A SYSTEMS APPROACH FOR USING HUMAN FACTOR MANAGEMENT STANDARDS TO PREVENT RAIL ACCIDENTS IN SOUTH AFRICA

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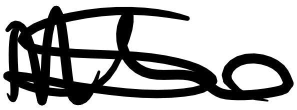
Declaration by the candidate

I declare that the research project, "A systems approach for using human factor management standards to prevent rail accidents in South Africa", is my own work and that each source of information used has been acknowledged by means of a complete reference. This dissertation has not been submitted before for any other research project, degree or examination at any university.



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Acknowledgements

“In everything give thanks; for this is the will of God for you in Jesus Christ” (1 Thessalonians 5:18). Foremost, I thank God the Almighty for covering me with His grace, for giving me the gift of life, the opportunity to work and to make a mark in the South African railway industry, and, lastly, for wisdom to see this journey through. His grace remains sufficient for me!

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To the victims of railway accidents in South Africa, this study is dedicated to all of you. Your lives mattered! To Abram Thuri Phago, who lost his life on the 24th of October 2016 in a train accident near Kaalfontein in the east of Johannesburg – May your precious soul continue to rest in peace and rise in glory “Setlogolo sa Baphuting”.

Abstract

The role of rail transportation across the world remains vital in enhancing economic development since it allows for mass transportation of passengers and goods. Equally, the need for efficiency and the safety of this mode of transport system cannot be underestimated. Within South Africa, there has been an alarming increase in the rate of railway incidents and accidents, which have resulted in huge costs for operators and the government. Despite South Africa's transport legislation being in place, including various railway safety standards and the oversight role of the Railway Safety Regulator, accidents still occur at a very frequent rate. It has therefore become necessary that a different view in managing risks be sourced.

The purpose of this research is to develop a systems approach for using human factor management standards to prevent rail accidents in South Africa. Human factors have been pointed out as the most prevalent causative factor of the high incidents of railway accidents, over and beyond other systemic issues which are crippling the railway operations. A broader accident/incident causation model, which considers the external environment, organisational issues, leadership and management issues and personal factors, has been analysed. A deeper inquiry into the governance structures, the overall risk management and compliance-related issues as other contributory factors to mitigate accidents in the railway sector were examined.

A critical review of the literature on the railway infrastructure, the governance of the South African railway system, human factor management standards and systems theory indicates the complexity that constitutes a railway system. This is demonstrated through the inter-relations of the various railway operating components, including the signalling system, Centralised Train Control system, the train describers and the track points. The governance structure of the South African railway system and hierarchical relations between various train operators, the South African Ministry of Transport, Railway Safety Regulator and the unit of analysis, namely Passenger Railway Association of South Africa (PRASA), is further discussed. Through the lens of a variety of authors, the human factor management and systems theory as it pertains to the railways is critically analysed. The analysis is demonstrated through the Swiss Cheese Model, which illustrates the importance of understanding the pre-conditions for accidents. The literature review is concluded with a discussion of the Human Factors Analysis and Classification System which has been advanced by Shappell and Wiegmann (2001) as one of the widely used models in the analysis of accident causation. The Human Factors Analysis and Classification System offers an explanation of the interrelatedness of various systems components in the management of human factors within the railway industry.

A mixed-method approach using a survey questionnaire and focus group discussion was adopted. The method included interviews conducted with safety-related workers at the Metrorail division of PRASA. Employees from eleven job categories all playing a role in ensuring safety in the movement of rolling stock were interviewed. The data were analysed using the computer program Statistical Package for Social Sciences version 22.

The results indicate that systemic factors influence the accident occurrence within the railway industry. Although the human factor emerges as the most prevalent cause of railway accidents, other factors, including the role of railway governance structure, safety rules and risk management education, cannot be ignored. In-depth root cause analysis of all systems components must be attended to in order to allow corrective actions that are holistic. From the results of the study, it is evident that systemic factors collectively influence the safety of the South African railway operations.

Keywords: human factor management, railway safety management system, railway transport, safety critical workers, systems thinking

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List of acronyms

ATSB	Australian Transportation Safety Bureau
BBC	British Broadcasting Commission
BOC	Bombela Operating Company
BOI	Board of Inquiry
BRICS	Brazil, Russia, India, China and South Africa
CEO	Chief Executive Officer
CIA	Central Intelligence Agency
CNN	Cable News Network
DoT	Department of Transport
DPE	Department of Public Enterprises
eNCA	eNews Channel Africa
EU	European Union
FRAM	Functional Resonance Accident Model
GAIN	Global Aviation Information Networking
GRC	Governance, Risk, Compliance
HAZOP	Hazard and Operability Study
HFACS	Human Factors Analysis and Classification System
HFM	Human Factor Management
HIS	Human Systems Integration
IEA	International Ergonomics Association

INCOSE	International Council on Systems Engineering
IoDSA	Institute of Directors South Africa
ISO	International Standard Organisation
NATMAP	National Transport Master Plan
NFLS	National Freight Logistics Strategy
NHS	National Health Services
NRSR	National Railway Safety Regulator
NTSB	National Transportation Safety Board
OECD	Organisation for Economic Cooperation Development
PRASA	Passenger Rail Agency of South Africa
RAIB	Rail Accident Investigations Branch
RCAT	Root Cause Analysis Technique
RIC	Rail Incident Commander
RSR	Railway Safety Regulator
RSSB	Rail Safety and Standards Board
SA	South Africa
SACAA	South African Civil Aviation Authority
SADC	Southern African Development Community
SANS	South African National Standard
SAPA	South African Press Association
SATAWU	South African Transport and Allied Workers Union
SCM	Swiss Cheese Model

SMS	Safety Management Systems
SOE	State-Owned Enterprises
SPAD	Signals Passed at Danger
STAMP	Systems Theoretic Accident Model and Processes
SWIFT	Structured What-If Technique
TAP	Train Accident Prevention
TCO	Train Control Officer
TFR	Transnet Freight Rail
TSB	Transportation Safety Board
UK	United Kingdom
UNTU	United National Transport Union
USA	United States of America
WEF	World Economic Forum

CHAPTER 1:
INTRODUCTION

1.1. Introduction

This study is an investigation of the systems approach in using human factor management (HFM) standards to prevent rail accidents in South Africa. The first chapter presents the background of the study and states the research problem. The chapter also provides the purpose of the study, research objectives and the research questions. The research philosophy, research methodology and significance of the study are also discussed briefly. Finally, the chapter overview and the conclusion of the study are provided. The next section provides the background to the study.

1.2. Background

Safety management is a critical factor in any operation, specifically in operations that can result in catastrophic loss of human life, such as the railway industry. Over the years, safety regulations have been continuously implemented and improved in countries that rely on rail for passenger movement. Within the railway industry, safety management systems (SMS) have attracted much attention as a framework to identify hazards, vulnerabilities, and risk and to put in place the appropriate mitigation measures to enable the highest level of safety performance in transport systems (International Transport Forum, 2018).

Hammerl and Vanderhaegen (2014) studied human factors in railway system safety in Europe and proposed the consideration of human factors in several life-cycle phases and in different risk perspectives in railway design and operation. Having found that a high percentage of accidents are attributed to human error, Hammerl and Vanderhaegen (2014) developed a straightforward model of working systems to structure the influence of human performance and to provide a practicable cause-and-effects diagram on railway accidents. Hammerl and Vanderhaegen (2014) pointed out the need for human factors integration in several phases of the railway system life-cycle, supported by European standards.

Ackermans (2019) reported that, in Canada, 31% of main track accidents (collisions and derailments) were caused by human factors; 92% of non-main track train collisions were as a result of human error, and human factors also caused 50% of non-main track train derailments. In Japan, Ugajin (2015) argued that while the number of accidents is not numerous, about 40% of train accidents are due to human error on the part of employees. Ackermans (2019) concluded that, today, the single largest cause of all train accidents is the "human element", and it is not only the "newbies" that cause accidents, but even experienced employees can make mistakes. Like Ugajin (2015), who suggested that it is a crucial on-going mission to keep accidents like these caused by human error from occurring again, and to contribute to establishing steps for preventing them, Ackermans (2019) posed the question: How can the system be made safer from those mistakes? Therefore, this study aims to find a systems approach for using HFM standards to prevent railway accidents.

Baysari, McIntosh and Wilson (2008), while studying the contribution of human factors to railway accidents and incidents in Australia, opined that there is little doubt that human error contributes to the majority of incidents and accidents which occur within complex systems, including the railway system. Human error includes accidents triggered by the actions of frontline personnel. Most unsafe acts are slips in attention (i.e., skill-based errors) associated with decreased alertness and physical fatigue (Baysari *et al.*, 2008). In more recent years, this assertion was supported by Strauch (2017), who echoed that slips and lapses happen when people are not focused on their work. Baysari *et al.* (2008) admitted that to prevent and/or reduce the number of accidents and incidents which occur, the railway industry must work towards reducing human error or making the system or organisation more error tolerant. This resulted in the need for this study to focus on a systems approach for using HFM standards to prevent rail accidents.

Hutchings and Thatcher (2019) found that South Africa has on average 4 500 railway occurrences annually, resulting in fatalities, injuries and damage to rolling stock. The railway safety performance trends in South Africa have fluctuated in the last ten years, indicating that there is a definite need for a review. The accident occurrence rate is still high even though interventions by the regulator and operators to improve railway safety performance are provided during investigations, indicating the rising need for a safety system review.

Within the South African context, the railway SMS was initially focused on technical and engineering safety in the early years of SMS development, which was between 2002 and 2006. As a result, volumes of technical and engineering safety standards were developed to meet the need. The engineering standards developed included commissioning and maintenance of the railway track, civil engineering infrastructure, electric traction infrastructure, rolling stock, train control systems and equipment, operational systems and railway interface with other modes and utilities. Later on, from 2009 onwards, the importance of human factors in the railway safety became eminent. The development of HFM standards was necessitated by the South African commuter rail operators, following a spate of rear-end collisions by commuter trains (Bouwer & Hubinger, 2014).

The railway industry in South Africa has seen major developments since the promulgation of the National Railway Safety Regulator Act (16 of 2002) (the NRSR Act). With the NRSR Act in place, the Railway Safety Regulator (RSR) came into effect and assumed the responsibility of being an independent safety regulator of railway operators within South Africa. Furthermore, the RSR was responsible for promoting railway safety performance, monitoring and ensuring compliance, and developing regulations and industry standards as stipulated in the NRSR Act. To date, the RSR has developed a series of standards per the guidelines of the South African Bureau of Standards (SABS) under the standard code SANS 3000 Railway Safety Management System. NRSR Act describes the railway safety management system (SMS) as a formal framework for integrating safety into day-to-day railway operations to ensure safe railway operations. The framework includes the various indicators, including safety goals and performance targets, risk assessment, responsibilities and authorities, rules and procedures, monitoring and evaluation processes and any other matter prescribed by the NRSR Act.

However, despite South Africa's advancements in railway safety standards, the volumes of technical and engineering standards that have been drawn up and the billions of rands being pumped into the railway infrastructure improvement, the rail incidents and accidents seem to be on the increase (Hutchings & Thatcher, 2019). The State of Rail Safety Report 2017/2018 shows that there has been an increase of 1.6% in train collisions compared to the previous reporting period (Railway Safety Regulator (RSR), 2019). Even though the 2020/2021 State of Rail Safety Report shows a decline of 38% in railway accidents compared to 2019/2020, the industry is warned not to celebrate this factor, as it is mostly attributed to markedly declined train kilometre travelled (Mabuza, 2021). The recent Metrorail train accident on 24 January 2022, where two brand new Metrorail trains collided, is a perfect demonstration of the accident plague that still hovers within the railway environment in South Africa. The preliminary investigation reports state that one of the train sets which was experiencing a technical fault, exactly a day after it was commissioned, rolled backwards during uncoupling, resulting in damages to both trains (News24, 2022). Most of the Board of Inquiry (BOI) reports from the Railway Safety Regulator state that these accidents are mostly due to human factors.

This study mainly focuses on developing a prevention system from an understanding of the role played by human factors in the continued prevalence of accidents within the railway operators of South Africa. In so doing, this research investigates the phenomenon in the context of the HFM standard (SANS 3000-4) framework that is used by the railway industry in South Africa.

The HFM standard in South Africa was implemented in 2011, as the South African RSR sought to manage the high prevalence of human factors in the operation of safe railway operations (RSR, 2019). The purpose of HFM is to reduce occurrences attributable to human error and, in addition, mitigate the risks associated with these errors in the workplace. The objective of this standard is to enhance the railway SMS and to assist railway operators to proactively manage the risks associated with human actions (RSR, 2019).

The HFM standard assists operators in managing the human factor aspects of the railway operator's safety critical and safety-related workers. Generally, "safety critical" workers are those whose performance error may result in worker injury, injury to co-workers or the general public and/or disruption of equipment, production or the environment (Fan *et al.*, 2016). Safety-related workers are defined as workers whose functions and activities have an impact on safe railway operations, either directly or indirectly. These include the certification of systems, sub-systems or components for introduction as new or modified technologies for a network, train or station operation (or a combination thereof). Additionally, safety-related workers are workers whose activities have an impact on the maintenance of systems, sub-systems or components which constitute a network, train or station operation (or a combination thereof), including the direct supervision of persons undertaking these functions and activities (SANS 3000:1, 2009).

From the two definitions above, safety critical workers are also safety-related workers because safety cannot be divorced from the function of movement of rolling stock. In this category of workers are train drivers, train assistants, train control officers, rail track maintainers, signal maintainers, electrical systems maintainers, rolling stock technicians and their supervisors.

The HFM standard, SANS 3000-4, is part of the SANS 3000, which provides minimum requirements to railway operators for the management of human factors for employees who undertake safety-related work (SANS 3000-4). The purpose of HFM is to reduce occurrences attributable to human error, by optimising human capital and by mitigating the risks associated with human factors in the workplace to acceptable levels. The standards require that operators follow a systematic approach to establish, develop or adopt, document, implement and maintain appropriate policies, processes and procedures for the implementation and management of risk exposures within their operations.

The HFM standard requires that the following three human factor aspects be managed: human factor in design, physical environmental factors, and organisational and psychological aspects. The human factor in design addresses the ergonomics of the work operation (man-machine interface). The physical environmental factors include noise, vibration, lighting, thermal environment, and hazardous substances and agents. The organisational and psychological factors include recruitment and selection; training and development; and medical surveillance. HFM acknowledges that not everyone can perform safety-related work in the railway industry. Therefore, operators should establish processes to ensure that competent people with certain physical and psychological attributes are selected for safety-related duties. Furthermore, to establish and maintain competency levels, operators should develop and implement plans to manage training and development. To ensure safety-related workers are physically and psychologically fit to perform their duties, the operator is also required to establish and implement a medical surveillance programme. Within the medical surveillance programme, many factors should be taken into account as they might impact fitness for duty and thus safe railway operations (SANS 3000-4). These factors include psychological and physical medical conditions, fatigue, substance abuse, medication, pregnancy and employee wellness.

1.3. Problem statement

Increased railway accidents, as experienced by operators of railway networks and users have led to devastating consequences in terms of loss of life and a negative impact on local economies and the environment. The RSR (2019/20) reported that the number of level-crossing occurrences for the 2019/20 reporting period increased by 20% over the 2014/15 reporting period (RSR, 2021). Derailments, collisions, level-crossing accidents, theft, vandalism and train fires cost the South African economy R961 million in the 2016/17 financial year, while the overall level of harm at level crossings recorded in the 2019/20 reporting period was 32,9 fatality and weight injury index (FWI) compared to the 32,5 FWI harm for the 2018/19 reporting period and a long-term average harm of 29,9 since the 2010/11 reporting period. This number reflects only the operational occurrences and security incidents mentioned and it was R70 million higher compared to the 2015/16 financial year (RSR, 2021).

The implementation of HFM standards in South Africa as a mechanism to reduce the occurrence of accidents among operators appears to have failed as incidents continue to persist. There are, on average, 4 500 railway occurrences annually that result in fatalities, injuries, damage to rolling stock and the environment (Hutchings & Thatcher, 2019). Railway safety performance trends in South Africa have deteriorated in the last nine years, indicating that there is a definite need to establish a stronger system (Hutchings & Thatcher, 2019). This is particularly important given that interventions by the regulator and operators to improve railway safety performance are provided during investigations, but the results are still not pleasing. This raises the need for this study to find a systems approach for using HFM standards to prevent rail accidents in South Africa.

The key research subjects are the safety-related workers who work in the accident-prone zones as they witness the accidents and events and have an idea of what could be causing or lacking, thereby resulting in the accidents. Transnet Freight Rail (TFR) and Passenger Rail Agency of South Africa (PRASA) are two dominant railway operators in South Africa. These two operators consistently record the highest number of occurrences and incidents annually (RSR, 2021), which is why this study chose one of them (PRASA) as the sample source. The public is most at risk during the night and morning peak hours, from 06:00 to 08:00 (16% of the daily people struck by trains are due to movement of rolling stock occurrences) and the extended evening peak between 16:00 and 20:00 (13%), when the daily Metrorail train density is at its highest (RSR, 2021). For this reason, the study sample was selected from within Metrorail.

The next section outlines the purpose of this study.

1.4. Purpose of study

The study aims to investigate the impact of HFM standards in rail accidents and how the findings can be used to improve safety among rail operators.

1.5. Research objectives

The research aims to determine why there continues to be high incidents of accidents despite the HFM standard in South Africa, what the reasons for these accidents could be and how the situation could be remedied. In order to achieve the aim of the study, the objectives of the study are as follows:

a) To investigate the role played by human factors in the occurrence of accidents;
b) To evaluate the effectiveness of the HFM standards in promoting rail safety;
c) To assess the extent to which compliance to regulations and standards contribute to safety among rail operators;
d) To examine the role that corporate governance plays in the implementation of HFM standards; and
e) To assess the importance of risk management as a promoting factor for HFM standards.

The next section provides the research questions of this study.

1.6. Research questions

To achieve the purpose of this study, the main research questions to be answered by participants were:

a) What factors influence human factor management in the prevention of railway accidents?
b) How can the identified factors be used to improve safety among rail operators?

From these main research questions, the following secondary research questions were formulated:

a) What are the perceptions of safety critical workers regarding causes of railway accidents in SA?

b) Which human factors are prevalent amongst railway operators and their role in railway accidents?

c) How does corporate governance, risk and compliance management influence human factor management standards?

The next section discusses the research philosophy and paradigm of this study.

1.7. Research philosophy and paradigm

Research philosophy, according to Saunders, Lewis and Thornhill (2019:130), is "a system of beliefs and assumptions about the development of knowledge". On the other hand, Žukauskas, Vveinhardt and Andriukaitienė (2018) described research philosophy as a system of the researcher's thought, whereafter new, reliable knowledge about the research object is obtained. The choice of the research philosophy is informed by ontological and epistemological assumptions which the researcher adopts when conducting a specific study. Therefore, the researcher will first discuss ontological and epistemological assumptions before discussing the research philosophy suitable for this study.

Before embarking on any study, researchers need to acknowledge their own paradigm, which is a term that describes the researcher's worldview (Mackenzie & Knipe cited in Kivunja & Kuyini, 2017). Paradigm constitutes the abstract beliefs and principles that shape how a researcher sees the world, and how they interpret and act within that world. It is the conceptual lens through which the researcher examines the methodological aspects of their research project to determine the research methods that will be used and how the data will be analysed. It is the researcher's duty to take a philosophical position regarding their perceptions of how things really are and how things really work (Scotland, 2012). Included in the research paradigm are ontology, epistemology and axiology.

1.7.1. Ontology

Prior to clarifying the type of ontology used in this study, it is important to define ontology. The paradigm of ontology is concerned with what constitutes reality. Al-Saadi (2014) defined ontology as "the study of being". It is concerned with "what kind of world we are investigating, with the nature of existence, with the structure of reality as such". The researcher enters this study from a point of existential identity of being an occupational medical practitioner (OMP), which is legally defined by the Occupational Health and Safety

Act (85 of 1993) as a person who holds a qualification in occupational health recognised as such by the Health Professional Council of South Africa (HPCSA).

In this study, the researcher locates herself as an expert participant in the implementation of HFM standards within the railway industry in South Africa. The researcher is a private medical practitioner with substantial experience as an occupational medical professional in the industry. In this role, the researcher provides professional services related to individual and group health matters within public and private workplaces. As a private consultant, the researcher has acquired wide knowledge and gained experience as a practising professional in projects aimed at implementing HFM standards for rail operators in South Africa.

The researcher considers her background to be a privilege for which she retains an expert "inside outside" view and understanding of the pertinent issues relating to railway safety, HFM standards and their role in railway accidents. This is a unique attribute that enriches the study by focusing the research on the core subject of solving the phenomenon of railway accidents.

The researcher is also aware of the subjectivity that emerges due to her active participation as an occupational medical professional working with South African rail operators. Based on the landscape of HFM and acknowledging the multitude of professional role players in the realisation of a comprehensive railway SMS, the researcher has the responsibility to furthermore accept the different professionals' ontological perspective on the subject matter, as will be revealed in the identification of participants and sampling sections of this study. The participants in the study can thus bring about objectivity, managing the bias that the researcher would otherwise carry. Objectivism is an ontological position that asserts that social phenomena and their meanings have an existence that is independent of social actors (Bryman & Bell, 2016).

1.7.2. Epistemology

Epistemology, on the other hand, is described as "a way of understanding and explaining how we know what we know" (Crotty, 2003, cited in Al-Saadi, 2014). Put simply, in research, epistemology is used to describe how we come to know something; how we know the truth or reality. Kivunja and Kuyini (2017:1) suggested that in order to understand the epistemology of a study, the researcher needs to ask questions like: What is the nature of knowledge and the relationship between the knower and the would-be known? What is the relationship between the inquirer and what is known?

In trying to articulate the response to the above questions, there are four sources of knowledge that the researcher can draw from. The sources are intuitive knowledge, authoritative knowledge, logical knowledge and empirical knowledge (Saunders, Lewis & Thornhill, 2016). With regard to the study at hand, authoritative and logical knowledge gained from prior research in the field of human factors and accident causation as well as data collection from participants was applied.

The study is aimed at deepening the understanding of a systems approach for using HFM standards to prevent rail accidents in South Africa. The fact that the researcher does not know if there is sufficient evidence that most railway accidents are caused by human factors or if other system elements contribute equally to accident causation is the basis for this study's epistemology.

To better understand the inquiry presented in the study, it is necessary to view it within its broadest context, with the aim of better comprehending and ultimately solving the problem. As explained by Salkind (2010), this epistemological position is aligned to pragmatism. Pragmatism is defined by Masoswere (2019) as a research philosophy based on the epistemology that there is no single approach to learning but many different ways of understanding because there are multiple realities. Pragmatists believe that the process of acquiring knowledge is a continuum rather than two conflicting and mutually exclusive poles of either objectivity and subjectivity (Goles & Hirschheim, 2000, cited in Kaushik & Walsh, 2019).

1.7.3. Axiology

Wilson (2016) asserted that axiology is concerned with the nature of value, including notable ethical issues that the researcher will encounter. Axiology is essentially concerned with the role that the researcher's own perception plays in the research (Tomar, 2014) because the values play a role throughout the entire research process. In this research, a mixed-methods approach was employed where value-free data were collected through questionnaires. Furthermore, the researcher considered measures for enhancing trustworthiness and reliability of the qualitative data. Interviews were used where the researcher's values are embedded. In short, values were included in the research process. Sometimes, these values were explicitly applied. For instance, judgemental sampling was chosen for interview participants, thereby choosing respondents whom the researcher perceived to be "adding value" to the study. Lastly, the collection of data using face-to-face interactions with participants requires that ethics be observed, where no harm is inflicted on the participants, including the researcher. This also included further precautionary measures such as seeking consent and permission, and the use of pseudonyms as some of the aspects considered for maintaining ethical standards throughout the research.

1.8. Research methodology

Mixed methods approach was used to collect data. Mixed methods research is defined by Tashakkori and Cresswell (2007) as a research in which the investigator collects and analyses data, integrates the findings, and draws inferences using both qualitative and quantitative approaches or methods in a single study or programme of inquiry. Mixed method design allows a research question to be studied thoroughly from different perspectives and furthermore allows the strengths of one approach to complement the restrictions of another (Regnault, Willgoss & Barbic, 2018). Supporting this view is Denzin (2010), who states the mixed methods design honours and celebrates paradigm and methodological diversity. This approach therefore gave the researcher a wider range of choices in choosing methods of data collection to fulfil the research objectives than when using either a quantitative or qualitative method only.

1.9. Significance of the study

The study seeks to build a body of valid and verifiable knowledge that railway operators can use to measure the effectiveness of the HFM standards as a mechanism to prevent rail accidents recurring and to mitigate the resultant consequences. In so doing, this research report will not only contribute to new academic knowledge but will also provide a valuable guide for the design of safer operating conditions by railway operators.

Several studies have been conducted on the phenomenon of railway accidents, as cited in Chapter 2 of this report. Hutchison (2017) studied the approach to accident investigation theory in the South African railway by focusing on the investigation process as a complex system. Another study relating to accident causation in railway accidents was by Tau (2017), who analysed the impact of lack of supervision on safety culture and accident rates. However, since the implementation of the HFM standards in 2011, no specific study has been conducted to establish the continued impact of HFM on railway accidents among railway operators in South Africa.

South Africa's railway sector is currently experiencing transformational changes under the aegis of the National Development Plan 2030 (NDP). The government has identified the sector as a major catalyst for national economic development in terms of the market-enabling function it plays as well as job creation. However, the persistence of unsafe conditions of usage in the railways draws attention to the need to continue finding ways of solving the safety challenges facing rail operators if the transformational agenda of the transportation system is to be achieved. This study will generate useful and valuable information that the academic community and the railway authorities may refer to since this study is the first to be conducted in South Africa. In the section that follows, the limitations of the study are provided.

1.10. Delimitations and scope of the study

The study is delimited to South Africa. For the scope, only one railway operator, PRASA, Metrorail, Gauteng, was considered. There are other railway operators besides Metrorail in South Africa. The operators include Gautrain (a rapid railway operator), Transnet (a freight operator) and multiple other operators, the bulk of which are privately owned. PRASA has over 16 000 employees, with more than 60% of the employees being in operational positions. The distribution of PRASA employees in order of size is Gauteng, Western Cape, KwaZulu-Natal and the Eastern Cape region while, in terms of dominant operations, PRASA commands 40%, TFR 56% and other operators 4% nationwide (RSR, 2021). Over the years, PRASA has experienced the highest number of railway accidents; TFR contributed 24% less train kilometres since the 2010/11 reporting period, yet it recorded an 8% increase in train collisions (RSR, 2021). PRASA contributed 322% less train kilometres since the 2010/11 reporting period, yet it recorded a 19% increase in train collisions (RSR, 2021). Limiting the study to PRASA was justifiable because the entity is the dominant provider of passenger rail services in South Africa. However, the findings of this study can be used by other railway operators who desire to create safer operating conditions for their workers and passengers. The next section offers an overview of the chapters.

1.11. Chapters overview

The dissertation is divided into five chapters. Chapter 1 introduces the identified research problem. It discusses the problem statement, needs and objectives for the research study and why such a research study is necessary for the railway industry in SA. The chapter also introduces the type of research methodology and sampling methods to be used. The chapter is concluded with a discussion on the significance and limitations of the study.

Chapter 2 discusses the work conducted by other researchers with regard to various key concepts in this research. The chapter starts by laying a foundation on understanding how the railway system functions, the various components thereof and how the South African railway operators are constituted. Causes of railway accidents, including the phenomenon linkage with HFM standards, are analysed. Furthermore, systems theory and application in the railway industry is explored.

Chapter 3 primarily focuses on the specifics of the research design and methodology to be used for conducting the research. The preferred type of research method to be used, the sampling plan for the identified population and the various data collection methods will be discussed in this chapter.

Chapter 4 presents the results of the data collected during the field survey. The data are presented through descriptive statistics and extrapolation in relation to the study's objectives.

In Chapter 5, the researcher provides a summary of the key conclusions that were drawn from the study. This last chapter contains a summary of the findings as gathered from the primary and secondary data sources; a designed system for the prevention of rail accident recurrence, and consequence mitigation is proposed as a recommendation and a conclusion of the study.

1.12. Conclusion

This chapter provided an introduction and background of the identified problem around the HFM standards in order to prevent rail accidents in South Africa. HFM is the basis for the problem statement, research purpose and main and corollary research questions. The study aims to identify and justify the need to develop an all-encompassing systems approach for using HFM standards to prevent rail accidents in South Africa. The next chapter reviews the literature on various aspects of the railway, including the governance of the rail industry, key technologies, railway accident reviews, the role of HFM in the rail operations, major railway accidents in South Africa, and the legislative requirements of HFM standards, among other aspects.

CHAPTER 2:
LITERATURE REVIEW

2.1. Introduction

This chapter contains a review of literature on the railway industry in South Africa and highlights the historical perspective of its development. The chapter furthermore focuses on risks involved in the railway operation, the central role that human beings play in the railway operations, the contribution of human error in railway accidents in South Africa and systems thinking as it relates to human factors and railway accidents. The literature review is organised thematically, covering and discussing the following topics: (1) background to railway industry development in South Africa; (2) the theoretical framework underpinning the study; (3) role players in the South African railway industry; (4) key technologies in the railway system; (5) review and analysis of major railway accidents in South Africa; (6) understanding the role of humans in railway operations; (7) unpacking legislative requirements of human factors standard – SANS 3000-4:2011; and (8) system approach, latent conditions contributing to railway accidents.

2.2. Background to the railway industry development in South Africa

The railway transport system is one of the basic transportation technologies that are imperative to the continuing development of industrialised nations. The railway is also one of the highly specialised transport systems. It is observed by Sussman and Raslear (2007) that the railway is different from other transport systems in that the routes of the trains are pre-determined by the track, not by the driver. The rail network in South Africa is extensive, totalling 20 986 km. The Central Intelligence Agency (CIA) (2019) world ranking for railway networks ranked South Africa number 13 in the world in terms of the length of the rail network. In comparison to other BRICS countries (Brazil, Russia, India, China and South Africa) with whom South Africa is in a trade partnership, South Africa's rail network is the second smallest, with Brazil at 29 850 km, India at 68 625 km, Russia totalling 87 157 km and the longest being China at 124 000 km (CIA, 2019).

The development of railways in other African countries continues to lag compared to South Africa. In the late nineteenth and early twentieth century, railway transport made an impressive start in Southern Africa, Sudan, and the Western and Eastern African block (Beck, Klaeger & Stasik, 2017). The colonial railway network in Africa started in Alexandria, Egypt, in 1852 and continued to grow until the 1950s in some countries (Chege, Wang, Suntu & Bishoge, 2019). However, in the vast parts of the continent, especially sub-Saharan Africa, railway transportation systems collapsed shortly after independence due to lack of skilled manpower to manage and maintain the infrastructure, and due to the dominance of road transportation (British Broadcasting Corporation, 2017). It is estimated that the total size of the railway network in Africa is 70 000 km, but most of it has fallen into disuse (Beck *et al.*, 2017). In many parts of the continent, the railway network is designed to cater for the extraction economy, with lines connecting sources of raw materials to coastal ports (Gwilliam, 2011). The extraction lines exist in Mozambique, Algeria, Sudan and Zambia, to mention a few (Global Mass transit report, 2014).

By far, the largest commuter rail networks in Sub-Saharan Africa are in South Africa, where Metrorail operates extensive services in Pretoria, Johannesburg, Cape Town and Durban, each carrying around half a million or more commuters daily, and much smaller loco-hauled operations in Port Elizabeth and East London (Bullock, 2009). In total, at its highest performance peak, Metrorail used to carry over 500 million paying passengers each year. However, in the recent years, this picture has drastically changed; as evidenced by the National Household Travel Survey conducted in 2020, the number of people using the train has declined by 80% since 2013 (StatsSA, 2020). Metrorail was operated as a distinct business unit within Transnet until 2006, when it became part of the South Africa Rail Commuter Corporation (SARCC) (World Bank, 2009). It had a fleet of 4 200 carriages (about 70% of which are operational) and ran services over more than 2 000 route-km, some of which it owns and some of which belongs to Spoornet (World Bank, 2009).

The railway network has been at the core of South Africa's development since its establishment in the second half of the 19th century in the Cape Colony. The rail network construction in the 1860s was a turning point in South Africa's connectivity with other territories of the world as railway lines penetrated the land connecting the main harbours to areas of agricultural production, such as the winelands or the breeding areas (Baffi, Turok & Vacchiani-Marcuzzo, 2018). The reticular pattern implemented led to the foundation of towns along the new rail communication axis. The colonial government's design of the railway system in South Africa in the 19th century was a complex system of interconnected railway networks linking the international economy to the country's mining areas of Kimberley and the then Transvaal (Fourie & Herranz-Loncan, 2015). Baffi *et al.* (2018) affirmed that the South African railway network was designed with penetrating lines connecting the main harbours to areas of natural and mineral resources. Besides the mines and harbours, it is also noted by Nair and Roberts (2017) that the apartheid government pursued a railway development policy that also catered for the needs of grain farmers by installing sidings linked to silos.

In addition, the geopolitical role of the railway in the transportation of labourers cannot be ignored. In the early 20th century, the railway played a major role in the transportation of migrant labourers, some from as far as Mozambique and Zimbabwe to the gold and coal mines of South Africa. A historian, Van Onselen (2019), in his book "The Night Trains: a masterly study into Southern Africa's murderous migrant system", details the substandard conditions that the Mozambican migrant labourers used to travel in while using trains. Besides the migrant labour system, geopolitics also influenced the transportation of labour in the metropolitan areas of South Africa. This fact is evidenced by Khosa (1995:167), cited in Thomas (2018), who observed that the transportation system in South Africa routinely involved transporting people of African descent from the outskirts of urban centres into the inner cities for work.

The evolution of the South African railway system from a socio-economic perspective from the 19th century onwards cannot be ignored. The end of the 19th century in SA was marked by the second Anglo-Boer War, which resulted in South Africa's transport infrastructure, mainly the railway, being damaged through sabotaged actions. The 20th century was set apart by unprecedented industrial and economic changes through the birth of South African democracy in 1994. However, PRASA (born 1990) has historically experienced a lack of investment, resulting in dilapidated rail infrastructure and rolling stock (George, Mokoena & Rust, 2018). With the change in the political structure, there was a requirement that the resources of the state serve the entire population of South Africa, as opposed to the previous regime (Apartheid), which was designed to serve only the minority. This new political construct came with an increased need for better and more railway infrastructure for economic and public transport. Fast forward into the 21st century, the railway industry is still addressing the inherent effects of inadequate infrastructure development and maintenance which had accumulated over the years (Department of Transport, 2015).

To this day, the railway network remains vital to the country's public transport system and it contributes about R160 billion to the national economy (Xungu *et al.*, 2017). As stated by Laurino, Ramella and Beria (2015), in most dynamic economies in Africa such as that of South Africa, the railway network is one of the essential components in the economy that connects ports to urban and industrial hinterlands as well as the transportation of labour to the mines and industries. According to the National Rail Policy Whitepaper (2017), the rail network is composed of 12 801 km of national network, 7 278 km of branch lines and 2 228 km of narrow-gauge urban network, as well as 80 km of standard gauge regional rapid transit network.

Initially, the railway network was steam-powered until its modernisation in later years in terms of electrification in the 1920s with the building of the Colenso Power Station (Mhlekwa, 2019). Gordon *et al.* (2019) pointed out that the track engineering design of the South African railway network system is predominantly modelled on the 1,067 mm (3 ft 6 in) gauge track also known as narrow gauge railway to manage construction expenses. The modern Gautrain line is a 1 435 mm (4 ft 8.5 in) high-speed standard gauge. Gordon *et al.* (2019) also recorded that about 80% of the track in South Africa is electrified and computerised and the rest is operated by diesel-powered trains. The commuter and freight railway systems are electrified differently, with commuter trains operating at 3 KV DC overhead, while heavy-duty freight systems use higher voltages of between 25 KV AC and 50 KV AC (both overhead).

Jones and Muller (2016) argued that the railway network began the process and acceleration of the modernisation of South Africa's economy. In the course of its modernisation, the South African railway network has continued to experience different safety challenges predisposed by human factors during its operation by different role players in the industry. Xungu *et al.* (2017) stressed safety on the South African railway network to be of critical importance and something that needs to be paid attention to as it is currently costing the country between R961 million to R1 billion a year in terms of accidents (RSR, 2021). From a Gross Domestic Product (GDP) perspective, South Africa has seen a decline in the railways contribution, with freight rail reaching 7.5% in 2020, which is down from 26.8% in 1990 (Engineering News, 2022).

2.3. Theoretical framework: Systems thinking approach

A theoretical framework is described by Grant and Osanloo (2014) as the foundation from which all knowledge for a research study is constructed (metaphorically and literally). Liamputtong and Ezzy (2005), as cited in (Nhan 2020) states that the theoretical framework fundamentally shapes the types of things the study focuses on as well as methods required for the study. Theoretical framework basically offers an anchoring base, for the literature review, research method and analysis. Theoretical framework for this study is systems thinking.

Aronson (1996), in his work on applications of systems thinking, stated that the systems thinking approach has proven value in solving problems that fall under the following categories: complex problems with multiple factors at play, where there is a recurrence of problems or problems are worsened by attempts to find solutions, where actions are affected by the environmental issues surrounding them and where solutions are not obvious. The railway accident problem in South Africa fits all criteria of Aronson's view in the application of systems thinking.

In resolving the ever-rising numbers of railway accidents, the traditional way of thinking by fragmenting problems into smaller understandable parts and reacting to events is not sustainable. This form of thinking only leads to quick fixes to problems, having individualistic approaches and thinking linearly. The railway operating environment has multiple complexities, and therefore problem definitions and solutions must be thought through holistically. To appreciate the holistic "bigger picture" view in managing the dynamic and complex contributors to railway operations and accidents, a systems thinking approach is presented herein.

The understanding of the concept of systems thinking has been espoused by many scholars including Richmond (1987), Senge (1990), Meadows (2008) and Plate (2010) to mention but a few. Arnold (2015) asserted that the greatest amount of work in the systems thinking field was conducted by Peter Senge. As such, he is referred to as "the father of systems thinking".

Peter Senge (2006) discussed systems thinking in a number of ways, which include "a discipline for seeing wholes … a framework for seeing interrelationships rather than things … a process of discovery and diagnosis … and as a sensibility for the subtle interconnectedness that gives living systems their unique character" (Senge, 2006:68–69). This discipline helps us to see how to change systems more effectively, and to act more in tune with the natural processes of the ever-changing world. Arnold and Wade (2015) emphasised the fact that systems thinking definition must contain three elements, namely purpose of the system, elements of the system and their interconnections. Arnold and Wade (2015) have more recently defined systems thinking as a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviours, and devising modifications to them in order to produce desired effects. These skills work together as a system. It is evident from the definitions that systems thinking encompasses a holistic approach to addressing problems, looking for underlying causes, recognising longer-term patterns of change, adaptable approaches and dynamic thinking. Systems thinking looks at synergistic ways of doing things with the purpose of arriving at a systems function. The systems approach is further supported by Zeid (2008:11), who argued that we lose something when we decompose a system into constituent parts. This is based on the fact that relationships and interactions between parts are of crucial importance to the system.

Gharajedaghi (2011) argued that the behaviour of a system is characterised by five principles: openness, purposefulness, multidimensionality, emergent property and counter-intuitiveness. These principles continually interact with each other and are a basis of systems thinking and design. Openness means that the behaviour of a system can be understood in its context. Within a system, controllable and uncontrollable factors must be understood. These factors include the contextual, operational and transactional environments of the business.

One cannot separate an understanding of a particular element from its contextual basis. Understanding context allows for prediction and preparedness in dealing with a particular element. In the case of the research, the factors that influence human factor causes need to be understood in a broader context. The factors include social, political, technological, economic and cultural contextual forces. In understanding this approach, we can further understand why humans behave in a particular manner, where an in-depth understanding of safety can be viewed from a societal perspective. The question of safety in South Africa is a big one and relates to other aspects of our lives, including crime, road accidents and railway safety. A society that is not safety-conscious is unlikely to comply with general health and safety rules.

Accepting a system's contextual environment leads to the ability to convert the uncontrollable variables into being influenced. The variables of a system that could be influenced are called transactional environment. This framework includes all critical stakeholders of the system, including customers, suppliers and regulators who determine certain minimum requirements in the provision of services. Operational environment, on the other hand, is defined by the systems engineering guide as those statements that "identify the essential capabilities associated requirements, performance measures, and the process or series of actions to be taken in effecting the results that are desired in order to address mission area deficiencies, evolving applications or threats, emerging technologies, or system cost improvements". They form the basis for system requirements.

The above argument is supported by several accident causation models, including the Swiss Cheese Model (SCM) and the HFCAS, which will be discussed in section 2.8. Depicted in Figure 2.1 below is the SCM. The model likens safety systems to multiple slices of Swiss cheese, stacked side by side, in which the risk of a threat becoming a reality is mitigated by the differing layers and types of defences "layered" behind each other. Therefore, in theory, lapses and weaknesses in one defence do not allow a risk to materialise, since other defences exist to prevent a single point of failure. It allows accident investigators to view human error problem in two ways: the person approach and the system approach.

The main aspect of this model of systems thinking is that latent conditions interact with the local triggering conditions; in case of safety barriers being unavailable, it could lead to an accident (Reason, 2016:10). From the analysis of the SCM, Hill (2007:11) argued that the SCM (Figure 2.1) explains how human beings contribute to the breakdown of complex, interactive and well-guarded systems such as rail transportation systems. Hill (2007) further added that, in such a system, accidents rarely originate from active failures or unsafe acts made by frontline employees alone. According to Reason, accidents result from the interaction of a series of flaws or latent failures, already present in the system. The latent failures are the factors that the researcher seeks to explore as contributory factors to human factor as a cause of accidents in the railway industry in SA.

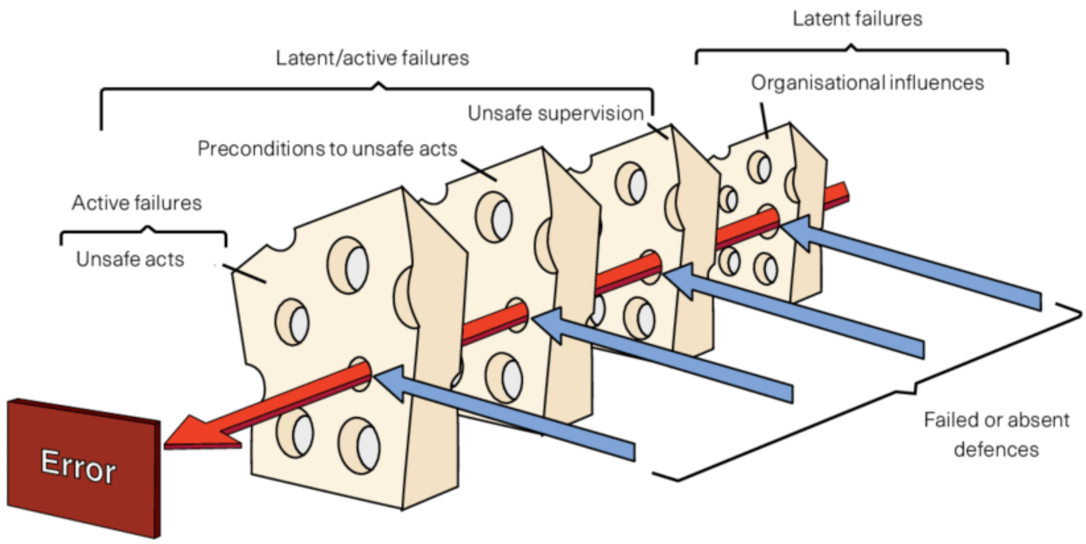

Figure 2.1: Swiss Cheese Model of Human Error

Source: Brennan (2019)

2.4. Governance of the rail industry in South Africa

The governance of the rail industry in South Africa involves various stakeholders. The following are the structures forming the governance of the rail industry.

2.4.1. Department of Transport

The rail network in South Africa is regulated by the Department of Transport (DoT). The DoT in South Africa is responsible for the regulation of all transport systems, including railway, maritime, air and road. The mission of the DoT as mandated by South African national government, is "to lead the development of integrated and efficient transport systems by creating a framework of sustainable policies, regulations and implementable models to support government strategies" (DoT, 2022). The work of the DoT ultimately contributes to the realisation of the vision of improved social and economic development articulated in the South African National Development Plan.

The regulation and control of railway transportation by national government in South Africa started in 1909 (Janse van Rensburg, 1996) and has over the years evolved until the establishment of DoT in 1998. National government regulation of the railway system is not uniquely South African phenomenon. Janse van Rensburg (1996) stated that the history of state intervention in the railway began in Britain in 1840. In 1937, the French government successfully completed a take-over of the railway system which had started in 1850 and, similarly, this occurred in Belgium in 1835.

As an overseer of the legislative framework, the DoT assumes a parental role in the hierarchical relationship between the DoT, the RSR and the operators in the railway industry in South Africa. The hierarchical relationship between the role players in the South African railway industry is depicted in Figure 2.2.

2.4.2. Railway Safety Regulator

Succeeding the DoT in management of railway operations in South Africa is the RSR. The RSR oversees and promotes safe railway operations of all rail operators in South Africa and those of neighbouring countries whose rail operations enter South Africa. The RSR offers appropriate support, monitoring and enforcement of railway standards guided by a regulatory framework.

The RSR was established in 2002 to promote and regulate safety in the railway environment. Before 2002, the South African railway industry was self-regulating in respect of standards and investigations, causing acute conflict of interest in its accountability on safety performance (Railway Safety Africa, 2011). The operators were essentially "players and referees" in the same game when it came to investigations of their own incidents and accidents. The DoT mandates the RSR to monitor the safety performance of the railway industry, a duty they undertake through investigations, compliance enforcement and annual reports based on analysis of occurrences given to them by railway operators (Hutchings, 2017).

Furthermore, the RSR through the National Railway Safety Act (16 of 2002) is mandated to develop regulations; conclude appropriate cooperative agreements or other arrangements with organs of state to ensure effective management of safe railway operations; and promote the harmonisation of the railway safety regime of South Africa with SADC railway operations (RSR, 2020). The RSR functions are described, as stipulated in Figure 2.2, under the NRSR Act (16 of 2002). The NRSR Act and its regulations constitute regulatory policies within which the RSR functions, while the audits, permits and investigations fall under the compliance component of the RSR. Hutchings (2017) summarised the functions of the RSR by stating that RSR is not only obliged to oversee the safety of railway operations, monitor and enforce compliance to safety standards but also to promote the railway as the best mode of transportation.

Regulation of the railway sector is a function of the national government in terms of policy formulation and safety regulation directly expedited by the DoT. The NRSR Act is the primary legislation in South Africa that deals with railway safety after it had been discovered that the Occupational Health and Safety Act (85 of 1993) was lacking. The NRSR Act has undergone two amendments that are in effect intended to streamline its operations; in 2007 by the Transport Agencies General Law Amendment Act (42 of 2007) and in 2008 by the National Railway Safety Regulator Amendment Act (69 of 2008) (Mashoko & Shivambu, 2015).

Mashoko and Shivambu (2015) also reported that the strength of the NRSR Act (2002) is that it is a permission-based Act, requiring railway operators to carry out duties only after the obtainment of safety permits. Huntley, Shai and Poya (2013) explained that rendering services as an operator requires receipt of a safety permit renewable at intervals from RSR. By this token, therefore, Hutchings (2017) stressed that RSR are by mandate obliged to oversee the railway safety by ascertaining levels of risk due to operators and issuing permits categorised as class A (high risk) and class B (low risk) accordingly. It is further stated by Hutchings (2017) that as a measure to managing occurrences, operators are required to put in place the development and implementation of railway SMS that comply with legislation. This requirement obliges operators to manage safety on the South African railway systems in a more structured way with full documentation of the operator's SMS. The SMS is directly proportional to the size and complexity of railway operations.

Besides developing standards and regulations to ensure railway systems safety, the RSR also conducts investigations to identify factors responsible for the railway occurrences. Investigations are a coordinated effort between the operator and the regulator. However, in determining occurrences, operators are supposed to carry out their investigations first and submit findings report to the RSR. Therefore, the RSR can, based on operators' findings, do their investigations to eliminate similar situations (Mashoko & Shivambu, 2015).

Within the mandate of the RSR is the compliance enforcement of standards and regulations. For operators that default on their safety requirements, the RSR issues penalties (Hutchings, 2017). An example of the extent of the penalty is revoking a safety permit. In 2018, PRASA was given two hours by RSR to elaborate on its safety measures and to respond to the RSR's intention to revoke its safety permit, following a train accident where two Metrorail trains in Kempton Park collided, resulting in at least 320 people being injured (ENW News, 2018).

The South African model of an independent regulator is shared by other countries where there is an established railway network. In the United States the Federal Railroad Administration, in the UK the British Office of Rail Regulation, in Australia the Office of the National Railway Safety Regulator and in Canada the Rail Safety Directorate serve the same role as the RSR in South Africa.

2.4.3. The operator

In Figure 2.2, the position where the operators sit in relation to the RSR and DoT is portrayed in light blue. Huntley *et al.* (2013) revealed that rendering services as an operator requires receiving a renewable safety permit renewable at intervals from RSR. The responsibility of the operators is to carry out its mandate in terms of the safe management of its operations (RSR, 2022). The NRSA describes the operators in the railway industry as "the person or persons who have the ultimate accountability for one or more of the following:

a) the safety of a network or part thereof, including the proper design, construction, maintenance and integrity of the network;

b) ensuring compliance of rolling stock with the applicable standards of the network; or

c) the authorising and directing of the safe movement of rolling stock on the network."

Mashoko and Shivambu (2015) affirmed this level of accountability by defining railway operators as falling in the following categories of businesses: railway network operator, train operator, station operator and rolling stock manufacturers.

George *et al.* (2018) pointed out that the South African railway system comprises two primary units. The first is the freight and passenger railway network, which is owned by state entities, namely Transnet and PRASA, and the second is the public-private venture Gautrain. PRASA has two divisions which operate the railway, namely Metrorail, which operates commuter rail services in urban areas, and Main Line Passenger Services (MLPS), formerly known as Shosholoza Meyl, which operates regional and inter-city rail services (PRASA, 2022).

Metrorail, which is the study's unit of analysis, operates in four of South Africa's provinces, namely the Eastern Cape, Gauteng, KwaZulu-Natal and the Western Cape. These regions operate independently of one another and report to the Metrorail Head Office in Johannesburg. Metrorail transports an estimated two million passengers daily, accounting for almost 15% of the people using public transport daily in South Africa. They operate at 468 stations with the rolling stock fleet consisting of 400 trains (PRASA, 2022).

Gautrain, a passenger rail operator which runs a relatively high-speed train is an 80-kilometre commuter rail system in Gauteng, South Africa. It is the biggest public-private partnership railway operator in Africa. Gautrain's day-to-day operations are under the management of Bombela Operating Company (BOC). The Gautrain network links Johannesburg, Pretoria and O.R. Tambo International Airport. It commenced its operations in 2010 to relieve the traffic congestion in the Johannesburg–Pretoria traffic corridor. The Gautrain operates between 10 stations within its rail commuter corridor (Gautrain, 2022).

On the other hand, Transnet is the major player in freight transportation in South Africa. Transnet owns, operates and maintains some of the country's principal transport assets through its Freight Rail, Engineering, National Ports Authority, Port Terminals and Pipelines divisions. TFR operates the national long-distance rail network and, in addition to its own capacity requirements, also provides access to PRASA's long-distance trains (National Rail Policy Whitepaper, 2017). Just like PRASA, Transnet is a state-owned enterprise but is falls under the Ministry of Public Enterprises.

According to the National Rail Policy Whitepaper (2017), there are also some 250 small rail operators within the railway transport in South Africa. These operators include passenger and freight operators. Examples of freight operators range from railways integrated into industrial and mining production to private sidings in, for example, the agricultural sector. Examples of passenger operators range from world-class hotels-on-wheels, the most famous of which is The Blue Train, to day trippers using steam locomotives and heritage coaches (Department of Transport, 2015).

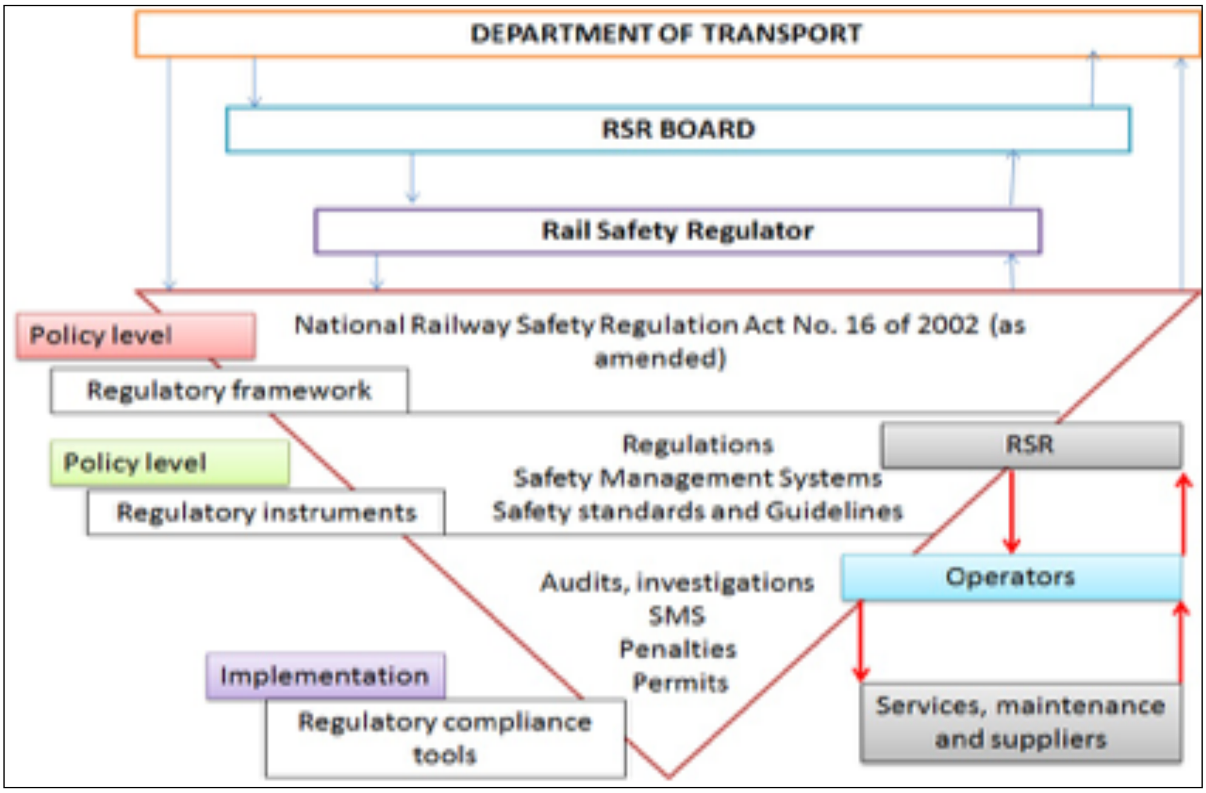

Figure 2.2: Role players in the railway industry in South Africa

Source: Huntley *et al.* (2013)

2.5. Key technologies in the railway system and safety

The infrastructure requirements that allow coherent operations of railway systems are complex and consist of certain key technologies that are central to the system operating in a safe manner. Railway systems, from manufacture to operation, are highly technical in terms of engineering works and human resource requirements. The railway system comprises a broad and complex infrastructure characterised by technological and material properties (Fourie & Zhuwaki, 2017).

The complexity in the infrastructure and material covers large areas of the railway system as outlined in detail by Profillidis (2016). He explained the complexity of the rail system when he documented that the railway industry is characterised by systems that comprise infrastructure such as sub-grade, sub-ballast, ballast, sleepers, fastenings, rails and electrification equipment; engineering systems, including telecommunications and control/safety; and locomotives, passenger vehicles, freight vehicles, high-speed vehicles and metro vehicles. Profillidis (2016) described the railway system more from an infrastructure perspective and focused on overall components of the railway system from the railway tract to the rolling stock. In addition to the stated components, Brahimi *et al.* (2017) described the railway as infrastructure comprising linear assets spanning long distances with large populations of components, one of them being the Overhead Contact System (OCS) which consists of cables and pulleys carrying necessary electrical energy to the train.

The railway infrastructure as described by Jidahi (2015) comprises the following components: "the tracks (railway lines), Perway (bridges, platforms), signalling technology (robots, points machines and relay rooms), telecommunications systems (surveillance cameras), PA systems and Centralised Train Control (CTCs) and the electrical systems (cables, power lines, gantries)". Understanding the aforementioned railway components is central to the study as it links with the functions of safety critical workers with whom the HFM standard is concerned. Before elaborating on the human error element that comes with managing each railway infrastructure component, the author will explain the role that the Perway, signalling, telecommunication and electrical system play in safe railway operations. Figure 2.3 is a diagrammatic depiction of the railway infrastructure which is discussed further in the sections that follow.

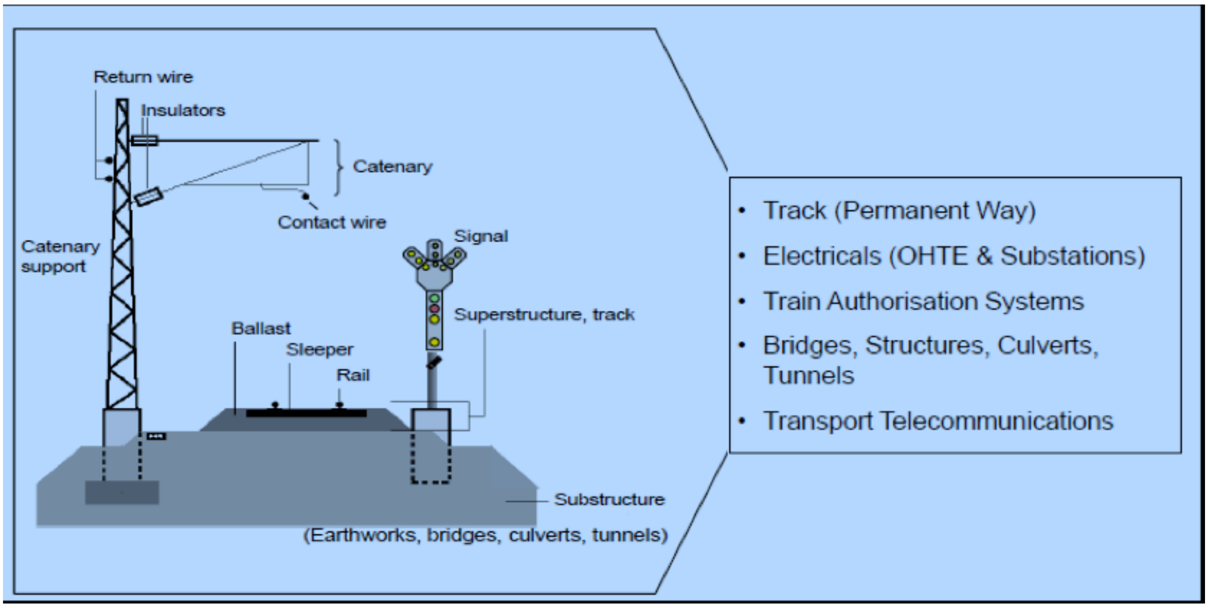

Figure 2.3: Railway infrastructure components

Source: Adapted from Mukwena, Wessels and Pretorius (2019)

2.5.1. Perway system

The Transportation Engineering (2016) defines a permanent way (Perway) as the combination of rails, sleepers, ballasts, fixtures and fastenings. The function of the Perway is to give the track a surface stability, give the train a "road" and prevent trains from overturning, should there be a derailment. Perway is a major factor in determining the speed limits as well as the size and weight limits for wagons and trains (Martland, 2001). For the train to move properly, all components of the Perway must work together. The rail sleepers can be wooden or cast iron; they are laid transverse to the track alignment to support the rails and to transfer the load from the rails to the underlying ballast. Ballast, on the other hand, is defined by Transportation Engineering (2015) as "a layer of broken stone, gravel, moorum or any other material placed under and around the sleepers to distribute the load from the sleepers to the formation and for providing drainage as well as providing lateral and longitudinal stability to the track. The track consists of the two steel rails secured on sleepers to keep the rails at the correct distance apart (the gauge) and capable of supporting the weight of trains." A visual representation of the Perway is depicted in Figure 2.4.

Substandard engineering principles and lack of maintenance can cause Perway failure and lead to accidents. Several studies, including the U.S. study by Liu, Saat and Barkan (2012), found the major cause of derailment in the railway to be broken welding in rail sections followed by track geometry defects. It is asserted by Tracy and Reznik (2015) that, according to data from the Federal Railroad Administration in the U.S., 15% of derailments are caused by broken welding. This is because pressure between the steel rail and train wheels can cause wear and tear of the steel structure, especially on the weak points where the rail has been welded. With lack of maintenance, the welded points can break, resulting in an uneven and ineffective surface for the train's wheels. A train that travels across such conditions may suffer stability issues and derail. In South Africa, Perway defects also contributed to 23% of railway accidents (Huntley *et al.*, 2013). Perway failures disrupt operations as well as present safety hazards and cost complications to infrastructure maintenance.

Figure 2.4: Perway system

Source: Adapted from Engineering News (2013)

2.5.2. Railway points

Related to the Perway infrastructure is the railway points. One of the key infrastructure components in railways is the switch and crossing (S&C) system, also known as a turnout or railway points system. The railway points system has been explained in detail by Hamadache *et al.* (2019) in their UK study where they asserted that a railway points system is a safety critical asset that is always required to be highly reliable since its failure or downtime can cause system delay or even fatal accidents. Points are used to move trains from one track to another. They are used for purposes of enabling the movement of trains from one line to another and to allocate and control train movement on specific lines, especially where two lines are joined or at a junction. The points also prevent unauthorised movements of trains, including the unlawful deviation of a train from its intended direction, which can result in an accident or collision with another train. Previously, these were manually operated but are currently switched electronically. Figure 2.5 is an illustration of the railway points.

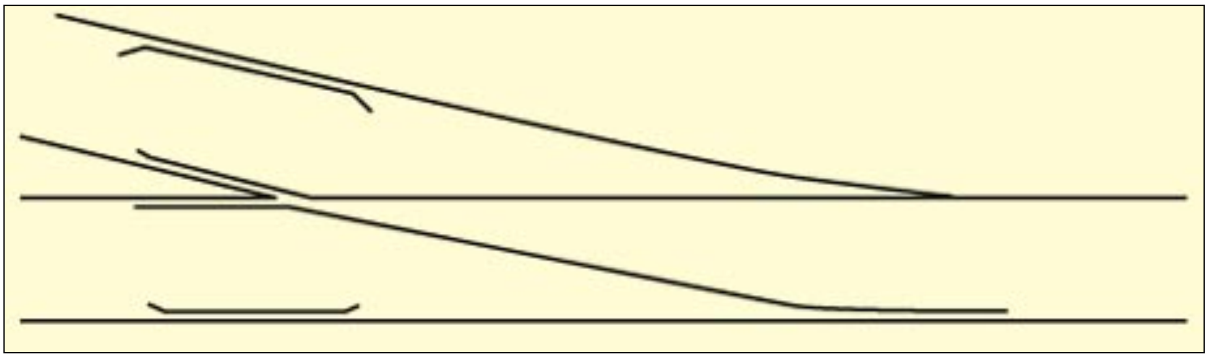

Figure 2.5: Railway points

Source: Metrorail (2022)

2.5.3. Signal systems

A signal system (Figure 2.6) is an apparatus that is part of the communication system used to provide visual information to a train driver about the availability of a specific line. Signalling systems are used to control train movement to and from the communication system between the train and the operating CTC, allowing safe movement of trains at maximum permissible speed and minimum headway. Signals are usually located at train interchange stations. Signalling uses spell check systems to regulate and safeguard the movements of trains at crossings and to ensure safe travelling distances between trains using the same track. As stated by Dhillon (2007), signals are very important because a train passing a signal displaying a stop is a very dangerous occurrence, as this can lead to an immediate conflict with another train. This contravention is referred to as signal passed at danger (SPAD). Dhillon (2007) advanced the following human factor causes of SPADs, namely poor vision, misjudging the brakes, oversight or disregard of signals, over-speeding, driver falling asleep and misunderstanding of signalling aspects.

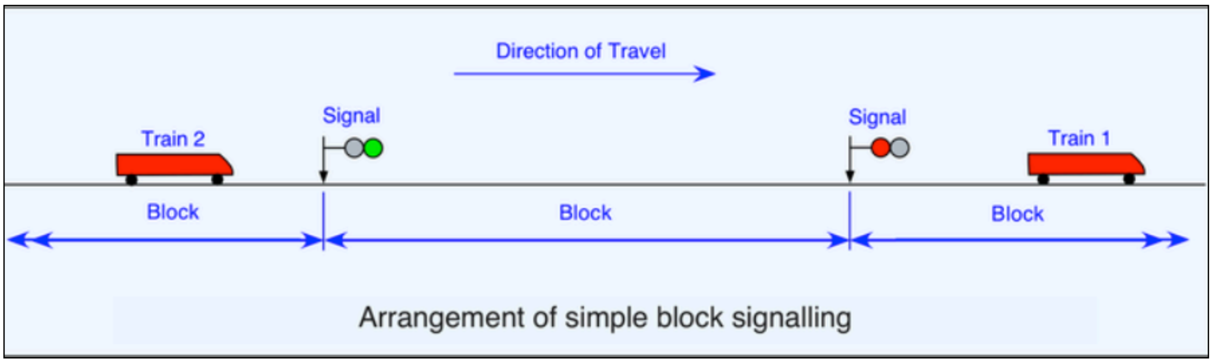

Figure 2.6: Railway signalling system

Source: Railway Technical (2019)

2.5.4. Centralised train control

CTC is a control room where a number of signals are controlled. CTC facilities have control panels that enable operators to remotely monitor and control the movements of trains in a particular area. According to Metrorail, panels are like a map on the wall and on the table with sets of points, route maps, diagrams and displays, which are used to display train information such as the direction of a particular train. There are diagrammatic representations of the geographic layout of the physical tracks with illuminated route lights to show which signal the driver is facing (Metrorail, 2022). Train traffic controllers manage the CTC, also called traffic planners, train dispatchers or signallers. The traffic controllers are engaged in a remote-control process, monitoring, and manually taking actions that control train paths, points and signals. If required, the traffic controller reschedules the traffic plan should the train traffic situation change (Andreasson, Jansson & Lindblom, 2019). As with air traffic controllers, railway traffic controllers are the central point of communication with one or more train drivers, maintenance workers, technicians and even security personnel. CTC becomes the first point of call if something goes wrong with the train.

CTC uses train describers to identify trains in order to assist the traffic controllers to control the trains. Metrorail explains that the main function of the train describer is to display the number allocated to a particular train on the CTC diagram, thereby showing the operator the location of the train. The number follows the train as it progresses from station to station on the diagram in pre-determined steps. The operator knows the location of all the trains under his control (Metrorail, 2022). The CTC uses an interlocking control mechanism to interface between the operator (CTC) and the equipment. It combines and interlocks the points, signals and track circuits to ensure no conflicting movements occur. Wang (2018) explained that CTC system combines professional techniques such as railway signalling, railway communication and railway transportation with modern information technologies such as computers and the Internet. This equipment is used to detect the occupation of a train on a particular line.

As depicted in Figure 2.7, CTC centralises the operation of railroad signals, switches and crossings in the hands of one individual operator. Hay (2003) elaborated that the CTC operator oversees a computerised illuminated track diagram board that shows by appropriate colour lights the position of each switch, signal and the location and movement of all trains. As Wang (2018) asserted, the CTC operator makes judgements regarding various safety critical issues of the railway, which includes the meeting and passing points for trains and furthermore sets the switches and signals accordingly.

Accidents related to the CTC have been shown to be from a malfunction of the CTC or CTC operator-related problems. NPR (2011) discussed one of China's most horrific high-speed trains in 2011. The accident resulted in 40 fatalities, when two high-speed trains collided, falling off a bridge 50 feet above the ground. Severe lightning struck the CTC and caused a fault in the control system, which failed to restart while other trains were on the circuit. The loss of communication and faulty signals resulted in the fatal collision.

Figure 2.7: Centralised train control system

Source: Network rail (2022)

2.5.5. Stations

Train stations are the hubs of a railway system. Connor (2015) described them as focal points at the various intervals where trains stop to collect and deposit passengers and goods. There are several designs of stations; the structure will depend on the purposes for which it has been established. Such designs include side platform stations with a ticket office and other passenger facilities such as toilets. A footbridge connects the platforms for passengers to cross over to the alternative side. Depending on the area infrastructure, other stations have island platform stations that serve as two tracks passing on either side of the station; a bridge or underpass is provided to access the facility. In areas with space limitations, the stations are normally on an elevated platform. The main consideration for the design of a station is that they must be comfortable and convenient for passengers and their operations should be conducted in such a way as to enable efficient use of the infrastructure and to meet high levels of compliance to safety standards (Connor, 2015).

In a study conducted in India by Nayak and Tripathy (2018), several station-related factors were noted as susceptible incidents that can lead to train accidents. Amongst these factors were an upslope gradient of a train station which can allow the train to slide back, should brakes not be properly fastened. Another factor noted was wrong reception of a train, where the train coach/head is placed in a track that will allow shunting (pushing or pulling part of a train apart) in face of an approaching train. Other accidents that occur due to station- and platform-related incidents are largely passenger related and not due to train-related technologies. Hunter-Zaworski *et al.* (2017) observed a number of factors contributing to injury incidents that are not specific to a particular mode of rail transit. The accidents include train door design (width and mechanics during opening and closing), intoxication and suicides, footwear, distracted passengers, pushing and crowding, and wheelchair incidents (Jiang *et al.*, 2020).

When looking broadly at the complexity and functional requirements of railway technologies, it is evident that all key technologies in the railway need to function optimally to ensure that there are no incidents and accidents. A study by George *et al.* (2015) concluded that there is a significant and increasing maintenance backlog of track infrastructure along the general freight and branch line network, especially on PRASA's passenger rail network. In addition, George *et al.* (2015) also observed that there is an increasing trend of theft and vandalism, and an underinvestment of resources required to maintain the condition of certain network sectors. This has left the overall condition of most rail networks in a poor state.

A report by Frankson (2018) stated that "since 2010, on average, the South African railway system experiences one (extrinsic) railway incident and one (intrinsic) operator occurrence every sixteen minutes". The report further noted that close to 60% of occurrences can be directly attributed to human factors, while Perway defects contributed 23% and rolling stock-related issues 10% of the enumerated accidents.

2.6. A review and analysis of major railway accidents in South Africa

The context of rail passenger and freight services implies that a number of occurrences exist in the course of their operations. Railway occurrences by definition of the RSRA are railway safety incidents and accidents, for example train derailment, collisions and level crossing that may cause damage, injuries and fatalities. Railway accidents are of a serious nature, whether they arise on railway premises or out of railway activity due to natural or man-made causes, as they may lead to grievous injuries or loss of many lives and damage to rolling stock.

PRASA's trains have been identified as the greatest threat to personal safety on the country's rail networks, according to the RSR's report of 2018. Some of the railway accident reports alluded to possible causative factors, for example miscommunication between driver and controller noted as the cause of the Pretoria train crash (Timeslive, 2019), and deadly derailment due to train track vandalism, which was noted by Timeslive (2019). With each railway accident, the RSR is mandated to conduct an enquiry and to release a report on the causal factors of the accident. Over the years, the RSR has reported that in a number of forums where train occurrences were discussed, human factors have been noted as the biggest contributor to the high number of incidents (News24, 2015). The human factors listed include drivers not adhering to rules of operational speed restrictions, train control officers not complying to the rules, train drivers found to be inexperienced, little supervision from supervisors and line managers and reportable medical conditions not disclosed by affected staff members (Bouwer & Hubinger, 2014).

On the other hand, PRASA leadership has blamed vandalism and cable theft as the major contributory factor to the accidents. The effect of lack of electricity due to cable theft results in the use of a manual signalling process. Pressreader (2018) observed human error in the manual signalling process as a major cause of accidents involving PRASA commuter trains over the past few years. Below is the narrated summary of some of the major train accidents that have occurred in the past 10 years and the root cause analysis of the accident as stated in the various RSR BOI reports.

Accident 1 – Mzimhlophe 2011

On 19 May 2011 at Mzimhlope Station, Soweto, Gauteng province, two trains collided due to contravention of rules by passing intermediate block signals. The collision resulted in 857 commuters' being injured; even though no fatalities were registered, both trains were severely damaged (Tau, 2011). The primary causative factor of the accident was reported to be driver error. The report stated that "the driver of the train that collided with a stationery one is prone to substandard acts. He exceeded the speed limit and passed 2 danger point signals" (Polity, 2012). A further analysis of the BOI report into Mzimhlophe train accident stated that there was a power outage at George Goch signal cabin (the main signal cabin which controls route to Mzimhlophe station) and no backup generators. The two-way radio communication was not working either. One cellular phone was utilised to control 5 trains.

The report further acknowledged that there was a high vacancy rate on train drivers and train control officers (TCO) (RSR, 2022).

Accident 2 – Blaney 2015

On the morning of 20 May 2015, at approximately 11h30, the Shosholoza Meyl train en route to Johannesburg and a TFR train en route to East London collided head-on in the section between Blaney and Southdown stations in the Eastern Cape province (News24, 2022). The accident resulted in two MLPS personnel being fatally wounded, commuters sustaining severe injuries and extensive infrastructure damage. A background report on the railway infrastructure on the route where the accident occurred revealed that the potential old train control system was a contributory factor to the accident. The area where the accident occurred was not signalled but operated by an old train control system, called the track warrant system (TWS).

The TWS is defined by the General Code of Operation Rules (GCOR) as a verbal authorisation system used to authorise trains to occupy main tracks (Lundsten, 1998). The TWS communication system warrants the TCO and the driver to repeat each other's instructions to ensure its correctness. According to the TFR rule book, the message relay should be communicated as follows: Step 1: Person giving an instruction or transmitting information (in this case the train driver) initiates the process. Step 2: The person receiving the message (in this case the TCO) repeats the message to the sender. Step 3: The sender (the train driver in this case) verifies correctness and then acknowledges received message.

The BOI revealed that the TCO never repeated the message and, as such, was unaware that the same section that he authorised was already occupied by another train. This human error resulted in the unfortunate head-on collision. A further inquiry in the accident causes revealed the other systems challenges which contributed to the accident. Included in this was possible fatigue, unsupervised work and noise interference. The Blaney accident report expanded the reasons for fatigue in relation to the work roster plan. The CTC work roster analysis showed that the TCOs work a 12-hour shift for 4 days and are off duty for 2 days. This is followed by 12-hour shifts for 8 days and being off duty for 4 days. This implies that by the eighth day shift, the TCO has worked for a total of 96 hours. Three out of the eight are night shifts and five are day shifts. The BOI revealed that hours worked in the train control environment increase the risk for developing fatigue and may result in TCOs making mistakes.

In addition to the number of hours worked in the CTC, the other concern was the lack of a suitable time for the TCOs to take breaks from their stations. The time when employees at the CTC can take a break from their stations was not visible in their schedules or recorded anywhere. The other risk factor for fatigue was continuous work for over 5 hours without at least a 30-minute break. The TCO on duty in the TWS Office at the time of the collision felt that she did not receive adequate formal training on the application of the newly installed on-board computer system. The crew on board the TFR train furthermore reported that the on-board radio handset was malfunctioning. Compounded with all these, the investigation found out that there was a high vacancy rate, with posts not being filled for a considerable period of time. At the time of the incident, there were only 8 TCOs instead of the approved staff complement of 16. This posed a challenge as the TCO co-ordinators could not fulfil their supervisory duties because they also have to control trains. The shortage of staff has also resulted in the excessive number worked by the CTC employees (RSR, 2022).

Accident 3 – Booysens 2015

Metrorail reported yet another train accident the afternoon of 17 July 2015 at Booysens, Johannesburg, Gauteng Province, where poor maintenance and old systems were blamed for the accident (ENCA, 2022). To aid in the explanation of what occurred in the rear-end collision of two trains, their train numbering system is used. Train no. 9404 collided with the rear-end of Train no. 9934, which had stopped at a signal to indicate danger (a red signal). The incident occurred in the section between Booysens and Crown Stations. The BOI was unable to determine the speed at which Train no. 9404 was travelling as the speedometer was faulty. The collision resulted from the signal incorrectly displaying a yellow (proceed) aspect inside the CTC. The TCO gave Train no. 9404 permission to proceed to an already occupied section of the rail track.

The evidence revealed that a false feed had been erroneously connected to the relevant track circuit relay controlling the system, which prevented the track circuit from detecting Train no. 9934. Periodic maintenance procedures and checks were not performed on safety critical equipment, (including signalling equipment, systems within the TCO environment, as well as equipment within the trains), due to resource constraints, lack of training or understanding and shortage of personnel. The shortage of spares affected the ability of technicians to adequately attend to faults and ensure that this is done in line with standard procedures.

Further findings revealed that the technician did not adhere to accepted and required procedures when attending to a fault, which follows the sequence: checking, testing after repairs and reporting back. No refresher training was provided to TCOs on the system that they use daily to perform their duties and there was lack of supervision of signal personnel and TCOs by supervisors (RSR, 2022).

Accident 4 – Kroonstad 2018

As an example, the last accident that the author focused on is the infamous inferno train, which occurred on 4 January 2018, whereby an MLPS train hauling 18 coaches collided with the second trailer of an articulated truck. The collision occurred at a railway level crossing which is approximately 20 km from the Kroonstad station in the Free State Province. From the said occurrence, 24 passengers on the train lost their lives, some bodies burnt beyond recognition and more than 260 passengers suffered serious to moderate bodily injuries (Timeslive, 2018). The BOI revealed following underlying factors.

The locomotive's black box report revealed that the train driver did not apply the brakes at any point, even though he had observed the truck 500 metres prior to impact. The arching of the 3 kV DC overhead track equipment did not switch off as expected during circuit braking. The lack of circuit braking during the collision allowed the coaches to catch fire soon after the accident. The coaches involved in the occurrence did not have enough emergency exits. A contributing factor to the number of injuries that occurred was that the windows on the coaches were too small for a human being to escape through them. Reviewing the events leading to this accident revealed that PRASA had leased the used locomotives from a company called Sheltan. This lease necessitated the RSR to give a conditional utilisation permit. The process leading to the granting of the permits to operate the locomotives leased by PRASA during December 2017 by the RSR was a concern especially in circumstances where the approval was granted with conditions which appeared not to have been met by PRASA. No risk assessments were conducted before the introduction and the use of the affected locomotive by PRASA; also, the coaches used were not fire resistant (RSR, 2022).

From the cited train accident examples, there is clear evidence that the causes of train accidents are multifactorial. However, the role of human factors in the centre of the complex railway system cannot be ignored. Williams (2009) opined that human error remains a contributor to railway incidents and accidents. He further alluded that consequences of human error are not only evident at the front end of railway operations, such as those involving train drivers, signallers and shunters, but also within the complex organisations of individuals responsible for controlling, supporting and managing the railway system (Williams, 2009).

Various RSR reports echoed human error as the driving force of accidents within the South African railway. Following the Mountain View accident in Pretoria, Gauteng province, in January 2019, the newspaper headlines by Pretoria News stated “Human error behind fatal train crash” (Pretoria News, 2019). Another publication by Watson (2018) stated that the RSR has blamed human error for rear-end collision between two Metrorail trains at a station in Germiston, Gauteng province (Watson, 2018). Of the many examples that can be pointed out is the Selby accident, also in Gauteng province in 2015, where Metrorail stated that human error was responsible for the accident.

The RSR surmised that human error accounted for 71% of railway accidents happening in South Africa (RSR, 2022). On the other hand, while the labour unions in the railway industry are not denying that human error is the leading cause of accidents in South African railway, they are of the opinion that a focus on human error allows the railway operators to ignore other contributing factors, such as poor maintenance (Swart, 2015). “Maintenance is so poor that cracked rails, broken wheels lead to many of those accidents. Training is also very poor; this should be redressed to prevent further loss of life,” claimed Swart (2015). Analysis of the root cause of the accidents discussed in this section above, also cited, revealed lack of supervision, poor personnel training and inadequate staffing as other emerging contributory factors to railway accidents.

The influence of human error in railway accidents is not a uniquely South African. An analysis by Nayak *et al.* (2018) of Indian railway accidents between 1980 and 2010 revealed that the percentage of accidents and incidents caused due to human error was as high as 70%. In Europe, a study conducted by Kyriakidis, Pak and Majumdar (2015) on the historic analysis of UK railway accidents also exposed similar findings to the Indian study. At least 75% of the fatal railway accidents between 1990–2013 in the UK were due to human error involving travelling at exceeding speed, SPAD and signalling/dispatching error. To further demonstrate this consistent finding, the conclusion from the USA study by Lowry (2021) stated that “human error can be rooted in negligence, whether the fault lies with the railroad employee or the company. Railroad company policies can put their employees in the position of cutting corners to meet maintenance deadlines or budgets.” This affirms human error as the most common cause of train accidents, even in the USA.

Accident 5 – Between Sandhills and Orchards 2019

A joint (TFR and PRASA) BOI investigated the level-crossing collision between Passenger Train no. 17007 (Premier Class) and a white Isuzu bakkie, at a level crossing situated between Sandhills and Orchards, north of Worcester, at approximately 14:14 on Friday, 15 February 2019. Two passengers were fatally injured and five others injured and hospitalised.

The level-crossing collision was caused by the bakkie driver failing to stop and observe the oncoming train before crossing over the railway line. The root cause could not be determined as the bakkie driver is deceased. The RSR planned to put the following measures in place to prevent similar accidents: (1) Conduct joint level-crossing awareness; (2) Engage the local municipality to re-paint faded GM7 (stop wording) and RTM1 (stop line) at the level crossing; and (3) Conduct physical assessment in line with the requirements of the latest level-crossing standard (SANS 3000-2-2-1:2012), (RSR, 2020).

Accident 6 – Roodepoort: Prasa and Transnet collision 2020

The RSR (2020) reported that the PRASA train, the Shosholoza Meyl, travelling from Cape Town to Johannesburg collided with a TFR train between Horizon and Princess stations in Roodepoort, Johannesburg at approximately 21h25 on 13 February 2020. Over and above one fatality, one passenger was critically injured and admitted to hospital while eight other passengers escaped with minor injuries. The Maraisburg CTC authorised both trains. Furthermore, this section used manual authorisation as the working method for controlling train movement. The causes of the accident were not known, but the CTC obviously shoulder the blame.

Accident 7: Level crossing – Cape Town

A train and a taxi collided in an early morning accident at a Cape Town level crossing, leaving commuters stranded between Fish Hoek and Retreat (RSR, 2022). Metrorail spokesperson Riana Scott said the collision took place at the False Bay level crossing at 07:31 on Monday, 12 July 2021. Train no. 0105 was travelling towards Fish Hoek when it crashed into a taxi at the level crossing. It was not clear how exactly the accident occurred, but it was believed the taxi tried to cross the rail line as the train was approaching and the taxi driver misjudged the speed of the train. The train was just leaving the station when it crashed into the van; the taxi driver was one of those injured.

2.7. Understanding the role of human beings in railway operations

In trying to manage human errors in the railway, research has been conducted to delve into a deeper inquiry on human factors and human performance in the railway industry, with the aim of investigating the influence of people performing tasks on the railway system. In their UK-based research, Majumdar, Ochieng and Kyriakidis (2015) concluded that human performance is a significant contributor to railway incidents and accidents.

Simpson and Horberry (2018) proposed that error is an inevitable consequence of being human; therefore, in spheres where safety is critical, potential errors need to be controlled and their effects minimised. Shepherd and Marshall (2005) suggested that to minimise human factor weaknesses, attention needs to be paid to how people work in order to understand their strengths and weaknesses. Simpson and Horberry (2018) continued to explain that human errors can also arise from limitations caused by anatomical, physiological, and psychological state. Therefore, each limitation makes each human error distinct; Simpson and Horberry (2018) suggested that knowledge of each type of error can help identify causes and remove its potential and mitigating effects.

To demonstrate the interaction of various human factor issues with the overall work environment, Hammerl and Vanderhaegen (2014) conducted a study in Europe to highlight the influence of human performance on the safety of the railway system. Depicted in Figure 2.8 below is the work system model, Alter (2013), cited in Ingemarsdotter *et al.* (2021) defined a work system as "a system in which human participants and/or machines perform work using information, technology, and other resources to produce specific products/services for specific internal and/or external customers". The core of the work system model shows the interaction of the person performing the task (human) and the instrument. The depicted model starts with an input, which has an influence on the work system core to produce a particular output.

The case of a train driver input includes information gathered by track observation, signal aspects, transmitted information by train cabin instruments or radio communication. The output in the cited example of the train driver would be controlling movement of the rolling stock to get to the desired destination.

The human element of the system comprises specific individual factors such as the individual's health status, emotional liability, age and other job-dependant factors, which include skills, experience, motivation, fatigue and safety awareness (Hammerl, 2011). To demonstrate the complexity of a work system in the railway industry, Hammerl (2011) stressed that the interaction of a human, his task and his instruments is influenced and impacted by performance-shaping factors. Performance-shaping factors are defined as variables that may affect human performance in systems that rely on humans (Arigi *et al.* 2019). Boring *et al.* (2010) further elaborated on the definition by stating that performance-shaping factors are "all these factors such as age, working conditions, team collaboration, mental and physical health, work experience or training which enhance or degrade human performance". Figure 2.8 illustrates the work system model and performance-shaping factors.

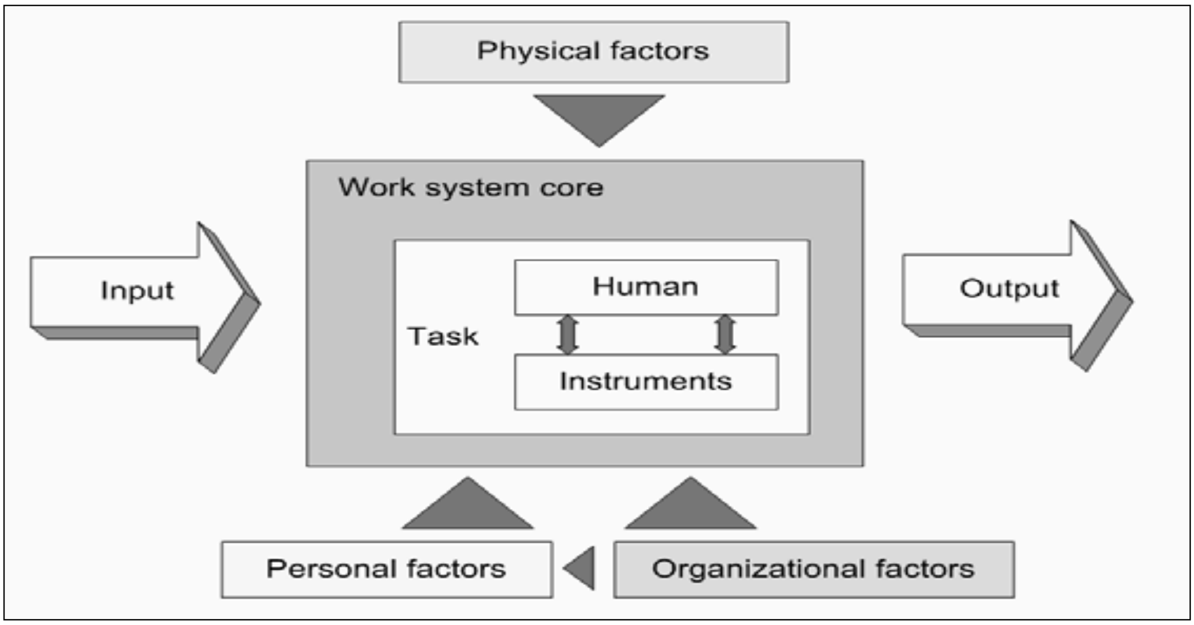

Figure 2.8: Work system model and performance-shaping factors

Source: Adapted from Hammerl *et al.* (2009)

In view of the central role that human beings play in the centre of complex social and technical systems, such as the railway environment, it is vital that the performance-shaping factors that enhance or degrade the human performance be elaborated upon. As depicted in

Figure 2.8 above, the performance-shaping factors include personal, organisational and physical environment.

Personal factors were explained by Kyriakidis, Ochieng and Majumdar (2015) to be those characteristics that affect individuals' performance and are strongly related to the precise moment of an operational occurrence. Examples include levels of stress, distraction, fatigue and vigilance. Hammerl (2011), on the other hand, defined personal factors by dividing them into personal individual factors such as health status, emotional tension, age and gender and personal dependant factors such as tiredness, motivation and experience. An example and impact of fatigue within a work system model will be discussed to demonstrate the role of personal factors in the railway industry.

Fatigue and its impact on safety critical performance have been suggested as a key issue in the rail industry (Bowler & Gibbon, 2015). Rudin-Brown, Harris and Rosberg (2014) conducted analyses on 18 occurrences within the Canadian railway sector. They identified fatigue of railway operating employees as a causal and contributing factor to accidents. In the UK, Fan and Smith (2018) conducted a qualitative study on causes of fatigue in the railway industry. The UK study concluded that the factors contributing to rail staff fatigue included long working hours, heavy workload, shift work, insufficient sleep and poor working environment. In tasks requiring sustained vigilance, such as train driving, signalling and train control operations, identifying and managing causes of fatigue is of paramount importance.

In studying the impact of long hours and railway safety, Anderson, Grunstein and Rajaratnam (2013) highlighted that shift durations of more than 12 hours are associated with a doubling of risk for accident and injury. According to their findings in an Australian study, fatigue builds up cumulatively with each successive shift where rest of less than 12 hours in-between is inadequate. As such, most regulatory frameworks for fatigue management within the rail industry prescribe a limit on hours of work and rest, including maximum shift duration and successive number of shifts. In South Africa, the RSR mandates railway operators to manage fatigue by allowing a maximum of 8 hours' work on the foot plate, with a minimum of 30 minutes' rest in-between for train drivers, and a minimum of 12 hours rest between shifts (RSR, 2022).

Long hours of work, shift patterns, and individual factors such as poor eating habits, smoking, drug and alcohol consumption have also been found to contribute to fatigue (Leso *et al.*, 2021). A series of studies done by several researchers through the British Office of Rail Regulation concluded that lifestyle and individual factors such as sleep patterns and diet contribute to fatigue. Fan and Smith (2017) found that train crew members with an unhealthy lifestyle or negative personality were more likely to report high fatigue. Looking deeper into unhealthy lifestyle, Paterson *et al.* (2012) suggested that smoking and drinking alcohol were related to performance impairment, and that smokers and alcohol drinkers reported lower subjective sleep quality, which could increase fatigue-related risk.

Besides personal factors, organisational factors also play a role in shaping performance of humans within a work system such as the railways. Organisational factors include the factors defined and controlled by an organisation, which include roster planning, leadership, education, training, social environment, safety culture, workplace standards, rules and guidelines and task design (Hammerl & Vanderhaegen, 2012). Kyriakidis (2013) stated that organisational factors embrace the characteristics and attitudes of an organisation as well as certain organisational behaviours that influence the performance of employees. If not managed appropriately, organisational factors can result in a work system distress and increased errors, and can lead to accidents (Eskandari *et al.*, 2017).

An example would be a situation where safety culture is compromised and where lack of safety awareness is rampant in a highly workload environment. This results in incomplete situational awareness and reduced risk awareness, inevitably leading to error-favouring conditions. The cited examples of interaction between the person performing a task (train driver) and other work system interactions, for instance training, are evidently demonstrated in the narrated BOI accident reports. The Blaney, Booysens and Geneva accidents discussed earlier (section 2.6) in this paper are illustrative examples of how organisational factors such as refresher training, inadequate staffing, rostering, lack of adherence to permit conditions and lack of supervision can influence human performance in a task and lead to error-favouring conditions.

Another example of an organisational factor that has emerged as a contributory factor to accident in PRASA Rail is the issue of train driver training (Bouwer & Hubinger, 2014). In South Africa, train driving qualification is pegged at National Qualifications Framework (NQF) Level 5. The NQF is the South African framework used to arrange levels of learning achievements required for a particular qualification. So, the higher the NQF level of a qualification, the more intellectually skilled that person is (South African Qualification Authority (SAQA), 2022). According to South African Qualification Authority (SAQA), the train driver qualification provides the broad knowledge, skills and values needed in the rail transport industry and facilitates access to and mobility and progression within the railway industry. The minimum requirement for entry is a matric equivalent to mathematics and science. The course is a 12-months theoretical course followed by practical road knowledge testing. According to SAQA, the course was benchmarked against other international standards, namely Burlington North Railway Academic Science School (BNRAS), Canadian Rail and Australia Rail (SAQA, 2018). The setup of the qualification is, however, not without controversy and in some instances has been blamed as a contributory factor to train accidents.

Bouwer and Hubinger (2014) opined that the current train driving training course, as offered in South Africa, is insufficient and has, in fact, contributed to railway accidents. According to Bouwer and Hubinger's (2014) paper on the methods and options for preserving railway safety knowledge in a changing environment, commuter train drivers were sourced from highly experienced freight train drivers. The practice came to an end in the late 1990s, due to some restructuring of the South Africa rail industry. An accelerated training programme was implemented for commuter train operating staff, including train drivers. This drastically reduced the duration of their training period and also removed the practice of train drivers progressing from junior freight rail driver grades to the grade of commuter train driver. Bouwer and Hubinger (2014) furthermore observed that qualified train operating personnel were rapidly promoted to supervisory grades, without receiving sufficient training to fulfil their new role as supervisors to the junior train operating personnel.

Hammerl *et al.* (2011) have demonstrated the complexity of the environment within which a train driver functions and other influences of the driver's safety performance. The complexity of the work of the train driver as a human element within the already discussed complex and technical system is surmised by Kecklund *et al.* (1999), cited in Fan and Smith 2018 in their Swedish study. They asserted that train driving is a demanding and full of responsibility. Kecklund *et al.* (1999) purported that the complexity of responsibilities facing a train driver concerns both safety and punctuality. He described this job as requiring a high level of concentration and alertness when it comes to signals, information, tracks and the drivers' immediate operational environment.

The physical working environment can also give rise to workload, including noise vibrations or an uncomfortable cab climate (too hot, too cold, draughty). The train driver is also exposed to a demanding psychosocial working environment, which includes solitary work and limited opportunities for social contact with colleagues. The stress from the psychological effects of train driving has been studied intensely by Samerei, Aghabayk and Akbarzade (2020), who concluded that "conducting and controlling the metro trains is a psychological task that requires long-term work and intense concentration to pay attention to signals and stimuli. Failure to pay attention to train and metro drivers' psychological needs will lead to mistakes, and an accident may occur."

It has been demonstrated throughout this section that centrality of humans as a critical factor in the safety of a system cannot be ignored. Wilson and Norris (2005) emphasised that the human factor is at the heart of the railway in terms of engineering operation and maintenance. The human factor is central to the operation of railways with regard to performance aspects such as safety, reliability and efficiency. Hollnagel (2014:44) stated that human elements are often a key factor in the complications that arise in any complex social and technical system. As such, South Africa embarked on a legislative framework to ensure that human factors as contributory cause of railway accidents is addressed by formulating and adopting the Human Factor Management Standard, SANS 3000-4.

2.8. Unpacking legislative requirements of Human Factors Standard – SANS 3000-4:2011

The RSR, together with a railway industry specialist, in 2009 sought to formulate a legislation framework that would assist railway operators to manage human factors. This step was taken to manage the complexities that surround human factors within the railway operations in South Africa. Benchmarking with Canadian and Australian standards, the work put together led to publishing the Human Factor Management Standard, SANS 3000-4:2011, by the SABS in 2011. According to the RSR, this standard aims to provide railway operators with the minimum requirements needed to manage human factors to reduce occurrences attributable to human error. Shepherd and Marshall (2005) argued that human factors management is concerned with the health, safety and well-being of workers for whom managers have a duty of care.

Naidoo, cited in Engineering news (2010) further mentioned that the HFM standard focuses on managing human factors, including people's perceptual, physical and mental capabilities, the influence of equipment and system design on human performance and the organisational characteristics that influence safety-related behaviour at work. SANS 3000-4 is critical for railway safety because it sets the minimum requirements needed to be implemented by railway operators for all employees undertaking safety-related work (SANS 3000-4:2011). With the standard in place, railway operators are guided on how to optimise human capital by mitigating the risks associated with human factors in the workplace to acceptable levels. The three external factors impacting the human and the task as alluded to in section 2.7 above are exactly what the HFM standard is centred around. The HFM standard recognises three factors which affect the performance of safety-related workers, namely: first, physical environmental factors; second, organisational and psychological factors; and, third, human factor in design (SANS 3000-4:2011).

SANS 3000-4:2011 mandates railway operators to establish, develop, adopt, document, implement and maintain policies, processes and procedures for conducting risk assessments that relate to the management of the stated physical environmental factors. The physical environmental factors include noise, vibration, lighting, thermal environment and hazardous substances and agents. Physical factors are physical hazards defined by the Occupational Health and Safety Act as a "physical agent, factor or circumstance that can cause harm with contact. They can be classified as type of occupational hazard or environmental hazard." SANS 3000-4 acknowledges that lack of management of each physical environmental factor might negatively impact a safety-related worker in the railway industry. An example is the effect of noise on the safe work operations.

Various medical, safety and environmental journals and work safety organisations, for instance the International Labour Organization (ILO) and the World Health Organization (WHO), have enumerated on the adverse effects of noise on the human body. In its Guidelines for Community Noise, the WHO declared that "worldwide, noise-induced hearing impairment is the most prevalent irreversible occupational hazard, and it is estimated that more 120 million people worldwide have disabling hearing difficulties". Other effects of noise include nausea, headaches, blood pressure, changes in mood, irritability, insomnia, distractions and annoyances, which negatively affect productivity (Hahad *et al.*, 2019).

Within the railway environment, noise can impact effective communication between CTC and train driver, resulting in accidents, as mentioned in the Blaney BOI report.

The second factor, human factors in design (HFID) SANS 3000-4 2011:16, includes the matching of tools, equipment, machines, systems, tasks, jobs, work processes, workstations and environments to the physical and psychological capabilities and limitations of people. The standard states that poor design, which includes awkward body positions, excessive forces (handgrip, lifting, pushing or pulling), manual material handling and repetitive strain, might expose employees to hazards that could impact on safe railway operations.

The effects of the poor design elements are impaired cognitive functioning, reduced concentration and vigilance, irritability and confusion, impaired vision, changes in reaction time, burnout, stress and fatigue to name but a few (SANS 3000-4). Chatterjee *et al.* (2015) conducted a study in India to determine the effects of poor ergonomic design in accident causation. The findings of the study proved that poor interface between the train driver and the following train cabin components – control panels, seat, mirror positions – resulted in musculoskeletal and visual strains to the train driver and thus contributed to driver fatigue. Therefore, with this context in place, SANS 3000-4 mandates railway operators to develop, adopt, document, implement and maintain policies, processes and procedures for managing human factors in design.

Grote (2014) reported that HFID knowledge and methods have been used extensively in systems with high risk for accidents. HFID are synonymous with the concept of ergonomics. Wilson and Norris (2005) define ergonomics as a scientific discipline that seeks to understand interactions among humans and other system elements, applying theory, principles, data and methods to optimise human well-being and overall system performance. Dul *et al.* (2012) also explained that human factors and ergonomics focus on systems in which humans interact with their environment. These systems should be designed to increase system performance and system well-being.

Lastly, the HFM standard requires the operators to deal with the following components that pertain to organisational and psychological factors. The listed factors to be managed have been categorised as recruitment and selection; training and development; medical surveillance; use of medication; chronic diseases; fitness for duty; fatigue management substance abuse; pregnancy; and employee wellness. Similar to the physical environmental factors and HFID, the SANS 3000-4 requires the operator to establish, develop or adopt, document, implement and maintain policies, processes and procedures for the management of all the above-mentioned organisational and psychological factors.

When recruitment and selection is being conducted, the operator is advised to, amongst other actions, consider appropriate staffing requirements, manage vacancies so not to overload safety critical workers and, more specifically, ensure recruitment of employees who have core mental and behavioural criteria necessary for adequate job performance (SANS 3000-4 2011:34). In order to achieve this component, appropriate battery tests must be sourced. These are used to measure cognition: vigilance, attention and concentration, memory, perception, reasoning and judgement, communication and literacy; psychomotor abilities: reaction time and coordination; and behavioural qualities: emotional stability and self-control, reliability and conscientiousness. Evidence from the Iraq study on fitness for duty assessments of train drivers by Loukzadeh (2013) stressed that the health and fitness of railway workers, especially their vigilance and attentiveness to their job, are of paramount importance.

On the issue on medical surveillance, operators are required to conduct health assessment with the purpose of provide information on the physical and psychological health status of employees, effect of work on the health of employees, and fitness of employees to perform safety-related work (SANS 3000-4 2011:44). In order to achieve this, operators must ensure that issues of confidentiality and declaration of medical conditions are adhered to in line with appropriate national standards. During medical surveillance, the employees shall declare the existence of a medical condition, the use of any medication (prescribed or over the counter), and any unwanted or undesirable effects caused by a medical condition or medication. A fitness-for-work evaluation's primary purpose is to ensure that an individual can perform the tasks involved in their job effectively and without risk to their own or others’ health and safety.

2.9. System approach, latent conditions contributing to railway accidents

Rooted in the theoretical framework of systems thinking, the understanding of the multifactorial causes of accidents as advanced in the BOI report under section 2.6 above, the complexity of railway technologies and possible errors that can occur in railway operations, the researcher seeks to borrow from other accident investigation models to advance a discussion that accidents occur where fertile ground for failures already exists. As an evolution from Reason's SCM, Shappell and Wiegmann (2001) formulated the Human Factor Classification and Analysis System (HFCAS), which allowed a more elaborate systemic classification of human errors and offered a deeper inquiry into the latent conditions contributing to accidents.

The model was initially formulated in 2000 to classify injuries in the aviation sector, and has since been used by a number of authors to classify injuries in different industry sectors. Examples include Theophilus *et al.* (2017), who conducted a HFACS study for the oil and gas industry; in the United Kingdom railway industry Madigan *et al.* (2016) analysed railway incidents using the HFACS model. Currently, in the field of accident causation, the HFACS is one of the most extensively applied tools for human factor analysis (Harris & Li, 2011).

The HFACS described four levels of latent failures which lead to accident occurrence. The levels are organisational influences, unsafe supervision, pre-conditions for unsafe acts and unsafe acts of significance. The HFACS model stipulates that for an incident to occur, failures in defences at all system levels must line up. In this regard, it is therefore important to highlight the importance of identifying the factors which contribute at each level. Their classification of human errors is divided into four different levels, as discussed next.

Level one outlines organisational factors to include three factors: resource management, organisational climate and organisational process. To fully understand what constitutes organisational factors, the author will describe each of the components herein. Maiti (2021) referred to resource management as "the process of promoting various types of business resources efficiently and productively. These resources can be human resources, equipment, facilities, assets, and more."

Organisational climate on the other hand is defined by Chiavenato (2016) as "a set of measurable properties of the perceived work environment, directly or indirectly, created by individuals who live and work in this environment and that influence the motivation and behaviour of these people". Organisational climate is a reflection of the overall view that an employee has about the ecosystem of work. Bhasin (2020) contended that organisational climate has a significant impact on job satisfaction, productivity and motivational levels of the employees in the organisation. Justifying the relationship between organisational climate and safety, Bayram (2018) put forward an argument that there is an incremental benefit to management commitment to organisational climate, which has a positive effect on employee job satisfaction, which then has a direct significant impact on safety performance.

Level two failure is termed “unsafe supervision, " which includes four factors: inadequate supervision, planned inappropriate operations, failure to correct known problems, and supervisory violations. In the formulation of the HFCAS, Wiegmann and Shappell (2006) referred to unsafe supervision as failures within the supervisory chain of command, which was a direct result of some supervisory action or inaction. At a minimum, supervisors must provide the opportunity for individuals to succeed. Gilarranz (2018) asserted that the success of the safety programme is affected directly by the extent to which the managers and supervisors actively participate. Shappell *et al.* (2006) concluded that it is expected, therefore, that individuals will receive adequate training, professional guidance, oversight and operational leadership, and that all will be managed appropriately.

Level three constitutes pre-conditions for unsafe acts to include environmental factors, which are divided into physical and technological environment and personnel, and, lastly, conditions of an operator, which include physical or internal limitations, adverse mental states and adverse physiological states. The impact of physical factors on accident causation cannot be underestimated. Physical factors are described as physical hazards which can be expressed in physical quantities such as noise, vibration, light, thermal climate and radiation. Salman (2012), in his research on work and technology in human terms, stated that occupational life is strongly related with physical factors; an example used was that of physical lighting which not only contributes to good visual ergonomics but can also reduce the risk of accidents and can prevent poor postures (Salman, 2012).

Lastly, level four represents unsafe acts which include four factors: decision errors, skill-based errors, perceptual errors and violations. Holcomb *et al.* (2006) defined errors as events which occur while workers are behaving within the rules and regulations implemented by an organisation; this is in contrast to violations which represent the wilful disregard for the rules and regulations that govern safety. Holcomb *et al.* (2006) defined unsafe acts or decisions, skill-based and perceptual errors as errors of “thinking”, “doing” and “perceiving” respectively. Decision errors were purported as conscious decisions/choices made by an individual that are carried out as intended but prove to be inadequate for the situation at hand.

On the other hand, skill-based errors occur without significant conscious thought because the operators are doing work in a complacent and routine manner. Holcomb *et al.* (2006) asserted that, as a result, skill-based actions are particularly vulnerable to failures of attention, memory or simply poor technique. Lastly, perceptual errors occur when sensory input is degraded or "unusual" (Holcomb *et al.*, 2006). An example will be conducting track maintenance at night, in a rainy weather or in other visually impoverished conditions.

Several research works have been conducted on the contribution of unsafe acts to accident causation. The studies include Patterson and Shappell (2010), who used the HFACS model to analyse 508 coal mine accidents in Queensland. They concluded that skill-based errors are the most common unsafe behaviour, with no significant difference between different types of mines. Chauvin *et al.* (2013) analysed the human factors and organisational factors of ship collision accidents in Britain and Canada using the improved HFACS; they concluded that most collision accidents were caused by decision errors.

Within the railway environment, Baysari *et al.* (2008) conducted a study in Australia where 40 rail safety investigation reports were reviewed using HFACS as a means of identifying errors associated with rail accidents/incidents. The study revealed that nearly half the incidents resulted from an equipment failure; most of these were the product of inadequate maintenance or monitoring programmes. In the remaining cases, skilled-based errors associated with decreased alertness and physical fatigue were the most common unsafe acts leading to accidents and incidents. Inadequate equipment design (e.g. driver safety systems) was frequently identified as an organisational influence and possibly contributed to the relatively large number of incidents/accidents resulting from attention failures. Nearly all incidents were associated with at least one organisational influence, suggesting that improvements to resource management, organisational climate and organisational processes are critical for Australian accident and incident reduction (Baysari *et al.*, 2008).

Without considering the systemic view in accident causation, a myopic position on railway accident causation in South Africa will be taken, thus limiting holistic corrective actions which can improve railway safety in the country. Poya (2018) in his analysis of train accidents in SA alluded that root causes of the investigation outcomes show a range of overwhelming factors. He stated in the 2018 state of safety report that aspects such as understaffing of safety critical grades, poor levels of supervision, communication deficiencies, when combined with other root causes such as theft and vandalism, signalling and infrastructure defects, remain areas of concern in the South African railway environment (SA State of Railway Safety Report, 2018).

2.10. Summary

From the various literature sources that the author has considered in this study, it is evident that the railway environment is a very complex system, consisting of vital infrastructural components, which, when not well designed or maintained, can result in railway accidents. Further, the governance of the South African railway sector was explored. The role of the national DoT, RSR and various operators was discussed in detail, with the aim of demonstrating the pre-requisite regulatory framework within the railway industry in South Africa. The author further reviewed BOI reports into major train accidents within the past 10 years in SA. From the BOI reports, various root causes of accidents, which included dilapidated infrastructure, inadequate supervision, physical factors, violation of train rules, lack of maintenance and lack of refresher training, emerged as root causes of some accidents. The various accident models studied revealed that accidents arise out of a multitude of factors and therefore a systems approach is an acceptable way to study human factors as a cause of railway accidents in South Africa.

Even though human error has been central to the cause of railway accidents, a call to investigate latent and contributory factors to human error has been growing. Various scholars have enumerated this call, including Hadj-Mabrouk (2018) in France and Nayak (2018) in India. With the understanding of latent errors as advanced by HFCAS model it is evident that preconditions to unsafe acts exists and cannot be ignored in the HFM inquiry. With the HFCAS in mind, the researcher was therefore able to formulate the following HFM study questions which were included in the study questionnaire (See Annexure 3).

a) What are the factors that influence HFM in the prevention of railway accidents?
b) From the preconditions listed below, please rate the ones that are likely to be causing railway accidents?
c) Of the unsafe supervision acts listed, which ones have been found to frequently cause railway accidents in South Africa?
d) How effective have the below listed organisational influences been in managing safety in railway operations in South Africa?

From the BOI accident reviews, key technologies in the railway and unpacking of SANS 3000-4 (2011), human factor related causes were argued as causes of railway accident and they included fatigue, inattention, communication, technical errors, etc. Based on the information advanced, the researcher formulated the questions relating to that, which asked:

e) From the list of human factors below, please rate how each has been found to likely cause railway passenger accidents in South Africa

With the understanding of the structures that govern the railway industry in South Africa, the researcher formulated the following questions.

f) From the list below, rate how effective has each of the following corporate governance structures has been or have been instrumental in the implementation of human factor management in rail operations in South Africa?
g) From the list below, please rate how effective each of the standards is being or has been utilised managing railway safety operations.

CHAPTER 3:
RESEARCH DESIGN AND METHODOLOGY

3.1. Introduction

This chapter presents the research philosophy, design and methodology that was used to explore the human factor and its role in accident causation in railway operations with the aim of improving rail passenger safety within South Africa. The researcher undertook this study with the main purpose of outlining the railway safety phenomena as it exists within the South African railway operator, PRASA. Included herein is a discussion of the strategy and procedures that were used to conduct the study at Metrorail, PRASA.

3.2. Research philosophy

Research philosophy as explained by Žukauskas *et al*. (2018) is "a system of the researcher's thought, following which, new and reliable knowledge about the research object is obtained". Saunders *et al*. (2015) simply referred to research philosophy as a system of beliefs and assumptions about the development of knowledge. There are different classes of philosophical paradigms which were explored before the most suitable one was selected. Žukauskas *et al.* (2018) suggested four research philosophies: positivism, interpretivism, pragmatism and realism. These are discussed in relation to the topic to determine which philosophy would be the most suitable for the study.

According to Bryman and Bell (2016), positivism is an epistemological position that advocates using natural science principles to investigate and explain social reality. According to Dammak (2015), positivism is concerned with the establishment of cause-and-effect relationships and often uses observation and experiments. Soraya and Abdullah (2019) stated that a theory guides positivists to establish the relationships between dependent and independent variables. When knowledge that is viewed as objective and tangible aligns to the methods of natural science, it is associated with an epistemological position known as "positivism" (Dieronitou, 2014). Positivism is often associated with quantitative research (Mukherji & Albon, 2014).

Interpretivism is a philosophical position that advocates the understanding of the world based on inner-directed reality or experience rather than facts (Ponelis, 2015). Coleman (2019) described interpretivism as “a qualitative approach that views human beings as different from the material world, hence the need for distinction between humans and subject matters has to be done through adequate methods of investigation”. Ryan (2018) explained that interpretivists consider the world as a socially constructed reality and an important lens by which one understands this reality. According to Makombe (2017), interpretivism is often associated with qualitative research and data are collected and analysed concurrently.

Realism is concerned with providing “an account of the nature of scientific practice” (Bryman et al., 2014:13). This philosophical position is domain-specific and revolves around facts of entities that differ from that domain and operates in an objective and independent manner (Coleman, 2019). Realism is criticised for failing to emphasise principles and values (Meharunnisa, 2011).

Saunders *et al.* (2019) described pragmatism as a philosophical position that “strives to reconcile both objectivism and subjectivism, facts and values, accurate and rigorous knowledge and different contextualised experiences”. In conducting this research, this philosophy emphasises not only facts but also the relation between actions and consequences (Žukauskas *et al*., 2018). Shannon-Baker (2016) stated that pragmatism uses communication as a vehicle by which researchers produce real-life solutions to address social challenges. This philosophy is also based on the epistemology that there is no single way to learning but many different ways of understanding because there are multiple realities (Collis *et al*., 2014). According to Makombe (2017), pragmatism is well suited for study designs that combine both qualitative and quantitative approaches.

Besides the four philosophies alluded to by Žukauskas *et al*. (2018), two more philosophies exist, namely constructivism and transformative philosophy. Constructivism, described by Bryman (2012) as an ontological position of a researcher who asserts that social actors are continually accomplishing social phenomenon and their meanings. This means that social phenomena are not only produced through social interaction, but they are in a constant state of revision by social actors. The constructivism philosophy emphasises understanding of phenomena through the researcher and their subjective views on the subject. Hogue (2011) asserted that constructivism is associated with qualitative inquiry.

Lastly, transformative philosophy advocates for research that is informed by an agenda. A transformative worldview holds that research inquiry needs to be intertwined with a political agenda to confront social oppression at whatever level it occurs (Creswell & Creswell, 2018). Mertens *et al.* (2010) further explains that the political agenda alluded to, is where issues such as inequities, gender, race, ethnicity, disability and sexual orientation get key attention.

Altogether, the six philosophical approaches were explored, namely positivism, interpretivism, pragmatism, realism, constructivism, and transformative philosophy. Aspects of each were considered relevant for the research. Pragmatism was, however, considered the most suitable philosophical paradigm for conducting the HFM study. Pragmatism paradigm allows both positivist and constructivist assumptions are employed as long as they are found fitting (Collins & Hussey, 2014). Furthermore, pragmatism was found to be most congruent with the theoretical principle of systems thinking, which is the basis of this study. As argued by Barton(1999) cited in (Vázquez & Liz, 2014) , pragmatism rejects the atomistic thinking in favour of a structure of thinking which acknowledges the existence of wholes within the context of a continuous world view. Pragmatism allowed the researcher to explore the HFM study widely and to use both objective and subjective methods which included conducting questionnaires, desk-top research and focus group discussions, thus providing a mixed methods approach.

3.3. Research design

A research design is described by Marais and Pienaar-Marais (2016) as the plan that is followed by the researcher to collect, measure and analyse data. According to Green and Tull (2019), a research design is the specification of methods and procedures for acquiring the information needed. Kothari (2020) supported the assertion and added that a research design is a strategy that specifies the approach that a researcher will use for data gathering and analysis. Robson (2002) as cited in (Buro, 2018), argues that there are three possible forms of research design, namely exploratory, descriptive and explanatory, which are mainly based on the purpose of the research. An exploratory study is useful in studying where limited prior understanding exists (Stebbins, 2011). A descriptive study on the other hand serves to provide a picture of a situation, person or event or show how things are related to each other and as it naturally occurs (Blumberg, Cooper & Schindler, 2014). Lastly , an explanatory study looks for causes and reasons and provides evidence to support or refute an explanation or prediction (Buro, 2018). The HFM study fits the description of an explanatory study as it sought to identify, explain and account the actual reasons why the accident phenomenon occurs. In conducting the explanatory study, a case study approach was utilised.

A case study approach, bounded within the real-life context of PRASA, was employed to investigate contemporary phenomena of railway safety and HFM. The benefit of using the case study method is that it is grounded in and applicable to real-life, contemporary human situations, provides in-depth relevant data and promotes an understanding of complex real-life situations (Krusenvik, 2016). A mixed method research strategy was used, thus making the study a mixed method case study. Mixed method case study design is defined by Creswell and Plano Clark (2018:116) as "a type of mixed methods study in which the quantitative and qualitative data collection, results, and integration are used to provide in-depth evidence for a case/cases or develop cases for comparative analysis".

3.4. Research methodology

Prior to deciding on mixed methods research, the researcher explored three research methods namely, quantitative, qualitative and mixed method approach to examine the suitability of each in answering the HFM study research questions.

Firstly, quantitative research method was considered. Quantitative method is broadly defined as a distinctive research strategy that entails the collection of numerical data, providing a deductive view of the relationship between theory and research while demonstrating a preference for an objectivist conception of social reality (Bryman, 2016). Chipeta (2020), states that quantitative data answers questions such as "who?", "when?" "what?", and "where?" The quantitative method was found to be best suited to address some aspects of the aim of the study which is to explore the human factor management standards and its role in improving rail passenger safety.

Using the lens of safety critical workers (questionnaire respondents) the following aspects of the study were explored using qualitative method- prevalent causes of railway accidents, most likely human factors responsible for railway accident, gender representation within the railway industry, level of qualification of safety, critical works in percentage format, etc. As argued by Busetto,Wick and Gumbinger (2020), quantitative research enabled the researcher to study the HFM phenomena by exploring their range, frequency and place in an objectively determined chain of cause and effect.

However, after utilising the quantitative method, the researcher was still left with the question, why? Despite getting the understanding of the prevalence rate of railway accidents, the most common cause of railway accidents, the most common human factor contributing to railway accidents, the question on why do railway accidents continue to escalate was still unanswered. As such, a qualitative method to get in-depth answers to the research questions was explored. Qualitative method is defined as the study of “the nature of phenomena, including their quality, different manifestations, the context in which they appear or the perspectives from which they can be perceived” (Philipsen & Vernooij-Dassen, 2007). It is especially appropriate for answering questions of why something is/not observed (Busetto, Wick & Gumbinger 2020). Furthermore qualitative research offers a platform for assessing complex multi-component problems, such as the complexity of HFM study and railway accidents. The qualitative approach enabled the researcher to delve into the depth of the inquiry, by understanding why South Africa continues to observe railway accidents at an alarming rate despite the existing legislative guidelines.

It is for the stated reasons that the study employed a mixed-methods design where both quantitative and qualitative methods were used. Mixed methodology enhances the comprehension of the topic area in greater depth (Bowen, Rose & Pilkington, 2017). Mixing methods enhances validity and reliability of the study findings as the weaknesses of one method are covered by the strengths of the other method.

The study brought together the findings from various data sources or methods used for the research inquiry through triangulation. Triangulation can be used to enhance the confirmability of research findings (Kumar, 2017) and was done in data collection methods, sampling methods and data analysis techniques. The study could therefore benefit from the advantage of one method’s strengths that cover for the other method’s weaknesses. The triangulation of methods strengthens the validity and reliability of the findings.

Questionnaire respondents were requested to indicate the extent to which a list of reasons presented to them are the likely cause for railway accidents, while focus group discussions were important for elaborating on the reasons why the HFM standards already in place are failing to work to acceptable levels. Through observations of the accident scenes, the workers at work and the equipment malfunctions, the study aimed to unearth the reasons why railway accidents still happen despite the HFM standards frameworks being in place.

3.5. Research strategy

In offering an in-depth understanding of the mixed method research strategy (Creswell & Plano Clark, 2011, cited in Schoonenboom & Johnson, 2017) have classified the mixed methods designs into six types, namely convergent parallel design, explanatory sequential design, exploratory sequential design, embedded design, transformative design and multiphase design.

The study used explanatory sequential mixed methods, where the researcher first conducts quantitative research, analyses the results and then builds on the results to explain them in more detail with qualitative research (Creswell & Creswell, 2018). Quantitative data were obtained through questionnaires and were used to explore the HFM standards and their role in improving rail passenger safety, while a qualitative method by way of a focus group discussion was used to explain the reasons for human factors' influences on rail accidents.

The value of multiple methods – called mixed-methods research – resides in the idea that all methods have biases and weaknesses, and the use of both quantitative and qualitative data neutralises the weaknesses of each form of data (Creswell & Creswell, 2018). This explanatory sequential mixed-methods design was considered because it has the room to explain quantitative findings using qualitative data, unlike merely obtaining quantitative data and making inferences. The initial quantitative data results in this method are explained further with the qualitative data. It is considered sequential because the initial quantitative phase is followed by the qualitative phase (Creswell & Creswell, 2018). Using a mixed methodology enhances the comprehension of the topic area in greater depth (Bowen et al., 2017). Sequential explanatory method was chosen for increasing confidence in findings, providing more evidence while offsetting possible shortcomings of using a single approach (Creswell & Creswell, 2018). Population and sampling is discussed in the following section.

3.6. Population and sampling strategy

Haralambos and Holborn (2016) described a population as a group of elements, individuals, objects or events that conform to the specific criterion of which the researcher intends to apply in their study. It refers to all people or items with the characteristic one wishes to understand. There is rarely enough time and resources to gather information from everyone in a large population, thus the goal becomes finding a representative sample or subject of that population. If a target population is not selected, considerable time and money will be wasted depending on the size of the population (Murthy & Bhojanna, 2016). The following sections discuss the target sample, sample formulation and the sampling strategies thereof.

3.6.1. Target population

The target population is the group of elements to which the researcher makes inferences related to the study (Martínez-Mesa *et al.*, 2016). The purpose of a target population is to serve as a universe of units to which the results of a study are then generalised (Shukla, 2020). The study targeted employees working at Metrorail, Gauteng region, defined under section 2.4.3 as a metropolitan passenger rail operator of PRASA. Staff members who at the time of the study held responsibilities related to safety of railway operations at Metrorail were deemed to be best suited to respond with knowledge relating to the aims and objectives of the study as listed in section 1.6. The participants' jobs had a direct impact on the safety of movement of rolling stock. Included in the target population were train drivers, train assistants, TCO, signal officers, rail track maintainers, section managers and safety supervisors. A total of 1 000 employees were found to occupy safety-related operational positions in Metrorail, PRASA. From the target population, a sample population, which is the group of individuals who were deemed appropriate to participate in the study, was selected through a process of stratified random sampling and purposive sampling.

3.6.2. Sampling method

Sampling is the process of selecting a segment of the population to participate in a study (Bryman & Bell, 2016). The basis of sampling is to get a representative population from which the researcher can draw inferences (Adwok, 2015). There are two main strategies of sampling in research, namely non-probability sampling and probability sampling as explained below. The study used both probability and non-probability methods as it embraced mixed methods. Probability sampling is the most appropriate strategy for a quantitative study because it gives every member of the population a chance of being selected (McCombes, 2019), while non-probability sampling best suits the qualitative part because there is need to pick the candidate possessing the right characteristics (Etikan, 2017).

Probability sampling is a sampling method which permits every single item from the universe to have an equal chance of presence in the sample (Etikan, 2017). There are five main types of probability sampling, namely simple random, systematic, stratified random, cluster and multi-stage sampling. Simple random sampling is sampling in which each unit of the population has an equal probability of inclusion in the sample. Systematic sampling, on the other hand, is explained by Taherdoost (2016) as sampling where every n'th case after a random start is selected, for example every fifth person in a queue. Another type of probability sampling is stratified random sampling, which involves sampling from a population whereby the population is divided into sub-groups and units are randomly selected from the subgroup (Frey, 2016). The fourth type of probability sampling is cluster sampling, where the whole population is divided into clusters or groups and a random sample is taken from these clusters, all of which are used in the final sample (Wilson, 2010). Lastly, multi-stage sampling is a process of moving from a broad to a narrow sample, using a step-by-step process.

Stratified random sampling was used for quantitative data. It is described by Frey (2018) as a method for sampling from a population whereby the population is divided into sub-groups and units are randomly selected from the subgroups. In complex operations such as passenger rail services, where several technologies, responsibilities and functions are required to transport people, a diversity of experiences are encountered by the different actors and these need to be taken into account when observing the railway safety phenomenon. Stratified random sampling, therefore, offered a systematic process of selecting respondents according to their specific safety-related duties, as elaborated in section 3.6.1 above. To minimise the potential for bias that would arise from recording knowledge from a limited section of the population, for instance train drivers, the sampling of respondents from different job categories within the Metrorail employee database allowed for findings that have external validity.

For the qualitative data, the judgemental sampling method was used because the successful participants needed to meet researchers' expectations in terms certain characteristics such as education, experience and job descriptions (Etikan, 2017). Judgemental sampling, also referred to as a purposive sampling, involves selecting elements in the sample for a specific purpose (Hair, Celsi, Money, Samouel & Page, 2017). The purpose here entailed selecting participants who possess the knowledge of causes of accidents, HFM standards, and with job experience or involvement in handling accidents. The advantages of judgemental samples are their convenience, speed and low-cost, owing to the researcher's choosing those participants with proven requirements in terms of ability to answer the questions in the focus group discussion.

3.6.3. Sampling frame

A sampling frame represents a list of all units in the population from which the sample is drawn (Bryman, 2012). The sample frame for the study on HFM standards consisted of a database of staff members working at Metrorail. The population found to be working at Metrorail were a diverse group with responsibilities for different functions within the organisation. The individuals in the population were found to occupy a variety of jobs. Amongst these were track workers, who ensure that the track points and Perway are properly maintained, thus avoiding derailments. Train drivers, train assistants and section managers control the movement of the train by adhering to the rules of safe railway operations, and thus avoid collision. TCOs, on the other hand, ensure that all signals and track points direct the train in terms of route to follow, when to stop and when to proceed by showing red or green signals. Signal technicians ensure that all signals work correctly and are aligned to the CTCs.

3.6.4. Sample size for questionnaires

After defining the sample frame, the researcher proceeded to calculate the sample size. An adequate sample size is important as it allows researchers to generalise findings and avoid sampling biases (Taherdoost, 2016). Two variables are important when choosing a sample size; these are confidence interval and margin of error. Confidence interval is described by McLeod (2019) as a range of values that are likely to include a population value with a certain degree of confidence. Confidence interval tells us about how stable the estimate of population proportion is, while a stable estimate is one that would be close to the same value if the survey were repeated. On the other hand, margin of error means the level of precision or the risk of inaccurate sample size the researcher is willing to accept (Taherdoost, 2016). The process of selecting the sample size considered was based on the importance placed on data accuracy as this is a critical element in ensuring the validity of the study. Martens (2010) explained that this can be achieved by setting the margin of error at +-5% for a confidence interval of 95%. This assertion has been supported by a number of authors, including Taherdoost (2016: 25), who echoed that "95% confidence interval and 5 % margin of error are acceptable levels in social research".

Using an online tool called Qualtrics, the questionnaire sample size was calculated to be 278 respondents, which was considered large enough to represent the population at Metrorail. The sample size represented 95% confidence interval and 5% margin of error, as demonstrated by the used calculator, and supported by Gill *et al.* (2010:185), on their work on "sample size based on desired accuracy".

Once the target population, sampling frame, sampling technique and sample size had been established, the next step was to collect data. Data collection is described by Kabir (2016:207) as "the process of gathering and measuring information on variables of interest, in an established systematic fashion that enables one to answer stated research questions, test hypotheses, and evaluate outcomes".

3.6.5. The sample size for the focus group discussion

Participants of the focus group were selected from the job categories as follows. From each job category, only one participant was selected. Representatives were chosen from the following categories: train driver, train control officer, signalling technician, safety officer, section manager and train assistant. The criteria for choosing the participant within each job category were judgemental; the most qualified and most senior workers were selected from each category and the participants were balanced between males and females. The total number of participants was six from the six job categories. A focus group of six participants is manageable, according to Creswell and Creswell (2018).

3.7. Data collection

Data collection is defined by the U.S. Department of Health and Human Services as the process of gathering and measuring information on variables of interest, in an established systematic fashion that enables one to answer stated research questions, test hypotheses and evaluate outcomes. The following instruments were applied.

3.7.1. Data collection instruments

Data collection tools refer to the devices or instruments used to collect data. Examples include a paper questionnaire or computer-assisted interviewing system, checklists, interviews and observation. A survey questionnaire, focus group discussion guide and observation guide were the tools used for data collection, which were used to address the objectives of the study. Surveying is the process by which the researcher collects data through a questionnaire or interviews (O'Leary, 2014). The chosen data collection instruments are described and justified as follows.

3.7.1.1 Questionnaire template

A structured questionnaire, SurveyMonkey, was designed as the primary tool for data collection, (see Annexure 3 for print-out version). The questionnaire consisted of 16 questions on demographic information, closed-ended questions with answer options from a Likert scale and one open-ended question. Sullivan and Artino (2013) described a Likert scale as a 5- or 7-point ordinal scale used by respondents to rate the degree to which they agree or disagree with a statement. In the case of the HFM study, a 5-point Likert scale was utilised for closed-ended questions.

The questionnaire served three specific purposes; firstly, to evaluate the extent and impact of passenger railway accidents at Metrorail; secondly, to evaluate pre-conditions leading to accidents and the resultant compromise to passenger safety; and, thirdly, to evaluate existing risk management systems in accident prevention. Part 1 of the questionnaire included items requiring respondents' demographics such as age, gender, occupation and education. Demographics are often used as predictor variables during analysis of the data to determine whether participant characteristics correlate with or predict responses to the other items of the survey (Bordens & Abbott, 2018).

Part 2 of the questionnaire included questions about railway accidents, staff members' perceptions of the extent of the problem of railway accidents, and the factors accounting for the incidence of railways accidents. Additionally, organisational influences on the occurrence of railways accidents, and the evaluation of HFM standards within the organisation were also included. Lastly, the role of corporate governance towards fulfilling HFM in rail operations, and an evaluation of risk management systems in promoting HFM were added.

A questionnaire is described by Christensen *et al.* (2015) as a self-report data collection instrument that is filled out by research participants. As the study mixed positivism and constructivism ideas, the use of a survey is closely linked with the philosophy of positivism. This is affirmed by Thompson (2016:125), who stated that: "Positivists favour survey questionnaires because they are a detached and objective (unbiased) method, where the sociologist's personal involvement with respondents is kept to a minimum." Furthermore, aligned to positivism, Thompson (2016) added the fact that questionnaires are useful in testing hypotheses about cause and effect between different variables, such as in the case of this study. For the study of HFM, a questionnaire was used for the systematic gathering and collection of data pertinent to the study.

The use of a questionnaire enabled the following advantages for the study: self-administration of the questionnaires by the respondents and the ability of respondents to respond and complete their questionnaires at their own convenience. Data were collected over a three-month period. Follow-up reminders were done through SMS and notice reminders given by safety supervisors at various work engagement meetings. The employees who did not have smartphones or data on their phones to complete the questionnaire were encouraged to use work-based computers to complete the questionnaire. Prior to embarking on the large-scale study, a pilot study to investigate the feasibility of using the designed questionnaire was embarked upon and changes were made as presented in section 3.7.2 of this chapter.

3.7.1.2 Focus group interview or discussion guide

The second instrument was a focus group interview or discussion guide. The instrument had six questions which formed a follow-up investigation on the reasons why HFM standards already in place were not delivering the desired results. The template required that each question takes at most 12 minutes so that each participant is given a maximum of two minutes deliberating on the question. The guide relaxed the sequential order of the discussion questions such that the last question could become the first, depending on the flow of the discussion.

Focus groups are used across all business disciplines. For example, focus groups can be instrumental in developing ideas related to supervisory issues, including compensation systems and flexible work scheduling (Hair *et al.*, 2017). Focus groups are useful in discovering issues that can reinforce or build a candidate's image. They are particularly useful when the public's opinion is diverse. The group size must be small in order to capture the utterances and feelings of the participants more carefully; for example, six focus groups of ten participants is a sample of only sixty (Hair *et al.*, 2017). If the participants are more carefully selected, the results are much more likely to represent the target population as a whole. Sometimes, opinions are dependent on a particular group's chemistry (Creswell & Creswell, 2018). Researchers usually recommend four to six focus groups at a minimum to develop a clear idea of the consistency or diversity of responses (Saunders *et al.*, 2016). Therefore, conclusions drawn from focus groups are best tested using another, more confirmatory approach (Hair *et al.*, 2017); that is why, in this case, they were used together with questionnaires.

3.7.1.3 Observation guide

The instrument used for observation was an observation grid. The places or points to be observed as well as the people, the behaviours, events and machines were outlined. Timelines and dates were also stated on the grid. The grid had six work points to be observed from the six job categories. The timing was arranged in a manner that captures starting of the shift, middle of the shift and the end of the shift. At the starting point of the shift, the observation included ticking a box on the grid if, for example, safety precautions were observed and machine handover and take-over data sheets were completed. A cross was used if such an exercise had been omitted.

Observation data were collected through a systematic approach to recognise and record occurrences associated with people, events, behaviour and objects (Hair *et al.*, 2017). Collection of such data can be achieved through trained observers or through mechanical or digital means such as videos, scanning at checkout counters or other electronic methods (Cooper & Schindler, 2016). Observation data can be of a narrative, visual or numeric nature (Srivastava & Rego, 2015). In this study, the data were collected through all the forms mentioned above.

3.7.2. Pilot study

Pilot studies are described by Thabane *et al.* (2010) as small-scale, preliminary studies which aim to investigate whether crucial components of a main study are feasible. Viechtbauer (2015) argued that pilot studies are a necessary step in social research as they assist in identifying problems such as ambiguous inclusion or exclusion criteria or misinterpretations of questionnaire items. To ensure that the survey questionnaire is understandable and yields reliable results, the researcher therefore embarked on a pilot study. Johanson and Brooks (2010) suggested that 30 representative participants from the population of interest is a reasonable minimum recommendation for a pilot study. The choice of 30 participants has been asserted by various researchers, including Hertzog (2008), who argued that the choice of number of participants in a pilot study is dependent on what the pilot study aims to achieve. For instrument development and measurement, Hertzog's recommendation was 25 to 40 participants (Hertzog, 2008). In consideration of the suggested number, the questionnaire was presented to 30 respondents randomly drawn from the sample of 278 staff members of Metrorail.

The respondents were requested to complete the questionnaire within two weeks. Furthermore, they were requested to give an opinion on the time taken to complete the questionnaire and the ease of completion, as well as send enquiries to the researcher should they require clarification during completion of questionnaire. The questionnaires were designed in a Word document and emailed to the respondents. The returned questionnaires were tested for question validity and response reliability. The responses were also analysed for consistency and changes to the master questionnaire were made before distribution to the larger sample of the study's respondents.

The changes effected included the presentation format, which was changed from a Word document to SurveyMonkey format. The Word document was not easy to complete online and required most respondents to print the document, which inevitably had negative cost and time implications. SurveyMonkey offered a pure web-based tool, which reduced cost and time. Revilla and Onchoa (2017) published a study on "Ideal and Maximum Length for a Web Survey". The results of their study concluded that the ideal survey length should be a median of 10 minutes and a maximum of 20 minutes to complete the questionnaire. Changing the questionnaire to web-based SurveyMonkey enabled an average of 15 minutes' completion time.

Another change effected was moving from double-barrel questions to asking one question at a time. An example of this appeared in more than one question where, for example, item 6 of the questionnaire was initially phrased as "How frequent or infrequent are the following railway occurrences in South Africa?" The respondents stated that they were confused about the usage of two contradicting descriptors and were not certain if their choice of answer was for frequent or infrequent. The question was changed to "how frequent are the following railway occurrences in South Africa?"

The last change made was the removal of numerical values to accompany answer categories on all questions where the Likert scale was applied. The example of item 6, as mentioned above, "How frequent are the following railway occurrences in South Africa?" was used. The answer options were designed using a Likert scale with the following options: 1 = Not frequent, 2 = Infrequent, 3 = Less frequent, 4 = Frequent, and 5 = Very frequent. Furthermore, there was numbering on the type occurrences, namely (1) Derailment, (2) Collision with another train, (3) Collision with cars/buses, (4) Level crossing, (5) Electrocution, (6) Train robberies, (7) Other. Respondents' criticism was that there was too much numbering and they needed to read the questions several times to understand what they were rating. Moors, Kieruj and Vermunt (2014) conducted a study in the Netherlands to determine the effect of labelling and numbering of response scales on the likelihood of response bias. According to the study, it was concluded that end labelling evokes more Extreme Response Style (ERS), which is defined as the tendency to choose only the extreme endpoints of the scale. Based on this, and the difficulties experienced by the pilot participants, the author opted for the removal of numerical value on the Likert scale. The limitations of this study are discussed in the following section.

Focus group discussion questions were also tested through a pilot study. Two participants from the safety critical workers were chosen to participate in the pilot study. Those who participated in the pilot study did not participate in the final study. The three major questions from which follow-up questions were framed remained unchanged. Adding to the main questions (What are the perceptions of safety critical workers regarding causes of railway accidents in SA? Which human factors are prevalent amongst railway operators and their role in railway accidents? How do corporate governance, risk and compliance management influence HFM standards?), the following questions were added: What are the reasons for the causes of the accidents still not being addressed, or, if addressed, why are accidents recurring? Can you suggest a system to make HFM standards more effective?

3.7.3. Data collection procedure

To persuade the participants for a response, the researcher explained her position within the organisation, the purpose of the research and how their individual participation would contribute to improvement of passenger railway safety. Once granted the go-ahead by the potential participants, the researcher sent the link and prompted the participant to let her know once they had completed the survey.

The survey link was sent to the respondents as a text message or WhatsApp link or, in some cases, by email. The database of names and cell phone numbers was obtained from managers of different job categories in Metrorail. Upon receipt of the number, the researcher made an outbound telephonic call to each respondent, asking them personal permission to be included in the study as well as their preferred platform to send the survey link.

The researcher also made sure she used personalised text, survey participation and data quality. Respi and Sala (2017) found that personalised salutations in email or text messages have a positive impact on the response rate. Asserting this position in an earlier study, Heerwegh *et al.* (2003) stated that personalisation significantly increases the web survey response rate by 8.6 percentage points. This strategy elicited an 80% response rate. A response rate is defined by Frey (2018) as the ratio of the number of respondents in a study to the number of participants who were asked to participate. Mandy (2002) argued that while there is no magical figure in response rates, as it is dependent on the type of survey and the purpose of the study, the higher the response rate, the better. As a general rule, Mandy (2002) stated that a 60% response rate would be marginal, 70% would be reasonable, 80% would be good, and 90% would be excellent.

With the use of online surveys, there was no need to type the results, as they could be directly uploaded into Excel or CSV for analysis. SurveyMonkey was advantageous to use in the study, as argued by Waclawski (2012), because it provided for input of a variety of variables; questions could be easily read, and it allowed for a survey completion progress bar showing the total number of survey questionnaires completed. Another advantage was that the Survey Monkey uses a Hypertext Transfer Protocol Secure otherwise known as HTTPS. Ku (2018) stated that, at its core, HTTPS encrypts the traffic between one's browser and the server to prevent eavesdropping on web requests and responses.

3.8. Data analysis and interpretation

Data analysis was done using two methods for the two different databases. A quantitative data analysis for the questionnaire and content analysis for focus group discussion data are explained in detail next.

3.8.1. Quantitative data analysis for questionnaires

After obtaining data from 223 respondents, representing 80% of respondents, data analysis and interpretation was done through statistical software which enables coordinated analysis of large data, such as the one in the study. SPSS version 22 was used to analyse data from the HFM study.The SPSS program generated elements such as descriptive statistics that represented the responses in the form of frequencies, cross-tabulations between variables and descriptive ratio statistics for the variables. Furthermore, the system generated bivariate statistics to present analysis of variance between variables, means and standard deviations between the variables.

3.8.2. Content analysis for focus group discussion data

To conduct the analysis for the focus group discussions, the data were in audio format on a flash disk. The researcher listened to the audios and transcribed the audio responses from the participants into written texts and read the text from all the focus group scripts to understand each participant's narrative. The researcher read back and forth across the responses to understand patterns and themes. This process involves a number of steps to identify the main themes. The researcher carefully went through descriptive responses given by respondents to each question in order to understand the meaning they communicated. From these responses broad themes were developed that reflect these meanings.

The first step was to select the wording of themes in a way that accurately represented the meaning of the responses categorised under a theme. These themes became the basis for analysing the text of responses. The second step began with assigning codes to the main themes and then identifying the themes from the same question until saturation point had been reached, writing these themes and assigning a code to each of them, using numbers or keywords. The third step was to classify responses under the main themes. After the themes had been identified, the next step involved going through the transcripts of all participants to classify the responses. Finally, the fourth step was the integration of themes and responses into the text of the report, after responses had been identified that fell within different themes.

3.8.3. Data analysis for observed data

Analysis of observed data involved the process of transforming collected information or observations to a set of meaningful, cohesive categories. The process involved summarising and representing data to provide a systematic account of the recorded or observed phenomenon (Omilion-Hodges, 2017). The observation results were used to augment the information gleaned from the questionnaires and the focus group discussions.

The observation grid classified the data into the types of jobs, places where accidents happened, the state of the machinery, procedure observation and supervision. A checklist was also used where the observer ticked or crossed a box to indicate the presence or absence of an expected behaviour or item. The results were analysed using thematic analysis where premeditated themes were used to classify the data. Human factors, machine factors, corporate governance and risk management were the themes into which data were coded. The information was analysed in a way that made it possible to draft questionnaires from the observed data.

Absence of an observed expectation, such as the use of changeover inspection sheets, presence of slumber, fatigue and sleeping among the workers, was classified under HFM. Observations where the presence of faulty machinery or an absence of service roster and checks was noted were classified under maintenance. The findings were important for forming the basis or hinting on areas of inquiry using questionnaires and discussion in the focus group.

3.9. Validity and reliability

The data collected from the survey were validated and checked for reliability. The purpose of establishing reliability and validity in research is essentially to ensure that data are sound and replicable, and the results are accurate. According to Patino and Ferreira (2018), the validity of a research study refers to how well the results among the study participants represent true findings among similar individuals outside the study. In essence, validity is the degree to which a result from a study is likely to be true and free from bias (Khorsan & Crawford, 2014). The main purpose of data validation is to establish whether a measurement of a concept really measures what it is supposed to measure (Bryman, 2012). In checking for validity, two spheres, namely internal and external validity, are probed. Patino and Ferreira (2018) defined internal validity as the extent to which the researcher can be confident that a cause-and-effect relationship established in a study cannot be explained by other factors. Internal validity signifies whether the study results and conclusions are valid for the study population. Internal validity addresses the question of whether the study on HFM standards in rail passenger safety, its findings and conclusions are in line with the aim of the study.

Andrade (2018) referred to external validity as the extent to which the results from a study can be generalised to other situations, groups or events. Establishing external validity for an instrument, then, follows directly from sampling. Choosing participants from diverse job category groups allowed the studies external validity to be realised. In relation to the study, the author ensured that participants were selected from safety-related grade as defined in section 1.2 of this study.

Reliability, on the other hand, measures consistency, precision, repeatability and trustworthiness of a research (Chakrabartty, 2013). Reliability is tested through measurement of internal consistency, which is described as the extent to which all the items in a test measure the same concept or construct; it is therefore connected to the inter-relatedness of the items within the test (Tavakol & Dennick, 2011). According to Heale and Twycross (2018), reliability can be assessed using the following statistical constructs: item-to-total correlation, split-half reliability, Kuder-Richardson coefficient and Cronbach's alpha, the latter being the most commonly used. The Cronbach's alpha result is a number between 0 and 1, with an acceptable reliability score being one that is 0.7 and higher (Shuttleworth, 2015). For the study, the Cronbach alpha score was calculated using SPSS and the score was 0.965, indicating an excellent reliability score.

Furthermore, another process of subjecting the data to a reliability test was sought to establish the stability of the data by checking whether it remained the same when measured at different times and consistency of the responses as provided by the different participants who attempted the questionnaire. In this regard, the reliability was further tested by including the pilot participants in the main study and observing consistency of their responses to the questionnaire. A high level of consistency was found, thus affirming high reliability score as demonstrated by the Cronbach alpha score.

3.10. Limitations of the study

The findings of this study must be seen in light of some limitations. Ross and Zaidi (2018) explained that study limitations represent weaknesses within a research design that may influence outcomes and conclusions of the research. The HFM study was limited in the following aspects, firstly from the target population perspective and secondly from resources that the respondents needed to complete the questionnaire. As it relates to the target population, the researcher could not obtain properly documented nor a verifiable number of safety-related employees per job category within Metrorail, from the Human Resources Department. None of the officials wanted to offer information, for fear of victimisation. Culture of fear and victimization within PRASA has been reported in numerous publications, including the 2015 public protector report entitled ‘derailed’, and the News24 report by SATAWU which states that senior officials abuse power by victimising employees as well as settling personal battles through disciplinary actions (News24, 2016).As argued by (Cresswell, 2013), improper representation of the target population might lead to miscalculation of probability distribution and thus lead to falsity in proposition. As such, in addressing this limitation, deductive reasoning based on documented annual reports and anecdotal reports was used as elaborated upon in section 3.6.

Secondly, some of the participants did not have data or smartphones to complete the survey and therefore relied on work-based computers to complete the questionnaire. The lack of data posed a limitation because it restricted the times within which the questionnaire could have been answered and might have posed a challenge on the respondents’ honest response to the questions. To manage the fears of the respondents in terms of privacy and utilisation of work-based computers, the privacy that SurveyMonkey offers through use of HTTPS was explained to participants (section 3.6.3). Respondents were assured that they were secure because HTTPS encrypts the traffic between one's browser and the server to prevent eavesdropping on web requests and responses.

3.11. Ethical considerations

The researcher paid due consideration to research ethics as one of the strategies to ensure credibility of the research and the study's findings. The proposal for this study was approved by the research committee at The Da Vinci Institute (see Annexure 1). The respondents were presented with a consent form for their voluntary participation. Contained in the consent form is an explanation of the purpose of the study and its implications to the subject matter. Respondents were also assured that all the information they provided was only for academic purposes. Respondents were also informed that their participation in the study was voluntary and that they were at liberty to withdraw from the study in the event of their feeling the slightest discomfort.

The researcher ensured that the study was conducted without exploiting the respondents or damaging their reputation with Metrorail or its parent company PRASA or their relationship with colleagues at work. As such, all responses were anonymised. The researcher also obtained permission from the management of Metrorail to conduct the study (Annexure 2).

3.12. Summary

This chapter presents an overview of the research design and methods used to conduct the study on the impact of HFM standards in rail accidents and how the findings can be used to improve safety among rail operators. The study methodology was mainly an application of mixed methods in the collection of data and the data analysis procedures to ensure the fulfilment of the aim and objectives of the study. The methodology followed a pragmatist philosophy in the extraction of knowledge for the study. The target population in this study was safety-related employees working at PRASA, Metrorail, who were deemed suitable to participate in the study. Stratified random sampling was used to select respondents for questionnaires from the members of staff at Metrorail who work in areas related to safety, while purposive non-probability sampling was used for selecting focus group discussion participants. Data collection procedures involved the administration of a structured online questionnaire on SurveyMonkey, a focus group discussion and an observation exercise

The use of technology and innovation in modern social research cannot be underestimated. Internet-based technology was used for various aspects of the research, which included a data collection tool, calculating an appropriate sample size and assessing the reliability of the study. The researcher opted to use e-based technology in the form of SurveyMonkey to develop and distribute questionnaire to 278 participants, which would have been costly to reach using traditional paper-based questionnaires. Regmi *et al.* (2016) listed advantages of data collection through an online survey, which include the potential to collect large amounts of data efficiently.

The last stages of the research design involved data analysis and interpretation. Begum and Ahmed (2015) argued that each and every researcher should have some knowledge in statistics and must use statistical tools in research. The researcher opted for the use of innovative computational statistical software, namely SPSS version 22. The purpose of the analysis was to determine the relationship between the variables accounting for HFM standards and how they can improve rail passenger safety. This procedure provided data results that formed the basis for the interpretation of the findings. The results of the study will be discussed in Chapter 4.

CHAPTER 4:
RESEARCH FINDINGS

4.1. Introduction

As discussed in Chapter 3, a mixed-method study was conducted in PRASA, Metrorail, Gauteng division, to investigate whether a systems approach to HFM standards could prevent rail accidents in South Africa. The research focused mainly on the perceptions of safety critical workers on whether developing a systems approach to HFM standards could prevent rail accidents in South Africa. This is because while the HFM standards are already in use, accidents have not significantly reduced, so safety critical workers are important because they are "on the ground" and are tasked with ensuring safe railway operations on a daily basis. The researcher considered it prudent to follow this route, recognising the intrinsic involvement of safety critical workers as core and critical stakeholders in the HFM standards. Therefore, getting their perspective, and "giving them a voice" on factors that need to be considered in HFM to prevent railway accidents is important. Discussed in this chapter are the findings of the study.

The chapter is divided into three sections: the first section of the chapter deals with presentation of research results; the second part deals with discussion of results, and the third part deals with secondary literature review that serves to shed light on how the same human factors considered in this study have been noted elsewhere. The research findings are presented in the following format. First, the name of the factor being analysed is mentioned, followed by the relevance of the factor in relation to the research questions and objectives. This is followed by the descriptive statistics presented in text and, lastly, a discussion of the results.

The findings are presented in the chronological order of the questions in the survey questionnaire. First, the researcher presents the demographics of the participants in terms of age, gender, years of experience in their jobs, job category and qualifications. These will be used in discussion in relation to railway accidents. The demographic profile is important to the study as it provides in-depth information about the current profile of Metrorail's safety critical workers and the inherent relationship that the profile represents with regard to accidents. This is followed by the causes of railway accidents in South Africa, which include an analysis of human factors, malfunctioning of equipment, lack of maintenance, environmental factors and lack of appropriate rules and regulations. In addition, other railway ecosystems that contribute to HFM standards are also explored. These include the role of supervision, organisational resources, and governance, risk and compliance in the management of human factors. Lastly, to illustrate the consequences of railway accidents, the researcher looked into the severity of the accidents in terms of injuries, fatalities, damage to equipment and environmental damage.

In investigating a systems approach for using HFM standards to prevent rail accidents in South Africa, the research questions listed below, as detailed in Chapter 1, section 1.6, are addressed in the discussion of the findings of the study.

a) What are the factors that influence human factor management?

b) How can the identified factors be used to improve safety among rail operators?

c) Which human factors are prevalent among railway operators and their role in railway accidents?

d) What role do pre-existing operational conditions play in the management of human factors?

e) How does corporate governance, risk and compliance management influence human factor management standards?

Before detailing the HFM study findings, PRASA, Metrorail, Gauteng region is presented below in section 4.2, in terms of geographical demarcations, routes and kilometre reach.

4.2. Primary research findings

The section comprises the demographic characteristics of the research participants and inferences of the results on each demographic characteristic of the population. The primary results, mainly from observations, questionnaires and focus group discussions, are presented in a discussive manner where they complement one another. Observations gave the researcher an insight into safety critical workers' roles and daily encounters, thus enabling the development of questionnaires. The results are presented before the questionnaire results. Questionnaire results lacked the explanation relating to HFM. After the results had been obtain from the questionnaires, there remained the need to get an in-depth analysis of the phenomenon through probing further. Therefore, a focus group of six employees was established from those who had not participated in the questionnaires, as illustrated in section 3.4.2.1 of Chapter 3. The focus group participants were purposively chosen from each job category and priority was given to the most senior workers with the highest qualification. A fair distribution of females and males was also considered. The results from the focus group are therefore presented as supplementary, explaining or confirming results from questionnaires within the following subheadings.

4.2.1. PRASA, Metrorail, Gauteng Division

The study observed that Metrorail, Gauteng, is divided into two regions, namely Gauteng North and Gauteng South. The northern region covers areas which fall under the City of Tshwane Metropolitan area. The southern region covers areas under City of Johannesburg Metropolitan area. The Gauteng network map showing the source of the target population of safety critical workers who participated in the study is presented in Figure 4.1 below. The map details the observed 11 Metrorail lines, named mainly after the destination points. The rail network covers a 150 km north-to-south and a 120 km east-to-west distance between the two major cities of Johannesburg and Pretoria. The study focused on the accidents that occurred in these two regions.

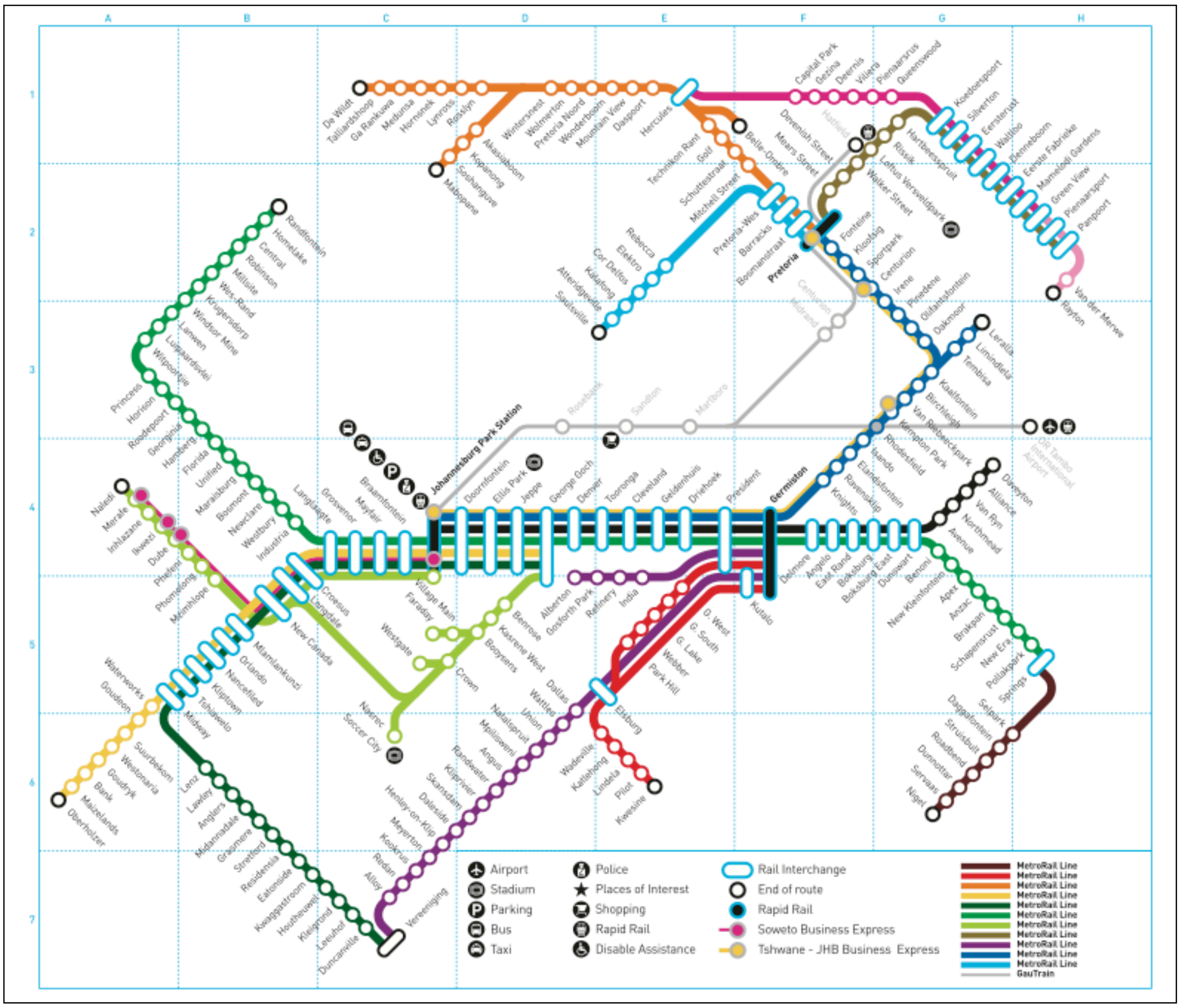

Figure 4.1: Metrorail Gauteng rail network

Source: Metrorail (2013)

4.2.2. Demographic profile of safety critical workers

Presented in this section are findings from the safety critical workers' demographic profile, which include job category, qualifications, gender, age and job experience. The demographics provide a collective picture of the baseline information of the safety critical workers and some characteristics of the inherent adequacy that this population has in the prevention of accidents. Comprehending the demographic profile gives an understanding of the "human" element in HFM, partly providing feedback to the question, "What factors influence human factor management?" The demographics also offer information about the profiles of individuals who responded to the HFM survey, which profiles will help in the analysis and subsequent attribution of the causal relationship between accidents and the human factor causes, as well as which demographic group appears more responsible for causing the accidents.

Qualifications and appropriate and adequate training qualify a person to practise their trade with basic knowledge relatable to the job at hand. As part of human factor analysis, the study sought to understand the level of education that was being offered to safety critical workers as well as look into the different trades that those qualifications afford the rail industry. Focus group results concurred with the RSR (2019) that the adequacy of experiential learning for train drivers and railway technicians has been a source of concern in some of the railway accidents in South Africa. Related to this aspect of qualifications is the work experience and career path of railway workers, which includes promotion to supervisory positions. Participant 6 had the following to say:

"I should say, excelling workers should not be promoted based on current performance and academic excellence only. There is need for considering the experience that the candidate has in terms of train operations … you will see that most of our accidents are due to lack of adequate supervision … being a supervisor in an area needs longer experience within the 'area', I suggest say a minimum of six years before one is seconded to supervisory posts …"

In this study, document analysis from desk-top research findings found that of the 3 990 accidents recorded, 71% were caused by human error (RSR, 2019), which proves that there is need for more attention on supervision and qualifications. Other demographics reflected on with regard to safety critical workers profiles are gender and age. Gender and age are associated with certain physical attributes which may be necessary in executing certain types of jobs. For example, physically demanding jobs may be more suitable for younger workers. Elderly workers have a higher prevalence of certain conditions such as high blood pressure and diabetes, which may impact work performance. There are also certain stereotypes in terms of attitudes and behaviours that are associated with gender and age profiles.

4.2.3. Results of job categories of safety critical workers

As stated in Chapter 2, section 2.3 of the study, various skills sets are required to ensure safe railway operations. The respondents were asked to indicate their job categories in order to evaluate the availability of pre-requisite skills within the safety critical workers community of PRASA, bearing in mind their importance in HFM and railway accident prevention. The results of the safety critical workers' job categories that responded to the HFM study are reflected in Figure 4.2 below. The results reflect that train operation workers, namely train drivers (47,77%), train assistants (16,52%), section managers (12,50%) and TCO (5,36%), contributed 82,15% of the responses to the study.

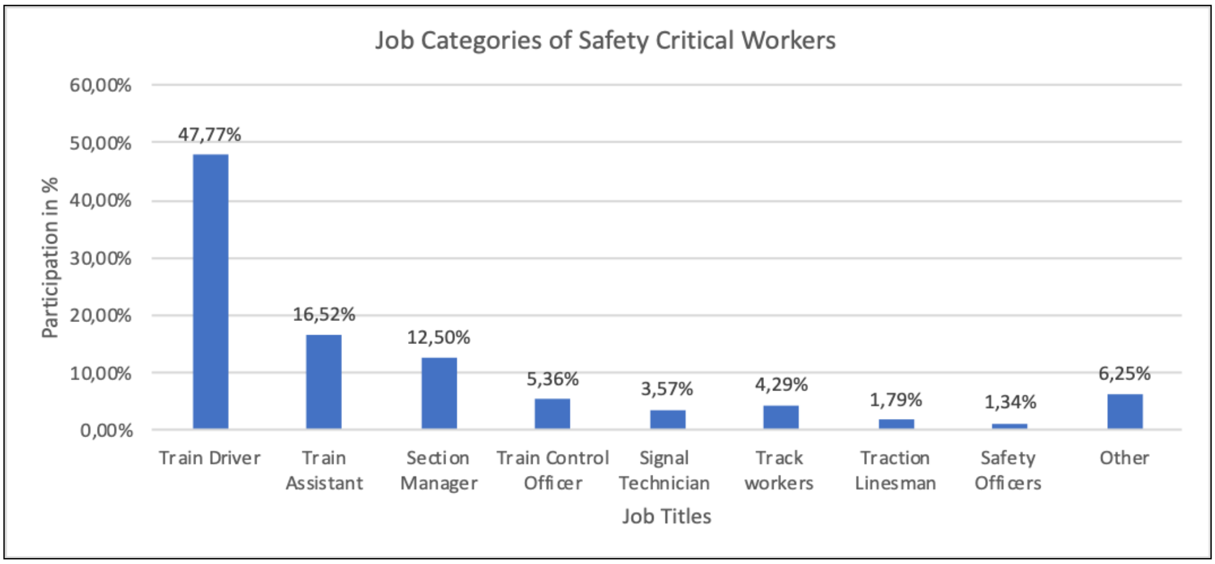

Figure 4.2: Job categories of respondents

The contribution by train operations far exceeded the contributions from technical, infrastructure and maintenance divisions, whose combined response rate was 10,28%. This figure consisted of signal technicians (3,57%), track workers (4,29%) and traction linesman (1,79%). To better appreciate the stark difference in the response rate, Figure 4.3 below shows train operations (blue) vs infrastructure skills sets (orange).

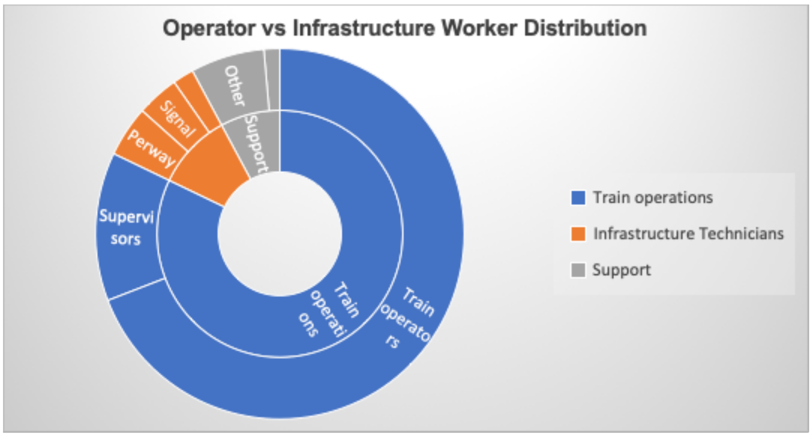

Figure 4.3: Operators vs infrastructure workers

The shown response rate of train operations versus technical and maintenance to the HFM study is of interest as it might indicate lower availability of skills sets in some of the critical areas that contribute to railway safety. As PRASA manages four types of infrastructure, namely Perway, electrical, telecommunications and signalling (discussed at length in Chapter 2, section 2.4), it is expected that safety critical workers from the four key technologies in the railway technical and maintenance job categories would have contributed more than 10.28% to the study. To cite an example of the importance of some of these key technologies over the years, malfunction of signal infrastructure has had the greatest impact on train accidents (PRASA, 2019).

In the absence of signals, trains are manually authorised, causing the system to perform below capacity, and increasing the likelihood of accidents. It was therefore expected that a reasonably higher number of signalling professionals would have contributed to the study. Another observation from the job category profile results is an indication that PRASA's operations rely strongly on train movements and, more specifically, PRASA is reliant on human beings and not technology to operate its trains. The results indicate that most accidents (86.1%) occur due to technical or operational errors (Figure 4.9) which translate to the train operators' being the responsible demographic group for the majority of accidents. This interpretation comes from the notion that, in relation to human factors being causes of accidents, workers involved in the technical departments and operational departments according to the results contribute the most towards accidents.

4.2.4. Gender representation of participants

Figure 4.4 is an illustration of the gender profile in the sample. The majority of the respondents were male, representing 71.9% (161), and females representing 28.1% (63) of the total sample.

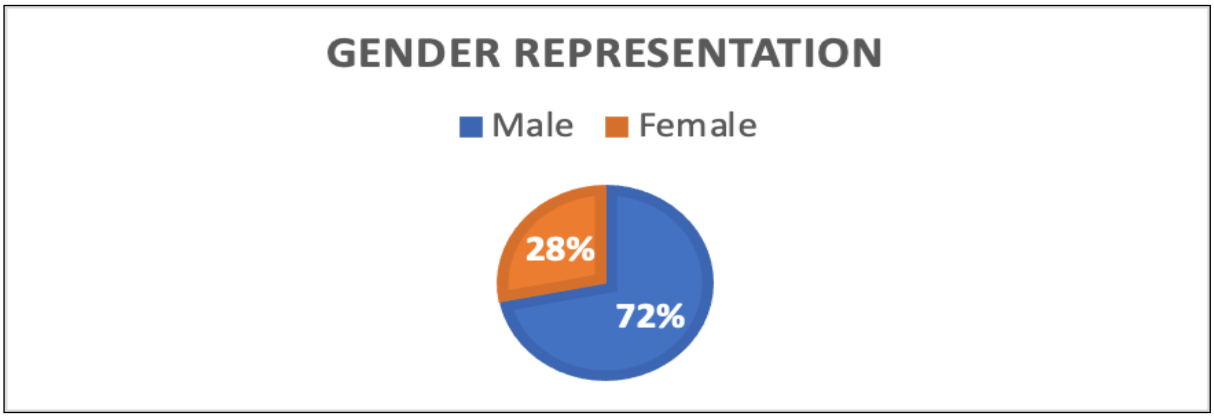

Figure 4.4: Gender analysis of railway employees

With the magnitude of the railway accidents in the South African railway industry (Table 4.1), understanding the gender and age profile of the safety critical workers offers a comprehensive view of HF-related stereotypes. Over the years in the transport sector, female drivers have often been labelled as being precarious drivers and having higher accident risk profiles compared to their male counterparts.

The results obtained from the focus group discussion indicated that there is no basis for believing that female train drivers cause more accidents. Participant 4 had the following to say:

"The occurrences of accidents have nothing to do with whether one is male or female because there has not been any convincing analysis that can relate the two or prove that males do not fall into the same errors that women commit."

Participant 2 also concurred with the above sentiments, and added:

"The fact that there are more males in the train operations than there are females could have seen the accident falling if it was true that females cause more accidents than men."

However, when one looks at Table 4.1 below, one will see increases in the occurrences of accidents.

Table 4.1: Overview of operational safety occurrences for 2013/14 – 2018/19

Reporting Year	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19				
South African National Standards (SANS) Category	**All**	**All**	**All**	**All**	**All**	**TFR**	**PRASA**	**Other**	**All**	**Trend**
A: Collisions during movement of rolling stock	980	1059	1100	1006	1027	794	56	23	873	-15% ⬇
B: Derailments during movement of rolling stock	718	592	420	386	450	232	48	90	370	-18% ⬇
C: Unauthorised movements including rolling stock movements exceeding limit of authority	121	93	94	84	95	55	54	18	127	34% ⬆
D: Level crossing occurrences	119	109	87	119	126	104	21	8	133	6% ⬆
E: People struck by trains during movement of rolling stock	588	643	541	651	588	177	338	4	519	-12% ⬇
F: People-related occurrences: trains outside station platform areas or in section	209	338	337	325	169	0	165	0	165	-2% ⬇
G: Passenger-related occurrences: travelling outside designated area of train	94	163	131	140	160	0	169	0	169	6% ⬆
H: People related occurrences: platform-train interchange/ interface	715	612	658	573	744	0	625	0	625	-16% ⬇
I: People related occurrences: station infrastructure	190	166	130	111	116	0	110	0	110	-5% ⬇
J: Electric shock	35	34	27	30	46	17	28	0	45	-2% ⬇
K: Spillage/leakage,explosion or loss of dangerous goods	250	265	223	209	212	153	0	1	154	-27% ⬇
L: Fires	568	558.00	502	432	745	621	79	0	700	-6% ⬇
TOTAL	**4587**	**4632**	**4250**	**4066**	**4478**	**2153**	**1693**	**144**	**3990**	**-11%**

Source: RSR (2019)

4.2.5. Age and work experience of safety critical workers

Figure 4.5 is an illustration of the respondents' age brackets/groups. Amongst the respondents, 0.9% (2) were in the age group 25 years and below, while 23.7% (53) were in the age group 26–35 years. Those aged between 35 years and 45 years were 119 and constituted 53.1%. Additionally, 16.1% (36) of the respondents indicated that they belonged to the age group 46–55, and 5.8% (13) indicated that they are of the age group 56–65; there was 1 respondent (0.9%) that did not indicate their age group.

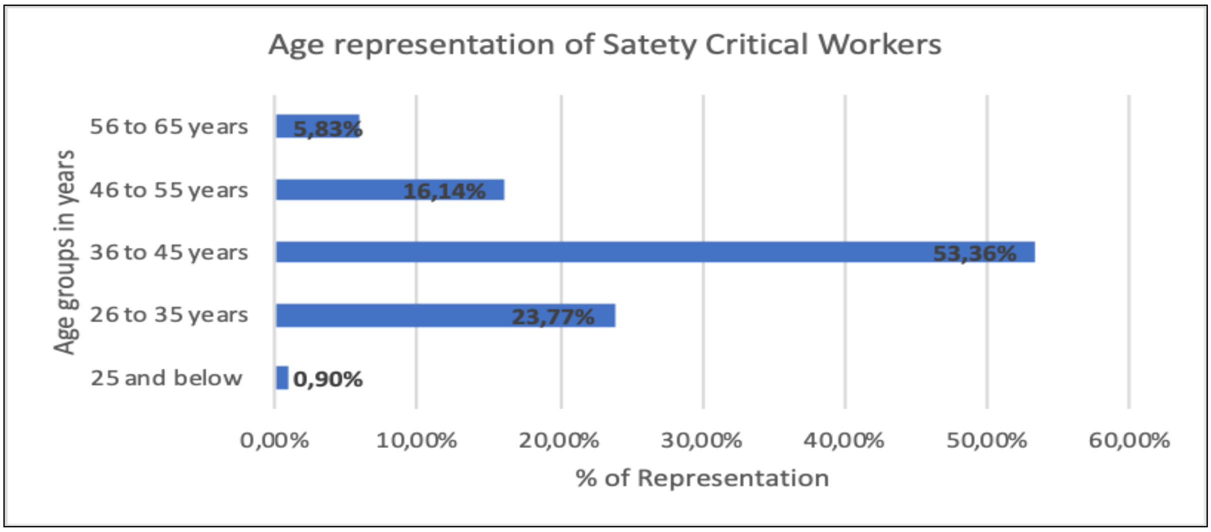

Figure 4.5: Age representation of safety critical workers

Looking at Figure 4.5, it can be deduced that 25 years is the average age on entry into safety critical positions in Metrorail. A low number of workers are aged below 25 years. It is also evident from age analysis that most safety critical workers in Metrorail are in the prime of their working life; that is, between 26 and 45 years. Related to the issue of age is years of work experience. Years of work experience for the safety critical workers are represented in the diagram below (Figure 4.6).

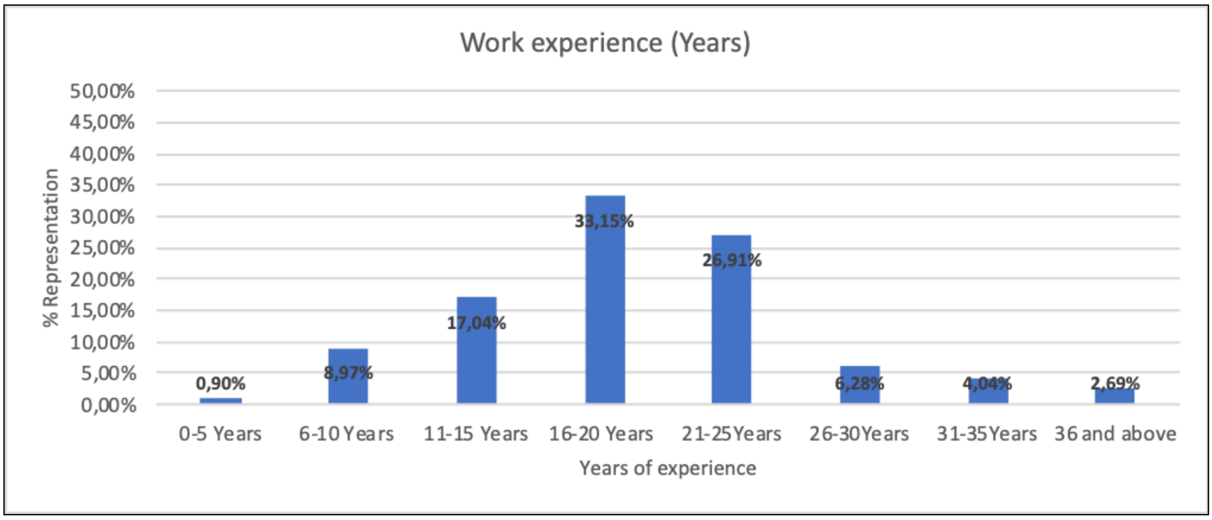

Figure 4.6: Work experience of safety critical workers

The question of job experience was asked as an open-ended question and the grouping was done after the survey for ease of reporting. The majority of the respondents (33.0%; 74) indicated that they have work experience of between 16 and 20 years, followed closely by those with work experience between 21 and 25 years, representing 26.8% of the sample. This was then followed by 17.0% (38) of those who indicated their work experience as between 11 to 15 years. Consequently, 8.9% (20) of the respondents indicated their work experience as between 6 to 10 years and 6.3% (14) indicated having work experience of between 26 to 30 years. In addition, 4.0% (9) of the respondents indicated their work experience was between 31 to 35 years and 2.7% (6) indicated a working experience of 36 years and above. Lastly, 0.9% (2) had work experience of 0 to 5 years, and 1 respondent (0.4%) did not indicate their working experience.

Based on the above, it can be concluded that Metrorail is a mature company, with the bulk of its employees' boasting extensive years of experience in railway operations. The age and collective years of experience of Metrorail workers is fairly progressive and, as such, should play a role in minimising railway accidents. The available records of accidents at Metrorail show that 15% of the accidents are caused by people in the above 50 years age range, followed by those in the below 25 years age range with the least responsible for accidents being from the age range of between 26 and 45 years.

The above sentiments were also echoed by Participant 2 in the focus group discussion. who indicated:

"The issue of exhaustion is something that, when we get to work, we are not prepared to endure; it is worse when age catches up with you. The body gets susceptible to exhaustion with advancing age. Consequently, you find that above 45 years of age, accidents due to inattentiveness and exhaustion are higher."

The issue of age should have been countered by the greater job experience, according to Participant 1. However, the issue of technology overshadows the experience as technology is changing and the use of cell phones distracts operators even more.

4.2.6. *Qualifications of the safety critical workers*

Figure 4.7 is an illustration of the respondents' highest academic qualifications. The majority of the respondents revealed that their highest qualification is a certificate or diploma, representing 57.1% (128) of the sample. This was followed by those who indicated they have a matric at 30.8% (69) and 6.3% (14) who indicated that they have a degree. An additional 3.1% (7) of the respondents indicated that their highest qualification is below matric level. There were 6 employees who indicated they have a post-graduate degree, representing 2.7% of the total sample.

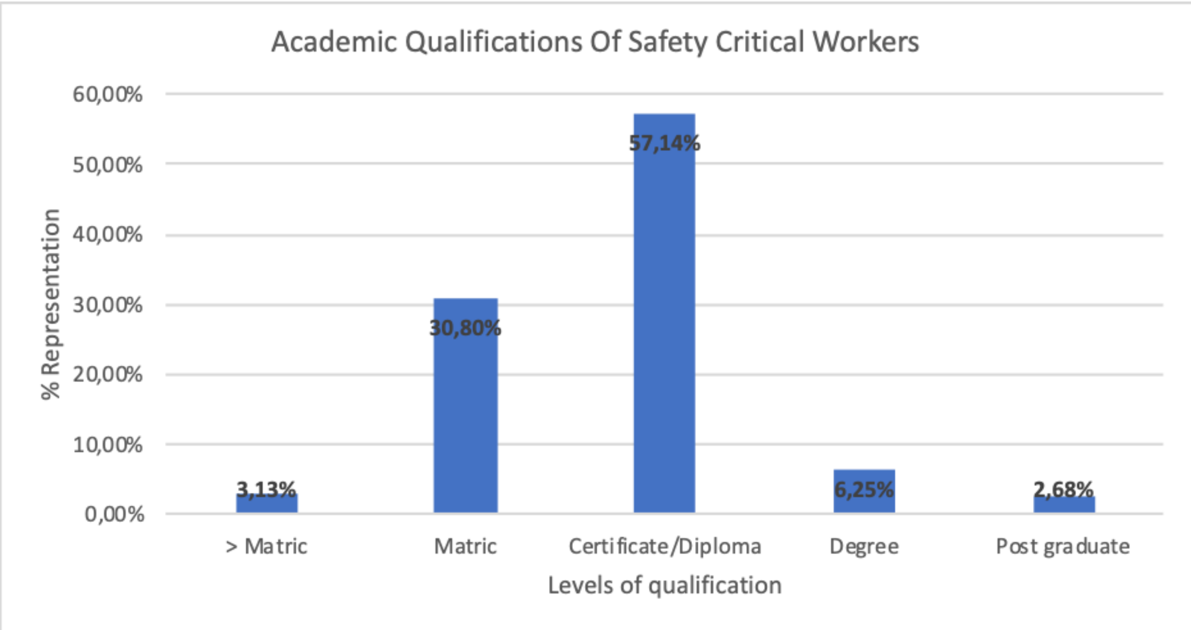

Figure 4.7: Academic qualifications

In view of the findings of the study in respect of academic qualifications of the participants, it is important to appreciate that even though the participants were all safety-related employees, their roles and functions within the railway necessitate different skillsets, technical knowledge and levels of education, as demonstrated in Figure 4.7 above. Safety critical workers with less than matric level education were 3.13%, those with matric level were 30.8% and those with a certificate or diploma levels of qualifications were 57.14%, indicating that the rail operator is mainly staffed by employees who have completed vocational training. Safety critical workers with a degree were 6.25%, indicating that the operator lacks high-level specialisation as it does not employ personnel who have attained university degrees and only 2.68% had post-graduate qualifications.

The importance of having pre-requisite skills sets to operate any system cannot be underestimated. Shortage of skills in South Africa has been a cause for concern over the years and the railway industry has not been spared. As discussed in Chapter 2 of this study, the railway environment is highly technical in nature and, as such, requires specialised skills sets. Most safety critical workers are diploma/higher certificate holders and very few have degrees from technical colleges (6,25%). With the plethora of accidents that have occurred over the years, the question of adequacy of qualifications has been asked many times. Looking into the findings of the HFM study, perhaps consideration of more advanced qualifications in certain job fields of safety critical workers would be necessary. However, Participant 3, a supervisor, suggested that refresher courses could be the correct remedy:

"… while the workers are noticeably possessing education certificates, what lacks are refresher courses and workshops for continued professional development, to keep lively the knowledge …"

4.2.7. Analysis of railway accidents occurrences

Since an understanding of the profile of the safety critical workers in Metrorail has been gained, the next section is a presentation of railway accidents from a possible causative factor perspective. The contribution of the human factor element, as well as the type of human factors leading to railway accidents, is presented.

4.2.7.1 Causes of railway accidents in South Africa

Questionnaire respondents were requested to indicate the extent to which a list of factors presented to them are likely to cause railway accidents. The results are indicated in the Figure 4.8 below. Looking at the highest possible causes, as depicted under highly likely and likely, poor equipment maintenance was cited as the most prevalent cause of railway accidents from the point of view of the safety critical workers at an 89,2% prevalence rate. This was followed by equipment malfunction at 77,24% and human factors at 49,11%. Environmental factors, rules and regulations were found to be the most unlikely causes of railway accidents in South Africa at 10,72% and 11,27% respectively.

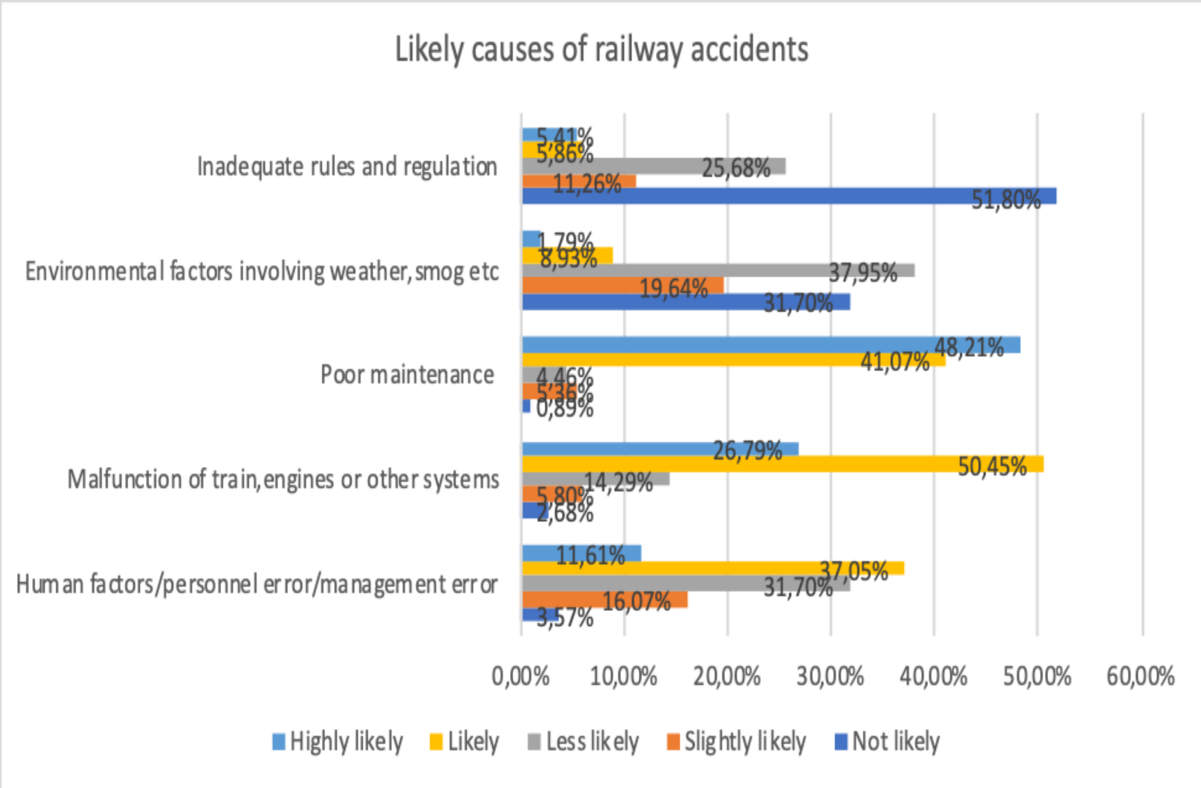

Figure 4.8: Causes of railway accidents

It is worth noting that from the perspective of the safety critical workers, that human factor is not the top cause of accidents. The likelihood of its contribution is 49%, which is a lower percentage compared to the findings of BOI reports in South Africa, which states 71%. There was a lively debate in the focus group with regard to malfunction of trains or poor maintenance being likened to human-related factors. Participant 5 believed the maintenance and malfunction were partly a responsibility of those who maintain the infrastructure and trains. He said:

"… while the infrastructure is old and susceptible to failures, the blame remains with the workers who maintain the infrastructure. It is their responsibility to condemn the use of those machines which are no longer worthy to be used … we should be seeing reports that a condemned infrastructure was being used that is why the failure occurred …"

However, Participant 4 disagreed. Instead, she viewed the issue as follows:

"… the maintenance is done and standards are met, tests are done, but the fact that the machines and infrastructures are aged cannot be taken away. The job of the maintenance team could be done splendidly, but the accident still happens because it was beyond their efforts … we should be talking of the aging machines requiring more frequent maintenance works than before and does the capacity of the operators sustain? Maybe that is where we should be calling in the need to condemn …"

The analysis of human-related factors that are pre-dominant in Metrorail are further discussed in section 4.1.7.2 below. The higher percentage of poor state of maintenance and malfunctioning equipment speaks to the state of infrastructure in Metrorail. The results are reflective of the fact that there is structural decay that has occurred due to infrastructure aging. Malfunctioning and poorly maintained equipment can easily lead to accidents, especially derailments and collisions. The RSR (2019) reported 370 accidents for the year 2018 to 2019 classified as derailments.

Other factors explored as possible causes of accidents were adequacy of rules and regulations, and environmental factors. The adequacy of rules and regulations results show the highest percentage (51,80%) of being an unlikely contributor to railway accidents. Only 5.41% of accidents were attributed to poor or the absence of rules and regulations. This basically supports the notion that the railway industry is highly regulated. Results from the focus group discussions indicated that regulation was adequate and formed part of the training to which the workers are subjected. Participant 2 had the following to say:

"Regulations are not an issue at all because, besides the regulator's contribution, we work with safety precautions which are always our priority; we are always set to observe such, and experience has been the major reminder. Nevertheless, the regulations are very clear and always up to scratch …"

A further discussion of the compliance to regulations in Metrorail is discussed in section 4.1.7.2 below. The results as they pertain to environmental causes show a very low percentage (10,72%) of contribution to railway accidents.

South Africa, although not regarded an "extreme" weather environment, has seen its share of notable weather conditions inclusive of flash floods, which result in railway infrastructure damage referred to as "wash-aways". Wash-aways occur when there are sudden heavy rains, which scour away the base of the railway track, leaving the rail and sleepers hanging without any support. Only 4% (79) of accidents caused by extreme weather conditions have been reported (RSR, 2019). A conclusive reflection from the findings, as depicted in Figure 4.8

above, is that railway accident causation in South Africa is unlikely to be due to environmental factors or the lack of adequate train operation rules and regulations, but are likely to be from human factors, equipment malfunction and poor maintenance.

4.2.7.2 Human factors among operators and their role in railway accidents

Respondents were presented with a list of human factors from which they were required to state the likelihood of those human factors to cause railway passenger accidents. The human factors which required rating by safety critical workers included fatigue, inattention, communication errors, judgement errors, deliberate violation of rules, technical errors, complacency and lack of teamwork, among other factors. The results of the likelihood analysis are presented in Table 4.2 below.

Table 4.2: Human factors causing railway accidents

Human factors	Not likely	Slightly likely	Less likely	Likely	Highly likely
Fatigue	3,57%	4,02%	16,52%	34,38%	41,52%
Inattention	3,14%	4,48%	13,45%	63,68%	15,25%
Absent/vague communication	6,70%	26,34%	25,00%	23,66%	18,30%
Poor judgement	8,48%	19,20%	32,14%	29,91%	10,27%
Deliberate rule violations	60,54%	9,87%	15,25%	5,83%	8,52%
Technical or operational errors	0,45%	4,91%	8,48%	41,52%	44,64%
Complacency	1,79%	8,93%	44,20%	41,07%	4,02%
Lack of teamwork	30,36%	17,86%	20,98%	22,77%	8,04%
Other	12,20%	14,63%	17,07%	31,71%	24,39%

A further diagrammatic analysis of the human factors that are likely to cause human factors was extrapolated from Table 4.2 above by combining responses from "likely" and "highly likely" responses. Figure 4.9 below, based on responses from participants, shows that the most likely human factor cause of accidents is technical errors (86%), inattentiveness (78,93%), fatigue (75,90%), complacency (45,09%), communication errors (41,96%), poor judgement (40,18%), lack of teamwork (30,81%) and, lastly, deliberate violation of rules at 14,35%.

These findings were complemented by the focus group findings where participants bemoaned lack of proper training, citing negative consequences of apprenticeship as a method of training. Participant X had the following to say:

"When operators go for apprenticeships, they are merely asked to do filing of papers and less of the practical machine handling … training should be structured … that is why there are poor judgement, inattentiveness and human error accidents …"

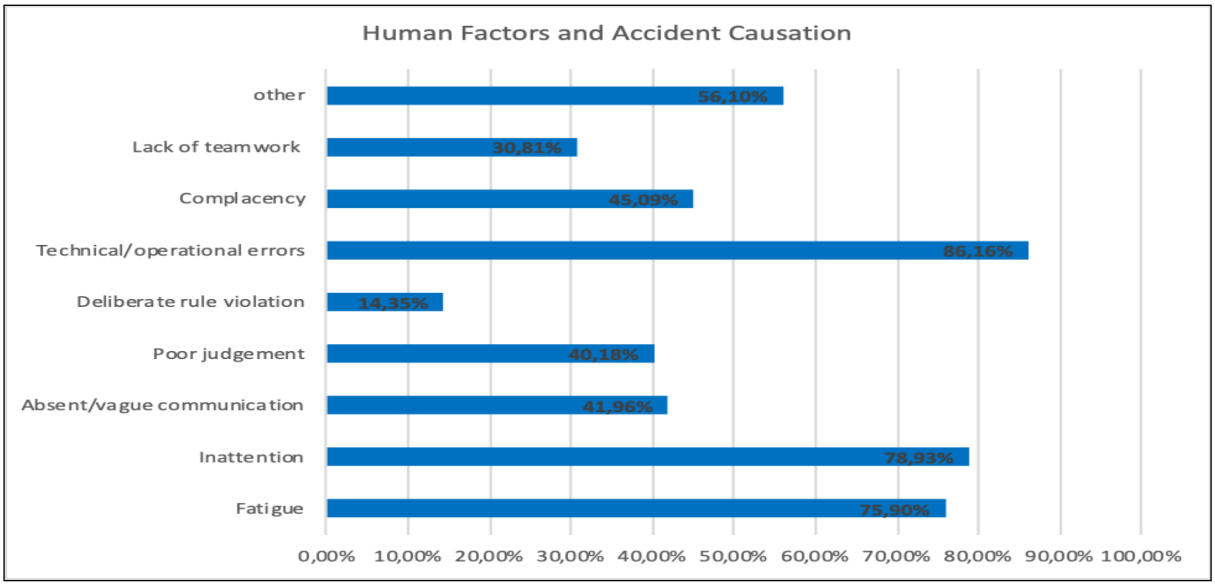

Figure 4.9: Summary of the most likely human factors causing accidents.

Related to the highest possible cause of accidents are operators committing technical/operational errors. Types of operational errors include SPAD, misjudgement of braking distance, over-speeding, momentary lapses of concentration by the driver and display of incorrect signals. The second highest human factor contributor to accidents was found to be inattentiveness. Inattentiveness/distraction happens when a worker loses focus of the primary task and concentrates on another factor. This may result in operational errors being committed by even the most experienced safety critical workers. This factor, however, is not easy to measure accurately.

Results obtained from focus group discussions also indicated that inattentiveness and/or distraction is also caused by technological advancements and over-reliance on automatic machine operations or robots. Participant 3 said:

"We thought that automation was going to reduce accidents, but alas, it has not. We were trained during the old days when there were no advanced automations which are now present; as olden-day operators, we are used to be checking the signals and exercising caution. It is different from the way those modern-day trained operators who put over-reliance on the automation, and are caught in the malfunctions of the robots …"

Another human factor contributing to accidents, but one which is not always easy to measure or verify, was found to be fatigue at 76%. The factors that can contribute to fatigue generally include long hours of work, shift work factors and physical conditions of work, for instance heat or noisy work environment. With the equipment malfunction mentioned in section 4.1.7.1 above, the safety critical workers in Metrorail tend to experience unplanned long hours and non-conducive work environments. To manage fatigue in Metrorail, the operator should not only deal with fatigue-related symptoms, but root cause as well.

Another notable response received is the low score rate of lack of communication as a human factor contributor to railway accidents. Communication has been a cornerstone of railway operations since trains started to run. Traditionally, communication occurs through use of trunk radio systems, signalling, use of flags, whistling and signage. Multiple publications on the causes of railway accidents in South Africa have attributable accidents to lack of or ineffective communication due to dysfunctional telephone and trunk radio systems, including ineffective communication during degraded mode, where signalling equipment is not functioning. Desk-top research revealed that 71% of the rail accidents recorded in South Africa were a result of human error while 29% accidents were caused by poor or a breakdown in communication systems (PRASA, 2015).

4.2.8. Severity of railway accidents

Railway accidents cost billions of rands to the economy and often result in fatalities and injuries to humans, damaged property and equipment, and negatively impact the environment and the economy. The safety critical workers were asked about the extent to which human factors caused accidents that resulted in serious consequences.

The results are from the experiences of the safety critical workers and are depicted in Figure 4.10. From the results, it is evident that the seriousness of the impact of railway accidents is significant in terms of injury to railway personnel, commuters, infrastructure and the environment. Looking at the "very serious" categories, damage to property is the highest at 63%; injuries accounted for 59% of the impact of railway accidents, fatalities accounted for 27%, while damage to environment (spillage of chemicals, degradation of fauna and flora) accounted for 22%. From the findings of the study, it remains evident that consequences of railway accidents affect every aspect of the railway ecosystem, from infrastructure to environment and human beings. It is thus important to put programmes in place to prevent railway accidents. The findings are in line with RSR observation as stated in the 2018/19 State of Railway Safety report that railway accidents cost the South African economy in excess of R961-million. During the launch of the 2018/19 state of safety report the deputy minister of transport alluded that while cost to the economy can be quantifiable, the biggest cost that the railway sector cannot quantify is the cost to families as a result of injuries and fatalities due to railway accidents. She mentioned further that, if not most of the rail accident victims are breadwinners who met their untimely deaths while on a quest to fend for their families resulting in a ripple effects that the families may never recover from (RSR, 2020).

Consequences marked as severe/critical were such that of the damage to property cases (marking 63%), 25% was attributable to ages above 50 years while 30% was for those below 25 years and 8% was attributable to the age group between 26 years and 49 years. Of the very serious injuries (marking 59%), the age group below 25 years topped the list at 30%, followed by the above 50 years age group at 20%, and, lastly, the age group between 26 and 49 years at 9%.

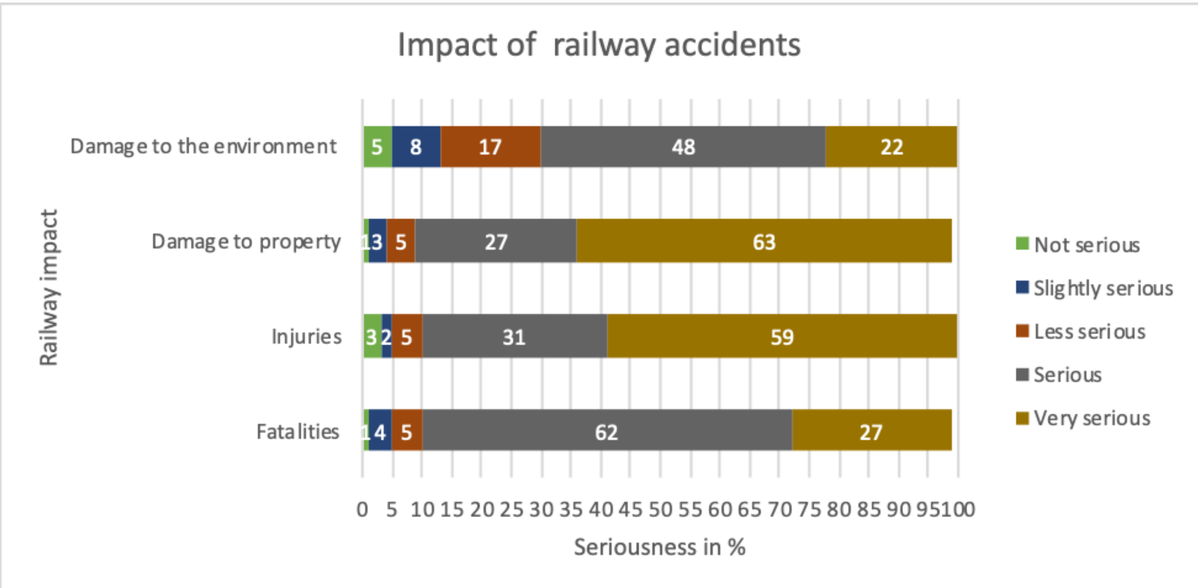

Figure 4.10: Severity of railway accidents

4.2.9. Pre-existing conditions to railway accidents

Analysis of a number of pre-existing conditions within Metrorail, which provide for a fertile ground for the occurrence of accidents, was also conducted. From the discussion on most prevalent human factors in section 4.1.7 above, it is evident that Metrorail safety critical workers mostly experience technical/operational errors. To get an understanding of what could be leading to the mentioned human errors, pre-existing or pre-conditions of railway accidents were analysed.

4.2.9.1 Pre-conditions for railway accidents

Respondents were presented a list of conditions from which they were required to indicate the extent to which each one of the causes was likely to result in railway passenger accidents. The results are indicated on Table 4.3 below.

Table 4.3: Pre-existing conditions to human factors

Preconditions for unsafe acts	Not likely	Slightly likely	Less likely	Likely	Highly likely
Lack of skill and knowledge	34,98%	20,63%	17,49%	20,63%	6,28%
Lack of proper rules and regulations	39,29%	21,43%	23,21%	8,04%	8,04%
Lack of proper or inadequate supervision	26,79%	21,88%	11,61%	26,34%	13,39%
Dilapidated equipment and systems	1,34%	2,23%	3,13%	45,54%	47,77%

When combining the "likely" and "highly likely" categories (Figure 4.11), it is apparent that dilapidated equipment and systems (93,31%) play a major role in accident causation in South Africa. In the presence of aged and dilapidated railway systems, the likelihood of accidents increases. This factor is related to section 4.1.7 above, where it was evident that poor maintenance and malfunction of train or system were found to be top causes of railway accidents. Due to the aged, dilapidated and "fatigued" railway infrastructure, the railway operations remain vulnerable to accidents. On the low side of the spectrum of pre-existing conditions to human factors is lack of proper rules and regulation at 16,04%.

The findings are consistent with the findings in section 4.1.6, further confirming the positive role of available regulatory standards in the prevention of railway accidents. On the role of supervision as a cause of railways accidents, 39,7% of the respondents were of the view that this was highly likely. Lastly, 26,91% reported that the lack of skills and knowledge of operators was a precondition to situations where railway accidents occurred. Over 50% of the respondents, however, thought the contrary. Even though the short duration of training for safety critical workers has raised questions, the combined years of experience within Metrorail is sufficiently high to cater for necessary skills and knowledge.

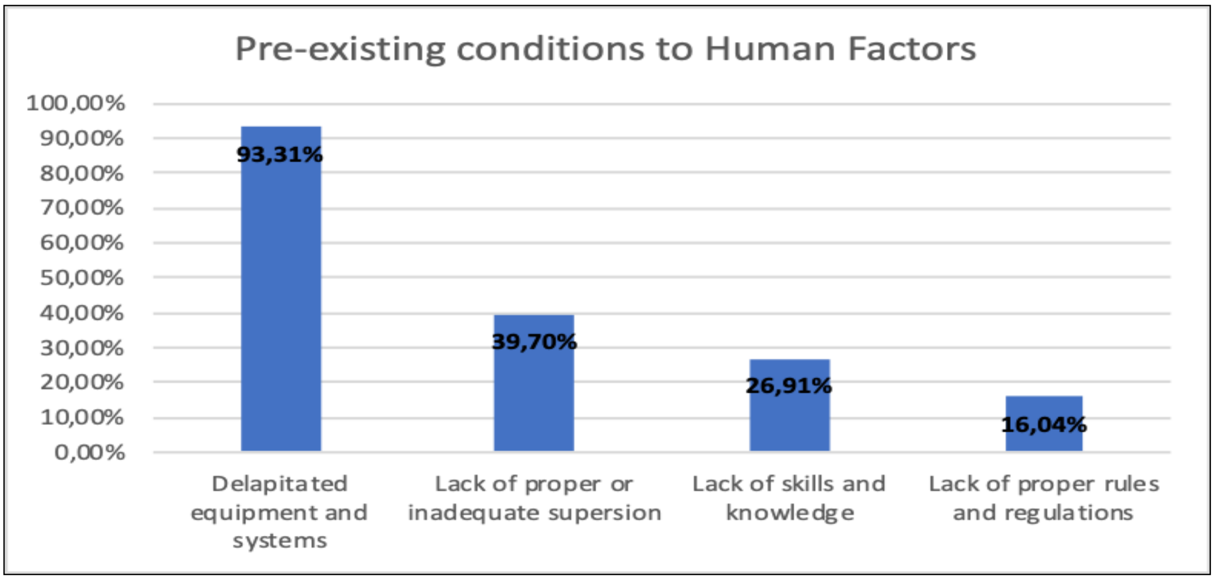

Figure 4.11: Most likely pre-existing conditions to human factors

4.2.10. Role of supervision in railway accidents

The railway environment has its own departmental hierarchical structures with well-defined supervisory roles. As stated in the demographics of the study (see section 4.1.2), section managers accounted for 12,03% of the study respondents. The following supervisor-related responsibilities were assessed: adequacy of supervision, supervisory violations, failure to correct problems and planned inappropriate operations. The results are tabled below in Table 4.4.

Table 4.4: Role of supervision in railway accidents

Unsafe supervision	Not frequent	Less frequent	Frequent	Very frequent
Inadequate supervision	28,57%	32,59%	29,02%	9,82%
Planned inappropriate operatio	35,71%	38,84%	20,54%	4,91%
Failure to correct problems	20,98%	31,25%	19,20%	28,57%
Supervisor violations	34,08%	48,43%	14,35%	3,14%

Even though the role of supervisors contributes to 39,7% of human factor-related accidents, the safety critical workers were of the opinion that the most frequent supervisor-related issue is failure to correct problems. When combining the "frequent" and "very frequent" categories, failure to correct problems is the most pre-dominant supervisor-related human factor at 47,77%; inadequate supervision at 38,84%, planned inappropriate operations at 25,45% and supervisor violations at 17,49%. Supervisors play a vital safety role in reinforcing proper procedures and work practices to correct system weaknesses. This supervisory gape was stressed in the focus group discussions with every participant agreeing with Participant 3, who said:

"… there is need for tightening supervisory roles through close monitoring, refresher training, and tests of competences … in actual fact, there is serious need for establishing log sheets that are signed with regard to identified safety critical infrastructure, times and events so as to consolidate control on the human factor …"

Based on the findings, it can be concluded that there are significant supervisor-related issues that contribute to railway accidents. An examination of the company's accident records shows that this is indeed the case.

4.2.11. The role of organisational climate on HFM

Respondents were required to state the extent to which organisational influences impact on the management of railway safety. The influences were grouped into three categories, namely resource management, organisational processes and safety climate.

4.2.11.1 Resource management

Respondents' opinions were sought on three elements of resource management, namely human resources, financial resources and equipment. As presented in the Table 4.5 below, 80% of the respondents said the human resource training and performance tracking had a positive effect on influencing safety in railway operations. The results pertaining to training can be related to mandatory refresher training that train drivers have to undergo annually for the operator to maintain the operational licence with RSR. Within the refresher training, rail incidents are discussed and corrective measures are adopted.

On the one hand, 73% of the respondents were of the view that financial resources also played an effective role in the influence of HFM. The result reflected by the safety critical workers implies a positive financial resource management. This is contrary to what has been reported in various publications, including the infamous 2015 Public Protector report, entitled "Derailed", in which Metrorail was accused of improper financial conduct.

The safety critical workers showed less confidence in the role of equipment on passenger safety, with 24,1% believing there is effective management of equipment resources, and the majority (45%) believing that it is slightly effective. The findings on the role of equipment resources playing a role in HFM are congruent with the earlier findings in the study in section 4.4.2, which show that equipment malfunction and poor maintenance are leading causes of railway accidents.

4.2.11.2 Organisational processes

Respondents were required to express their opinions on how three elements of organisational processes, namely operational standards, system policies and system procedures, are effective in influencing HFM. From the data results presented in Table 4.5 below, 92% of the respondents reported that standard operating procedures played an effective role in managing safety in railway operations, 84% attributed safety management to the policies used by the railways while 82% listed system procedures. The results reflect the attitude that safety critical workers have on railway environment regulations. The same mention of poor organisational processes made its way into the Public Protector's report.

4.2.11.3 Safety environment

Lastly, another organisational climate factor was assessed which looks at the opinions of safety critical workers on safety. The railway operation's safety environment was tested on two elements, namely culture and safety programmes. A total of 66% of the respondents reported that a culture of safety management had been effective in reducing accidents and fatalities in their operations, while 63% reported that the reduction in accidents was also due to the safety programmes that have been implemented at Metrorail. Despite the number of accidents at Metrorail (90 in 2018; and 87 in 2019) (Department of Transport Annual Report, 2019), the safety critical workers are of the opinion that safety dignity is still maintained.

Table 4.5: Organisational influences

Organisational influences		Ineffective	Less effective	Slightly Effective	Effective	Very Effective
Resource management	Human Resource (training & tracking assessment)	3,13%	9,82%	16,52%	44,64%	25,89%
	Financial resources	7,14%	19,64%	16,96%	39,29%	16,96%
	Equipment resources	8,93%	21,43%	45,54%	16,96%	7,14%
Organisational processes	Operation standards	1,80%	6,31%	19,82%	53,60%	18,47%
	System policies	2,23%	3,57%	9,82%	61,61%	22,77%
	System procedures	3,13%	3,57%	11,61%	58,04%	23,66%
Safety climate	Safety Culture	4,02%	10,27%	19,20%	44,64%	21,88%
	Safety programs	6,70%	12,95%	17,41%	40,18%	22,77%

Results from focus group discussions showed that safety critical workers expected the safety environment to be accident risk free in all aspects where infrastructure and HFM were chief factors. Participant 6 had the following to say:

"… a safe environment will consist of a systematically managed infrastructure, vehicles and human resources because they often get involved in accidents together. It is important to have a documented procedure dictating the safety culture … implementation of checks and balances are lacking in Metrorail; this is worsened by the fact that the controls are manual … but still automation without a systematic approach will cause adoption challenges …"

Relating to the environment, although the rating of the questionnaires gave an impression that the effectiveness of the safety environment controls were satisfactory, a further inquiry through focus group discussions revealed that the environment could be improved through an integrated approach to safety controls. This finding supports the earlier suggestions for a checklist and follow-up system of risk areas and hazard-inflicting factors in the HFM standards.

4.2.12. Role of risk management

Respondents were also presented with a list of risk management processes from which they were required to analyse the extent to which they had been effective in promoting HFM at their workplace. The results are presented in Table 4.6 below. PRASA's risk management strategy is based on the following key elements as identified by the respondents: risk identification and analysis, evaluation of the identified risks on operations, and communication of risk information to the relevant stakeholders. The results indicate that the organisation undertakes effective risk management processes. PRASA (2016) reported that the Board of Directors (BoD) was responsible for the total risk identification and management process, including physical and operational risks, human resource risks, technology risks, business continuity and disaster recovery, and compliance risks.

Table 4.6: Role of risk management in promoting human factors

Risk management processes	Ineffective	Less effective	Slightly Effective	Effective	Very Effective
Risk identification and analysis	0,90%	9,42%	21,08%	33,63%	34,98%
Risk evaluation	2,24%	12,56%	18,83%	32,29%	34,08%
Risk control	4,48%	15,70%	21,52%	26,46%	31,84%
Risk communication	4,93%	15,70%	22,42%	24,22%	32,74%

From the views of the safety critical workers, there is emphasis on the management of risk factors as reflected by the effectiveness scoring at identification and analysis (68,61%), risk evaluation (66,37%), risk control (58,3%) and risk communication (56,96%). Results from the focus group discussions indicated that, in the training sessions, there is need for training risk management because the ignorance of the basics of risk management is causing rise in human factor-based accidents. Participant 4 said:

"… the weakness that is in our operators' being less conscious about operational risks, resulting in accidents, could be avoidable through risk training …"

In addition, Participant 2 said:

"… continuous improvement should be systematically adopted where total quality management of risk is aimed to prevent and control risk in totality … Failure to identify risk should carry penalties on the accountable person; risk recurrence should be avoided by closing the gap through which the risk recur … Infrastructure, machines and humans who fail the risk avoidance tests should be stopped from being used until they pass the tests …"

4.2.13. The influence of compliance standards on HFM

Respondents were also presented with a list of railway compliance standards from which they were required to state how effective or ineffective these standards had been when used to manage safety operations at railway companies. From the results presented in Table 4.7 and Figure 4.12 below, the levels of effectiveness (by combining "effective" and "very effective") were observed. Compliance to external railway authorities and internal railway standards is of paramount importance in ensuring safe railway operations. The safety critical workers at Metrorail are of the opinion that there is awareness and adherence to railway compliance standards. The results reflect that the compliance standards being implemented the most to manage safety at railway operations are, in order of most to least effective, as follows: safety legislations, policies, rules and regulations at 89,48%. This is followed by safety management standards and procedures at 87,45%. Operational permits, licences and RSR rules are at 86,55%, and, lastly, fines, penalties, incident investigation are at 71%.

Table 4.7: Compliance standards

Compliance Standards	**Ineffective**	**Less Effective**	**Slightly Effective**	**Effective**	**Very Effective**
Policy and legislation	2,24%	3,59%	7,62%	60,09%	26,46%
Rules and regulations	1,35%	2,69%	6,28%	58,74%	30,94%
Safety management systems	1,79%	5,83%	4,93%	55,16%	32,29%
Operations permits and licences	2,69%	2,69%	8,52%	56,95%	28,15%
Fines and penalties	4,95%	7,66%	15,77%	50,90%	20,72%
Incident investigations	2,70%	11,71%	13,96%	47,30%	24,32%
Regulatory authorities (RSR)	4,04%	4,93%	4,93%	49,33%	36,77%
Others	27,03%	10,81%	16,22%	27,03%	18,92%

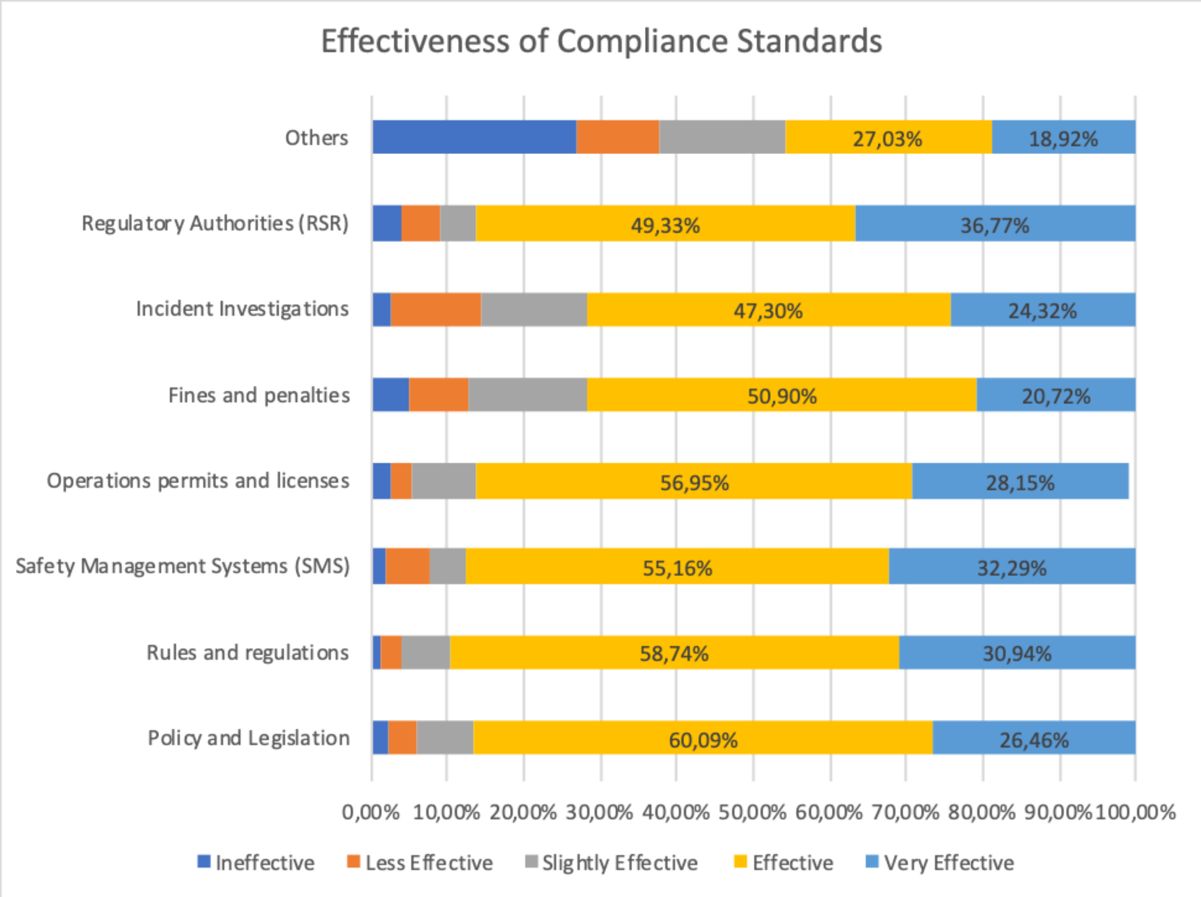

Figure 4.12: Effectiveness of compliance standards

The results from the HFM study show that passenger railway operators in South Africa are cognisant of the need to comply with required standards and rely on legislation to uphold safety within their operations. In reality, this is not always the case. On 4 February 2012, two trains collided between Lebaleng and Soshanguve because one of the drivers did not adhere to the train operating rules and point 7.4.1 of the motor coach manual, which requires that the driver must stop the train immediately when electrical traction power to the train is lost (Bouwer & Hubinger, 2014).

Findings from focus group discussions indicated that there is need for a tool or a systematic approach to the identification of threats or hazards to the organisation and/or evaluating them, by quantifying risk and by putting in place measures to treat, transfer, terminate or tolerate risk. Participant 6 had the following to say:

"… Barriers have to be put, for example fitness for duty check-ups, proactive indicators and training so that risk is barred. Risk mitigation efforts like alarms, automated controls (like those in Gautrain). This is referred to as safe-guarding … CTC should have authorisation tokens or authorisation procedures …"

Other participants opined that the application of the HFM standards needs to go beyond competence to include capability. Participant 4 said:

"… competence comprises qualifications, skill and experience, and this is not enough; there is need for assessments based on capability, and capability includes qualifications, skill, experience and application … workers should be time and again tested for capability …"

4.2.14. Role of corporate governance structures in leading HFM standards

Respondents were presented with a list of railway governance authorities from which they were required to state how effective or ineffective these authorities are in the implementation of HFM standards. The authorities responsible to ensure Metrorail achieves its business mandate, which includes assurance of implementation of relevant standards to achieve safe operations, are DoT, the RSR, BoD, chief executive officer and executive managers. The results are represented below in Table 4.8.

4.2.14.1 Department of Transport

From the results below, 35% of the respondents reported the Ministry of Transport is slightly effective in ensuring that HFM standards are implemented; 34% said the Ministry was effective, and 14% said it was less effective.

4.2.14.2 Railway safety regulator

On the rating of the rail safety regulating agency as having a significant influence on the implementation of HFM standards, 54% said it was effective, 32% found it to be very effective while 6% thought it was less effective.

4.2.14.3 Board of directors

The BoD at PRASA was found to be slightly effective (47%). It was commented that it is influential in the implementation of HFM standards, with 25% saying the board is not as effective, 25% saying it is less effective and 14% saying it is effective.

4.2.14.4 The office of the chief executive officer

The majority of respondents (45%) reported the chief executive office as being less effective in implementing HFM standards, while 31% said the office is slightly effective and 11% reported it as being ineffective. During the review of the 2015 performance, the BoD assured the Executive Authority that, notwithstanding the shortcomings and challenges of PRASA, the board was satisfied with the major strides that the organisation was making with the implementation of its Bold Strategy aimed at delivering a new, world-class train system for the people of South Africa, in line with the vision of the Executive Authority and the Goals of the National Development Plan (NDP) (PRASA, 2016).

4.2.14.5 The role of senior managers

Most respondents (34%) reported that senior managers had a slightly effective role in the implementation of HFM standards, 32% said their role was less effective while 22% reported that they were effective.

Table 4.8: Role of railway governance authorities

Corporate Governance	Ineffective	Less effective	Slightly Effective	Effective	Very Effective
Department of Transport	6,28%	14,35%	35,43%	33,63%	10,31%
Railway Safety Regulator (RSR)	3,60%	5,86%	5,41%	53,60%	31,53%
Board of directors	9,01%	24,77%	46,85%	14,41%	4,95%
Organizational CEO	11,26%	45,50%	31,53%	7,21%	4,50%
Senior management	7,66%	32,43%	33,78%	21,62%	4,50%

Adapted from Table 4.8 above is Figure 4.13 below, where results from "effective" and "very effective" were combined to demonstrate the most effective governance structures in the railway sector.

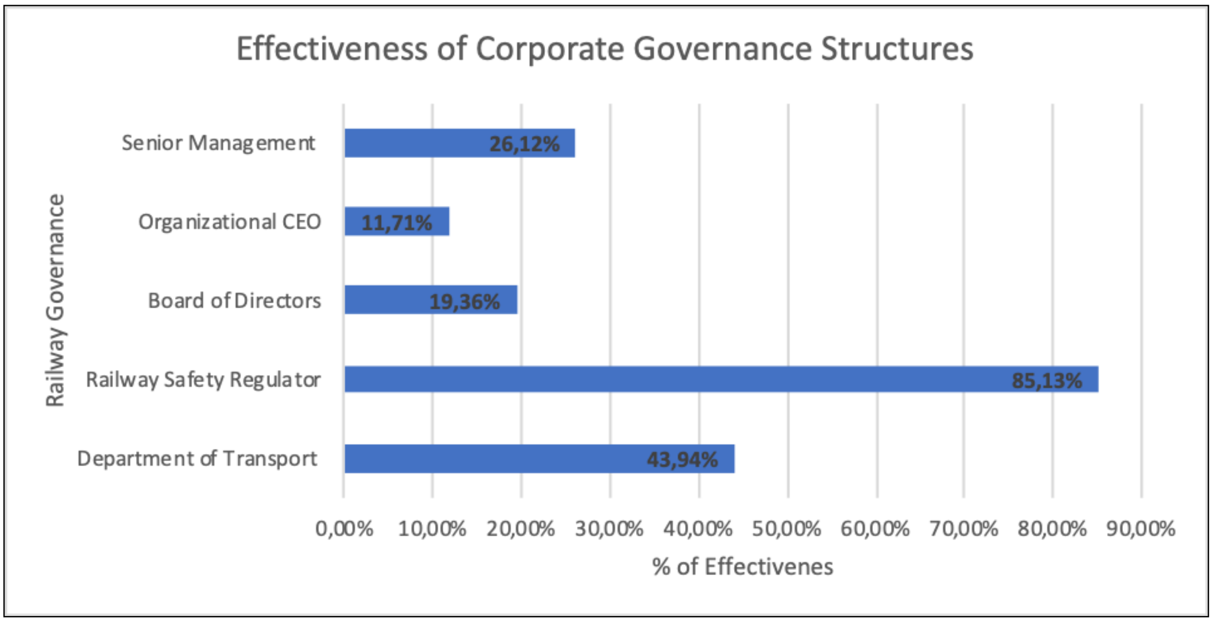

Figure 4.13: The role of senior managers

The results from Figure 4.13 above show that government agencies have a significant influence on the implementation of HFM standards at PRASA. The DoT, which is the national ministry and principal shareholder of PRASA, is considered by respondents as having an effective role (43,94%) in ensuring the implementation of HFM standards. The RSR, the entity that provides safety standards, investigation of incidents, issuance of licences, fines and penalties in rail operations was assigned a score of 85,13% by safety critical workers. The results indicate that respondents have confidence in the current national governance structures.

The governance of an organisation rests on the company's BoD (Khan & Wang, 2021). On aspects of governance within PRASA, 47% of the respondents reported that the BoD is slightly effective, 25% claimed it to be less effective and only 19,36% said it was effective. The majority (45%) also reported that the office of the chief executive officer was less effective in implementing HFM standards while 31% said the office was slightly effective. These results demonstrated subdued confidence in the ability for these structures to implement effective HFM standards. The low confidence is also reflected in the results for the senior managers; 34% reported that senior managers had a slightly effective role while only 26,12% said they were effective.

In the review for the year 2015, asset-related crimes and vandalism were reported as having affected the performance of infrastructure and availability of rolling stock (PRASA, 2016). A total of 588 asset-related incidents were recorded in the year 2015 review, including 113 incidents of cable theft, 44 incidents of signal equipment theft, 64 incidents of Perway and electrical equipment theft and more than 120 incidents of vandalism to rolling stock, including arson (PRASA, 2016). A systems approach was therefore suggested by participants of the focus group in such a way that the BoD get an assessment every year on the effectiveness of policies towards accident reduction, especially focusing on human factors. Participant 3 had the following to say:

"… a rating of the policies and their shortcomings should be done every year, with implementation action plans, continuous assessments and key persons whose key result areas are linked to the success of the policies …"

Focus group discussion results also indicated that management needs to accelerate all the programmes that will address the performance challenges, as a result of the destruction of assets, by ensuring that the fencing programme, maintenance programme and the accelerated general overhaul programme is made effective. Participant 1 had the following to say:

"… although the directive for corrective action to infrastructure maintenance was supposed to receive urgent priority and the allocation of the necessary resources, there seems to be no satisfactory adherence to the order because we are still bemoaning poor infrastructure …"

These findings agree with the PRASA (2016) findings that, while the BoD continued to address the systemic failures of the business on the one hand and ensured delivery of building a modern rail company on the other, the immediate focus is to ensure that Metrorail delivers quality rail services. Such quality services should enable individuals and communities to access socio-economic opportunities and contribute to a better quality of life for the people of South Africa (PRASA, 2016).

The findings suggest that senior management should craft the framework for a systematic approach to the whole organisation where the HFM is addressed in conjunction with the rest of other factors, such as infrastructure management. Focus group discussions suggested a wholistic approach to risk management; participants agreed that a helicopter view was required to address the occurrence of accidents through total quality management systems. Participant 5 suggested:

"…while the legislation for HFM standards is laid down (SANS 3000-4:2011), the actioning of the legislation requires standard operating procedures for application of the legislative requirements, showing commitment of the organisation. Departments should not operate in silos. Governance (enterprise-wide risk management), maintenance, the human factor, risk and supervision should be integrated. Procedures for compliance should be drafted, reviewed, signed for adherence by operators and workers, and be implemented on a daily basis … Accountability checks from department to department, individual to individual, with handover take-over agreements, a systematic procedure that is clearly spelt in the SOPs and that can be followed …"

4.3. Secondary literature findings

In the secondary literature review, the author will briefly review comparative results of some of the findings, as well as discuss new themes which emerged from the findings.

4.3.1. Review of demographics

The findings of the demographic profile of the respondents were compared to that of other countries. Firstly, the dominant male representation in South Africa is equivalent to railway industry representation in other countries such as the UK. In the UK, an average of 16% (14,024 out of 85,723 workers) of rail workers are females (Ginn, 2019). This finding is comparable to HFM study results in SA, where the female representation stands at 13% (PRASA, 2018).

A study by Casale, Posel and Mosomi (2020), which looked into employment data from 1994 to 2019, states that female labour force participation rose from about 40% in 1994 to 54% in 2019. Despite this "feminisation" of the workplace, growth has been more realised in low-skilled jobs (Casale *et al.*, 2020). It can therefore be concluded that even though female representation in the South African labour market is evident, there is still a substantial shortage of female safety critical worker representation within passenger rail operators in South Africa.

Certain stereotypes exist in accident causation when compared to gender and age. A BOI report from Metrorail following a train accident in Western Cape brought to the fore the issue of gender when one of the recommendations pointed to "lifestyle management enhancement for train drivers, especially women drivers, because of the fatigue resulting from their working hours" (IOL, 2003). By this statement, the BOI was inferring that there was a correlation between female drivers and train accidents. However, ARA (2020) argues that there is not enough evidence supporting the view that women incur more accidents in rail operations than their male counterparts.

While the HFM study found that most employees are at their prime working age, the few employees above 45 years of age were found to be more prone to accidents. Advancing this similar argument is Chau *et al.* (2010), who concluded that older workers (older than 50 years and who struggle with the handling of machinery) are more prone to accidents compared to the 30- to 40-year work experience group. Looking at the findings by Chau (2010) and the OECD (2018) reports in relation to the findings of the study, it can be concluded that since Metrorail workers' average age is between 25 and 45 years, the railway accidents should be minimal, as earlier stated.

In terms of educational qualifications, Mukwena (2018) argued that the railway industry in South Africa suffers from lack of academically sound skills, and that there are no sufficient railway-specific courses offered in universities and colleges in the country. This argument has been further advanced by the Department of Higher Education and Training (2016), who concluded that there is a mismatch between qualifications and occupations, high unemployment and skills shortages.

Another reference of qualification and accident causation in South Africa is Bouwer and Hubinger (2014) who argued that commuter train drivers were in the past (prior to 1990) sourced from highly experienced freight train drivers. Due to some restructuring of the South Africa rail industry, this practice was changed. An accelerated training programme for commuter train operating staff was implemented, resulting in drastically reducing the duration of the train driver training period from two years to six months which (PRASA, 2019). Compounding the negative effects of this new practice of train driver progressing from junior driver grades to the grade of commuter train driver was the rapid promotion to supervisory grades of operating personnel, without receiving sufficient training to fulfil their new role as supervisors. This period of change can be directly linked to a 34% rise in accidents due to unauthorised movements, rolling stock and movements exceeding limit of authority from 2016 to 2019 in South Africa.

Based on the results of the study and the literature evidence stated above, a review of safety critical workers qualification and training skills as a contributory factor to railway accidents cannot be ignored. The fact that most railway operators in South Africa manage their own training and qualification requirements is concerning and could be one major cause of accidents.

4.3.2. Review of accident causation

From the results regarding the pre-existing conditions and causes of accidents in the railway, it is evident that dilapidated equipment and systems play a major role in accident causation in South Africa. The issue of aging infrastructure in the railways has been a factor of discussion over the years. South African railway transport systems have been suffering from reliability challenges due to its aging infrastructure and high utilisation of its physical assets (Jidayi, 2015). The issue of reliability is closely related to maintenance, as enumerated by Mukwena (2018). The study observed that all components of the railway track have an expected life span, under specific working conditions, and their reliability is guaranteed only under such conditions. As such, the lack of an effective maintenance strategy can lead to major compromise of the railway infrastructure. Supporting this notion is Zaayman (2016), who stated that for a railway system to be considered efficient and effective, its infrastructure must be reliable, available, maintainable, affordable and safe (RAMAS). Zaayman (2016) further argued that RAMAS can be achieved only by implementing an effective infrastructure maintenance strategy.

This view was also expressed on a continental spectrum by the African Development Bank, which stated that Africa runs a risk of not realising its full potential in exploiting its abundant natural resources and wealth. The reason is the current conditions of existing railway infrastructure and rolling stock, which is poor and sometimes appalling as a result of lack of investment in infrastructure and the absence of a supporting institutional framework (African Development Bank, 2015).

4.3.3. Human factor causes of accidents

Further literature review was conducted to investigate available statistical data on human factors contributing to railway accidents. Fan and Smith (2018) concluded in a UK study that fatigue contributed to 21% of railway accidents. Inattentiveness, which was mostly due to distraction, was found to contribute to 31% of road accidents in Australia (Wundersitz, 2019). Other human factors found as contributory to railway accidents elsewhere were enumerated by Nayak and Tripathy (2018), who concluded that failure to observe rules contributed 40%, lack of alertness contributed 9% and failure to observe rules, check signals and observe speed contributed 21% to railway accidents. The results are fairly low in frequency compared to those found in the HFM study as discussed in section 4.1.7.1.

Driver distraction is defined by Naweed (2013) as "the diversion of attention away from activities critical for safe driving towards a competing activity". A study by Dambuza (2017) concluded that factors that contribute to driver distraction and inattentiveness originate from the technologies introduced to improve driver performance. Dambuza (2017) included excessive noise from the cab design, the lack of toilets on the trains, the use of the dead man's switch (which allows power shut off and emergency brake application in case the driver falls ill/dies while driving), use of mobile phones, listening to music and conversing with a passenger, as well as the use of a train driver assistant among the distractors. Therefore, in addressing inattentiveness as a cause of accidents, the stated causative factors require attention as part of HFM.

On the issue of fatigue as a major contributory human factor to railway accidents, a review of an exploratory study of UK rail workers' perceptions of accident risk factors by Morgan *et al.* (2016) was investigated. The study demonstrated that fatigue is largely due to the impact of shift work, commuting time (between work and home), work-life balance, and time pressure on perceived work deliverables. Fatigue inevitably affects decision-making and risk-management abilities, resulting in increased risks of error, accidents and incidents, and the increased likelihood of near-miss occurrences. An earlier study by Dorrian *et al.* (2007), cited in Fan and Smith (2018) opined that train operators with a higher risk of fatigue had more frequent speed violations and heavier brake use on flat sections of the route, both of which would increase the safety risk.

4.3.4. Impact of railway governance, compliance and risk on accidents

According to the findings of the HFM study, there is low confidence in the corporate governance structure of PRASA to manage accidents within the railway sector. The findings are consistent with the public views and opinions that lack proper governance. Corruption, which is rampant within the organisation, diverts resource utilisation, leading to shortages in vital structures that allow safe railway operations. The 2018 South African Parliamentary Monitoring Group PRASA Board was subpoenaed to present a recovery response plan to parliament for the multitude of crises that PRASA was facing. Amongst the crises that required intervention at the time were updates on train accident investigations, plans to prevent future accidents and progress on support for affected families and victims of train accidents. In addition, PRASA asset destruction, impact and solutions, causes of delays and line suspensions caused by vandalism and signal cable theft, and interventions for safe working during manual train authorisations (MTAs) also required intervention (www.pmg.org.za).

Another example of governance issues in PRASA is found in the 2015/2016 South African Public Protector's damning report on the gross mismanagement of finances within PRASA, which has led to the operator being compromised. The report entitled "Derailed", details the maladministration relating to financial mismanagement, tender irregularities and appointment irregularities. Due to the mismanagement of financial resources, safety of the railway has been severely compromised; resources that would have assisted to manage rolling stock procurement, maintenance of the track and security of the rail track have been depleted.

The impact of poor governance is explained further by Safer Spaces blogger (2018), which states that due to the lack of financial resources in PRASA, it is a common scene for people to run across the tracks, hang out of doors and windows, travel between carriages or even ride on the roof, thus increasing the number of accidents on the railway (Polit & Beck, 2014). Williams (2019) further argued that compromised investment in technology and manual authorisations of trains result in many safety violations, which are responsible factors for multiple railway accidents within PRASA, Gauteng region. The manual authorisation usually occurs as a result of cable theft, poor maintenance or a lack of spares for the automatic signalling system, all of which are due to poor governance.

Even though there is lack of confidence in the PRASA management, including its BoD, CEO and senior managers, the safety critical workers reported confidence with RSR. This was also reflected in the results on compliance. An example of the robustness of RSR in ensuring commuter safety is stated by (BusinessLive, 2019). The report alludes to the fact that, in 2019, PRASA presented an Annual Safety Improvement Plan to the RSR after being ordered by the High Court to do so. Two versions of this plan were rejected by RSR. The rejection of the Annual Safety Improvement plan by the RSR shows that RSR plays an important role in ensuring adherence to safe railway operations by PRASA. This is the basis of the confidence that the respondents had on RSR's ability to implement HFM standards.

The safety critical workers opined that risk management at PRASA receives appropriate attention. Perhaps this interpretation comes from the culture of Metrorail, where there are high levels of intolerance to violation of safety rules. An example of this is multiple suspensions, dismissals and disciplinary actions that are embarked upon following railway accidents. For example, 19 train drivers faced disciplinary action following the Sowetan 2011 accident that left 644 injured (Sowetan, 2011). PRASA Rail divisional CEO reiterated this point by stating that "Metrorail will not tolerate any deviation from the updated and strengthened safety procedures and will take stern action against any transgression by our employees. Our main mandate and commitment is to transport our passengers safely to and from their areas of work, school and recreation" (Mofi, cited in Newsroom, 2011).

However, reviewing the many accident BOIs over the years, it is evident that some core aspects of railway risk management are not being addressed by Metrorail. A study by Mathebula and Sopazi (2016) concluded that organisations like Metrorail should not allow a degraded mode of operations to be a permanent state. They should desist from the normalisation of operational deviance as they lead to disasters. It can be concluded that normalisation of abnormal conditions of work does not constitute risk management.

4.4. Reflection on findings from a Technology, Innovation, People and System (TIPS) model perspective

Observing HFM study findings, the researcher used the Da Vinci TIPS model lens to test PRASA's current competitive performance. TIPS is an acronym for a Da Vinci model which constitutes four critical management areas, namely technology, innovation, people and system. TIPS specifies that any organisation that strives to be globally competitive must be extremely competent in managing the above-mentioned areas of management. These concepts are defined by Da Vinci Institute as follows.

The management of technology pertains to the tools and metrics organisations use to gain competitive advantage. It is a way of doing things better and may involve the use of anything from computers and hi-tech, to simple hand-held tools (The Da Vinci Institute, 2022). For

PRASA, technology is applicable. Through observation, the researcher found that manual operations such as CTC can be enhanced remotely by interface aids with train drivers, improving visualisations and reducing human error.

The management of innovation is all about how an organisation stimulates and capitalises on the ideation process to develop an innovative product or service, which has either commercial or social value. It is about hard metrics such as income generated from new products, processes or services as well as success rates in commercialising new offerings (The Da Vinci Institute, 2022).

The management of people pertains to the human interface. It embraces both the employee and the end user. It is about the processes that organisations deploy in the development of their human capital. It includes processes of engaging people, how people choose their levels of engagement, creating and sharing of knowledge by all involved, how they incentivise their people and how they plan for succession to ensure organisational longevity (The Da Vinci Institute, 2022).

The management of systems is the process of synthesis, where systemic integration of all organisational activities and performance is used to solve unique problems, and where hyper-competitive redesign of the landscape occurs. This includes internal synovation and organisational ecology that allows the parts to become greater than the whole (The Da Vinci Institute, 2022).

The TIPS model, shown in Figure 4.14, fundamentally starts with an organisation as a system, which is at the centre of the model. The “T” in the model stands for technology, the “I” stands for innovation and the “P” stands for people. Technology in this regard is different from hard technology; it is about the tools and metrics required to achieve differentiation. In the innovation space, ideation to create value occurs. The people space represents human interface with technology.

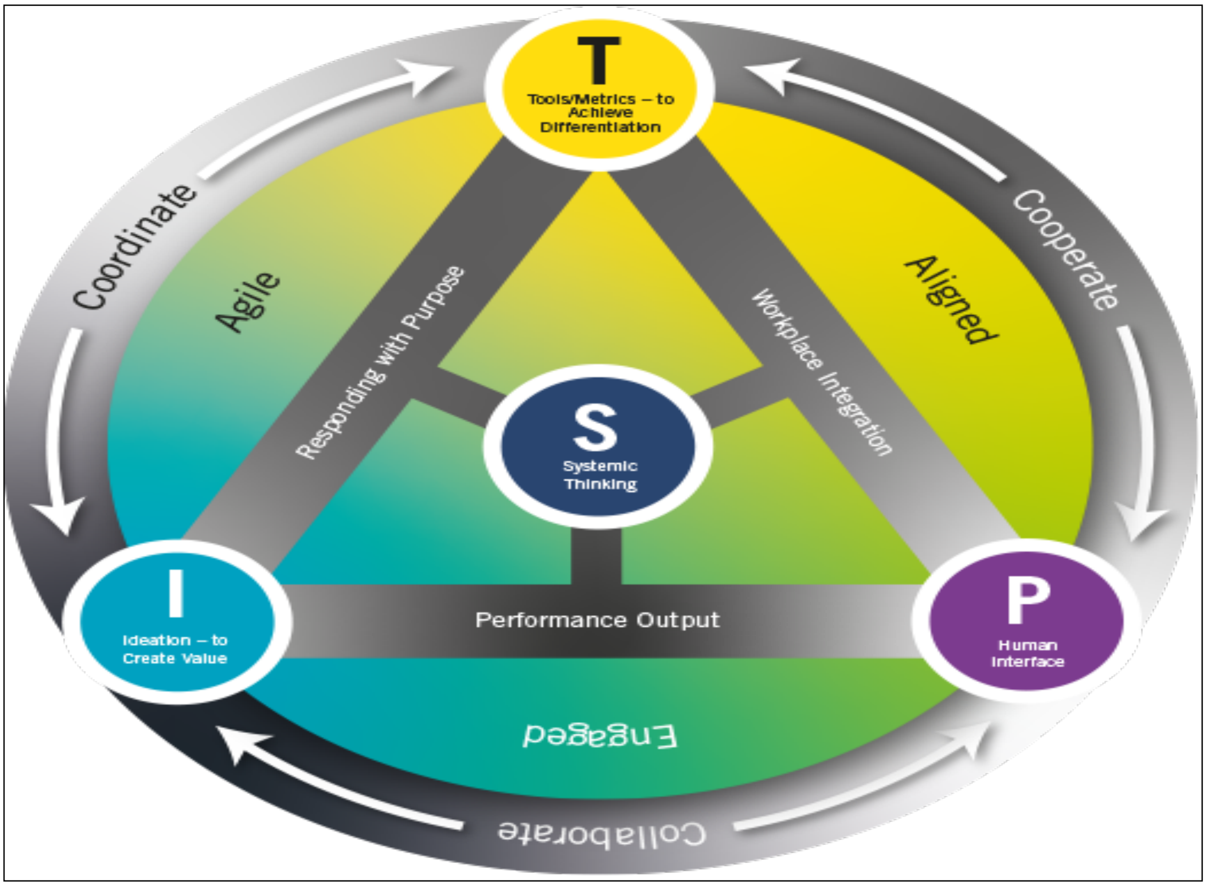

Figure 4.14: Da Vinci's TIPS model adapted from The Da Vinci Institute (2022)

Below is the discussion about the TIPS management areas within which the researcher viewed the HMF study.

4.4.1. Technology and innovation

When looking at the aspect of technology, it is a notable fact that technology automates the most complex of processes, be it in communication, education, medicine or any other industry. With the application of technology, critical and time-consuming processes can be executed with ease and in less time, allowing efficiency and speed. There are various methodologies that organisations can employ to choose the appropriate technological tools. Technology road mapping processes permit organisations to look at the congruencies in relation to business, customers and technology. It promotes use of value analysis to compare current ways of business versus ideal ways, and which allows organisations to have measurable intervention outcomes.

From the results of the study under section 4.2.7.1 and 4.2.7.2, where causes of railway accidents in South Africa are recorded and discussed, it is evident that PRASA is experiencing high rates of accidents due to poor state of maintenance, dilapidated and decaying railway infrastructure, and human-related factors such as fatigue. These factors are easily manageable through technology. Technology can allow access to systems such as asset management and predictive maintenance tools, which in turn will improve timely decision-making on issues that affect safety and resource availability, and will assist the operator to anticipate systems challenges as they emerge.

Technology and innovation can serve as a catalyst in ensuring that PRASA gains access to systems that have interconnected technological solutions. To remain relevant and competitive, PRASA should endeavour to move from its current manual operations to technology-based smart railways. A smart railway is defined by Fraga-Lamas, Fernández-Caramés and Castedo (2017) as a technologically advanced approach to efficiently manage railway operations through the sharing of rail data across rail infrastructure components, such as passengers, control centres, ticketing department and freight. Fraga-Lamas *et al.* (2017) advanced the fact that smart railways are integration of the latest technologies, including Internet of Things (IoT), big data, cloud, analytics, artificial intelligence (AI), global positioning system (GPS) and machine learning (ML) to make rail operations more efficient and accurate.

Technology in the innovation space reflects agility, which is an essential component to have in an organisation like PRASA. Agility is about the organisation's speed to market, respond to changes and cope with new world flexibly. At its current state, there is no evidence to prove that PRASA is an agile organisation. To the contrary, PRASA is on the verge of total collapse.

4.4.2. Innovation and people

In today's business environment, innovation has become a powerful and all-encompassing principle which drives all business sectors, transportation included. Daily, new companies are introducing technologies that have the potential to reshape entire industries and how people conduct their day-to-day lives. The capacity to create value through the development of new customer experiences, products, services, technologies, processes and business and delivery models is one of the keys to profitability, growth and survival.

The 2010 Global Railway Review report tells how the UK turned around their railway systems through innovation. Around 2002, the UK railway system had lost the confidence of the nation; train schedule punctuality was running at below 80% while the number of broken rails approached 1,000. Following innovative interventions, punctuality improved to 94%, while broken rails fell to 152, and safe railway operations were restored (Global Railway Review Report, 2010). What the UK faced then is not different from what PRASA is facing today. To combat its current state of disaster, PRASA has adopted a Railway Modernisation Programme, which promises a state-of-the-art rail service which entails modern, faster, reliable and cost-efficient train services. The programme focuses on the modernisation of stations and fleet. For the fleet management, PRASA appointed Gibela Rail Transport Consortium (Gibela) to supply 3,600 new Metrorail coaches at a cost amounting to R51 billion over a 10-year period (2015–2025) (PRASA, 2021). Results of this intended innovation are yet to be realised. Even though some fleets have been delivered in Gauteng and Western regions, systemic factors that Metrorail has not addressed have already emerged, reversing gains from this innovation. Tidd and Bessan (2014) argued that the innovation process in organisations needs to be managed in a systematic or integrated way. This would require strategic leadership and direction, and building an innovative organisation, which entails having a structure and climate that enables people to be innovative, and networking for innovation.

For PRASA to achieve its innovative goal of modern, faster, reliable and cost-efficient train services, it requires a robust portfolio of leaders who are ready to engage employees, push forward growth strategies, drive innovation and work directly with customers. A 2010 study by the Harris Group (2010) indicated that executives see a culture of innovation as crucial to not only growing their business (95%) and profitability (94%) but also for attracting and keeping talent (86%). Allowing employees space to be innovative is a great master tool for employee engagement. Sun (2018) referred to employee engagement as employees' physical, cognitive and emotional input in the work. Farndale (2015) argued that certain job resources (financial returns, team atmosphere, participation in decision-making) positively affect employee engagement.

Although employee engagement was not measured, it can be inferred from some results of the study that there are generally low engagement levels at various levels of employment (from safety critical workers to leadership structures). This is evidenced by the following findings. In section 4.2.7.2, human factor causes of accidents include inattentiveness (78,93%), complacency (45,09%) and lack of teamwork (30,81%). Section 4.2.7.9 alludes to supervisor-related causes of accidents at 47,11%, while section 4.2.14 alludes to lack of confidence in the organisation's leadership structures in the implementation of HFM standards. Included is the CEO being less effective at 45% and senior managers at 34%.

Stoyanova and Iliev (2017) described an engaged employee as having some of the following characteristics: positive attitudes about the job and the organisation, believing in the organisation, working actively to make things better, being reliable, going beyond the requirements of the job, and keeping up-to-date with developments in their field. From the results of the HFM study, the characteristics mentioned are lacking, thus the inattention, complacency, and lack of confidence in the CEO and senior managers. It remains the role of leadership to guide the innovation processes within the organisation through high levels of commitment and proactive participation through two-way communication.

4.4.3. Technology and people

If technology gets linked on the people side, then alignment becomes crucial. Alignment integrates technology and people by ensuring that the organisation has the necessary skills in place, matching new technology and skill needs, and developing skills from within. It is realised through total up-skilling cost (Stoyanova & Iliev, 2017). The advantage of up-skilling employees and ensuring alignment with technology needs is that PRASA receives immense return on investment as it will now have better skilled employees working at a higher level of productivity. This means that the work is completed faster with fewer mistakes, leading to a more profitable business. On the other hand, employees will take more pride in their work, having been made to feel important enough to invest in it. Such employees will have heightened levels of job satisfaction and confidence in what they are doing.

For PRASA to achieve its business performance through technology and innovation and mitigate railway accidents, it must strive to create a strong and positive relationship with its employees. Lee and Raschke (2016) put forward the argument that employees are motivated by jobs that challenge them and enable them to grow and learn, and are demoralised by those that seem to be monotonous. Motivated employees acquire new skills; gain confidence, capability and competence; improve their performance; and feel supported and enabled in their jobs. Through a skilled workforce, competitive products and services as a result of new technologies can be developed, resulting in high customer experience, employee retention, investment in people, business performance and consequently boost the economy of the country.

Finally, to have an agile, engaged and aligned management framework technology, innovation and people management need to be bound together by systems thinking. Systems thinking is a powerful approach in integrating all other elements of the TIPS model. It acknowledges that difficulties in problem-solving often stem from the fact that problems do not occur in isolation, but in relation to one another. This factor is already evident in the recent PRASA accident where two new trains from the modernisation programme collided a day after being commissioned, as mentioned in section 1.2 of this study. An innovative solution was plugged into operations without considering other systems-related interconnections and possible causal feedback loops. In conclusion, it is important to note that for an organisation to be considered as highly competitive, all the TIPS interfaces must blend systemically and synergistically into making the organisation socially relevant.

4.5. Summary of results

The findings reflected herein are drawn largely from the opinions of safety critical grade workers on the various aspects relating to HFM in the railway accident. The findings from questionnaires were in sync with the findings from the desk-top research observations and the focus group discussions, all pointing towards the need for a systems approach. The statistical results of the findings on the HFM study are presented through use of visual graphs and tables as well as described in text format. An effort was made to draw a correlation between the findings from the survey response and desk-top research on published company reports. A further comparative analysis of findings conducted in other studies was discussed under secondary data. Based on the comparative statistics from the literature and the results of some of the elements of HFM study, it can be concluded that railway accidents do not just happen due to human factors. There are multitudes of systemic factors at play, be it core pre-existing conditions or conditions that accelerate an already compromised ecosystem.

Emerging from the findings are demographic profiles of Metrorail's safety critical workers, which show that the company employs predominantly males, aged between 36 and 45 years, who have been working in the organisation's train operations division for over 15 years. Most of the safety critical workers have a trade-specific diploma or higher certificate, indicating that the general workforce is qualified for the operations.

It is also evident from the study demographics that there is a lack of representation in all infrastructure-related safety critical workers in the electrical, signalling and Perway departments, which are core technologies in ensuring safe railway operations. This shows an imbalance in skill sets and reveals that train drivers are the core of Metrorail operators. Supervisors were adequately represented at 12,03% of the respondents, and the safety critical workers cited that there are minimal supervisor-related violations that result in accidents. Although, from the perspective of safety critical workers, human factors are viewed as not being a pre-dominant cause of railway accidents, their prevalence remains high at 49%. Several human factor-related causes of accidents were explored; the topmost were technical and operational errors (86,18%), inattention (78,93%) and fatigue (75,90%). The dilapidated, aged, poorly maintained South African railway network remains a fertile ground for railway accidents to occur. The aged infrastructure is a pre-cursor to some of the human factor-related causes; for instance, due to the infrastructure problems, signals do not work properly, leading to operatives working in degraded mode. It is within this degraded mode that most technical and operational errors occur. In the focus group discussions, there was a lively debate with regard to malfunction of train or poor maintenance being likened to human-related factors. Participant 5 believed the maintenance and malfunction were partly a responsibility of those who maintain the infrastructure and trains. The focus group agreed that the maintenance is done and standards are met, tests are done, but the fact that the machines and infrastructures are aged cannot be taken away. The job of the maintenance team could be done perfectly, but the accident still happens because it was beyond their efforts. A system of checks and balances therefore should be brought on board where there should be calling in the need to condemn certain machines for aging and malfunctioning. This finding was further supported by the safety critical workers' response on their opinion about organisational resource management within Metrorail that all organisational resources that are being managed by Metrorail to ensure safety must be maintained (human resources, financial and equipment). Equipment management was viewed as the least effectively managed resource, further supporting the findings that equipment malfunctioning is amongst the causes for the accidents.

Risk, compliance and governance of Metrorail were assessed as factors that influence the implementation of HFM standard. From the results of the study, it is clear that RSR plays a crucial role in the compliance responsibilities of the railway environment. All compliance-related elements pertaining to RSR were very effective in managing railway accidents as well as in the promotion of HFM standards. Another pattern that emerged from the study is that the railway environment is highly regulated. The safety critical workers showed full confidence in risk management capabilities of the organisation. Lastly, on the issue of governance, several structures play a role in the assurance of successful implementation of HFM standards with the view of preventing railway accidents. Of these structures, which include DoT, PRASA Board, RSR, PRASA CEO and senior managers, it is the opinion of the safety critical workers that RSR and DoT play the most effective role in HFM implementation. There is less confidence, however, in the BoD, organisational CEO and senior managers. Conclusions drawn from the study as well as recommendations will be discussed Chapter 5.

CHAPTER 5:
CONCLUSIONS AND RECOMMENDATIONS

5.1. Introduction

This chapter presents a summary of findings from the literature review and the primary and secondary findings of the HFM study. The discussions about the findings as presented in this chapter will make conclusions about why accidents continue to be a feature in the railway system despite the HFM standards in place. An illustration and description of a system thinking approach to prevent the recurrence of railway accidents in South Africa, as a solution, will be presented. The chapter will also present the summary of contributions to the academic fraternity, the rail transport industry and regulators. The chapter ends with the suggestions for further research into other rail operators like TFR and Gautrain as stemming from the present research.

The primary aim and objective for this research journey was to investigate a systems approach for using HFM standards to prevent railway accidents in South Africa. With this in mind, it was necessary for the author to first understand the concept of human factors and the factors that influence human performance in the occurrence of railway accidents.

The research journey allowed the author to first explore available literature related to what constitutes functional railway technologies and explore the BOI reports on railway accidents that have occurred in South Africa and elsewhere, which led to the human factors debate. Furthermore, systems thinking in relation to railway accidents was also explored using multiple accident causation models, including the HFACS. The next step was to validate the information obtained from the railway literature by testing it against what was being experienced in South Africa. The researcher chose to focus the study on passenger railway operators in South Africa. Thus, the study was undertaken in the biggest passenger railway operator in South Africa, PRASA, Metrorail division. The author, having reviewed information from authorities in railway operations, for example RSR, sought to focus the study on primarily affected group in railway, namely safety critical workers. The researcher derived conclusions from sets of data obtained from a HFM survey questionnaire and a focus group discussion and compared them with the conclusions derived from the literature review.

In Chapter 1 of this research study, the researcher identified a number of primary objectives that needed to be achieved in order to support using HFM standards to prevent rail accidents in South Africa. The researcher is of the view that chapters 2 to 4 provide detailed answers and solutions to the primary objectives identified.

5.2. Summary of findings

The findings are divided into literature review findings and HFM study primary and secondary findings, which are presented according to the different objectives of the study. The study found the role played by human factors in the occurrence of accidents to be lower than other factors, which are poor equipment maintenance and equipment malfunction. The effectiveness of HFM standards in promoting rail safety is also found to be significant. Among the findings is the extent to which compliance to regulations and standards contribute to safety among rail operators. A discussion about the role that corporate governance plays in the implementation of HFM standards is also presented. Lastly, the importance of the risk management system as a promoting factor for HFM standards also forms part of the results presented.

5.2.1. Summary of literature review findings

Railways have been a part of South Africa's transport system for the past 160 years, a longevity which underscores their vital importance to the country's social and economic system and therefore bares a significant responsibility to the country's progress and development. In fact, Badholm, cited in News24 (2020) argued that South Africa's recovery will be limited without investment in maintaining the railway sector. With increasing demand for the services of trains by the rapidly expanding urban populations, PRASA is under pressure to expand the network and play its role in the social and economic development taking place in South Africa. In this regard, this expansion can be undertaken only if the railway promises and delivers a safe transportation system.

From the literature review in Chapter 2, it is evident that railway operations utilise a complex technical infrastructure. Some of the technologies used in the operation of trains have a direct effect on the state of safety. Included in the technologies are the following: train stations which are focal points in the transit of passengers or goods, signal systems which allow for the safe movement of trains at maximum permissible speed and minimum headway; points that enable the movement the train from one line to another, especially where two lines are joined or at a junction; a CTC, which is a control room facility that enabled operators to remotely monitor and control the movements of trains in a particular area; train describers used to display the identity of a train on the control board; and, lastly, an interlocking control mechanism to secure the railway line to ensure that no conflicting movements take place. The foregoing underscores the point that railways can also be viewed in the context of system theory.

A review of several BOI reports of some of the major accidents that have occurred was analysed. Even though the commonly echoed cause of accident was stated as human error, the analysis revealed the possibility of multifactorial root causes of railway accidents which required further understanding. Analysis of some of the root causes of railway accidents revealed a myriad of issues, which included poor maintenance, cracked tracks and wheels, lack of supervision, poor personnel training and inadequate staffing as other emerging contributory factors to railway accidents. Other causes that emerged were theft and vandalism, signalling and infrastructure defects and corruption.

As a means of delving deeper into an understanding of contributions to human performance, a human work performance model was analysed. Other significant analysis included human error related accident causation models, such as SCM and HFACS. The HFCAS framework which is dealt with in Chapter 2 details four levels of system errors which impact human performance in a system. At Level 1 is organisational factors, which entails resource management, organisational climate and organisational process. Unsafe supervision is on Level 2; issues tackled herein include inadequate supervision, planned inappropriate operations, failure to correct known problems and supervisory violations. Level 3 includes pre-conditions for unsafe acts to include seven factors, namely physical environment, technological environment, physical/internal limitations, adverse mental states, adverse physiological states, crew resource management and personal readiness. Lastly, on Level 4 is unsafe supervision, which includes four factors, namely decision errors, skill-based errors, perceptual errors and violations. The factors stated herein were considered in the formulation of some of the HFM survey questionnaires to explore systems approach in railway accident approach.

A systems thinking theoretical approach was also explored through the lens of various authors, including Senge (1990), Sweeney and Sterman (2000) and, more recently, Arnold and Wade (2015). The three elements of a systems thinking model, namely interconnectedness of various elements, synergism of the elements and the quest to bring about a desired goal, were explored. From the various definitions, it was argued that systems thinking provides a holistic way of seeing things. It provides a lens within which the interrelated and interdependent elements form collective entities. It is characterised by synergistic interactions, thereby allowing combined interaction of the various elements to produce a total effect that is greater than the sum of the individual elements. This led to the proposal to utilise systems thinking approach to mitigate railway accidents in South Africa

5.2.2. Summary of findings of the HFM study

5.2.2.1 The role played by human factors in the occurrence of accidents

The first objective was to look at the role played by human factors in the occurrence of accidents. The study established that, overall, human factors' contribution towards the occurrence of accidents was found to be 49.11%. The highest possible cause of accidents was found to be poor equipment maintenance from the point of view of the safety critical workers at 89,2%, and likely prevalence rate and equipment malfunction at 77,24%. The focus group discussions confirmed the questionnaire results by agreeing that equipment maintenance topped the list of the causes, together with equipment malfunction, thus negating the widely held opinion that the majority of accidents are caused by human error.

Furthermore, from the study's investigation into the role played by human factors in the occurrence of accidents, the following results were obtained. While it was found that the rail workers consisted of 28% females and 72% males as represented in the sample, the results obtained from the focus group discussion confirmed that occurrence of accidents could not be attributable to gender differences of the workers, as there is no empirical evidence for believing that either male or female train drivers cause more accidents. One participant even mentioned that occurrences of accidents have nothing to do with whether one is male or female because there has not been any convincing analysis that can relate the two or prove that males do not commit the same errors that women commit. In fact, the analysis suggests that if the high number of accidents are blindly appropriated to gender representations, male train drivers would get the greater blame because there are more male than the female train drivers.

Another demographic finding with regard to age and the occurrence of accidents is that 15% of the accidents caused by human error are caused by people in the age range above 50 years followed by those in the age range below 25 years, with the least accident occurrence probability being in the age range of between 26 and 45 years. The quantitative results were confirmed by qualitative findings where group discussions also agreed that the issue of exhaustion catches up with age as the body gets susceptible to exhaustion with advancing age, confirming that the employees above 45 years of age caused more accidents due to inattentiveness and exhaustion as these get more pronounced. Workers of an advanced age were also found to take long to comprehend the changes in technology. The findings are in agreement with earlier results from Hammerl (2011), who included age and experience in the human element that contributes to fatigue. Hammerl (2011) also observed that, with experience, mature workers know when to take a rest and recover from fatigue.

From the study, it was also found that the role of supervisors contributes 39% of the human factor-related causes of accidents. The study noted that quite a number of accidents result from lack of adequate supervision, leading to the inference that since the supervisors are mostly the workers with certificates and degrees, the promotion of graduates with little technical experience to supervisory level also contributes to accidents. The certificates and degrees were not found to be the problem, but rather the premature promotion to supervisory level because not all rail workers with degrees were suitable for supervisory roles, given that accidents were coming from lack of supervision. Lack of supervision was found to manifest in failure to correct problems, resulting in being the most frequent cause of accidents.

It was also found from the study that, while comparing human factor causes of accidents, the most likely cause was found to be failure to apply certain technical or operational skill, which was at 86%. Inattentiveness of the worker was found to be the likely cause of accidents by 78,93%, while fatigue was also a likely cause by 75,90%. Complacency of the worker was a likely cause by 45,09%, communication errors at 41,96%, poor judgement at 40,18%, lack of teamwork at 30,81% and, lastly, deliberate violation of rules contributed to 14,35% of accidents. These findings were complemented by the focus group findings where participants bemoaned lack of proper training, citing negative consequences of apprenticeship as a method of training, resulting in the above deficiencies.

5.2.2.2 The effectiveness of the (HFM) standards in promoting rail safety

The second objective of the study was to evaluate the effectiveness of the HFM standards in promoting rail safety. The effectiveness of the HFM standards in promoting rail safety was found to have been maintained although the desk research showed high number of accidents. Sixty-six percent (66%) of the respondents reported that a culture of safety management had been effective in reducing accidents and fatalities in their operations, while 63% reported that the reduction in accidents was also due to the safety programmes that have been implemented at Metrorail. The DoT, which is the national ministry and principal shareholder of PRASA, is considered by respondents as playing an effective role (43,94%) in ensuring the implementation of HFM standards. The RSR – the entity that provides safety standards, investigation of incidents, issuance of licences, fines and penalties in rail operations – was assigned a score of 85,13% by safety critical workers. The results indicate that respondents have confidence in the current national governance structures, namely DoT and RSR.

5.2.2.3 The extent to which compliance to regulations and standards contribute to safety

The third objective was to assess the extent to which compliance to regulations and standards contribute to safety among rail operators. The extent to which compliance to regulations and standards contribute to safety among rail operators was found to be less than planned according to PRASA (2021) in their strategy review document. The safety critical workers at Metrorail are of the opinion that there is awareness and adherence to railway compliance standards. The results reflect that the compliance standards being implemented the most to manage safety at railway operations are, in order of most to least effective, as follows: safety legislations, policies, rules and regulations at 89,48%. This is followed by safety management standards and procedures at 87,45%. Operational permits, licences and RSR rules at 86,55%, and, lastly, fines, penalties, incident investigation at 71%.

5.2.2.4 The role that corporate governance plays in the implementation of HFM standards

The fourth objective was to examine the role that corporate governance plays in the implementation of HFM standards. The role that corporate governance plays in the implementation of HFM standards was found to be varying. The Ministry of Transport was found to be slightly effective in ensuring that HFM standards are implemented, with a rating of 69% effectiveness and 14% less effective. The rail safety regulating agency was found to be having a significant influence on the implementation of HFM standards at 86% effectiveness. The corporate governance of the rail transport is mainly centred on the BoD, and the BoD at PRASA was found to be less effective at a rate of 72%. A systems approach that puts ratings on the board's performance towards accident prevention through HFM every accounting year will be helpful to minimise human factors.

5.2.2.5 Risk management system as a promoting factor for HFM standards

The fifth and last objective was to assess the importance of risk management as a promoting factor for HFM standards. The safety critical workers believed risk management at PRASA receives appropriate attention. However, when reviewing the many BOI accident reports over the years, it is evident that some core aspects of railway risk management are not being addressed by Metrorail, such as risk supervision, awareness, and sensitisation. For example, in the Kroonstad 2018 accident, no risk assessments were conducted before the introduction and the use of the affected locomotive by PRASA and the coaches used were not fire resistant (RSR, 2022). A system should therefore be engaged where the locomotives are locked for inspection with unlocking passwords (with software in use) in the hands of a "risk accountable" officer. This system should carry along accountability officers throughout the processes to traces every incident to an officer who should be responsible.

According to the findings, a systems approach to the implementation of SANS 3000-4:2011 needs to be encouraged in order to enhance workers' capability above bottom-line competence. Procedures for HFM standards compliance should be drafted with a wholesome approach inter-relating the addressing of governance, maintenance, risk and supervision in an interdependent way. A total quality management system where no risks or hazards are allowed to proceed to the next person, department or process without assurance that the possible harm is dealt with should be implemented as the solution to recurrence of accidents.

The drafting and integration of procedures, their review and continuous improvement, involving identification of any accident breeding threats or hazards by quantifying risk so as to put measures to treat, transfer or tolerate risks should be prioritised across the whole organisation.

The study put forward that every route and trip should have a proactive report in terms of risk assessments. Every safety critical worker who operates machinery, infrastructure or locomotives should do so with a risk assessment proactively carried out on the intended operation. At every point of departure, arrival or maintenance, standard documentation has to be done to the effect of revealing the safety environment and if it was free of any risks or hazards. This would highlight the systems approach that needs to be adopted in order to enhance the effectiveness of the HFM standards, which should result in the significant reduction of accidents.

In fact, a systems approach to the HFM standards should eradicate the occurrence of accidents. Should any accidents still occur despite the preventive measures being in place, this study established that the recurrence of accidents caused by the same cause was a result of deficiencies in systems control measures. For example, the CTC centre should have enough communication systems interlinked to avoid collisions. No collision should happen. In fact, one collision should be enough to plug out any system malfunction and is not supposed to be repeated.

5.3. Conclusion against research questions

In conclusion, the overall impact of HFM standards in rail accidents as well as how they can be used to improve safety among rail operators was as follows.

a) Human factors, though not a pre-dominant cause of railway accidents, remain prevalent at 49%. The top human factor-related causes of accidents were technical and operational errors (86,18%), inattention (78,93%) and fatigue (75,90%).

b) The dilapidated, aged, poorly maintained South African railway network remains a fertile ground for railway accidents to occur.

c) Of all organisational resources that are being managed by Metrorail to ensure safety is maintained (human resources, financial and equipment), equipment management was viewed as the least effectively managed resource, further supporting the findings that equipment malfunctioning is amongst the causes of the majority of accidents.

The findings also led to the conclusion that there are significant supervisor-related issues that contribute to railway accidents. An examination of the company's accident records for the period 2017 to 2021 showed that indeed this was the case. Concluding on the factors that can contribute to fatigue, problem-laden work environment, physical conditions of work, such as heat or noisy work environment, were listed among fatigue-breeding conditions. Equipment malfunctions were found to influence human factors, such as fatigue, as increased errors added to the unfriendly working conditions.

From the findings, it was also concluded that a culture of safety management had been effective in reducing accidents and fatalities in employee operations, while 63% reported that the reduction in accidents was also due to the safety programmes that have been implemented at Metrorail. It was also concluded that financial resources also played an effective role in the influence of HFM. Corruption, which is rampant within the organisation, diverts resource utilisation, leading to shortages in vital structures that allow safe railway operations. The results reflected by the safety critical workers imply that there is a need for positive financial resource management.

According to the findings of the HFM study, there is low confidence in the corporate governance structure of PRASA to manage accidents within the railway sector. The findings are consistent with the views drawn from PRASA Strategic Plan document for 2021 to 2023 that there is lack of alignment in organisational structures with inefficiencies and duplications due to silo culture (PRASA, 2021). The findings of the 2018 to 2020 reviews reflect that PRASA's operating model and governance structure is weak due to unclear lines of accountability and control span, as well as the existence of disjointed and duplicated businesses, including subsidiaries (PRASA, 2021). In addition, because decision-making happens primarily at the executive level, the need for quick decisions and improvements is undermined. This model also perpetuates inefficient group structures, revealing redundant and overstaffed functions in some areas as well as an abnormally large corporate office (PRASA, 2021).

5.4. A systems approach model for HFM in the railway

In order to remedy the disjointed way of managing prevalent accidents in the railway, the researcher proposes a system-based approach for accident prevention, as illustrated in Figure 5.1, taking into consideration data obtained from the study. The researcher is of the opinion that viewing human factors using a systems approach lens will assist railway operators in mitigating accidents by managing the root causes, as well by being aware of what contributes to system equilibrium disturbance. In this section, the research presents an illustration and discussion of the proposed system for the prevention and mitigation of railway accidents. The system can be used by a passenger railway operator such as PRASA to make note of different elements that can impact on HFM, to understand the interconnectedness of the individual elements and to understand causal loops relationships between different element in order to anticipate and manage all aspects of HFM in the prevention of railway accidents.

The proposed system views accidents in the context of systems theory. This essentially means rail accidents do not happen in isolation; they are raised by many system factors which affect one another. In a railway traffic system, the occurrence of an accident is a result of a multitude of factors, a composite experience in which many system factors change themselves. These factors affect each other to construct a causation chain, which leads to accident occurrence (Li & Wang, 2018).

As observed in Figure 5.1 below, there are causal link relationships in all the elements impacting HFM standards. The system recognises this and observes other factors likely to affect the effective management of HFM.

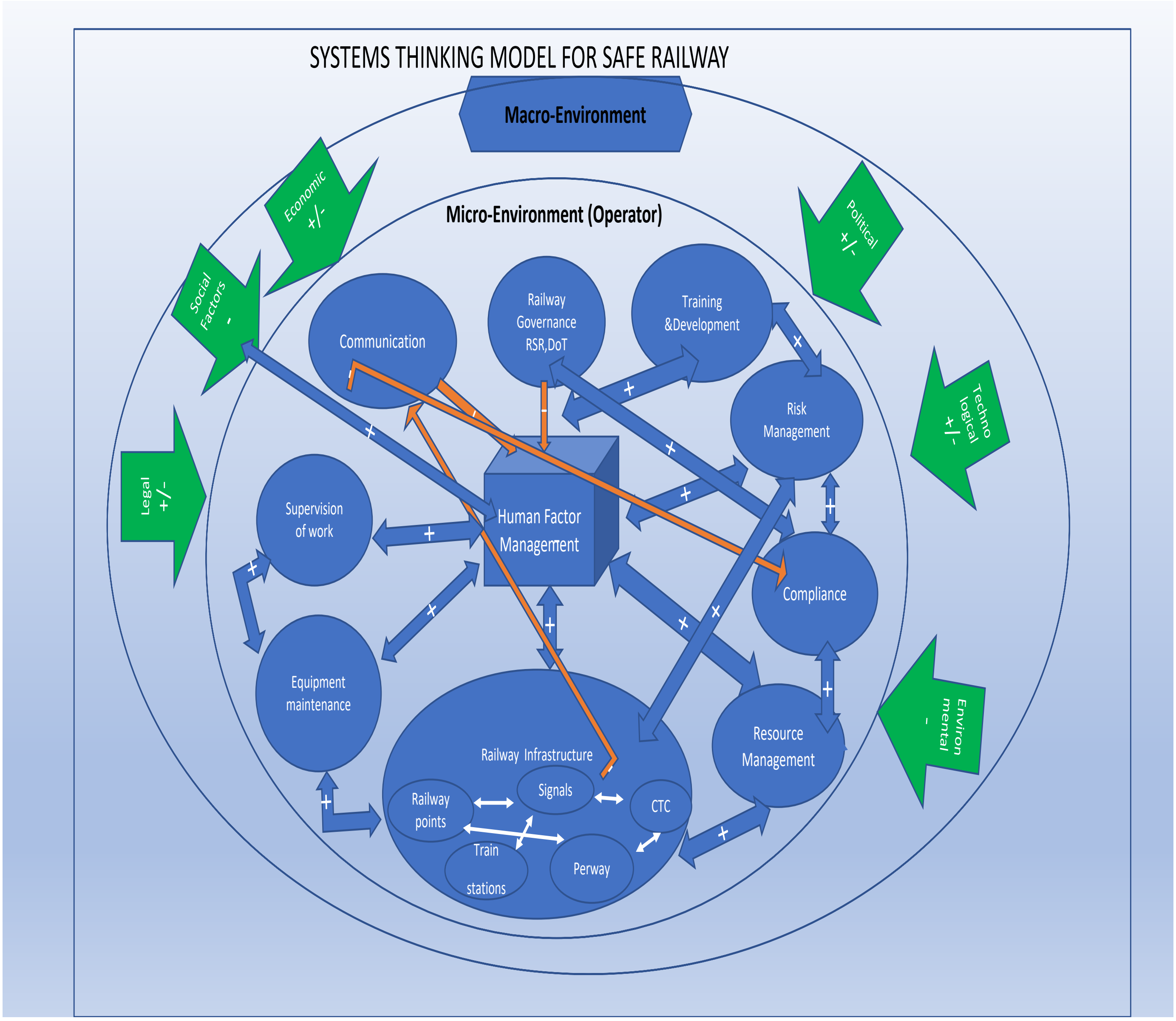

Figure 5.1: Systems Approach Model for HFM in the railway

The above systems thinking model illustrates the factors discussed in the findings of the study. The model is synthesised from the definition of systems thinking as espoused in the study. It is important to note that the model serves as an example which is meant to prompt a deeper enquiry into accident causation and can be adapted to add more factors which were not part of this HFM study. The notable aspects of the model are the recognisable interconnections and the identification and understating of synergistic relations between the elements. The system shows HFM in the middle of the model and other systemic factors that can impact its effectiveness around it. The micro-environment is shown in blue while the macro-environmental elements are represented in green arrows. The bi-directional lines with a plus (+) sign show that the interconnect elements can influence each other positively or negatively. The orange lines with minus (-) sign denotes a one-directional element being negatively affected by the other. The green macro-environment plus/minus (+/-) shows that the macro-environment element can have either a positive or negative impact depending on the scenario at play, while the one with plus (+) denotes only a positive influence and one with minus (-) sign denotes a negative influence.

As demonstrated in diagram 5.1 above, there are interconnections between HFM and other systems factors, namely governance, risk management, compliance, resource management, railway infrastructure, equipment maintenance and macro-environmental elements. The elements are interconnected to form cause-and-effect feedback loops. An example at hand is the relationship between resource management and HFM. Lack of resources in the form of financial, equipment or human resources can impact human factors in the railway system. With fewer resources, the operator might be unable to ensure that some aspects of HFM standards are implemented, thus resulting in an accident. Conversely, if human factors are not managed appropriately, accidents can occur. The operator thereby incurs unnecessary resource implications, such as damage to property. Another example to note in the model is the relationship between the macro-environment within which the railway is functioning and HFM, which is located in the micro-environment. An example is alluded to in the secondary literature review; some accidents are caused by human errors in the manual authorisation of trains, which occur as a result of theft and vandalism of the cables.

5.5. Limitations of the study

The HFM study was limited in the following aspects: firstly, from the target population perspective and, secondly, from resources that the respondents needed to complete the questionnaire. Firstly, relating to the target population, the researcher could not obtain a properly documented and verifiable number of safety-related employees per job category within Metrorail from the Human Resource Department. Also, even though the responses from the focus group discussion had been a representative sample, it did not cover all eleven safety critical jobs. The interest to participate was mostly from senior managers in train operations, safety management and signalling departments. Secondly, some of the participants did not have data or smartphones to complete the survey and, as such, relied on work-based computers to complete the questionnaire.

5.6. Summary of contributions

The study made the following contributions to the company and the industry.

The major contribution of the study is the suggestion that an integrated and comprehensive approach be adopted in addressing human factors in rail accidents. It cannot be denied that the railway, as a system, is complex. There is an interconnectedness of various elements at both a macro- and a micro-environment level. There are also intrinsic and extrinsic operator-related issues which impact safe railway operations. With the use of a skill set called systems thinking, one can hope to better understand the deep roots of this complex system to better predict its behaviour and, ultimately, influence the outcome of various systems elements.

With the required exponential growth of South African railway systems comes a growing need for systems thinking to be applied to tackle the complex railway transport problems. This need stretches far beyond Metrorail as an organisation but encompasses every aspect of the railway life-cycle. The ripple effect of misalignment of any of the interconnected elements in railway operations cannot be avoided and must therefore be decisively managed. Based on this reasoning, it could be strongly argued that all people in decision-making roles within the railway sector of South Africa should have a solid grasp of systems thinking.

The identification and evaluation of risks and hazards should be systematically carried out and communicated throughout the company, events, routes and trips in a total quality management (TQM) approach. With the TQM approach, which is primarily aimed at improving customer experience, various aspects of the system, including organisational culture, participation and commitment of all stakeholders, innovation, resource management and continuous improvement strategies, will at least be in the forefront of all employee interaction with the system.

There is need for slots (in the system) of training in risk management because the ignorance of the basics of risk management is causing a rise in human factor-based accidents. Tests and retests should emphasise capability over competence. It was also recommended that training should be based on identified risk or hazard areas and structured to include all aspects of the job situation to avoid poor judgement, inattentiveness and human error.

There is need for the systematic enhancing of maintenance of equipment for the rail operators and continuous review of the functionality of the equipment. The study also contributes to the need for training in technical and operational professions and that the organisation should continue professional development at all levels especially considering the changes in technology.

There is also need for reviewing the institutional governance in the company's implementation of rail industry regulation, such that standard operating procedures are clear, and their supervision is clear. Governance should inter-relate with the goals to reduce human factors in accident occurrence management.

Considering submissions from the PRASA Strategy Document for 2021 to 2023, one can see that there is need for a communication method and integration of the departments and Strategic Business Units (SBUs) into one functional system. PRASA, through their 2021 to 2023 Strategic Plan document, admitted that one of the weaknesses of PRASA was disjoint departments and uncoordinated operations (PRASA, 2021). This was also noted in the study under 4.1.12, where the rating of different departments obtained different weights, signalling that lack of synergy. In that regard, a safe railway system should have a framework of communicating within, across and about departments and SBUs. Human error factor should always be checked, and signals be sent to all stakeholders in the company that an operation has been certified to be safe, and the next responsible gate keepers be alerted. Constant supervision from training, infrastructure management, compliance, governance and financial resources management should be done in a TQM approach where no error is passed on to the next internal customer

5.7. Future research

As the research was completed and based on only one operator, PRASA, there is need for carrying out a country-wide research that involves other operators, such as TFR, to be able to generalise the findings and conclusions. A longer study in terms of time can also assist in the validation of the results. With the advent of the fourth industrial revolution technologies, it will also be worth researching the occurrences of accidents where rail automation is adopted to the fullest compared to where there are human-intensive operations comparing scenarios of full automation and less automation in terms of susceptibility to accidents.

5.8. Return on investment

The researcher believes that application of the concepts and mental model of systems thinking will benefit organisations where safety of operations is at the core of the business. The world of work is operating in a VUCA (volatile, uncertain, complex and ambiguous) environment. With this, the approach to problem-solving cannot remain linear. The researcher advances that Metrorail should adopt a management style centred around systems thinking to solve the scourge of railway accidents occurring in its operations. The systems thinking model for safe railway (Figure 5.1) should be adopted by Metrorail to view the causes of railway accidents.

From a leadership perspective, the researcher hopes that leaders in the different railway business units can approach any business challenge by mapping out interconnections between different elements within their entire business ecosystems. The benefit of mapping complex systems can make leaders navigate into adaptive strategies, which are required in the dynamic world of work. Employing adaptive strategies can assist leaders to anticipate problems, challenge the status quo positions and interpret problems using multiple lenses, and thus make informed decisions. The ultimate gain from adopting systems thinking is to create an ability for organisations to be responsive to the changes in their own ecosystems and to be prepared to adapt parts of their business operations where necessary. Systems thinking helps in framing complex problems, which are often being misdiagnosed, and provides alternative directions for improvement with respect to the organisation's inner and outer connections. It gives a significant advantage to leaders' capacity to steer their organisations for change and consequently business sustainability.

For Metrorail to achieve its new strategic goal of being modern, faster, reliable and cost-effective train services, it has to recognise the need for better cohesive relationships with its stakeholders. The HFM study hopes to offer an emphasis of the importance of stakeholder engagement as a return on investment to readers who will engage with the study. Stakeholder engagement is premised on the notion that those groups who can affect or are affected by the achievements of an organisation's purpose should be given the opportunity to comment and give input into the development of decisions that affect them. Within the transportation industry such as the railways, there are multiple stakeholder groups, which include suppliers of different components and systems of the railway infrastructure, political principles, employees, labour unions, customers, community, media, citizen action groups, special interest groups, financial institutions and government. To ensure beneficial and non-conflictual relations in managing this diverse group of stakeholders, the principle of systems thinking should be applied. Systems thinking will allow meaningful engagement, awareness of changes in the wider society and how they relate to organisational performance, and thus establish relations with stakeholders to manage the impact of those changes.

On a personal level, the return on investment that the researcher hopes to enhance is twofold. Firstly, the researcher hopes to be a systems thinker, and achieve principles of systems thinking at all levels of her life. To achieve this, she intends to further explore the field of systems thinking and learning of mental models. Secondly, the researcher hopes to achieve the status of being a Key Opinion Leader (KOL) in the HFM field in railway industry in South Africa by actively participating in the field. Having vast experience as an occupational medical doctor in the railway industry and with the knowledge gained through achieving this Masters' degree, the researcher has developed professional confidence which is backed by academic qualification to achieve the status of KOL. Being a KOL will place the researcher in strategic positions to offer services such as speaking at national conferences and being on advisory boards as a professional member in organisations, as well as career advancement opportunities where she can influence policy decision and contribute to standard formulations. The researcher will have the academic backing of being an author of published research in professional journals, as well as being top-rated by the industry and peers.

5.9. Conclusion

From the findings of the study, it is also evident that plugging in HFM standards as a legislative imperative to reduce accidents has not achieved desired results. Even though its introduction more than 10 years ago was hailed as a game changer to manage human error related causes of accidents, thus ensuring safe railway operations in South Africa, the continued accident scourge is living proof that the HFM standards have not managed to achieve that. The study shows that infrastructural, maintenance, resource management, training, supervisory issues, governance and risk management form significant elements in the causation of railway accident. These factors contribute a fertile ground where human factors (as a prevalent cause of accident) will continue to thrive, despite the best implemented tool to manage the very human factors. Therefore, to address the challenges, a holistic approach, systematically applied across the organisation, will be the best way to addressing the human factor in dealing with the occurrence of accidents. The study has revealed and confirmed other system-influencing factors which have to be considered to ensure safe railway operations, which has necessitated the development of a systems thinking model for effective management of human factors to prevent railway accidents in South Africa.

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Appendices

Appendix A: Clearance Certificate

The Da Vinci Institute for Technology Management (Pty) Ltd
PO Box 185, Modderfontein, 1645, South Africa
Tel + 27 11 608 1331 Fax +27 11 608 1332
www.davinci.ac.za

Ethical Declaration

I, the undersigned, hereby declare that the Masters Research of the student named below has received ethical clearance from The Da Vinci Institute Ethics Committee. The student and supervisor will be expected to continue to uphold the Da Vinci Institute's Research Ethics Policy as indicated during the application.

Proposed Title: The Framework for the Effective Implementation of Operational Risk Management within South African Railway Operations

Student Name: Millicent Tlakula

Student number: 7889

Supervisor: Dr Linda Chipunza

Co-Supervisor: n/a

Period: Ethics approval is granted from 2019/10/06 to 2019/10/31

Chairperson: Ethics Committee

Krishna Govender
Dean: Research

Signature: ____________________

Date: 06 October 2019

Appendix B: Permission letter from Metrorail

Contact person's name: Mrs. Maserame Selekane
Risk manager
PRASA Metrorail _Gauteng
Shosholoza Junction
Private Bag X101
Braamfontein
2017
011 085 7365
maserame.selekane@prasa.com

Dear: Ms.Maserame Selekane

Re: Request for permission to conduct research and contact participants of Risk Department, Metrorail Gauteng

Your permission is herewith requested to allow Dr. Millicent Tlakula, student of DaVinci Institute, studying MSc -Management of Technology and Innovation (MOTI) to conduct academic research in PRASA Gauteng Risk Department. Attached is the letter from the university as a proof of my registration. As part of my studies, I am conducting a research and writing dissertation on a topic that I am passionate about which is "The framework for the effective implementation of effective Corporate Governance within corporate SA : South African railway operators", and I am specifically zoning in on the factors that influence the implementation of Human Factor Standards (SANS 3000-4).

This is largely based on the fact that the industry is still recording a big number of railway accident despite the HFM standards promulgation. My research is largely work based and as such, I request that PRASA Gauteng Risk Department , grant me the permission to utilize the learnings within my scope of practice and as well grant permission for me to interview its senior personnel with the aim of establishing their opinion on the factors which affect the implementation of Human Factor Standards' within PRASA Metrorail Gauteng.

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The results of the study will be used for academic purposes only and may be published in an academic journal. We will provide you with a summary of our findings on request.

Please contact my supervisor, Mr. D M Matsapola
email: monamodi.matsapola@gmail.com
if you have any questions or comments regarding the study.

Kindly sign below to indicate your willingness to allow PRASA Risk Department Gauteng to participate in the study.

Yours sincerely

Millicent Tlakula

082 498 4540

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I, Maserame Selekane

herewith give my permission for the study to be conducted at Metrorail

Signature: 01/10/2018

Appendix C: Human Factor Management Questionnaire

Human Factor Management (HFM) Questionnaire

Human Factor Management (HFM) Questionnaire

Thank you for taking the time to complete this questionnaire. The questionnaire seeks to get your perception of the contribution of human factors as a cause of accidents within the railway industry. The researcher is an Occupational Medical Practitioner within the railway industry in South Africa. The research is focused on the analysis of human factors as a prevalent cause of accidents within the railway operators in South Africa. The researcher also seeks to understand other major contributory factors to railway accidents in South Africa.

Human Factor Management (HFM) Standards, (SANS 3000-4) were developed by the Railway Safety Regulator in recognition of the dynamic role that human factors play in safe railway operations. The purpose of Human Factor Management is to reduce occurrences attributable to human error by optimizing human capital and by mitigating the risks associated with human factors in the workplace to acceptable levels.

OK

1. Gender

- ◯ Male
- ◯ Female

2. Highest Academic Qualification

- ◯ Below Matric
- ◯ Matric
- ◯ Certificate/Diploma
- ◯ Degree
- ◯ Postgraduate

3. What is your Job Tittle?

4. What is your Age category?

- ◯ 25 and Below
- ◯ 26 - 35
- ◯ 36 - 45
- ◯ 46 - 55
- ◯ 56 - 65
- ◯ 66 and above

5. What is your years of working experience?

[ ]

6. How **frequent** are the following **railway accidents** in South Africa? Please rate each **occurrence**:

	Not Frequent	Infrequent	Less frequent	Frequent	Very frequent
Railway Derailment	◯	◯	◯	◯	◯
Railway Collision with another train	◯	◯	◯	◯	◯
Railway Level Crossing Collision with vehicles/cars/buses	◯	◯	◯	◯	◯
Railway Run over accidents	◯	◯	◯	◯	◯
Railway Electrocution	◯	◯	◯	◯	◯
Other	◯	◯	◯	◯	◯

Other (please specify)

[ ]

7. From the list below, please rate how each **factor** is likely to be **responsible** for **causing railway accidents** in South Africa?

	Not likely	Slightly likely	Less likely	Likely	Highly likely
Human factors/personnel error/management error	◯	◯	◯	◯	◯
Malfunction of train, engines or other systems	◯	◯	◯	◯	◯
Poor maintenance	◯	◯	◯	◯	◯
Environmental factors involving weather, smog, etc.	◯	◯	◯	◯	◯
Inadequate rules and regulation	◯	◯	◯	◯	◯

8. From the list of **human factors** below, please rate how each has been found to likely **cause railway passenger accidents** in South Africa

	Not likely	Slightly likely	Less likely	Likely	Highly likely
Fatigue	○	○	○	○	○
Inattention	○	○	○	○	○
Absent/vague communication	○	○	○	○	○
Poor judgement	○	○	○	○	○
Deliberate rule violations	○	○	○	○	○
Technical or operational errors	○	○	○	○	○
Complacency	○	○	○	○	○
Lack of teamwork	○	○	○	○	○
Other	○	○	○	○	○

Other (please specify)

9. In the **railway accidents** that occurred in 2019 in South Africa, how **serious** have they been in terms of their **impact**? Please rate different **accident occurrences** interns of their **seriousness** below:

	Not serious	Slightly serious	Less serious	Serious	Very serious
Fatalities	○	○	○	○	○
Injuries	○	○	○	○	○
Damage to property	○	○	○	○	○
Damage to the environment	○	○	○	○	○

10. From the **preconditions** listed below, please rate the ones that are likely to be **causing railway accidents**?

	Not likely	Slightly likely	Less likely	Likely	Highly likely
Lack of skill and knowledge	○	○	○	○	○
Lack of proper rules and regulations	○	○	○	○	○
Lack of proper or inadequate supervision	○	○	○	○	○
Dilapidated equipment and systems	○	○	○	○	○

11. Of the **unsafe supervision acts** listed, which ones have been found to **frequently cause railway accidents** in South Africa?

	Not frequent	Less frequent	Frequent	Very frequent
Inadequate supervision	○	○	○	○
Planned inappropriate operations	○	○	○	○
Failure to correct problems	○	○	○	○
Supervisor violations	○	○	○	○

12. How **effective** have the below listed **organisational influences** been in **managing safety** in railway operations in South Africa?

	Ineffective	Less effective	Slightly Effective	Effective	Very Effective
Human Resource (training & tracking assessment)	○	○	○	○	○
Financial resources	○	○	○	○	○
Equipment resources	○	○	○	○	○
Operation standards	○	○	○	○	○
System policies	○	○	○	○	○
System procedures	○	○	○	○	○
Safety Culture	○	○	○	○	○
Safety programs	○	○	○	○	○

13. What **human factor management tools** are being used **to avoid occurrences** in railway operations in South Africa?
(Please list at least 3)

14. From the list below, please rate how **effective** each of the **standards** is being or has been utilised managing railway safety operations.

	Ineffective	Less effective	Slightly Effective	Effective	Very Effective
Policy and legislation	○	○	○	○	○
Rules and regulations	○	○	○	○	○
Safety Management Systems (SMS)	○	○	○	○	○
Operations permits and licenses	○	○	○	○	○
Fines and penalties	○	○	○	○	○
Incident Investigations	○	○	○	○	○
Regulatory Authorities (RSR)	○	○	○	○	○
Other	○	○	○	○	○

Other (please specify)

15. From the list below, rate how **effective** has each of the following **corporate governance structures** has been or have been instrumental in the implementation of human factor management in rail operations in South Africa?

	Ineffective	Less effective	Slightly Effective	Effective	Very Effective
Department of Transport	○	○	○	○	○
Railway Safety Regulator (RSR)	○	○	○	○	○
Board of directors	○	○	○	○	○
Organizational CEO	○	○	○	○	○
Senior management	○	○	○	○	○

16. How **effective** have the following components of the **risk management processes** been instrumental in promoting human factor management? Please rate their **effectiveness** below:

	Ineffective	Less effective	Slightly Effective	Effective	Very Effective
Risk identification and analysis	○	○	○	○	○
Risk evaluation	○	○	○	○	○
Risk control	○	○	○	○	○
Risk communication	○	○	○	○	○

CLICK HERE TO SUBMIT YOUR RESPONSES