INVESTIGATION INTO FACTORS CONTRIBUTING TO DERAILMENTS: EFFECT OF ROLLING STOCK MAINTENANCE

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DECLARATION

I declare that this assignment is my own, unaided work. It is submitted in partial fulfilment of the requirements for the MEng degree. It has not been submitted before for any degree or examination in any other university.

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(Signature of Candidate)

25 day of September, 2018

ABSTRACT

Transnet Freight Rail (TFR) is the largest division of Transnet transporting bulk and containerised freight along the vast rail network across South Africa. With its revitalisation programme of infrastructure and rolling stock, TFR plans to reverse the decline in railway services where a huge market share was transferred from rail to road. The Market Demand Strategy (MDS) was implemented for this purpose, where focus was shifted back to how well the company can satisfy the customer by meeting market demand (Transnet, 2012).

Due to operational inefficiencies and unfavourable market conditions, TFR has yet to meet the targets set out in the MDS. Operational occurrences have also contributed to unfavourable railway safety performance which also negatively impacted on TFR meeting the MDS targets. An example of a frequently occurring operational occurrence is that of derailments. Derailments continue to affect the business and progress of the MDS with 80 line derailments reported for the 2017/18 financial year (Transnet , 2018). Hutchings (2017) states this is despite the fact that incidents are investigated, recommendations made and awareness of safety incidents promoted throughout the company.

This study aims at investigating the major contributing factors leading to derailments with the hope of shining the spot light on these. A particular focus was on the effects of rolling stock maintenance as a possible contributor to these occurrences. 17% of mainline derailments were found to be contributed by rolling stock. Unavailability of specification was found to be leading cause of maintenance problems. This led to deviation from processes. By understanding the factors that impact on the number of derailments, the author hopes that the company can eliminate operational inefficiencies and run scheduled railways more efficiently. In this way the service provided to the customer can be improved.

ACKNOWLEDGEMENTS

It has been a great privilege for me to be in a position to carry out this research as it has given me an opportunity to grow my knowledge and understand Transnet even better.
I would like to offer my sincere gratitude to Dr Jessica Hutchings for supervising this project. I thank you for availing yourself for consultations and guidance.

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Thank you to Transnet Freight Rail for sponsoring my studies, thus helping me to further my knowledge.

To my grandmother Gedezi Elizabeth Ndaba, my mother’s Tholakele Ngwenya and Sibongile Mabi, your love and support never go unnoticed.

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LIST OF ACRONYMS

NDP	National Development Plan
SPAD	Signal Passed at Danger
RSR	Railway Safety Regulator
TFR	Transnet Freight Rail
MDS	Market Demand Strategy
PRASA	Passenger Rail Agency of South Africa
BU	Business Unit
POD	Point of Derailment
CAB	Container and Automotive
SAC	Steel and Cement
ABL	Agriculture and Bulk Liquids
IOM	Iron Ore and Manganese
MMC	Mineral Mining and Chrome

1. INTRODUCTION

The South African Government launched a National Development Plan (NDP) that would enable the state to solve complex problems by 2030. The plan focuses on the critical capabilities needed to transform the South African economy and society in a highly charged global environment spearheaded by the emergence of fast growing economies (National Planning Commission, 2012). Transport is critical and plays a significant role in this vision by ensuring that people are given access to economic opportunities and that goods are transported from points of production to where they are consumed. Rail transport is ideal for this purpose. However, poor transport links and infrastructure network raises the cost of doing business and makes movement of goods and people difficult. The NDP and Vision 2030 (National Planning Commission, 2012) makes a case of investment in the transport sector that will support economic development and facilitate regional and international trade.

Structural weaknesses in railways hinder economic progress. Derailments and train unreliability, renders railway transport inefficient. Thus, 69% of all freight transport activity is conveyed by road (National Planning Commission, 2012), further straining the road network. To effectively run an efficient railway network, safety should be a priority and safety occurrences such as derailments should be minimised if not eliminated completely as envisioned by the Railway Safety Regulator (RSR).

Work has been undertaken in the railway industry in South Africa through safety occurrence investigations to find the root causes of accidents. The RSR's State of Safety reporting, and research on understanding how effectively these occurrences are investigated in South Africa (Hutchings, 2017), are some examples of work done in determining why railway occurrences happen in South Africa. This study aims to consolidate the available information, with the focus being placed on the effect of rolling stock maintenance in preventing occurrences, with a particular focus on derailments.

The RSR defines two types of occurrences: *Operational Occurrences* and *Security Related Incidents.* Operational occurrences deal with unsafe or system related faults within operations. These include derailment, collisions, level crossing occurrences, unauthorised movements such as Signals Passed at Danger (SPAD), etc. While, security related incidents deal with criminal intent. These include theft of assets, malicious damage, threat to operational safety, etc. as categorised in the South African National Standard (SANS 3000-1:2016) Railway Safety Management, Part 1: General. This investigational project will focus on operational occurrences: derailments. The project takes into account that costs of achieving a level of safety that is as low as reasonably practicable might outweigh the benefit and limit the viability of railway operations. Railway operators are, however, obligated to run safe railways while protecting their commercial interests (South African National Standard, 2016)

1.1. Background

With its vast and most advanced railway network system in Africa, Transnet Freight Rail (TFR) has seen a decline in investment and utilisation of rail infrastructure and rolling stock, resulting in a decline in railway service. An exodus of cargo from rail to road is evident on South African's roads. Even with the boom in commodity markets of the 2000's, driven by China's aggressive infrastructure development programme; TFR could not capitalise due to a lack of capacity and severely degraded infrastructure (Africa, 2016). The company continued to carry record low volumes.

An intervention by Transnet Group management led to the development and introduction of the Market Demand Strategy (MDS). This is a seven year market oriented strategy adopted and implemented in 2012 to facilitate Transnet's core business of moving freight across the length and breadth of South Africa while increasing operating profits. The MDS provided extensive network and railway lines rehabilitation and revitalisation of rolling stock as more than R200-billion will be channelled to expand rail infrastructure to create capacity and increase cargo volumes (Transnet, 2012). The company envisages itself railing approximately 350 million tons (mt) of cargo by the end of the 2018/2019 financial year. The company will also acquire more than 1000 locomotives and an unspecified number of wagons during this period.

Together with market influences (commodity demand), railway occurrences threaten the likelihood of achieving this feat. The RSR reported a decrease in operational occurrences of 5% for the 2016/2017 reporting year. Of the 97% reported operational occurrences, 52% (2116 operational occurrences) was contributed by TFR. These operational occurrences resulted in 495 (5% increase) fatalities and 2079 (10% decrease) injuries. Derailments contributed 0.6% of fatalities, with people being struck by trains contributing the highest number of fatalities at 83.6%. On injuries, derailments contributed 1.0% injuries compared to 30% caused by collisions, with 11% attributed to people being struck by trains (RSR, 2018).

The total number on derailments on the running lines increased by 3% from 114 during the 2015/2016 to 118 in the 2016/2017 reporting period of the RSR, with TFR contributing 71.2% of all mainline derailments at the total cost (combined with Passenger Rail Agency of South Africa [PRASA]) of more than R130 million (RSR, 2018) .

As much as there is a slight decrease in operational occurrences, safety concerns still occupy the railway industry mainly because when accidents and incidents do happen the result is fatalities, injuries, and damage to the environment and infrastructure at a huge costs to operators and the country. This is the reason why the RSR has changed the way it operates towards zero occurrences. The focus is on five major contributing categories that have a large scale financial impact in terms of direct cost incurred for damage to rolling stock due to derailments and collisions and indirect costs due to closure of lines for recovery purposes. In order to reduce operational occurrences the RSR focuses mainly on risk reduction rather than compliance and enforcement so as to have an impact on the levels of safety (RSR, 2018).

This is the background of this research. TFR runs some of the longest operational trains in the world. Operations like the Iron Ore line and the Coal Line run 342 and 200 wagon trains respectively. Given the trend to operate longer trains, understanding the most important contributing factors affecting derailments is critical to the development of effective risk reduction strategies. Studies done in the United State of America (USA) have concluded a link between Track Class (track quality classification system for speed regulation) and the Derailment rate (the number of derailments normalized by traffic exposure). Higher track classes have lower derailment rates as these track classes are intended to ensure safe operation at higher speeds and, therefore require a variety of more stringent engineering safety and maintenance standards (Xiang, 2017). This exercise is crucial as the Iron Ore line in South Africa recently ran an unprecedented 375 wagon Manganese test train from Sishen to Saldanha on 05 September 2018. This is line with TFR's objective of applying the Heavy Haul operating, maintenance, design, construction and best practice principles on General Freight operations. (Nair R. , 2018). It is crucial then for TFR to understand, limit or eliminate the factors that prevent the company from meeting set targets. It is also an opportune moment to abandon the preoccupation with 'human error' as it has assumed an exaggerated significance which is often unhealthy and counterproductive. Langer (2015) advances that; this preoccupation to human error frequently blinds the railway industry to what is really going on in complex safety systems (Langer, 2015).

Limited research has been done with respect to human factors in the railway industry and accident causation compared to rail economics and logistics in South Africa (Hutchings, 2017). This study aims and giving a practical start towards zero occurrences by identifying major contributing factors to derailments to enable proper implementation of risk management and allocation of resources.

1.2. Problem Statement

Previous research tried to address the safety performance trends which, despite regular investigation and reporting by railway operators, remained high. The methods included the determination of why the number of occurrences remains high and what is being done by the railway industry to reduce the number of occurrences (Hutchings, 2017).

From 2012 to 2018, TFR found itself not meeting the set out targets due to operational inefficiencies and unfavourable market conditions. The following figures highlight the volume growth and safety performance trends and are useful in describing the problem statement of this report. Figure 1 illustrates how TFR has hauled 226.3mt of freight for the 2017/2018 financial year compared to 334mt that TFR committed to haul for the same period.

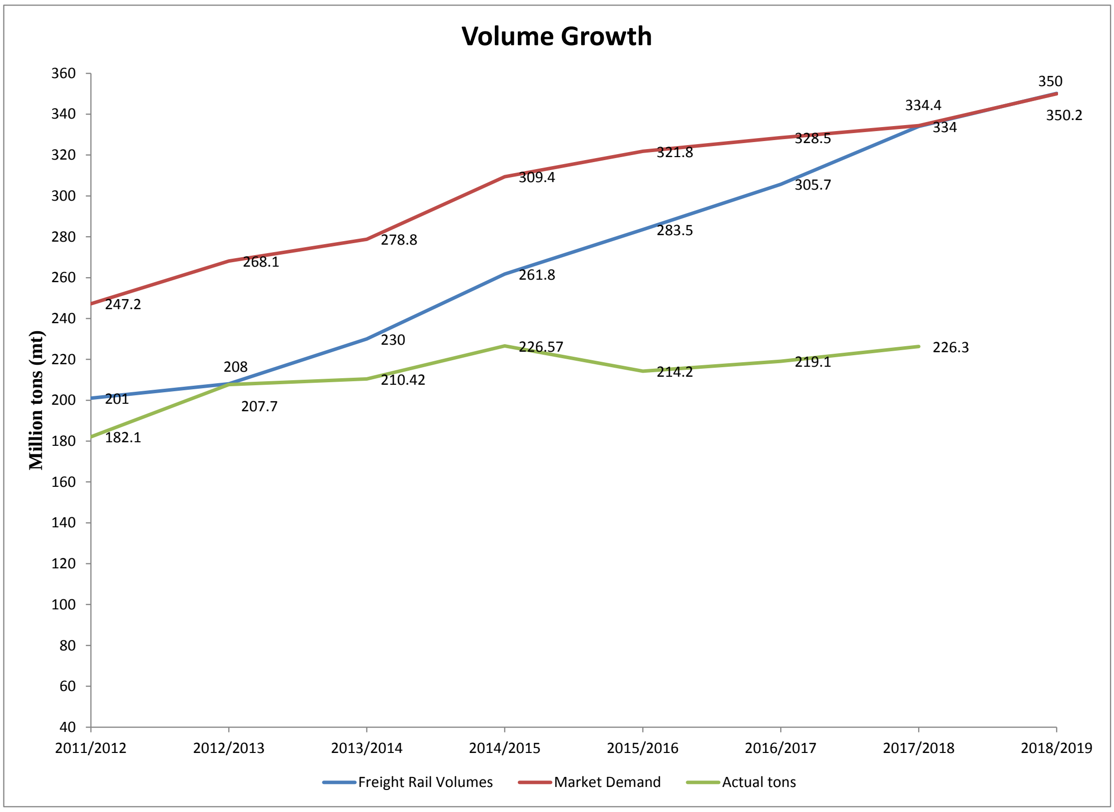


Figure 1.1 Rail validated demand and planned volumes (Gama, 2013)

The movement of TFR trains (in million train kilometres [km]) has decrease from more than 47 million train km to more than 39 million train km in 2016/17 contrasted with goods transported (in billion-ton km). The billion-ton km has increased between 2014/15 and 2016/17. A trend resembling the period between 2010/11 and 2014/15. This attributed increase in productivity is advanced by the MDS (RSR, 2018). Figure 2 shows a trend in TFR traffic volumes.

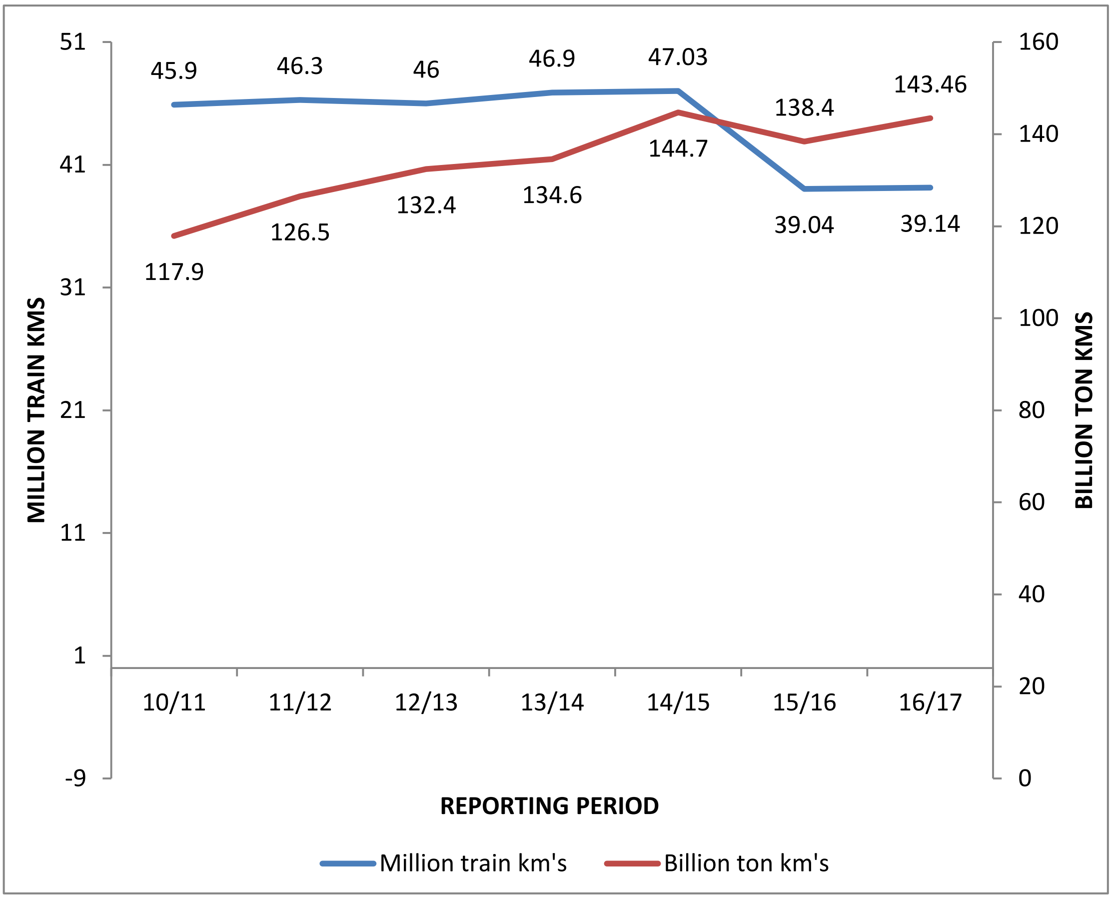


Figure 1.2 Reporting period 2010/2011-2016/2017 Traffic Volumes Trend

During the 2016/2017 reporting period of the RSR, there is a decrease in operational occurrences. Figure 3 illustrates the overall safety performance of the railway industry from the RSR's reporting period of 2010/2011 to the 2016/2017 reporting period.

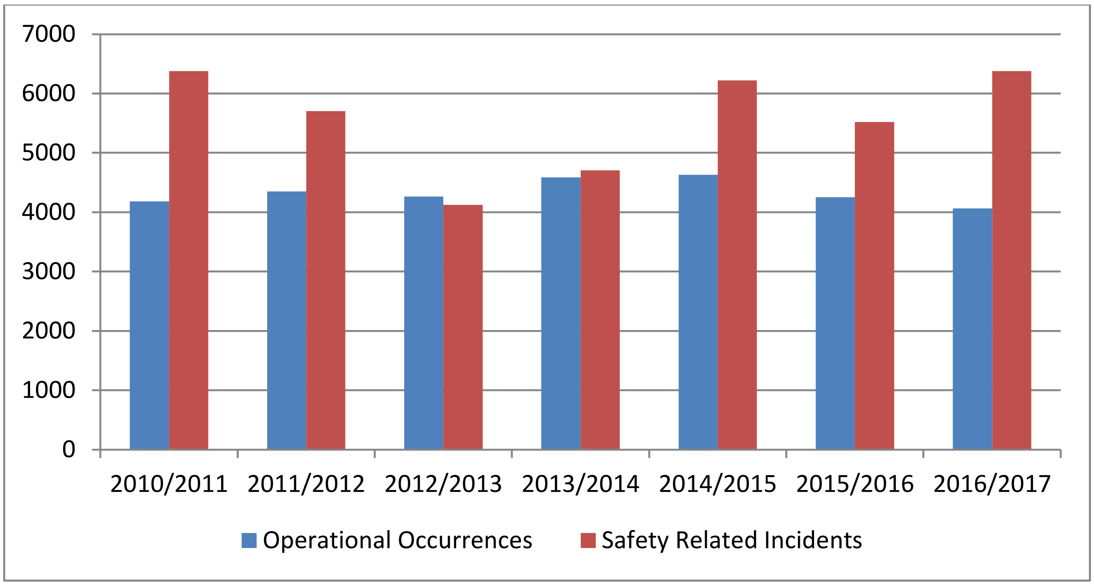


Figure 1.3 Overall railway safety performance trends since 2010/2011 (RSR, 2018)

Of the 4066 operational occurrences experienced for the 2016/17 year, TFR contributed 52% (2116). Table 2 indicates the total number of occurrences per category.

Table 1.1 2016/17 operational occurrences

REPORTING YEAR	**2016/2017**			
South African National Standards (Category)	TFR	PRASA	Other	All
A: Collision during movement of rolling stock	944	45	17	1006
B: Derailments during movement of rolling stock	268	28	90	386
C: Unauthorised movements including rolling stock movements exceeding limit of authority	41	33	10	84
D: Level crossing occurrences	93	19	7	119
E: People struck by trains during movement of rolling stock	189	460	2	651
F: People-related occurrences: trains outside station platform areas or in section	2	323	0	325
G: Passenger-related occurrences: travelling outside designated area of train	0	140	0	140
H: People-related occurrences: platform train interface	1	572	0	573
I: People-related occurrences: station infrastructure	0	111	0	111
J: electric shock	13	17	0	30
K: Spillage/leakage, explosion or loss of dangerous goods	208	0	1	209
L: Operational train fires	357	75	0	432
Total	**2116**	**1823**	**127**	**4066**

Persistent problems such as derailments, 268 for the 2016/17 reporting year, and inadequate maintenance interventions continue to affect the progress of the MDS. Train delays caused by safety occurrences (including fatalities) are featured in TFR weekly business performance reporting. These occurrences threaten the economic and environmental sustainability support that TFR provides to the country as infrastructure and rolling stock gets damaged and fatalities occur in some instances as is industry wide.

The problem that this research will attempt to address is that incident data is available from TFR's Safety Office and reported to the RSR; however limited consolidation of this information is available when it comes to derailments. Processes such as rolling stock maintenance are not perceived as contributing to these incidents as corrective actions continue to not address derailments with a number of recurrences observed through the manner occurrences are communicated throughout the company in the Business Performance Report (see sections of the report in Appendix A). Business performance is reporting as per BU. It is easy to see which BU is affecting the overall TFR target, which is not the case with Safety Incidents/Accidents reporting. Therefore there is a need for an overarching picture of the challenges experienced in this organisation that will provide a strategic framework to assist with the management of these types of occurrences. This study aims to provide a pattern of contributing factors to the causes of derailments. Through the identification of these causal factors, a deeper understanding of the risks associated with derailments will be determined. Without this knowledge, the ability of the business to continuously improve safety and risk management is limited.

With the methodology approach followed in derailment investigations, where the primary focus is to find the causes of occurrences and bring about safety learning to the business, the objective of these investigations is to prevent similar occurrences from happening. With the aid of the company's accident data, an investigation into the factors contributing to safety occurrences, in particular derailments is proposed. This research will help the business to identify the problems and therefore develop necessary technical and practical solutions in line with the business needs as recommended by the derailment investigations.

1.3. Objectives

TFR is on a quest to shift all rail friendly cargo from road to rail, a quest to grow the business and to become one of the Top Five railways in the world by 2020 (Nair R. , 2018). Part of achieving this goal is through modernising locomotives and infrastructure, creating additional capacity at various loading and offloading sites, and establishing and maintaining strong technical competency to test, maintain, and repair railway lines and rolling stock. To achieve these objectives, TFR needs to be resolute and unrelenting in adherence to processes as the company strives to become a process and data lead organisation. Safety remains a critical indicator of progress made. Quick responses to incidents and accidents like derailments enables TFR to make good on its promise of moving million tons of cargo safely (Nair R. , 2018).

A thorough analysis of all occurrences must be conducted and the results used to augment current safety improvement plans. This investigation seeks to provide one of the building blocks to this process by identifying factors contributing to derailments. The study recognises that there are a number of derailment causes across the rail network, thus the focus of this investigation will be on causes that relate to rolling stock maintenance to help business units to identify derailment linked problems to be able to develop necessary solutions in line with business needs. This investigation aims to:

- Identify factors contributing to railway safety occurrences, focusing on derailments.

- Evaluate the derailment investigation process and its impact on preventing railway occurrences from recurring.

- Evaluate the effects of rolling stock maintenance and interventions on derailments.

1.4. Research Question

Incidents and accidents are reported in accordance with the National Railway Safety Regulator Act No. 16 of 2002, and presented in the RSR State of Safety reports to measure railway safety in South Africa. The RSR has adopted a risk based approach in terms of its strategic objective of significantly reducing occurrences towards achieving zero occurrences. In the 2016/17 State of Safety Report, the RSR conducted a cost of risk analysis of the important freight and passenger corridors allowing the regulator to identify the high risk corridors and areas for specific risk-mitigation attention during the 207/18 reporting year (RSR, 2018).

Incremental reduction in railway occurrences occurs, with a 5% reduction for the 2016/17 reporting year. Huge numbers of occurrences are still reporting despite the wealth of knowledge gathered annually. The research question that this work seeks to answer is as follows:

What are the factors contributing to derailments at TFR?

The secondary impetus of this research is to look at the role of maintenance interventions in causing derailments by assessing processes applicable to and the technical expertise required in rolling stock maintenance to deliver products that comply with specified criteria

2. LITERATURE REVIEW

2.1. The South African Railway Industry: History and Background

The 1800's saw the beginning of the railway enterprise in South Africa with the formation of the Cape Town Railway and Dock Company and the first railway line being laid by the Natal Railway Company. By 1910, the unification of South African colonies was achieved leading to the formation of the South African Railway and Harbours (SAR&H). This period marked the expansion of the railway sector in South Africa as SAR&H came into being as one organisation to serve the whole country. The government restructured SAR&H in 1981 and made it a state business. It was then called the South African Transport Services (SATS) which later became Transnet Limited. Transnet was incorporated as a company in 01 April 1990 with the South African government as a sole shareholder. Spoornet as a rail operator became one of the major division of Transnet. In July 2007 Transnet unveiled a new image which entailed adopting a monolithic brand and Spoornet was renamed Transnet Freight Rail (TFR, 2018). Transnet operates as integrated freight Transport Company with five core operating divisions illustrated in Figure 2.1.

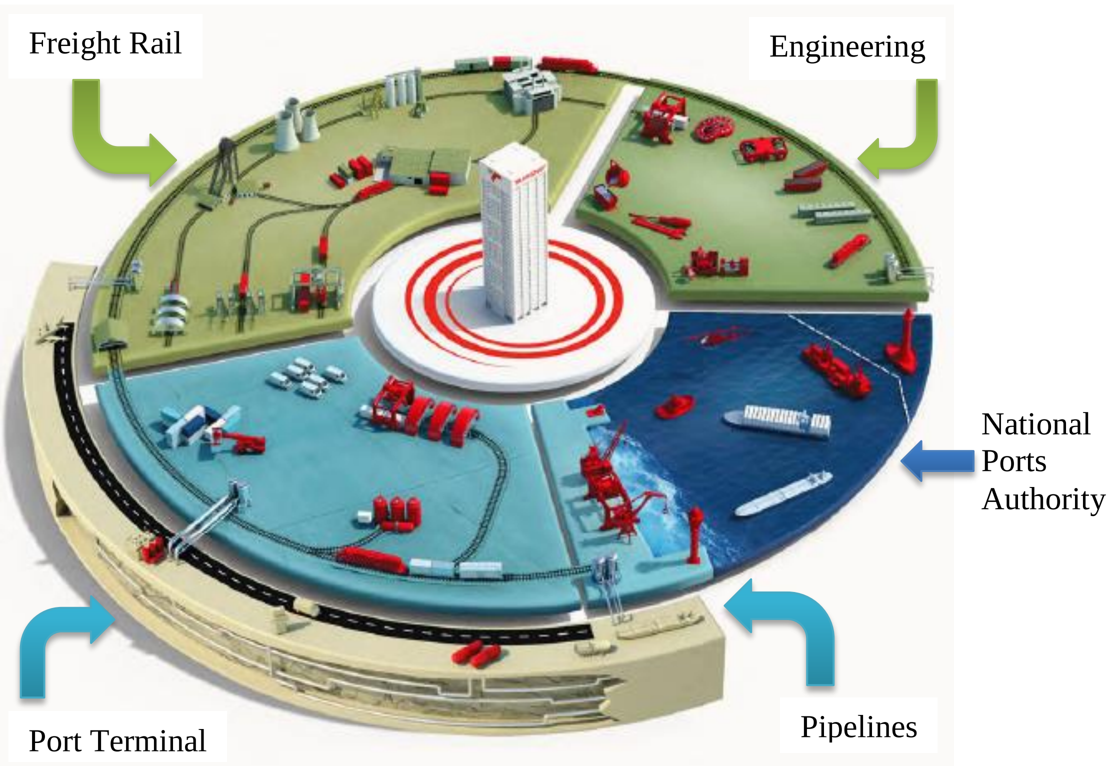


Figure 2.1 Transnet Group and Operating Divisions (Transnet, 2015)

2.2. Transnet Freight Rail

Transnet Freight Rail offers freight logistics solutions through the largest and most advanced railway network system in Africa. It is the largest division of Transnet with an extensive rail network across South Africa that connects with other rail networks in the Sub-Saharan region (Transnet, 2017).

TFR has committed and moved itself to become a profitable and self-sustaining freight business, thus relying less on government interventions while driving the competitiveness of the South African economy. The company is made up of six business units:

- Agriculture and Bulk Liquids (ABL),
- Coal,
- Container and Automotive Business (CAB),'
- Iron Ore and Manganese (IOM),
- Steel and Cement (SAC), and
- Mineral Mining and Chrome.

TFR moves about 17% of South Africa's freight annually with 100% coal and Iron Ore exports. The annual revenue contribution stands over R43 billion for the 2017/2018 financial year (Transnet, 2018).

2.3. Investigational Process

The investigation process of occurrences is meant solely to improve rail safety. Amongst finding the immediate cause of an incident, a root cause determination is also critical in improving rail safety. Its approach should, and must not be to apportion blame but to improve rail safety. Therefore, the highest level of independence is required from the process (Transnet , 2015).

At TFR rail occurrences are classified according to their severity. Those that cause damage greater than R10 million and R5 million are classified as Level 1 and 2 respectively. These occurrences cause varied business interruption from serious to significant, impacting severely on revenue and may result in hospitalisation or fatalities of people. Level 3 occurrence investigations deal with minor business interruptions amounting to more than R1 million damage. Physical harm is experienced on people but no hospitalisation required. Lastly, Level 4 deals with first aid cases and damages amounting to less than R1million (Transnet , 2015).

2.3.1. Rail Occurrence Investigation

Rail occurrences are investigated by the TFR Rail Occurrence Investigation consisting of two teams i.e. the TFR Rail Investigation Central Team (Central Team) and the TFR Rail Occurrence Cluster Team (Cluster Team). The Central Team is obligated to perform investigations of Levels 1 and 2 which occurred on TFR rail network and third party networks where TFR assets are involved. The team also has the right to investigate rail occurrences of Level 3 and 4. The Central Team is based at the company's head office. The Central team is multi-disciplinary consisting of Infrastructure, Operations, Rolling Stock, Technology Management and Safety/Risk departments. The Cluster teams are obliged to perform investigations of Level 3 and 4 which occurred on TFR's network and third party networks where TFR assets are involved. Cluster teams are situated in designated geographical areas covering regions of TFR rail network and consist of infrastructure, Operations and Rolling Stock teams with sufficient railway competences.

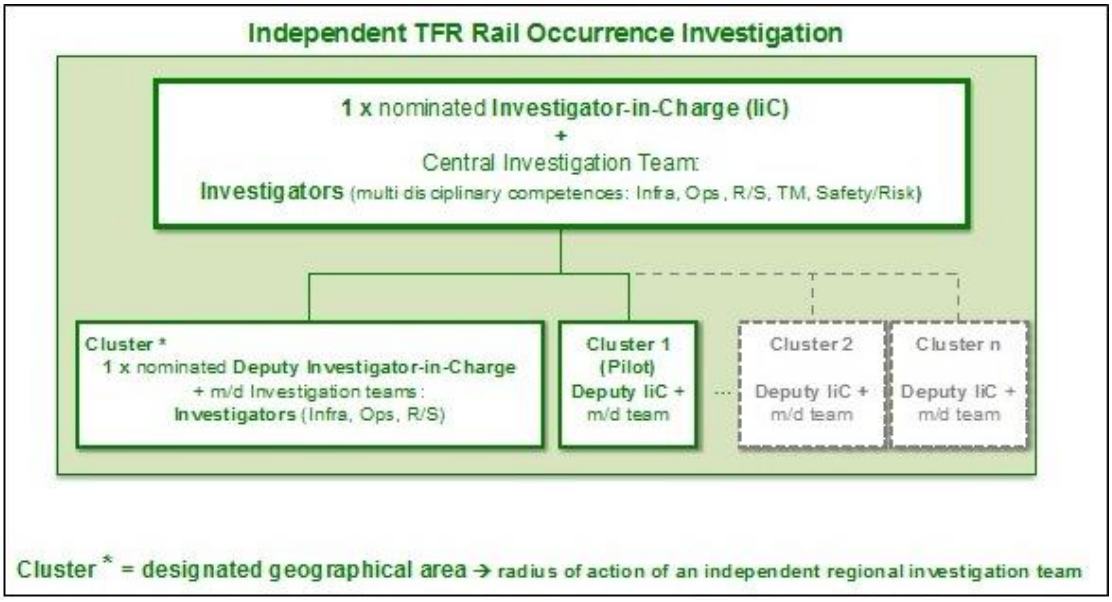


Figure 2.2 TFR Rail Occurrence Investigation Structure (Transnet , 2015)

The TFR Rail Occurrence Investigation must, amongst other things, determine the immediate and root causes of rail occurrences, develop corrective actions to address the determined causes and contributing factors to prevent recurrences and monitor and validate the effectiveness of the corrective actions. The corrective actions must be implemented fully as required by the relevant organisational unit. The TFR Rail Occurrence Investigation is obligated to supervise and monitor progress of the implementation and effectiveness of corrective actions and have the right to intervene where necessary with the aim of ensuring full compliance.

2.3.2. Rail Occurrence Investigation Process

The rail investigation process is depicted in Figure 2.2. It is designed to achieve a standardised execution of the TFR Rail Investigation. The process guides the investigation teams through the process of determining the sequence of events leading to the occurrence, identifying corrective action(s) to prevent the occurrence from recurring. There are two process steps preceding the actual process which need to be done following a rail occurrences i.e. to report and activate the rail occurrence. They give input into and initiate the TFR Rail Occurrence Investigation process (Transnet , 2015).

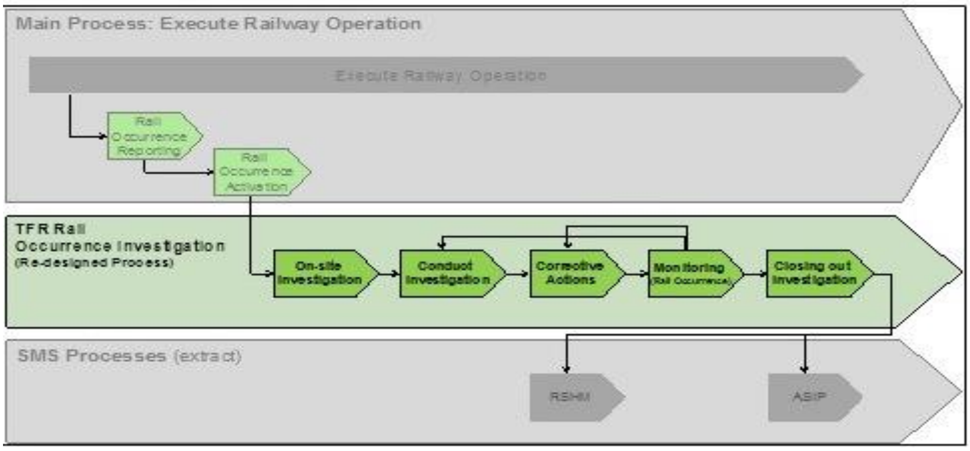


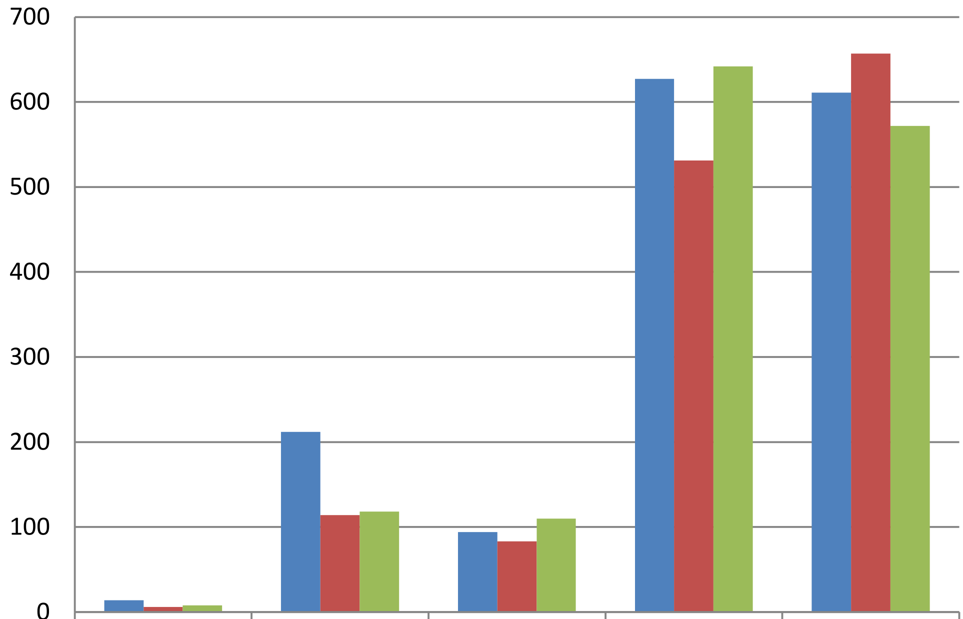
Figure 2.2 TFR Rail Occurrence Investigation Process (Transnet , 2015)

2.3.3. Derailment Handbook

In its quest to reduce occurrence risks, the RSR has selected and focused its resources on areas that have a large scale financial impact in terms of direct and indirect costs incurred as a result of damage to rolling stock and closure of lines for recovery purposes. The selected areas are operational-occurrence based (see Table 1) defined in SANS 3000:1 2009: General (RSR, 2018):

- Category A-a: Mainline collisions between rolling stock
- Category B-a: Mainline derailments of rolling stock
- Category D-a: Level crossing occurrences at authorised level crossings
- Category E-a: People struck by trains in a mainline
- Category H-a and H-b: Platform train interface occurrences.

A performance comparison of these categories is illustrated in Figure 2.3.



	A-a	B-a	D-a	E-a	H-a and H-b
YTD 14/15	14	212	94	627	611
YTD 15/16	6	114	83	531	657
YTD 16/17	8	118	110	642	572

Top five Oprational Occurrences

Figure 2.3 Top Five occurrences comparisons 2014/15-2016/17 (RSR, 2018)

The focus of this study is on running line derailments. Figure 2.3 indicates an increase of 3% for the 2016/2017 reporting period (118 derailments) compared with the 2015/2016 reporting period (114 derailments). TFR contributed 71.2% of all mainline derailments.

In dealing with derailment issues, Technology Management (as part of the TFR Rail Occurrence Investigation Central Team) issued a technical guide to investigate a train derailment, determining its root cause and specifying corrective actions. The handbook focuses on derailments; therefore other operational occurrences are not dealt with. The handbook classifies a derailment as when the normal wheel-rail relationship (i.e. the tread of the wheel on the running surface of the rail) is disturbed giving rise to the Point of Derailment (POD). Determining the POD is a very important part of derailment investigations as its location should be agreed by the Investigation Team before proceeding (Handbook, 2011). In the process of identifying the POD, the Investigation Team should identify, from the three possible wheel actions, the action by which the first wheel derailed. Figure 2.4 and 2.5 illustrates the three different types of wheel actions i.e. wheel climb, wheel lift or wheel drop-in and each are caused by different changes in vertical and/or lateral wheel forces. The handbook offers comprehensive tools required for an effective derailment investigation ranging from cause finding steps (e.g. determine and agree on POD, wheel action, etc.), data collection, evidence reconstruction and preservation to failure analysis. What is of interest is whether, after such extensive tools used in determining the causes of derailments, the information gathered is used to prevent the recurrences of occurrences. It will be of interests if the investigation can determine whether the Investigating Team is equipped sufficiently to realise the Corrective action and Monitoring steps of the investigation process as depicted on Figure 5.

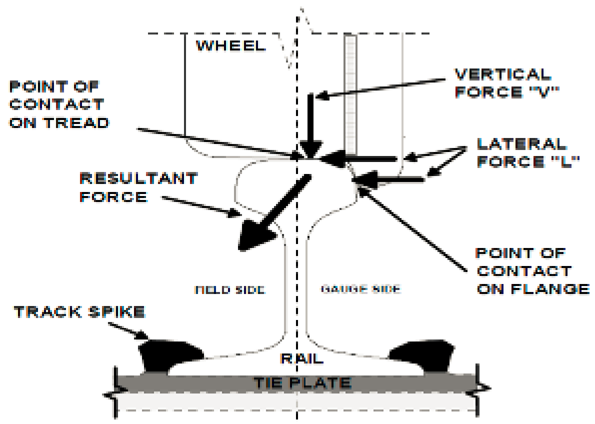


Figure 2.4 Wheel/Rail contact and contact forces (Handbook, 2011)

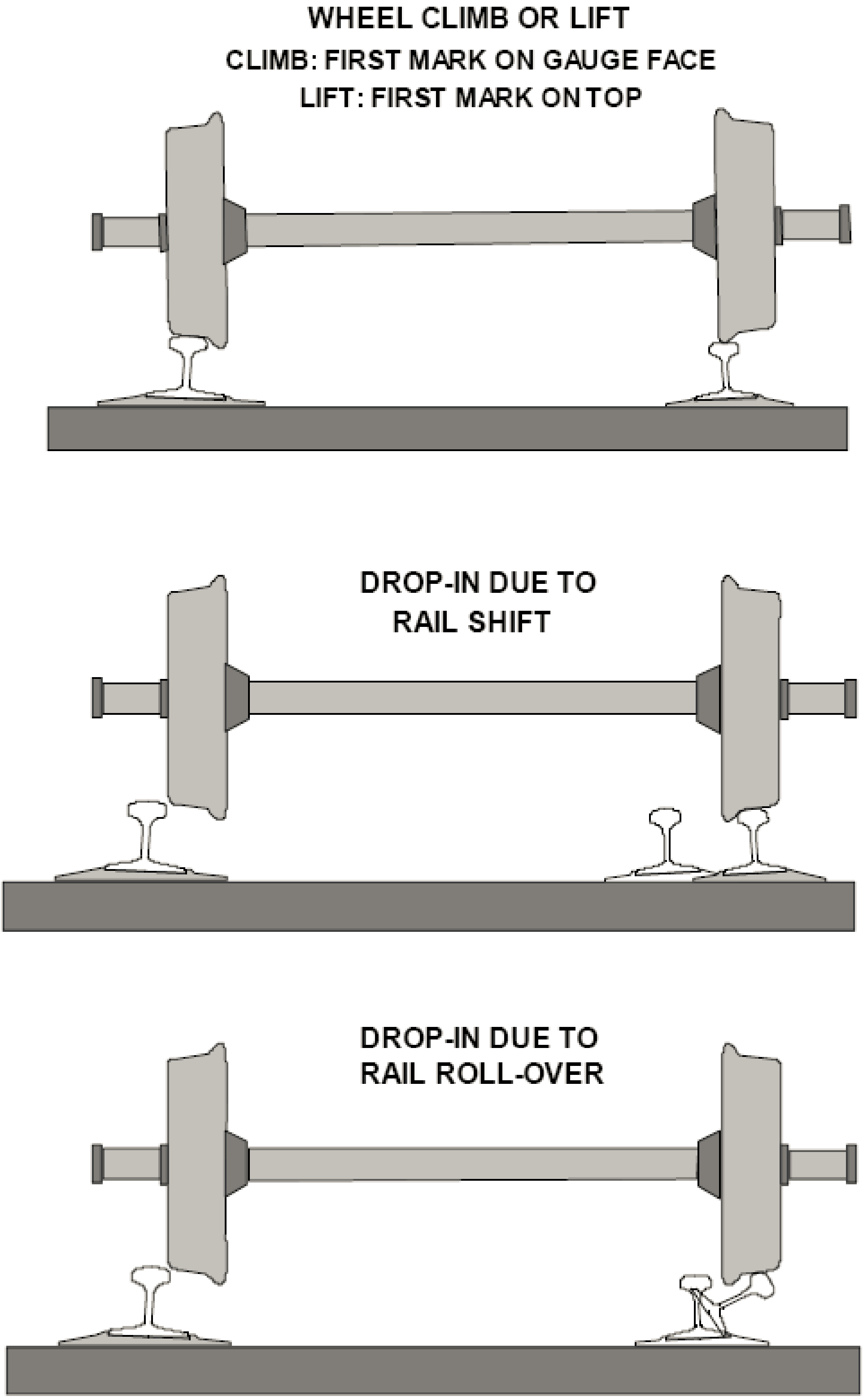


Figure 2.5 Possible wheel actions (Handbook, 2011)

2.3.4. Incident/Accident Analysis

Kumba Iron Ore reported R2 billion losses in sales opportunities caused by six derailed trains in the first half of 2018. The derailments resulted in stock piles increasing substantially to over 6 Mt (Ryan, 2018). Transnet, in response, acknowledged that derailments are a problem for all its customers and pinned them on a combination of configurations, network failures and equipment failures (Mathews, 2018). This illustrates the impact derailments can have on the system/supply chain.

The railway industry fully understands the costs associated with derailments as infrastructure and rolling stock gets damaged which results in service interruptions as with the Sishen-Saldanha Iron Ore single line case above. With this understanding and the reporting mechanisms the railway industry has put in place (RSR reported 98% of operator compliance with the reporting requirements as per the RSR Act) there has been no major breakthrough in curbing occurrences. One of the challenges attributed to this lack of progress is the difficulty in extracting effective information because of the vagueness and uncertainty of the collected data.

Efforts have been made in documenting occurrences by operators in line with the RSR, which is mandated to provide safety oversight and ensure safety in railway operations. The challenge is how to use the information collected to achieve zero safety occurrences. With the number of occurrences and the possible number of near-misses reported each year, it is possible to prevent accidents by making use of the reported data. However, if there is no system to adequately address the findings reported then the data becomes of no use. This is evident with the number of occurrences remaining high in South Africa despite interventions put in place by organisations and the regulator.

Fukudu (2002) argues that the decrease in operational occurrences with improvements in safety systems depends on how well incidents are controlled. Therefore, one needs to discover, remove and mitigate risks by constructing a systematic risk management system in order to decrease occurrences. This is evident in North America where there was a 39% reduction in derailments achieved. It is important to determine the different causes of derailments if safety is to be improved by applying effective safety measures (Wang B., Principal factors contributing to heavy haul freight train safety improvements in North America: a quantitative analysis, 2017). One then needs to appreciate that collection of information, analysing and evaluation of this information will not yield any tangible results unless the effects of the countermeasures are measured and evaluated. The control of accidents needs to extract information, construct a database, comprehensively analyse data, and establish a system to feedback information to related sites and networksas illustrated by Figure 2.6 (Fukudu, 2002). Fukuda (2002) emphasizes the importance of not relying on personal awareness by using phrases like "be careful" but to give a goal, measure and evaluate the effects of the application of corrective actions.

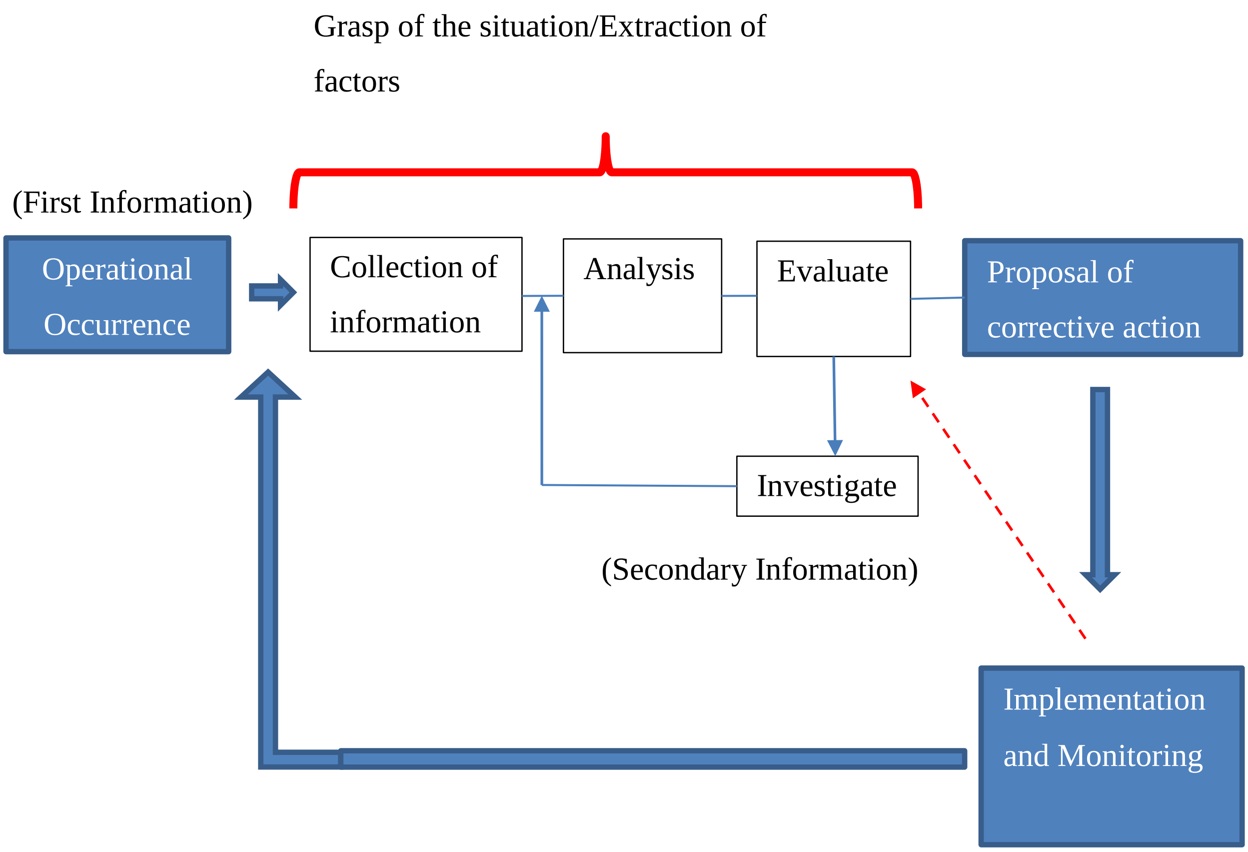


Figure 2.6 Flow of occurrence analysis for safety management Adapted from (Fukudu, 2002)

The important aspect of Figure 2.6 is the feeding back of information in the investigation of occurrences. This emphasises the fact that the investigation process of railway occurrences is a complex system and that the system principles that impact on the accident investigation system include the feedback of information (Hutchings, 2017).

In trying to understand why accidents happen, it is therefore prudent to conduct a thorough accident investigation, focusing on the system. This is to identify the systemic causes, the deep rooted underlying reasons rather than adopting the view of looking to apportion blame. Typically this is not what is happens in practise, questioning the validity of investigations (Hutchings, 2017). This study acknowledges this aspect; however the focus will be to attempt to understand the breakdown in the investigation process by determining and listing derailment contributing factors and looking at the effects of rolling stock maintenance in preventing occurrences from recurring as the effectiveness of the investigation process in preventing recurrences is a measure of the systems performance.

An objective of an investigation is to establish how the event happened and how it was permitted to happen. Determining how it was allowed to happen requires examination of risk control failures, human factors and organisational factors. There are many tools and models that can be used to establish causation, but whichever model is used, the integration of human factors is essential to ensure effective investigation practice (Abbot, 2013). There are a number of causation models referred to in the railway industry. One of them is the Reason's Swiss Cheese Model (Reason, 1990). This model illustrates the fact that accidents usually have a number of contributing factors, some of which are latently present in the routine working environment. The usefulness of this model is in the understanding of how latent failures surface and why accidents occur (Hutchings, 2017). Even though the model is not used in this study it serves as an illustration of how investigators ought to be looking at investigations. In doing so, real root causes of accidents may be determined and effective corrective actions recommended. A reduction in railway occurrences may be realised in this fashion.

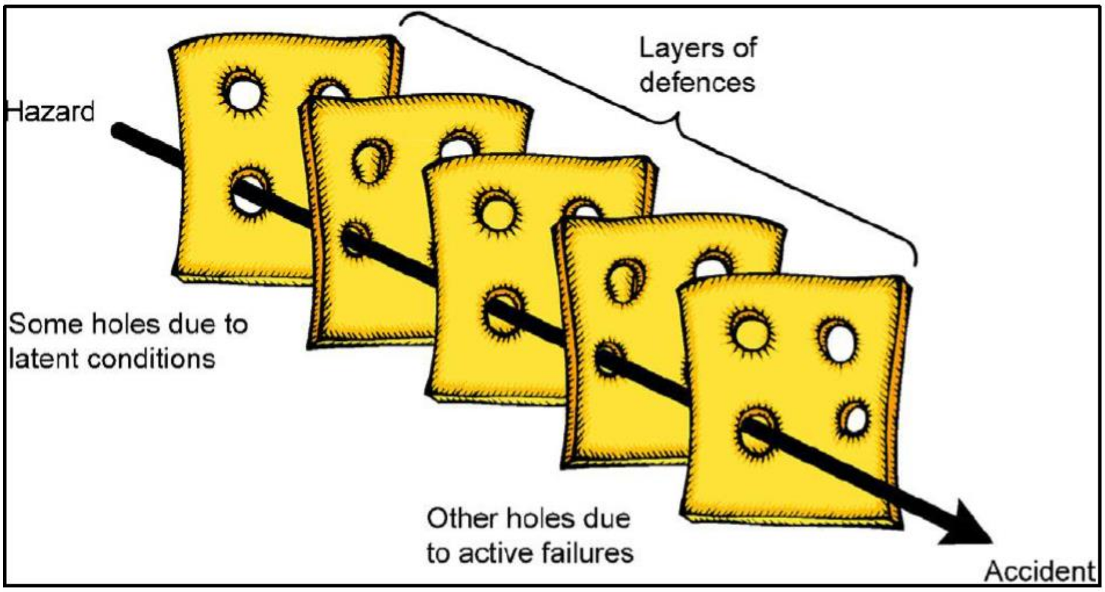


Figure 2.7 Reason's Swiss Cheese Model (Reason, 1990)

3. METHODOLOGY

In order to achieve the objectives of this investigational research and map out the relationship between derailments and rolling stock maintenance, a qualitative analysis was followed with a multi method approach including document analysis and interviews.

With Transnet having a vast network which stretches across the length and breadth of South Africa, it will be ineffective to cover every derailment in the time allocated. Therefore, Saldanha Locomotive and Wagon depots were chosen for analysis. The maintenance audit findings were analysed for this depot. This was to determine the quality of maintenance and establish a link (if any) between the depot and the derailments happening on the mainline. This was such that both the depot and operational area provide all the necessary information including data collection of which when analysed will achieve the objectives of this investigation. Also, because of the strategic nature of this line, it is believed that an in depth qualitative analysis of derailments can help the business directing necessary resources in mitigating derailment risks.

3.1. Derailment Data

The RSR requires railway operators to submit detailed reports of all incidents and accidents associated with railway operations. For TFR, this information is kept by the Risk Management and Safety department. The data is reported in Excel and is a database containing a large volume of information relating to: details about the track type, incident causes and description, etc. for each TFR Business Unit.

3.2. Document Analysis

An analysis of factors contributing significantly to derailments was conducted through a document analysis of derailment investigation reports and Corporate Quality Audit reports. These provided an idea of the factors contributing to derailments and major findings relating to rolling stock maintenance. The data collection methods included:

a) Analysis of accident trends.

b) Review the Technical Audit reports.

3.3. Derailment Frequency and Severity

A graphical method to illustrate the relationship between the train derailment causes, frequency and severity was introduced by Dick et al (2003) and Barkan et al (2003). Individual derailment causes are plotted in terms of the average frequency and average severity as illustrated in Figure 3.1. The graph is divided into four quadrants. Data points to the right of the vertical line indicate above average frequency and points above the horizontal line indicate above average severity. Therefore, the relative impact of different causes of different cause groups can be evaluated in terms of their respective quadrant as demonstrated by Wang, Barkan and Saat (2017). Wang et al. (2017) details derailment causes in the upper right quadrant as occurring more frequent and are more severe, thereby posing the greatest risk in terms of number of wagons derailed. Conversely, causes in the lower left quadrant are rare and tend to be lower severity derailments. The causes in the upper left quadrant have more severe consequences, but their lower frequency makes it more difficult to make consistent prediction. The lower right quadrant includes less severe, but higher frequency derailments causes, which are of secondary interests.

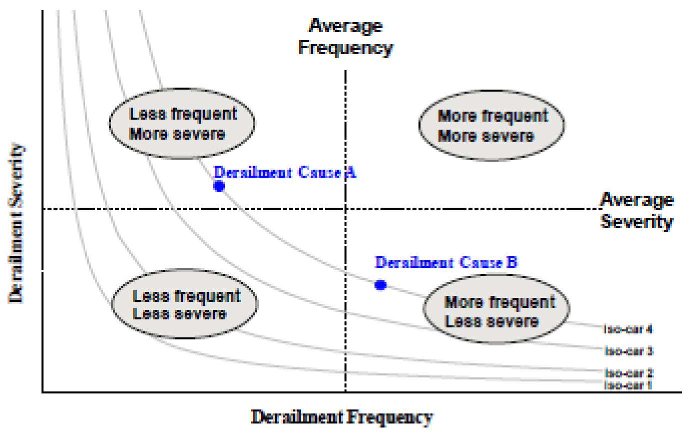


Figure 3.1 Frequency-Severity graph (Wang B., Principal factors contributing to heavy haul freight train safety improvements in North America: a quantitative analysis, 2017)

4. RESULTS

Derailments can happen anytime, anywhere and on different track types (yard, siding, mainline, etc). The focus of this investigation report is on mainline derailments because of the higher speeds and longer consists. The greater the mass and speed mean that the force and potential impact in regard to property damage, casualties, and environmental effects are all correspondingly greater (Xiang L., 2012). To prevent railway occurrences that result in derailments requires the understanding of the most causes contributing to derailments. This is considered by the industry as one of the critical steps in developing effective derailment prevention methods. Table 2 shows the number of derailments experienced by TFR, total number of railway wagons and the average number of wagons derailed for the period 2015-2018. The Container and Automotive Business unit (CAB) has the highest number of derailments with the COAL Line having the least number of derailments. Total derailments amounted to 227 for this period. The ORE Line has the most number of wagons derailed at 355.

Table 4.1 Occurrence Frequency, Severity, and Car Derailment by Track Type and BU

Track Type	Business Unit						
	SAC	MMC	CAB	ABL	IOM	COAL	Total
Number of Derailments							
Main	35	37	50	44	34	27	227
Total Number of Wagons Derailed							
Main	96	143	85	78	355	227	984
Average Number of Wagons Derailed							
Main	2.7	3.9	1.7	1.8	10.4	8.4	4.3

The most frequent causes of derailments include rail slack, rail kick and broken rail. A number of derailments (14.5%) have yet to be determined as to what the causes them. These occupy a large number by derailment frequency and severity. The top five causes contribute almost 40% of total causes by derailment frequency.

Table 4.2 Top Ten Frequent Derailment Causes 2015-2018

Rank	Freight Derailments		Wagons Derailed	
	Cause	Percentage	Cause	Percentage
1	Still under investigation	14.5	Still under investigation	27.4
2	Rail slack	7.0	Rail broken	11.3
3	Rail kick	5.7	Rail kick	9.0
4	Axle broken	5.7	Speed	8.6
5	Rail broken	5.3	Rail slack	6.6
6	Wrong track gauge	5.3	Wheel cracked	4.2
7	Points not set correctly	4.8	Axle broken	3.6
8	Speed	4.8	Wrong track gauge	3.0
9	Signal passed at danger	4.0	Loose counterweight on locomotive bogie	2.5
10	Points defective	3.5	Points not set correctly	2.2

4.1. Derailment Frequency and Severity

The analysis of derailment contributing factors was conducted to compare the frequency of derailments and the severity of derailments by causes. Accounting for severity is important because derailments where more wagons are involved are likely to be more damaging and more costly (Xiang L., 2012).

Derailment and severity were plotted against each other (See Figure 11). Those causes in the upper right quadrant are most likely to pose the greatest risk because they are both more frequent and severe than the average. Those causes in the lower right quadrant are of high frequency but are less severe. Causes in the upper left quadrant are less frequent but more severe.

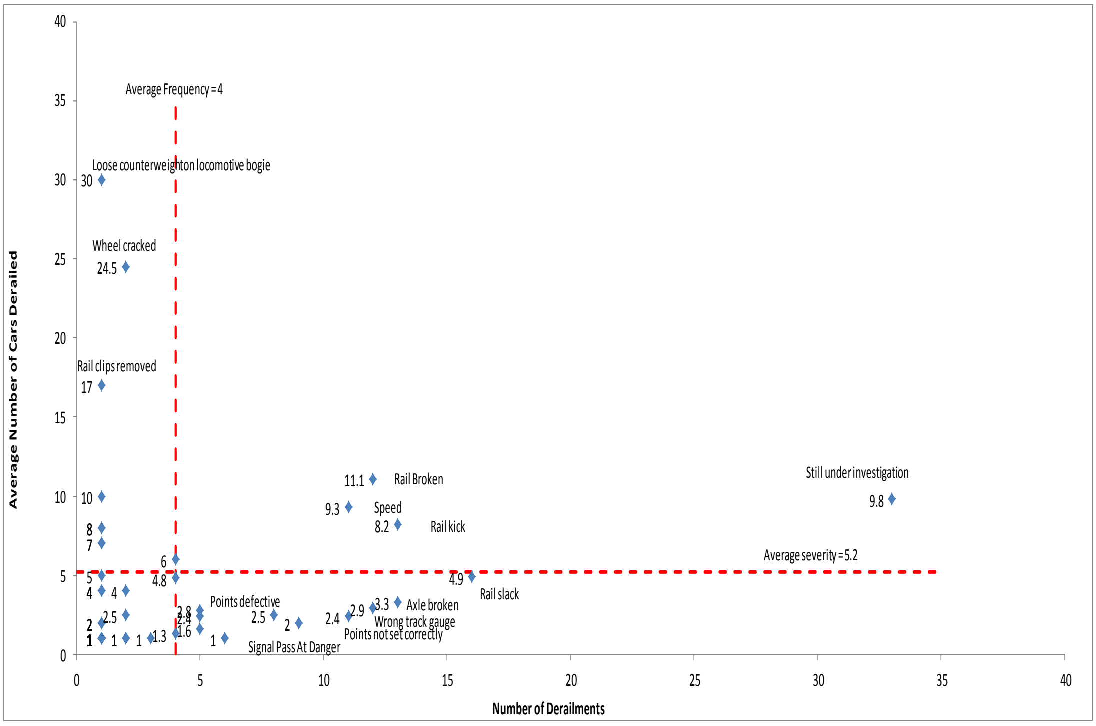


Figure 4.1 Frequency and severity graph of mainline derailments 2015-2018

4.2. Rolling Stock Related Causes

Rolling stock contributed about 17% to the number of derailments during the period 2015-2018. Wagon related derailments average about 0.25 derailment rate per million train kilometres. In the 2017-2018 financial year, there were 80 derailments recorded at a total cost of R634 135 340. Rolling stock derailments contributed 8 derailments at a cost of R85 152 731 with Brake Gear Loose and Axle Broken causes accounting for R13 865 000 and R71 197 731 respectively

Table 2.3 Rolling Stock Related Causes 2015-2018

Occurrence Cause	Business Unit						Total
	ABL	COAL	CAB	IOM	MMC	SAC	
Axle Broken	3	2		3	1	3	12
Brake gear loose	1	1		2			4
Knuckle broke		1					1
Push rod pin broke		1					1
Wheel cracked		1		1			2
Push rod loose				1			1
Skidded wheels				1			1
Coupler pull out	1		2		1	1	5
Side bearing clearance defective	1						1
Bogie stiff			1				1
Brake beam loose			2				2
Wheel shifted on Axle			1				1
Wheel flange sharp						1	1
Wheel profile not within specification					1		1
Loose counterweight on locomotive bogie	1						1
Traction motor came loose		1					1
Wheel tyre loose		1					1
Total	**7**	**8**	**6**	**8**	**3**	**5**	**37**

Table 4.3 indicate that both Heavy Haul lines (the COAL Line and the Iron Ore and Manganese line) carry the most rolling stock related derailments. This reinforces Xiang et al(2012) that the greater the mass and speed mean that the force and potential impact in regard to property damage, casualties, and environmental effects are all correspondingly greater. Therefore, either one of the two lines could be used to further interrogate the effect of rolling stock maintenance to derailments. For the period 2017-2018, the Coal line had 16 derailments, costing the company R167

801849. The Iron Ore and Manganese line on the other hand had 18 derailments at a total cost of R289 347 269. Based on this information, the ORE Line was then chosen for the analysis. Another factor that contributed to the ORE Line being chosen was the ease of accessing information on the ORE Line. For the limited time available, it was deemed to necessary and convenient to choose the ORE Line.

Upon researching through the findings data for the period 2015-2018, a number of issues were picked up. Table 4.4 shows the top 10 issues identified. These issues were determined by identifying related findings and place them in a category. The results of this research indicate that the depots do not, consistently, conduct processes with assurance that the processes applicable to and the technical expertise required for maintenance of rolling stock is of the standard that will ensure the products delivered comply with specified criteria. In most cases the depots do not possess maintenance specifications. This leads, directly, into the depot deviating from the specification or prescribed processes.

Table 4.4 Rolling stock maintenance issues and concerns 2015-2018

Number	**Issues/Concerns**	**Description**
1	Product perseveration	Components handled and stored outside the warehouse, etc.
2	Deviation from specification	Daily and months coil spring test not done, axles are not protected during the cutting of split pins, etc.
3	Instruments	No instrument/incorrect instrument used
4	Training	No training provided
5	Inspection	Inspection not conducted, inconsistent signing inspection checksheet, etc.
6	Document control	documents not signed, outdated, etc.
7	SOP	SOP’s not available
8	Record control	No control of jobcards, some stored in uncontrolled access areas.
9	Calibration	Tools not calibrated/calibration overdue
10	Safety	Gas cylinder storage not up to standard, wheelsets not secured with stoppers, etc.

Principles of value engineering were then used to determine which of these issues, if eliminated, could improve the quality of the work produced by the depots. From the list in Table 4.4 functions list was generated based on what is wished to achieve if the listed issues and concerns were addressed i.e. translating issues and concerns into positive statements. A numerical evaluation was conducted to prioritise the functions. The first function (Product protection =A) is compared to the next function (Specification availability =B)in order to determine which of the two is more important. A weight factor is assigned to show the difference in importance i.e. 1= small, 2= medium and 3= large. Once completed, the first function is then compared to the next i.e. function C and so on. When function A has been compared will each of the functions, function B is then compared with each of the other functions and so on. The next step is to add all the weight factors for each function. The function with the highest score is then regarded as a basic function. The rest are termed secondary functions. From these results Figure 4.2 is drawn. The graph indicates the causes of poor maintenance quality at depots. These are the basic functions determined from the numerical analysis. Secondary functions (effect) occur as the result of not addressing the basic functions.

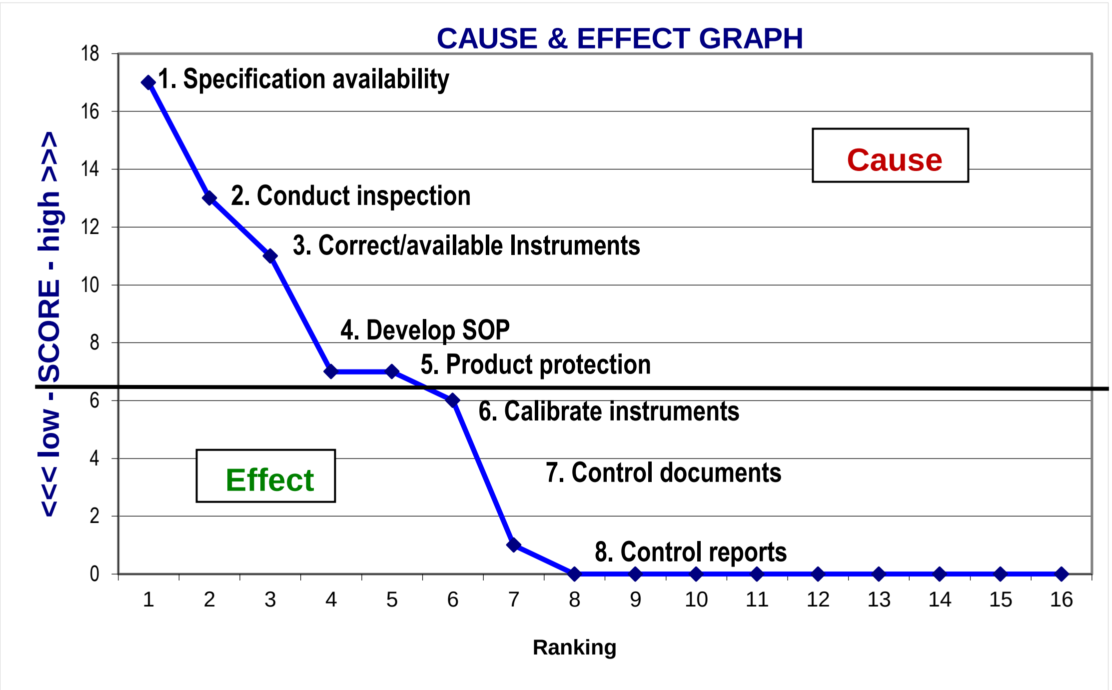


Figure 4.2 Cause and effect graph

5. DISCUSSION

An investigation was set out to determine the factors contributing to TFR derailments. The study focused on determining the effect rolling stock maintenance has on derailments.

Data was sourced from the TFR Safety Office. The data contained all TFR accidents from 2010 to 2018. The information could be classified through TFR Business Units and by Regions.

Chapter 4 detailed the results obtained from analysing the data. The analysis was conducted for the period from 2015 to 2018. In that period 227 mainline derailments occurred with the CAB accounting for 50 derailments and the coal business had the least number of derailments at 27. The total number of wagons derailed equalled 984 with the IOM accounting for 355 and ABL having the least number of wagons derailed at 78. From the number of derailments listed, each contributing cause was determined and listed. For all mainline derailments a total for each contributing factor was determined together with the associate number of wagons derailed (See Appendix B).

From the listing, most frequent derailment contributors were found. The Top five cause’s amount to 40%of total causes by derailment with 14.5% of those still not determined. This is notable concern given the time that passed questioning the reliability and accuracy of the findings should they be at all determined. Due to time constrains, it was difficult to determine exactly at what stage these investigations were at.

Frequency by derailment was then compared to severity. These variables were then plotted to give a graphical representation of which causes are more frequent and the level of severity. Rail break, speed and rail kick happen more frequent and were more severe as they are above the average severity line of 5.2 (see Figure 4.1). Wheel cracked, rail clips removed, etc. occurred less frequently but when they occurred they are likely to cause more damage at a high cost as they are above the average severity line and left of the average frequency line. Below the average severity line but right of the average frequency line lies causes that are frequent but less severe. These include Rail slack, Axle broken, SPAD, etc.

From the frequency list of derailments it was determined that rolling stock contributed 17%. Then rolling stock related causes were listed in Table 4.3 for all TFR business Units. From the list the Heavy Haul lines carried the most rolling stock related derailments. The IOM had 8 derailments for the reporting period 2015 to 2018, followed by the COAL line with 6 derailments. This finding was used to justify the use of the Saldanha depots in answering the research question:

What role the rolling stock maintenance plays in causing derailments at TFR?

Twenty (20) issues and concerns were determined from the Quality Audit findings made during the reporting period 2015-2018. From the list, ten were deemed the most frequent and were analysed further through Value Engineering principles where a ranking system was used to determine which associated issues were the cause of poor quality and lead to derailments on the TFR mainlines. Specification unavailability, not conducting inspection on products and the use of incorrect instruments and sometimes unavailability of maintenance instruments leads to the depot not able to produce products that meet specified criteria.

6. CONCLUSIONS

The following conclusions are made:

- Infrastructure is the leading cause of derailments in TFR mainlines.
- Even though rolling stock account for only 17% of mainline derailments, its impact is enough to cause service disruptions.
- Therefore, rolling stock maintenance plays a role in TFR derailments
- Further works needs to be done to include other yards and shunting derailments

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APPENDIX A

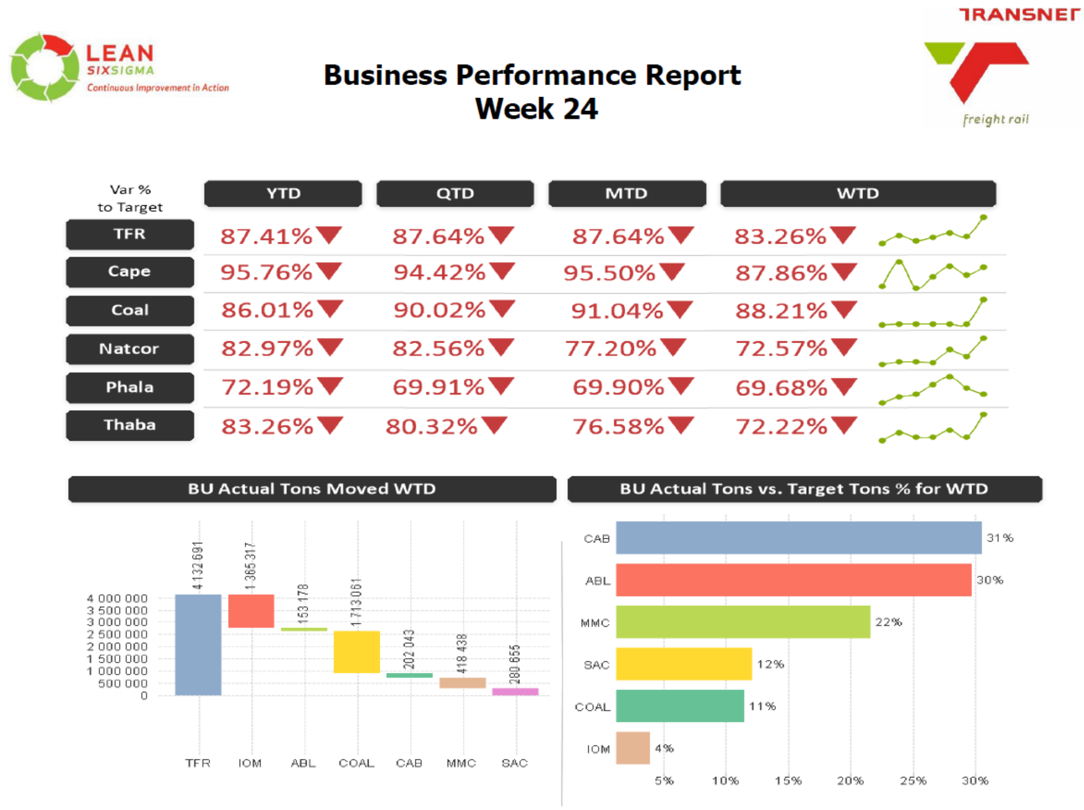

Figure A1 Business Performance Report

LEAN SIXSIGMA
Continuous Improvement in Action

TRANSNET
freight rail

A minus (-) indicates a decrease
No symbol indicates an increase

Business Performance Report
Week 24

Safety Incidents and Accidents - YTD:
26 Mar – 9 September 2017/18 & 2018/19 (Week 24)

Business Unit	R/Line Derailments			TFR Shunt Derailments			SPADs			Collisions			Number of Incidents			Rank
	2017/18	2018/19	%	2017/18	2018/19	%	2017/18	2018/19	%	2017/18	2018/19	%	2017/18	2018/19	%	
COAL	5	1	-80	8	5	-38	10	10	0	0	0	0	**23**	**16**	**-30**	1
SAC	6	3	-50	6	6	0	2	3	50	1	0	-100	**15**	**12**	**-20**	2
CAB	7	9	29	15	11	-27	6	6	0	0	0	0	**28**	**26**	**-7**	3
ABL	2	3	50	19	14	-26	1	3	200	1	3	200	**23**	**23**	**0**	4
MMC	5	6	20	8	14	75	7	2	-71	0	0	0	**20**	**22**	**10**	5
IOM	5	7	40	10	14	40	1	1	0	0	2	200	**16**	**24**	**50**	6
Grand Total	**30**	**29**	**-3**	**66**	**64**	**-3**	**27**	**25**	**-7**	**2**	**5**	**150**	**125**	**123**	**-2**	

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Feedback2TfrCOO@transnet.net

Figure A1 Safety Incident/Accidents Report

APPENDIX B

Table B1 Frequent Derailment Causes

Description	Derailments		Wagons Derailed		Average Number of Wagons Derailed per Derailment
	Number	Percentage	Number	Percentage	
Still under investigation	33	14.5	323	27.4	9.8
Rail slack	16	7.0	78	6.6	4.9
Rail kick	13	5.7	106	9.0	8.2
Axle broken	13	5.7	43	3.6	3.3
Rail broken	12	5.3	133	11.3	11.1
Wrong track gauge	12	5.3	35	3.0	2.9
Points not set correctly	11	4.8	26	2.2	2.4
Speed	11	4.8	102	8.6	9.3
Signal passed at danger	9	4.0	18	1.5	2
Points defective	8	3.5	20	1.7	2.5
Trolley defective	6	2.6	6	0.5	1
Wagon unevenly loaded	5	2.2	14	1.2	2.8
Buffer pulled out	5	2.2	12	1.0	2.4
Points indicator at danger ignored	5	2.2	8	0.7	1.6
Points run through	4	1.8	5	0.4	1.3
Wash away	4	1.8	24	2.0	6
Brake gear loose	4	1.8	19	1.6	4.8
Soil on level crossing	3	1.3	3	0.3	1
Tampering with points	2	0.9	2	0.2	1
Wheel profile not within specifications	2	0.9	5	0.4	2.5
Rocks on railway line	2	0.9	2	0.2	1
Brake beam loose	2	0.9	2	0.2	1
Run way vehicle	2	0.9	8	0.7	4
Wheel cracked	2	0.9	49	4.2	24.5
Check rail not secured	1	0.4	1	0.1	1
Defective curve with horizontal curvature exceeding C-standard in terms of the middle ordinate	1	0.4	1	0.1	1
Collision with road vehicle on line	1	0.4	2	0.2	2
Loading profile incorrect	1	0.4	1	0.1	1
Train handling	1	0.4	4	0.3	4
Collision with wild animal: elephant	1	0.4	1	0.1	1
Object placed in points	1	0.4	2	0.2	2
Object placed on railway line	1	0.4	1	0.1	1
Rail clips removed	1	0.4	17	1.4	17
Stolen tarpaulin between points blade	1	0.4	1	0.1	1
Theft of sleepers	1	0.4	7	0.6	7
Wooden sleepers taper keys stolen	1	0.4	1	0.1	1
Mismatch of rails after welding	1	0.4	1	0.1	1
Traction motor on stabilizer machine came loose	1	0.4	1	0.1	1
Wide gauge	1	0.4	1	0.1	1
Load shifted	1	0.4	1	0.1	1

Collision with rocks and soil	1	0.4	10	0.9	10
Bogie stiff	1	0.4	1	0.1	1
Wheel shifted on axle	1	0.4	1	0.1	1
Sleepers placed on railway line	1	0.4	1	0.1	1
Points moved under movement	1	0.4	2	0.2	2
Soil on railway due to blocked culverts	1	0.4	5	0.4	5
Movement not under control	1	0.4	1	0.1	1
Wagon side friction plate out of position and misalignment of track	1	0.4	1	0.1	1
Wheel flange sharp	1	0.4	4	0.3	4
Rail damaged by farmers equipment	1	0.4	1	0.1	1
Not determined	1	0.4	1	0.1	1
Theft of railway lines	1	0.4	8	0.7	8
Conveyer sweeper in work and not in travel mode	1	0.4	1	0.1	1
Run alway train	1	0.4	4	0.3	4
Wagon pushed out	1	0.4	7	0.6	7
Side bearing clearance defective	1	0.4	1	0.1	1
Loose counterweight on locomotive bogie	1	0.4	30	2.5	30
Points clamp not correctly fitted	1	0.4	1	0.1	1
Detection setting on points too wide	1	0.4	1	0.1	1
Derailer set before movement was completed	1	0.4	1	0.1	1
Allow train to proceed over points without verifying that points are still clamped	1	0.4	8	0.7	8
Wheel tyre loose	1	0.4	1	0.1	1
Knuckle broken	1	0.4	1	0.1	1
Push rod pin broke	1	0.4	1	0.1	1
Push rod loose	1	0.4	1	0.1	1
Skidded wheels	1	0.4	1	0.1	1
Total	**228**	**100**	**1181**	**100**	**5.2**

APPENDIX C

Table C1 Rolling Stock Maintenance Issues and Concerns

Number	Issues/Concerns
1	Product perseveration
2	Deviation from specification
3	Instruments
4	Training
5	Inspection
6	Document control
7	Tool protection
8	Identification/Traceability
9	SOP
10	Record control
11	Calibratio
12	WPS
13	Safety
14	Manual
15	Demarcation
16	Material
17	Skills matrix
18	NCR
19	Calibration schedule
20	Certification