me if you have any questions regarding the research and participation in the study.

I look forward to hearing from you.

Yours sincerely,

Pranell Naidoo

Email: 2613921@students.wits.ac.za

Contact Number: 0813248009

Supervisor: Bernadette Sunjka

Contact Details: bernadette.sunjka1@wits.ac.za

APPENDIX B: Consent Form



Dear Participant,

Thank you for accepting to participate in this study: *Investigating the impact of Railway Signalling Performance on Railway Operations & Performance in South Africa*.

Please complete the consent form by marking an X by the relevant options. By signing this consent form, you indicate that you agree to the terms below:

	Yes	No
I confirm that I have read and understood the information about this study as provided in the participant's information sheet.		
I understand that my participation is voluntary and that I am free to withdraw at any time without any penalties or negative consequences against me.		
I agree that the information I provide may be treated as strictly confidential and anonymous and only the researcher will have access to the interview data.		
I grant permission for the interview to be audio recorded.		
I agree that the results of this study may be recorded in academic journals and at conferences.		
I am aware that I may request a summary report, which will come as a result of this study.		

With full knowledge of all above-mentioned terms, I agree to participate in this study.

Participant		Consent taken by (Researcher)	
Name		Name	Pranell Naidoo
Signature		Signature	
Date		Date	

APPENDIX C: Interview Questions

Investigating the impact of Railway Signalling Performance on Railway Operations & Performance in South Africa

Section A: Demographics

- 1) Name and Surname
- 2) Number of years working in the railway industry
- 3) Number of years involved in railway signalling and/or operations
- 4) Role/job title

Section B: Railway Signalling Performance

- 1) How would you describe the current state and performance of the South African Railway Signalling System?
- 2) In your opinion, how does poor Signalling performance impact the performance of the railway operations, safety and the organization?
- 3) What are the key performance indicators (KPIs) used to measure railway signalling performance in South Africa?
- 4) Do you agree with how signalling performance is measured?
- 5) In your experience, what are the organizational factors that affect railway signalling performance?
- 6) In your experience, what are the systemic factors that cause poor signalling performance?
- 7) What are the human factors that impact signalling performance?
- 8) What are the external factors (e.g., other disciplines, external organizations, policies, regulations, environmental, etc.) that negatively impact signalling performance?
- 9) How does new projects and the roll out of new technology impact signalling performance?
- 10) What are the challenges faced in maintaining or upgrading the signalling systems in South Africa, and how does this contribute to poor performance?

Section C: Risk to the Organization

- 1) How would you define a risk?
- 2) In your opinion, what are the major risks, challenges, or hazards experienced as a result of poor signalling performance?
- 3) How does the above mentioned risks (from question 5, 6, 7 and 8) impact railway operations, safety, and the organization? *(Asked after questions 5, 6, 7 and 8 respectively)*
- 4) In your experience, do you feel that the impact of the risks associated with poor signalling performance is properly understood by the organization?

Section D: Next Steps / Closing the Gap

- 1) Considering the financial constraints, what are the priority areas or investments that should be made to address the critical factors affecting signalling performance?
- 2) Based on your experience, do you have any solutions (measures, initiatives, strategies or best practices) that could be implemented to improve the signalling performance in South Africa?
- 3) How can the collaboration between railway operations, infrastructure managers, and signalling experts be improved to address the critical factors and improve overall performance?

APPENDIX D: Detailed Codes generated through Thematic Analysis

Ageing Infrastructure	Lack of contracts	Poor Leadership
Anti-Theft Solutions	Lack of managerial skills	Poor management
Complexity	Lack of OEM support	Poor Quality of Maintenance
Constant change of leadership	Lack of Operating expenditure	Poor reputation
Derailments	Lack of official structure	Poor Solutions
Digitalization	Lack of Rewards and Recognition	Poor structure
Environment	Lack of skills transfer	Poor Talent Management
Extreme Heat	Lack of spares	Poor Technology Roadmap
Failure to understand the risks	Lack of strategic Planning	Procurement
Fatigue	Lack of support	Public Procurement Management Act
High number of Vacancies	Lack of Training & Development	Rationalization & Optimization
High stress environment	Lack of funds	Reactive Maintenance
High Unemployment Rate	Lack of investment	Research & Development
Human Error	Lack of OEM Support	Risk & Impact of Poor Signalling Performance
Impacts revenue	Lack of skills retention	Sabotage
Impacts safety	Lack of structure	Shift from rail to road
Impacts the economy	Lack of Talent Management	Skills
Inadequate Procurement processes	Latest Technology	Skills reward and recognition
Inadequate Resources	Leadership changes	Skills Retention
Inadequate Risk Assessment	Legacy Systems	Socio-Economic Climate
Ineffective Repairs	Load shedding	State of the signalling infrastructure
Ineffective management processes	Long lead time for spares	Technological Failures

Informal settlements	Loss of customers	Theft and Vandalism
Injuries	Loss of skilled employees	Throughput
Insufficient Maintenance	Loss of skills	TFR/PRASA interaction
Insufficient SCS skills and support	Loss of tonnages	TPPP
Interaction with External Factors	Maintenance Philosophy	Train Delays & Cancellations
Interaction with other disciplines	Near misses	Training and Development
Lack of accountability	Overtime	Unfavourable work environment
Lack of alignment	Overworked employees	Unhappy employees
Lack of budget	Poor communication	Upgrading Signalling Systems
Lack of consequence management	Poor decision Making	Work Environment
Social Imbalance	State of the art technologies	New technologies

APPENDIX E: Interview Transcripts

The interview transcripts and the analysis of the transcripts containing the main codes can be found in the link below:

https://drive.google.com/drive/folders/1WQr1R_7uQEcB5rDhm60rzsAGms3B?usp=drive_link

To ensure the confidentiality and anonymity of the research participants, the personal information and sensitive content have been redacted. Only a few transcripts have been shared to protect the sensitive and confidential information of the participating organization and research participants. This is according to the ethical considerations and permissions obtained from the participating organization.